Diversity of edible insects and their related indigenous knowledge: evidence from KwaZulu-Natal and Limpopo provinces, South Africa

by

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Ecological Sciences, School of Life Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg campus, South Africa. The research was financially supported by Sustainable and Health Food Systems (SHEFs) (grant number, 205200/Z/16/Z) and National Research Foundation (NRF) (grant number, MND200528525611).

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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DECLARATION 1: PLAGIARISM

I, Zabentungwa Thakasile Hlongwane, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation 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 re-written but the general information attributed to them has been referenced;

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(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

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DECLARATION 2: PUBLICATIONS

My role in each paper and presentation is indicated. The * indicates the corresponding author.

Presentations

1. Hlongwane ZT*, Slotow R, Munyai TC. 2019. Diversity and nutritional status of edible insects in Africa: A systematic review. Oral presentation to 21st National Congress of the Entomological Society of Southern Africa, 8th to 11th July, 2019, Durban, South Africa. Presented by ZT Hlongwane.

2. Hlongwane ZT*, Slotow R, Munyai TC. 2019. Nutritional composition and diversity of edible insects consumed in Africa: a Systematic Review. Poster presentation to the fourth BIMF-FBIP forum, 20th to 22nd August, 2019, Pretoria, South Africa. Presented by ZT Hlongwane.

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Publications

Chapter 2

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Conceptualization of the study was done by Z.T.H., R.S. and T.C.M. methodology, Z.T.H.; data collection, Z.T.H; writing—original draft preparation, Z.T.H.; writing—review and editing, R.S., T.C.M., and Z.T.H.; supervision, R.S. and T.C.M.; funding acquisition, R.S., and T.C.M.

Chapter 3

2. Hlongwane ZT*, Slotow R, Munyai TC. 2021. Indigenous knowledge about consumption of edible insects in South Africa. Insects 12, 22.

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Conceptualization, Z.T.H., R.S., and T.C.M.; methodology, Z.T.H and T.C.M; software, Z.T.H; validation, R.S., T.C.M.; formal analysis, Z.T.H.; investigation, Z.T.H, T.C.M; resources, R.S. and T.CM.; data curation, Z.T.H.; writing—original draft preparation, Z.T.H; writing—review and editing, Z.T.H., R.S., T.C.M.; visualization, Z.T.H.; supervision, R.S., T.C.M.; project administration, Z.T.H.; funding acquisition, R.S., T.C.M.

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ABSTRACT

Entomophagy is an ancient indigenous practice that has played a significant role in human nutrition around the world. In addition, the traditional use of edible insects forms an important part of food culture in Africa. Edible insects are widely consumed across the African continent for their taste, nutritional value, or as an emergency food source during times of food shortage. They have been proposed and recommended as a sustainable food source that can assure food security, because edible insects are rich in protein, fats, amino acids, iron, zinc, and energy. As a result, edible insects play an essential role in human nutrition. In addition, the trade of edible insects plays an important role in improving livelihoods in developing countries. However, little is known about the diversity and nutritional composition of various insects consumed in South Africa. In addition, little is being done to document traditional knowledge on the consumption of insects, and processes involved in harvesting, processing, and preparing edible insects. This study aimed to document indigenous knowledge regarding the consumption of edible insects, their diversity and distribution, and their nutritional composition. This was done by (i) reviewing existing literature on the diversity of insect and their nutritional status in Africa. (ii) documenting consumption patterns, methods, or techniques used in collecting and preparing insects in South Africa. (iii) determining the nutritional composition of some major insect groups consumed in Africa, (iv) determining the most preferred insect groups, and (v) by documenting the socio-economic benefits of trading insects. Closed and open-ended questions were conducted in various rural areas in five and four local municipalities in KwaZulu-Natal (KZN) and Limpopo. To document indigenous knowledge about trading, consumption, collection and preparation methods used in these provinces. Dried samples of four insect groups were procured from different markets across Vhembe district, Limpopo Province. The nutritional composition of the procured insect types was analysed using the standard Association of Official Analytical Chemist (AOAC) methods. A systematic review was conducted to determine the diversity and nutritional composition of edible insects consumed in Africa. A systematic review search resulted in 98 eligible papers listing 212 edible insect species from eight orders that are used as food in Africa. The highest protein (range: 20–80%) and fat (range: 10–50%) content were recorded in order Lepidoptera. While the highest carbohydrates (range: 7–54%) content was reported in order Coleoptera. Majority of the people still practice entomophagy in Limpopo while, there are only a few people consuming insects in KwaZulu-Natal. *Gynanisa caterpillar, Gonimbrasia belina* (mopane worm), termites, *Encosternum delegorguei* (stink bug), *Cirina forda* (emperor moth), *Locustana* spp. (brown locust), *Zenocerou*s spp. (grasshopper), *Carebara vidua* (ant), and Cicadoidea spp. (cicada) were used as food in Limpopo and KwaZulu-Natal. From these, mopane worms and termites were the most preferred species. These insects were primarily collected from the wild, and consumed either fried, boiled, roasted, sundried, or as relish. Nutritional benefits and tradition were the primary reason for consuming insects in the two provinces. However, religion and discomfort associated with consuming insects were the main reasons for not consuming insects. Findings from the nutritional analysis of four insect types showed that termite (soldiers/ workers) had the highest protein and iron content, while *Gynanisa* caterpillar had the highest zinc content. The ranges of the percentage contribution of the insects studied relative to the Estimated Average Requirement (EAR) for protein amongst different age groups, indicated that the insects would contribute significantly to addressing protein deficiencies, 89.5-160.4% EAR for 4-8 years old children and 29.9-53.6% EAR for childbearing women (19-50 years). However, because *Gonimbrasia belina* are consumed in a relatively higher portion size than the other edible insects, it would be a good source of protein for different population groups. Generally, boiling with or without salt added resulted in a significant increase in protein, iron, and zinc content of *Gonimbrasia belina* samples. On the other hand, frying resulted in a significant decrease in protein content of *Gonimbrasia belina* samples. Five insect groups were traded for cash income in Vhembe district, Limpopo province. Of these, mopane worm was the most traded insect. Trading insects provided financial support and cash income to unemployed people in this province. Income generated from trading insects range from R100 - R200 ($6, 2 - $12, 3) per week to above R2000 ($123, 3) per week with the majority of traders making an income of R600 -R1000 ($36, 9-$61, 6) per week. Unemployment and poverty were the main reason for trading insects. Despite the economic benefit associated with trading insects, few governmental organizations in Limpopo included edible insects in economic development strategies. In addition, insect trading took place in the informal markets along the street, pavements, and on table stalls made of cardboard and wood. Safety and hygiene were the major issues of concern stated by the respondents in Vhembe district. Therefore, government need to provide infrastructure and financial support to improve the trading conditions of edible insects. Also, policy and legislation that recognise and govern the consumption, trading, and harvesting of edible insects are required, because edible insects play an important role in income generation. In addition, edible insects contribute to food and nutrition security in developing

countries with chronic nutrient deficiencies. Therefore, the consumption of insects should be promoted and encouraged in poor communities.

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DEDICATION

This thesis is dedicated to my late mother Mrs. Tombi Irene Hadebe Hlongwane (1969 -1996)

I never got to know you, I know that you would have been proud of this accomplishment as it was your wish for me to be educated.

and

My late grandmother Mrs. Nomqikiza Hlongwane (1940 - 2018)

My pillar of strength, you taught me to be strong and to work hard in everything I do. Thank you so much. I still keep your words of wisdom dear to my heart.

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ABBREVIATIONS

ALASA	Agricultural Laboratory Association of Southern Africa
AOAC	Association of Official Analytical Chemists
EAR	Estimated Energy Requirements
FAO	Food and Agriculture Organisation
IDP	Integrated Development Plan
KZN	KwaZulu-Natal
LED	Local Economic Development strategy
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
SA	South Africa
SADC	Southern African Development Community
StatSA	Statistics South Africa
UKZN	University of KwaZulu-Natal
WHO	World Health Organisat

CHAPTER 1: GENERAL INTRODUCTION, THE PROBLEM AND OVERVIEW

1.1 Importance of study

Food insecurity is a major problem that we are faced with worldwide (Sasson, 2012). In 2015 and 2016, approximately 842 million people in the world were unable to meet dietary energy requirements (FAO, IFAD and WFP, 2013). The majority of these people (827 million) are found in developing countries where malnutrition and undernourishment are prevalent (FAO, IFAD and WFP, 2013). Africa remains the region with the highest prevalence of malnutrition, poverty, and hunger (FAO, IFAD and WFP, 2015). FAO (2017) reported that in 2017and 2018 approximately 277 million people were severely food insecure (do not have access to nutritious and sufficient food) in Sub-Saharan Africa. It was also reported that 239 million people were undernourished in the same region in 2017 and 2018 (FAO, 2017). These figures are likely to persist if drastic measures are not taken to mitigate food insecurity, malnutrition and hunger, because Africa is susceptible to food crises and famines caused by different environmental catastrophes, such as drought and floods (Fombong et al., 2017; Kelemu et al., 2015; Sasson, 2012). Also, rapid population growth and rising food prices are expected to accelerate food insecurity and malnutrition in Africa (Fombong et al., 2017).

Although South Africa is food secure at a national level, many households are still food insecure (Chakona and Shackleton, 2019; Stat SA, 2019). In 2017, approximately 20% of South African households were food insecure (severely inadequate food access) (Stat SA, 2019). Nutrition insecurity is another issue that is highly prevalent in South Africa (Govender et al., 2017). Approximately 6.8 million people are hungry and do not have access to nutritious food in South Africa (Stat SA, 2019). There is a correlation between nutrition, food security, and poverty. High levels of poverty, income inequality, and unemployment are major contributors to malnutrition in South Africa, and malnutrition is prevalent in low-income households (Sartorius et al., 2020; Tomita et al., 2020). As a result, most South Africans are food insecure and do not have access to nutritious and balanced food to meet their daily nutrient requirements (Vorster, 2010; Govender et al., 2017; Tomita et al., 2020). In addition, low-income South Africans do not have dietary diversity, their diets are predominantly comprised of starchy staples such as maize and bread with a low intake of vegetables and fruits (Claasen et al., 2016; Sartorius et al., 2020). Food insecurity and poor diets affect human health and wellbeing and contribute to stunting, protein, and micronutrient (zinc and iron) deficiencies in South Africa (McLachlan and Landman, 2013; Govender et al., 2017).

Zinc and iron deficiencies are prevalent in South Africa, and these micronutrients are lacking in the diets of many South Africans, particularly in rural areas (Motadi et al., 2015). Diets in rural communities are of poor quality and are made up of mainly carbohydrate rich food, with a low intake of animal protein, dairy products, and fruits, which contribute less iron, protein, and zinc intake (Mamabolo et al., 2006; Motadi et al., 2015). Zinc and iron deficiencies have a negative effect on the health and wellbeing of the affected population, and hinder the social progress and economic prosperity of an individual and a nation (Bhandari and Banjara, 2015; Siwela et al., 2020). In addition, they contribute to child stunting and are associated with 50% of all deaths of children under five years worldwide (Mamabolo et al., 2006; Siwela et al., 2020). Lack of access to micronutrient rich food such as fruits, meat, vegetables, and fortified food is a major contributor to zinc and iron deficiencies (Mamabolo et al., 2006). Poverty is the major contributor to micronutrient deficiency and malnutrition in South Africa because many people cannot afford balanced diets rich in micronutrients. Thus, they settle for cheap and poor quality food (Govender et al., 2017). Zinc and iron deficiency affect all age groups, but the most vulnerable are children, women of reproductive age and lactating women (Das et al., 2013).

Several strategies have been put in place to address malnutrition in South Africa (Siwela et al., 2020). These strategies include commercial food fortification with micronutrients, supplementation with adequate quality protein, vitamins and amino acids, and dietary diversification to increase micronutrient-rich food productivity (Faber and Wenhold, 2007; Siwela et al., 2020). However, these strategies have been in place for a long time and are not sustainable (Siwela et al., 2020). Besides, they have not adequately addressed malnutrition because supplements, fortified, and diversified food are expensive, and only reach the population that can buy the product (Awobusuyi, 2020).

The enormous growth in the human population, expected to reach or exceed 9 billion people by 2050, will increase demand for food, which is expected to rise by 70% by 2030 (United Nations Department of Economic and Social Affairs, 2017). This will increase the number of people who are food insecure and living with malnutrition issues. Therefore, calls to maximise food production have become urgent (Egan, 2013). Cheaper, innovative and sustainable measures are required to address food insecurity and malnutrition issues, particularly in developing countries. Edible insects have been recommended and promoted by Food and Agriculture

Organization (FAO) as sustainable protein and food sources, which can assure food security (Fombong et al., 2017; van Huis, 2013).

Edible insects are an important traditional food source that has played an important role in food and nutrition security over the years (Hlongwane et al., 2020; Kinyuru et al., 2015; Rumpold and Schlüter, 2013). Approximately 2111 species of insects are used as food globally, and, of these, 500 species are consumed in Africa (Kelemu et al., 2015; Jongema, 2017; Hlongwane et al., 2020). Edible insects have been proposed and recommended as sustainable food sources that can assure food security, because edible insects are rich in protein, fats, amino acids, iron, zinc, and energy (van Huis, 2013; Adámková et al., 2017). Farming and rearing insects is cheap, with less impact on the environment (van Huis and Oonincx, 2017); unlike livestock production, which negatively affects the environment (van Huis, 2015). Livestock production results in soil erosion, deforestation, water pollution, loss of plant biodiversity, and desertification (Steinfeld et al., 2006; van Huis, 2015). Also, livestock production accounts for more than 14% of all greenhouse emissions (Gerber et al., 2013; van Huis, 2015). With an increasing demand for meat in developing countries, these figures are expected to increase (van Huis, 2015). Across the world, meat demand is expected to increase by 76% by the year 2050 due to population growth (Alexandratos and Bruinsma, 2012). Edible insects were proposed as an alternative protein source because edible insect production is more sustainable than livestock production (van Huis and Oonincx, 2017). Insect production results in lower greenhouse gas emission, require less land, uses less water, and has more efficient feed conversion (Oonincx et al., 2010; van Huis and Oonincx, 2017).

Edible insects are collected in the wild and is a popular traditional food in many cultures in Africa (Baiyegunhi et al., 2016a, 2016b). Some edible insects are considered important traditional delicacies by different cultures (Hlongwane et al., 2021). For example, mopane worms are an essential delicacy in southern Africa (Mpuchane et al., 2000; Makhado et al., 2014). Stink bugs are a favourite delicacy for the vhaVenda people in Limpopo, South Africa (Teffo et al., 2007). Edible insects are also an important food source to supplement diets during times of food shortages and drought (Baiyegunhi et al., 2016a, 2016b; Manno et al., 2018). Edible insects are used as a food security safety net in many rural communities in Africa (Makhado et al., 2009). They play an essential role in improving rural livelihoods. They are traded to generate cash income, providing earning opportunities to the unemployed population (Thomas, 2013; Makhado et al., 2014; Sekonya et al., 2020). For example, the trade of mopane worms is a commercial business in southern Africa, which generates an income of approximately US$59 million per year (Makhado et al., 2014). Furthermore, Netshifhefhe et al. (2018) reported that the income generated from trading termites in Limpopo province, South Africa, is estimated to be R17 680 per year per trader. Thus, edible insect trade and consumption can be used as an important strategy to reduce poverty, generate income, improve household nutrition, and human wellbeing (Makhado et al., 2014).

In South Africa, the consumption of insects is a long standing traditional practice. As a result, the consumption of insects is influenced by culture and tradition (Hlongwane et al., 2021). Indigenous knowledge about entomophagy is passed down from generations through stories, songs, oral transmissions, hands on instructions, and experimentation (Acuña et al., 2011; Egan, 2013). This knowledge conveys important information about when to collect, where to collect, how to find, and how to prepare different insect species (Acuña et al., 2011; Hlongwane et al., 2021). However, this information is being lost over time because it is not documented in literature and is lost in translation over years. This research will help document indigenous knowledge about the consumption of insects in South Africa, which will help preserve this knowledge.

Over the years, the consumption of insects has declined in many societies in developing countries (Neves, 2015). In South Africa, religion and discomfort associated with consuming insects are the main reason for not consuming insects (Hlongwane et al., 2021). Several religions forbid the consumption of insects because they believe that insects are unholy and dirty (Manditsera et al., 2018), and, therefore they should not be consumed. The decline in consumption of insects is also attributed to their low sensory characteristics, unfamiliarity with insects, and the fear/ discomfort of consuming an insect whole (Awobusuyi et al., 2020). Some people react negatively to the thought of consuming insects because they view insects as pest rather than food (Awobusuyi et al., 2020).

1.2. Problem statements

Edible insects are an important food source that plays a significant role in human nutrition worldwide, particularly in Africa (Fasoranti and Ajibane, 1993; Anankware et al., 2016; Raheem et al., 2019). Their consumption is a long standing tradition in Africa and other parts of the world such as Latin America, China, Thailand, and Japan (Quin, 1959; Chen et al., 2009; Raheem et al., 2019). However, little is being done to document traditional knowledge on the consumption of insects, and processes involved in harvesting, processing, and preparing edible insects. Therefore, there is a need to understand how people value and use different insects as a food source. This information will help us understand the role and the importance of edible insects in human food culture and tradition. This information might help influence decision about important practices that play an important role in rural communities.

Malnutrition and macronutrient deficiencies continue to be a major public health problem, particularly in developing countries (Muller and Krawinkel, 2005). Zinc, iron and protein deficiencies still remain a challenge in many low-income countries (Motadi et al., 2015). In Africa, poverty and consumption of poor quality food that lacks essential nutrients is the primary causes of protein, zinc, and iron deficiencies (Govender et al., 2017). Hence, it is important to understand the nutritional value of edible insects, and if they can contribute to addressing iron, zinc, and protein deficiencies in communities of low economic potential. In addition, zinc and iron are generally lacking minerals in South African diet (Claasen et al., 2016). Sustainable food sources that can address mineral deficiencies should be studied to understand their contribution in nutrition security. The current study will help identify insects type that contains high zinc, iron, and protein content, and could be prioritised for higher nutritional (zinc, iron, and protein) intake. Edible insects are prepared and cooked using different methods; As a result, it is important to understand if cooking may effect the nutritional value of edible insects. Result from this study could help find the optimum cooking method that results in higher retention of nutrients.

Poverty and high rates of unemployment are major issues experienced in rural communities (Kalaba, 2009). As a result, rural communities depend on natural resources such as edible insects to sustain their livelihoods (Makhado et al., 2009; Sekonya et al., 2020). Edible insects trading is a good business that plays an important role in improving livelihoods in rural communities. Edible insects can be used as a strategy to alleviate poverty in rural areas. Therefore, there is a need to better understand the economic benefits of trading insects and traders' motivation. This information will guide policy formulation on the need to invest and expand edible insects commercialisation in South Africa, thus improve rural livelihoods by creating job opportunities for urban and rural dwellers.

1.3 Aim of the study

This study aimed to determine the diversity, distribution, nutritional composition, and economic and cultural benefits of edible insects consumed in South Africa.

1.4 Study objectives

The objectives of this study are to:

- Review existing literature on the nutritional composition of edible insects consumed in Africa.
- Document indigenous knowledge about consumption, collection, and preparation of insects in South Africa and to determine the most preferred and consumed insect groups.
- Determine the nutritional composition of commonly consumed insect species in South Africa.
- Determine the effect of cooking methods on the nutritional composition of edible insects.
- Determine socio-economic benefits of trading and harvesting insects in Vhembe district, South Africa.

1.5 Outline of the thesis

The structure of the thesis is as follows:

Chapter 1: General introduction, the problem and outline

Chapter 2: Nutritional composition of edible insects consumed in Africa: A systematic review (**published in Nutrients 12, 2786. https://doi.org/10.3390/nul2092786**)

Chapter 3: Indigenous knowledge about consumption of edible insects in South Africa (**published in Insects 12, 22. https://doi.org/10.3390/insects12010022**)

Chapter 4: Effect of geographic location, insect type and cooking method on nutritional composition of insect consumed in South Africa (**accepted for publication in the Journal of Insects as Food and Feed**)

Chapter 5: The role of edible insects in rural livelihoods, and challenges identified, in Vhembe district, Limpopo, South Africa (**under review in the journal Diversity**)

Chapter 6: General conclusions and recommendations

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CHAPTER 2: NUTRITIONAL COMPOSITION OF EDIBLE INSECTS CONSUMED IN AFRICA: A SYSTEMATIC REVIEW

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Abstract

Edible insects are an important protein rich natural resource that can contribute to resilient food security. Edible insects not only play an important role in traditional diets, but are also an excellent source of protein in traditional dishes in Africa. We systematically searched Web-of-Science and Google Scholar from year 2000–2019 for studies on the consumption of insects and their nutritional composition in Africa, resulting in 98 eligible papers, listing 212 edible insect species from nine orders. These insects were rich in protein, fats, and fibre. The highest protein content was reported for Lepidoptera (range: 20–80%). Coleoptera had the highest carbohydrate content (7–54%), while Lepidoptera had the highest fat content (10–50%). Considering the excellent source of nutrition, and potential socio-economic benefits, from edible insects, they can contribute strongly to improved food security, and rural development in developing countries. In addition, edible insects can be used as a sustainable food source to combat food shortages in the future, for example, providing resilience during times of drought or other climate stressors.

Keywords: entomophagy; Africa; edible insects; nutrition; food security

2. 1. Introduction

Consumption of insects has recently received more attention because of their promising potential for contributing to livelihoods and mitigating food security problems around the world (van Huis, 2013; Verbeke, 2015; Nowak et al., 2016). Food security problems are caused by an enormous increase in the global human population, which is estimated to increase to approximately 9 billion people by 2050 (FAO, 2013), resulting in a 70% increase in food demand, and an increase in food prices (van Huis, 2013; Van Huis, 2016; Myers and Pettigrew, 2018). The increase in food prices will prompt the search for cheap alternative sustainable protein sources (van Huis, 2013). Entomophagy, which refers to the consumption of insects by humans, is an environmentally friendly approach to increasing food for consumption, and contributing to food security across the world (Rumpold and Schlüter, 2013; Verbeke, 2015; Dobermann et al., 2017; Myers and Pettigrew, 2018).

Edible insects might be a solution to food shortages, owing to their promising potential in contributing to livelihoods and mitigating food security problems around the world (van Huis, 2013; Verbeke, 2015; Nowak et al., 2016). Insects are consumed as food in Thailand (Hanboonsong et al., 2013; Halloran et al., 2017), China (Chen et al., 2009; Feng et al., 2018), Mexico (Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1997; Ramos-Elorduy and Pino Moreno, 2002; Acuña et al., 2011), Latin America (Costa-Neto, 2015), Japan (Mitsuhashi, 1997), and Africa (Kelemu et al., 2015). Approximately 2 billion people worldwide regularly consume insects as part of their diets (van Huis, 2013; Bernard and Womeni, 2017; Gosh et al., 2018). The consumption of insects is not a new phenomenon, as it dates back to before the development of agriculture when humans relied on gathering plants and hunting wild animals (Kouřimská and Adámková, 2016; Van Huis, 2016; Feng et al., 2018).

Edible insects have played a very important traditional role in nutritious diets in various countries in Africa (Kelemu et al., 2015; Sogari et al., 2017). In addition, edible insects are an important natural resource that is used as a coping strategy, particularly in months of food shortage (Agea et al., 2008; DeFoliart, 1997; Mutungi et al., 2019). Unfavourable climatic conditions experienced in Africa affect small scale animal husbandry and reduce animal protein production, so diets are then supplemented with edible insect protein (Agea et al., 2008). Edible insects provide significant socio-economic and ecological benefits for developing countries (Nonaka, 2009; Alamu et al., 2013). Approximately 500 species of edible insects are consumed in Africa and form part of traditional diets (Kelemu et al., 2015). Of these 500 species, 256 species were consumed in the Central African region, 164 in southern Africa, 100 species in eastern Africa, 91 in western Africa, and only eight species in northern Africa (Kelemu et al., 2015). Insects are consumed among different African cultures because of their taste, cultural importance, and nutritive value, and as a supplementary food when staple food is limited (Nonaka, 2009; van Huis, 2013; Nowak et al., 2016; Nakimbugwe et al., 2020).

Various studies in Africa have focused on studying the nutritional content of a single species, group, or genus (Teffo et al., 2007; Siulapwa et al., 2012; Adepoju and Daboh, 2013; Badanaro et al., 2014; Adepoju and Ajayi, 2016). Little is known about the diversity and nutritional content of various insects consumed in Africa. Therefore, the current study will review the existing literature on the diversity of insects, and their nutritional status in Africa, and, therefore, compile information on the nutrient composition of edible insects consumed in Africa. This will be done by asking the following questions: (1) What is the nutritional value of edible insects consumed in Africa, (2) what are the most consumed, and (3) the most studied insect species, in terms of nutrition, in Africa?

2.2. Materials and Methods

2.2.1. Search Strategy

To explore the diversity and nutritional status of edible insects in Africa, we followed the PRISMA guidelines for a systematic review. Peer-reviewed literature was obtained using the Thomson Reuters' Web of Science database (https://apps.webofknowledge.com) and google scholar (https://scholar.google.co.za/) looking for publications that researched entomophagy in Africa, edible insects, diversity, nutrient content of edible insects, and consumption of insects. To source information, the following key words and phrases were used, "entomophagy", "edible insects", "diversity of edible insects", "entomophagy in Africa", "edible insects in eastern Africa", "edible insects in north Africa", "edible insects in western Africa", "edible insects in Central Africa", "edible insects in southern Africa" and "nutrient content of edible insects". We also screened references included in selected articles in order to identify studies that might be relevant but did not appear in our search. We limited the search to literature published from 2000 to 2019. We started in the year 2000 because it was a starting point where most researchers began investigating the use of edible insects as a food source and as a solution to combat food insecurity problems (Illgner and Nel, 2000; Mpuchane et al., 2000).

2.2.2 Data Collection

Data from the selected articles were independently screened and extracted by a single author (Z.T.H). The search result was done by reading the title and abstract of the retrieved papers to determine if the article was relevant to the study. Once it was determined that the article was relevant, the full text of the selected articles was further analysed to extract relevant information. The information that was collected and extracted after full text reading from each article included year, study area and country, study insect species, reported nutrient composition of insects, consumption stage of an insect, main research findings, and conclusions. Collected articles were categorized by country and insect order.

2.2.3. Inclusion and Exclusion Criteria

Inclusion criteria

- Original research articles and review papers focusing on entomophagy, nutrient composition of single or multiple edible insect species.
- Articles published in English.
- Articles of work done in African countries.
- Articles that reported nutrient composition of edible insects.

Exclusion criteria

- Conference papers, editorial material, book chapters
- Articles on insect rearing and farming.

2.2.4 Data Quality

To evaluate the quality of studies included in this systematic review, we assessed quality based on the following criteria: (1) A clear food description (scientific name(s) of insects studied or genus), (2) a clear description on the part of the insects used for analysis, e.g., whole, head, abdomen, indication of geographic origin of the insects, and the country where it is used as food in Africa, (3) analytical method used, number of analytical samples, (4) clear indication of whether the nutritional composition was based on the dry weight. Studies were included if they meet all the above criteria.

2.2.5. Data Analysis

The methods and data sources used in the included studies were highly heterogeneous and a statistical meta-analysis was not possible. Instead, a more narrative synthesis approach was used, and data from each study were tabulated. We synthesised the results according to study species and mean values of all insect species belonging to the same insect order were calculated and represented in bold, the nutritional composition of consumed species were presented in the table, most consumed species in different countries were presented graphically.

2.3. Results and Discussion

A total of 428 papers were identified for potential inclusion; after checking the title and abstract, 300 articles were excluded because they did not meet the inclusion criteria. From here, 128 articles were selected for full-text reading; from these, 29 articles were further excluded because they were not relevant or not conducted in Africa. After reading the full-text, 89 studies met all inclusion criteria, and a further nine articles were identified through screening references and confirming inclusion criteria were met. In total 98 articles were included in a systematic review (Figure 2. 1).

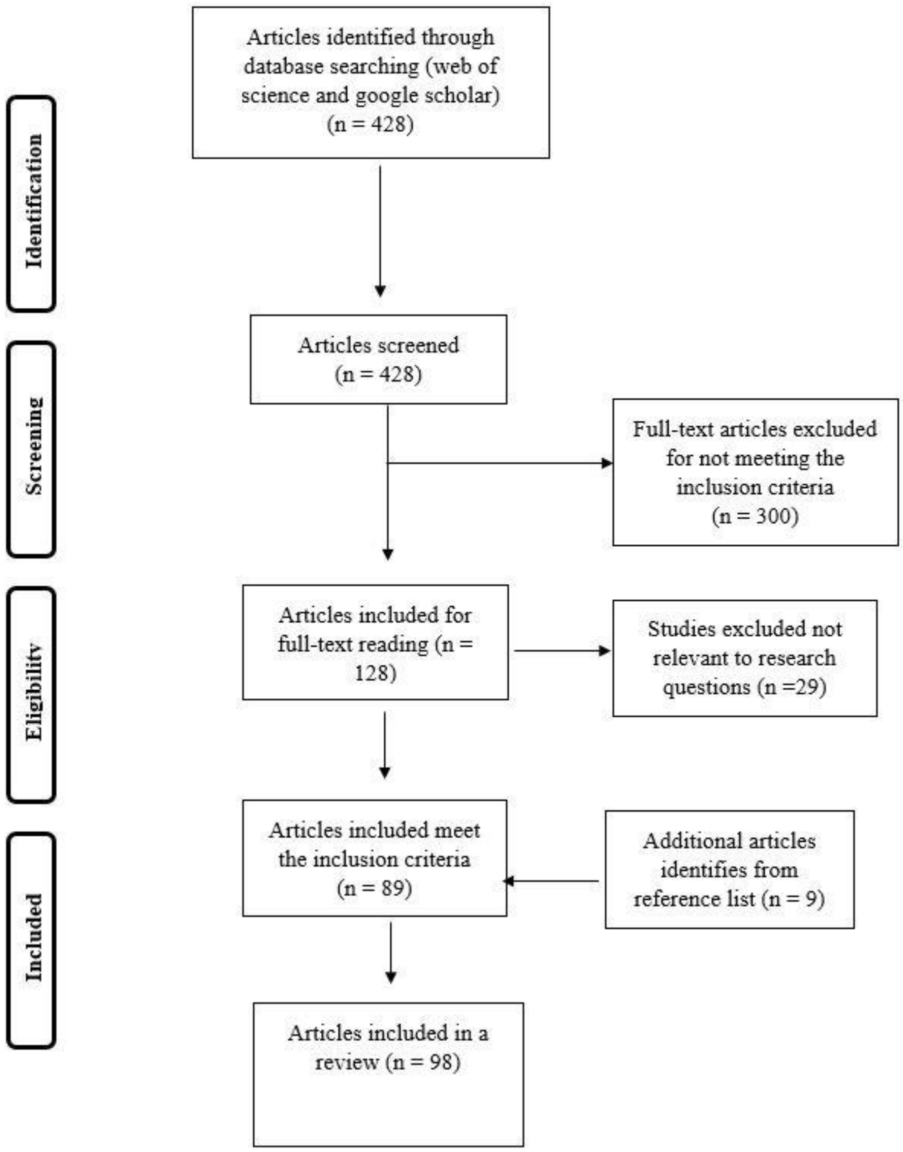

Figure 2. 1**.** Flow chart of the study selection process for systematic review of the nutritional composition of edible insects.

2.3.1. Consumption of Insect Patterns in Africa

For the research articles published since 2000, a total of 212 edible insect species from nine orders were recorded and are potentially consumed in different African countries (Appendix

2.1). Of these, 41% were Lepidoptera, 23% Orthoptera, 15% Coleoptera, 12% Blattodea (including both cockroaches and termites as recently classified), 4% Hemiptera, and Hymenoptera, Diptera, Blattodea, and Mantodea each contributed <1%. *Rhynchophorus phoenicis* (African palm weevil) and *Cirina forda* (Pallid emperor moth) were the most studied species in Africa, with 32 publications from 12 countries, and 18 publications from 10 countries, respectively (Figure 2. 2). Most research has been done in the western African countries, particularly in Nigeria, mainly on *Rhynchophorus phoenicis* and *Cirina forda*, which are the most consumed species in West Africa. However, southern African countries (Zimbabwe, South Africa, and Botswana) have the highest number of consumed species, but little research has been done on nutritional content and consumption patterns of edible insects.

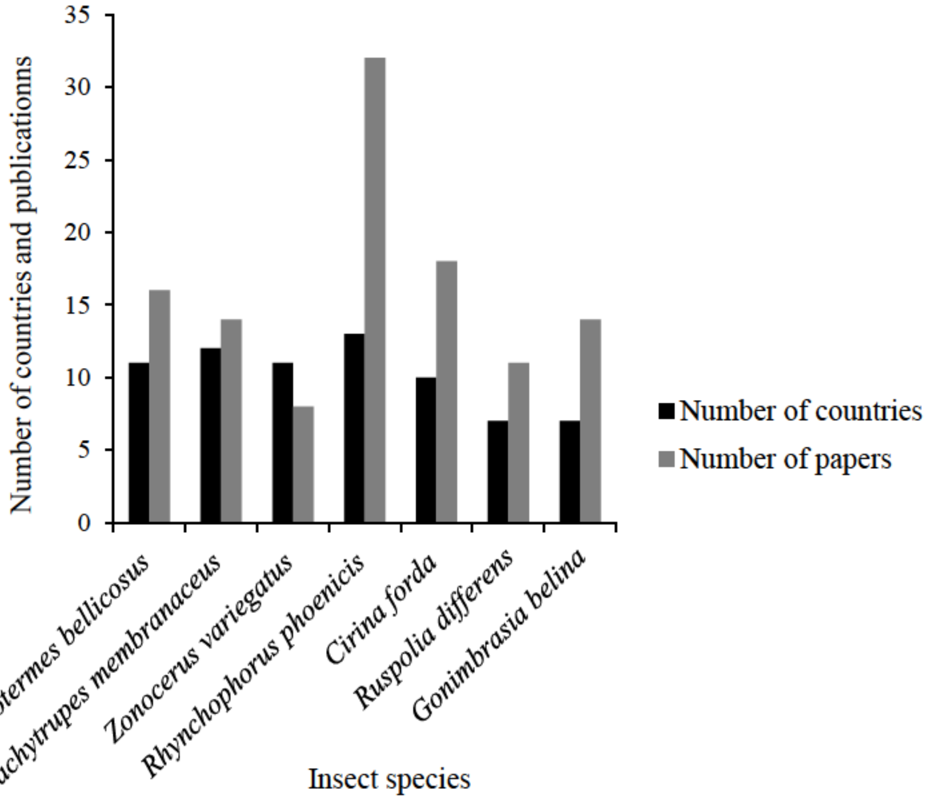

Figure 2. 2. The number of countries with journal peer-reviewed articles published on the most consumed and economically important insects in Africa.

2.3.2. Nutrient Composition of Edible Insects

A compilation of nutrient composition of 54 edible insects based on the dry matter is presented in Table 2. 1. Percentage of fat, protein, moisture, and ash content were calculated based on dry weight of the insect when ready for preparation to eat, noting that, in some cases, the insects had been processed since collecting. The highest protein was reported in Lepidoptera (range: 12–79%) and Orthoptera (12–73%), while the lowest protein content ranging from (0–39%) was reported for Blattodea.

The crude fibre was reported to be higher in Coleoptera (2–28%) and Lepidoptera (2–16%), while the crude fibre content was reported to be lowest in Hemiptera (0–5%). Lepidoptera had the highest moisture content (3–86%), while Blattodea had the lowest moisture content (2.8–3%) (Table 2. 1).

The highest carbohydrate content was recorded in Coleoptera (13–52%) and Orthoptera (15–47%), while the lowest carbohydrate content was recorded in Blattodea (0–32%). Fat content was the highest in Lepidoptera (2–55%) and lowest in Orthoptera (2–16%) (Table 1).

Orthoptera had the highest iron content (0.3–910 mg/100 g) followed by Blattodea (27–332 mg/100 g), while Hemiptera had the lowest iron content (0–20 mg/100 g). Calcium content was higher in Blattodea (18–132 mg/100 g) and lowest in Lepidoptera (8–15 mg/100 g). The highest Phosphorus was recorded in Lepidoptera (100–730 mg/100 g) and the lowest in Orthoptera (106–125 mg/100 g). Magnesium content was the highest in order Lepidoptera (1–160 mg/100 g), while Blattodea had the lowest magnesium content (0.1–0.3 mg/100 g) (Table 2. 1).

Table 2. 1. Nutritional composition of edible insects, based on dry matter, from six orders consumed by people in Africa.

Scientific Name	Stage of Consumption	Protein (%)	Crude Fibre (%)	Moisture (%)	Ash (%)	Carb (%)	Vitamin A (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Fe (mg/100 g)	Ca (mg/100 g)	Zn (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)	Fats (mg/100 g)	Reference
Blattodea (termites and cockroaches)		**33.2 ± 14.5**	**4.7 ± 3.9**	**2.9 ± 0.1**	**5.2 ± 2.5**	**23.2 ± 0**	**2.7 ± 0.2**	**1.8 ± 0.2**	**3.2 ± 0.2**	**86 ± 96.8**	**54.1 ± 42.6**	**13.8 ± 3.5**	**125 ± 11**	**0.2 ± 0.1**	**22.2 ± 9.8**	
Periplaneta Americana	Adult	39.6	13.1		6.2											(Mbah and Elekima, 2010)
Macrotermes nigeriensis	Adult	35.9	5.5		5.8											(Mbah and Elekima, 2010)
Macrotermes bellicosus	Adult	20.4	2.7	2.8	11.3	23.2	2.9	2.0	3.4	27.0	21.0		136.0	0.2	36.1	(Banjo et al., 2006)
Macrotermes natalensis	Adult	22.1	2.2	3.0	4.1		2.6	1.5	3.0	29.0	18.0		114.0	0.3	21.4	(Banjo et al., 2006)
Pseudacathotermes spinige	Adult				6.8					332.0	84.7	11.9				(Christensen et al., 2006)
Macrotermes spp.	Adult				2.4					93.9	83.7	8.1				(Christensen et al., 2006)
Macrotermes herus	Adult				6.8					161.0	132.0	14.3				(Christensen et al., 2006)
Macrotermes bellicosus	Adult	40.7			5.7					42.7		16.9			8.4	(Akullo et al., 2018)
Macrotermes bellicosus	Adult	20.4	2.7	2.8	2.9		2.9	2.0	3.4	27.0	21.0		136.0	0.2		(Banjo et al., 2006)
Syntermes soldiers	Adult	64.7			4.2					32.5		17.6			23.0	(Akullo et al., 2018)
Macrotermes natalensis	Adult	22.1	2.2	3.0	1.9		2.6	1.5	3.0	29.0	18.0		114.0	0.3		(Banjo et al., 2006)
Coleoptera (beetles)		**32.8 ± 11.5**	**6.2 ± 7.8**	**7.6 ± 15.7**	**4.7 ± 2.7**	**22.6 ±13.2**	**11.2 ± 1.4**	**1.9 ± 0.9**	**5.4 ± 1.2**	**14.1 ± 8.9**	**43.6 ±14.3**	**14.4 ± 12.1**	**109.6 ±48.5**	**10.1 ± 4.2**	**29.1 ± 16.6**	

Scientific name	Stage of consumption	Protein (%)	Crude fibre (%)	Moisture (%)	Ash (%)	Carb (%)	Vitamin A (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Fe (mg/100 g)	Ca (mg/100 g)	Zn (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)	Fats (mg/100 g)	Reference
Analeptes trifasciata	Larvae	20.1	2.0	2.2	5.1		12.5	2.6	5.4	18.2	61.2		136.4	18.2		(Banjo et al., 2006)
Oryctes boas	Larvae	26.0	1.5	1.9	1.5							2.3				(Banjo et al., 2006; Rumpold and Schlüter, 2013)
Oryctes monoceros	Larvae	26.4		4.7	7.8	51.6										(Edijala et al., 2009)
Aphodius rufipes	Larvae	22.4	28.1	3.3	2.7	13.1				30.9	42.2			11.7	30.5	(Banjo et al., 2006)
Rhynchophorus phoenicis	Larvae	28.4	2.8	2.7	2.7		11.3	2.2	4.3	12.2	39.6	26.5	126.4	7.5	66.6	(Rumpold and Schlüter, 2013)
Oryctes rhinoceros	Larvae	50.5								4.5					38.1	(Rumpold and Schlüter, 2013)
Oryctes owariensis	Larvae	50.6		8.4	7.7	14.3									18.9	(Assielou et al., 2015)
Eulopida mashona	Larvae	46.3	14.8		10.9	16.2									11.8	(Manditsera et al., 2018)
Heteroligus meles	Larvae	38.1	3.0	1.0	5.8	20.1									32.0	(Jonathan, 2012)
Rhynchophorus phoenicis	Larvae	50.0	2.6	1.2	4.9	20.2									21.1	(Jonathan, 2012)
Rhynchophorus phoenicis	Larvae	28.4	2.8	2.7	2.7		11.3	2.2	4.3	12.2	39.6		126.4	7.5		(Banjo et al., 2006)
Analeptes trifasciata	Larvae	29.6	2.0	2.2	4.2		12.5	2.6	5.4	18.2	61.3		136.4	6.1		(Banjo et al., 2006)
Oryctes boas	Larvae	26.0	3.4	1.9	1.5		8.6	0.1	7.6	2.3	45.7		130.2	6.3		(Banjo et al., 2006)
Apomecyna parumpunctata	Larvae	16.8	5.4	59.4	3.0						15.7		1.5	13.5	13.9	(Thomas, 2018)

Scientific name	Stage of consumption	Protein (%)	Crude fibre (%)	Moisture (%)	Ash (%)	Carb (%)	Vitamin A (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Fe (mg/100 g)	Ca (mg/100 g)	Zn (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)	Fats (mg/100 g)	Reference
Hemiptera (bugs)		**39.3 ± 4.0**	**5.3 ± 0**	**4.9 ± 0**	**1.7 ± 0**	**6.3 ± 1.3**	**0.2 ± 0**	**0.9 ± 0**		**20.2 ± 0**	**91.0 ± 0**	**46.0 ± 0**	**57 ± 0**	**109 ± 0**		
Encosternum delegorguei		43.3	5.3	4.9	1.7	5.0	0.2	0.9		20.2	91.0		575.0	109.0	45.0	(Rumpold and Schlüter, 2013)
Encosternum delegorguei		35.2		4.9	1.7	7.6				20.2	91.0	46.0		109.0		(Teffo et al., 2007)
Hymenoptera (bees and ants)		**33.9 ± 9.2**	**7.7 ± 4.6**	**3.9 ± 0.1**	**4.1 ± 3.2**		**12.4 ± 0**	**3.2 ± 0**	**10.3 ± 0**	**17.8 ± 6.6**	**21.6 ± 6.3**	**7.5 ± 2.5**	**115.6 ± 9.6**	**7.8 ± 2.6**	**42.9 ± 4.7**	
Apis mellifera	Adult	21.0	2.0	3.8	2.2		12.4	3.2	10.3	25.2	15.4		125.5	5.2		(Banjo et al., 2006; Rumpold and Schlüter, 2013)
Carebara vidua	Adult	42.5	9.1		8,6					10.4	22.3	5.7	106.0	10.4	38.2	(Rumpold and Schlüter, 2013)
Componotus spp.	Adult	40.1	14.1		9.6											(Mbah and Elekima, 2010)
Oecophylla longinoda	Adult	37.8	12.3		7.3											(Mbah and Elekima, 2010)
Crematogaster mimosa	Adult				1.7					17.7	32.6	11.1				(Christensen et al., 2006)
Carebara vidua Smith	Adult	40.8	6.9	3.9	1.6					10.7	22.2	5.7	106.0	10.4	47.5	(Ayieko et al., 2012)
Apis mellifera	Adult	21.0	2.0	3.8	2.2		12.4	3.2	10.3	25.2	15.4		125.0	5.2		(Banjo et al., 2006)
Lepidoptera (caterpillars)		**46.3 ± 21.7**	**5.9 ± 5.4**	**29.3 ± 36.5**	**4.6 ± 2.2**	**18.0 ± 13.0**	**3.1 ± 0.2**	**1.7 ± 0.6**	**2.8 ± 1.0**	**15.4 ± 22.2**	**9.4 ± 2.3**	**10.6 ± 2.2**	**320.7 ± 367.9**	**18.9 ± 45.5**	**18.3 ± 14.8**	
Anaphe venata	Larvae	60.0	3.2	3.3			3.1	1.3	2.2	2.0	8.6		100.5	1.6		(Rumpold and Schlüter, 2013)

Scientific name	Stage of consumption	Protein (%)	Crude fibre (%)	Moisture (%)	Ash (%)	Carb (%)	Vitamin A (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Fe (mg/100 g)	Ca (mg/100 g)	Zn (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)	Fats (mg/100 g)	Reference
Anaphe infracta	Larvae	20.0	2.4	2.7			3.0	2.0	4.5	1.8	8.6		113.3	1.0		(Banjo et al., 2006; Rumpold and Schlüter, 2013)
Anaphe recticulata	Larvae	23.0	3.1	3.2			3.4	2.0	2.2	2.2	10.5		102.4	2.6		(Banjo et al., 2006; Rumpold and Schlüter, 2013)
Cirina forda	Larvae	20.2	1.8	4.4			3.0	2.2	2.0	64.0	15.4	8.6	110.0	1.9		(Banjo et al., 2006; Rumpold and Schlüter, 2013)
Imbrasia epimethea	Larvae	73.1		79.8						13.0		11.1	402.0		12.4	(Banjo et al., 2006)
Imbrasia obscura	Larvae	62.3		83.0											12.2	(Lautenschläger et al., 2017a)
Gonimbrasia (*Nudaurelia*) *alopia*	Larvae	62.3		85.7											1.9	(Lautenschläger et al., 2017a)
Gonimbrasia (*Nudaurelia*) *dione*	Larvae															(Lautenschläger et al., 2017a)
Pseudantheraea discrepans	Larvae	48.9		72.2											21.3	(Lautenschläger et al., 2017a)
Anaphe panda	Larvae	53.2		83.4											55.0	(Illgner and Nel, 2000; Rumpold and Schlüter, 2013)
Cirina butyrospermi	Larvae	62.7	5.0		5.1					13.0						(Anvo et al., 2016)

Scientific name	Stage of consumption	Protein (%)	Crude fibre (%)	Moisture (%)	Ash (%)	Carb (%)	Vitamin A (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Fe (mg/100 g)	Ca (mg/100 g)	Zn (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)	Fats (mg/100 g)	Reference
Gonimbrasia belina	Larvae	55.3	16.0		8.3	8.2				31.0		14.0	543.0	160.0		(Musundire et al., 2016; Rumpold and Schlüter, 2013)
Gynanisa maia	Larvae	51.1	16.2		7.7	14.1									16.4	(Musundire et al., 2016)
Loba leopardina	Larvae	25.8	14.7		6.6	40.2									12.6	(Musundire et al., 2016)
Imbrasia macrothyris	Larvae	75.4														(Illgner and Nel, 2000)
Nudaurelia macrothyrus	Larvae	75.4														(Illgner and Nel, 2000)
Gonimbrasia richelmanni	Larvae	79.6														(Illgner and Nel, 2000)
Cirina spp.	Larvae									64.0	7.0	8.6	1090.0	32.4		(Akinnawo and Ketiku, 2000)
Cirina butyrospermi	Larvae	62.7			5.0								1160.0		14.3	(Anvo et al., 2016)
Hemijana variegata Rothschild,	Larvae		8.3	5.9	5.2	9.5										(Egan et al., 2014)
Anaphe infracta	Larvae	20.0	2.4	2.7	1.6		3.0	2.0	4.5	1.8	8.6		111.3	1.0		(Banjo et al., 2006)
Anaphe recticulata	Larvae	23.0	3.1	3.2	2.5		3.4	2.0	2.2	2.2	10.5		102.3	2.6		(Banjo et al., 2006)
Anaphe spp.	Larvae	18.9	1.7	2.5	4.1		2.8	0.1	3.2	1.6	7.6		122.2	1.0		(Banjo et al., 2006)
Anaphe venata	Larvae	25.7	2.3	3.3	3.2		3.1	1.3	2.2	2.0	8.6		100.5	1.6		(Banjo et al., 2006)
Orthoptera (grasshoppers, and crickets)		**39.8 ± 21.1**	**6.4 ± 4.8**	**3.5 ± 1.7**	**5.5 ± 4.0**	**26.8 ± 14.5**	**3.0 ± 3.5**	**0.2 ± 0.4**	**2.9 ± 4.0**	**120.1 ± 298.8**	**17.3 ± 15.8**	**91.1 ± 99.8**	**119.7 ± 12.7**	**2.8 ± 3.8**	**20.8 ± 18.9**	

Scientific name	Stage of consumption	Protein (%)	Crude fibre (%)	Moisture (%)	Ash (%)	Carb (%)	Vitamin A (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Fe (mg/100 g)	Ca (mg/100 g)	Zn (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)	Fats (mg/100 g)	Reference
Brachytrupes membranaceus	Adult	53.4	15.0	3.4	6.0	15.1	0.0	0.0	0.0	0.7	9.2		126.9	0.1	53.0	(Musundire et al., 2016; Rumpold and Schlüter, 2013)
Cytacanthacris naeruginosus unicolor	Adult	12.1	2.1	2.6			1.0	0.1	1.0	0.4	4.4		100.2	0.1		(Banjo et al., 2006; Rumpold and Schlüter, 2013)
Zonocerus variegatus	Adult	26.8	2.4	2.6			6.8	0.1	8.6	910.0	42.2		131.2	8.2		(Banjo et al., 2006; Rumpold and Schlüter, 2013)
Gryllotalpa africana	Adult	22.0	7.5		12.6	47.2									10.8	(Musundire et al., 2016)
Henicus whellani	Adult	53.6	10.6		14.0										4.3	(Musundire et al., 2014)
Cartarrtopsilus taeniolatus	Adult	40.6	13.3		6.9											(Mbah and Elekima, 2010)
Zulua cyanoptera	Adult	33.7	13.3		6.6											(Manditsera et al., 2019)
Ornithacris turbida	Adult	42.7	2.0		4.5	18.2									2.0	(Musundire et al., 2016)
Ruspolia differens	Adult	72.7	6.3		4.6			1.2	0.1	13.0	24.5	12.4	121.0	33,1	46.2	(Rumpold and Schlüter, 2013)
Anacridium melanorhodon melanorhodon (Walker)	Adult	66.2	8.4	7.5											12.4	(Elhassan et al., 2019)
Zonocerous variegatus	Adult	62.7	3.6		1.2		8.9	0.1	9.8		2.0	29.0				(Banjo et al., 2006)

Brachytrypes membranaceus L	Adult															(Adeyeye and Awokunmi, 2010)
Zonocerous variegatus	Adult	26.8	2.4	2.6	1.2					2.0	42.2		131.2	8.2		(Banjo et al., 2006)
Brachytrupes spp.	Adult	65.4			4.9					33.6		232.0			16.9	(Akullo et al., 2018)
Brachytrupes spp.	Adult	6.3	1.0	3.4	1.8		0.0	0.0	0.0	0.7	9.2		126.9	0.1		(Banjo et al., 2006)
Cytacanthacris aeruginosus unicolor	Adult	12.1	1.5	2.6	2.1		1.0	0.1	1.0	0.4	4.4		100.2	0.1		(Banjo et al., 2006)
* Recommended daily intakes (mg/day) for adults										45.0	7.5–58.8	1300.0	3.0–14.0	700.0	220–260	(Christensen et al., 2006)

Note the mineral abbreviations are Fe: iron; Zn: zinc; Ca: Calcium; P: Phosphorus; Mg: Magnesium. * Source (Christensen et al., 2006). Mean ± standard deviation of insects belonging to the same insect order are highlighted in bold and species names are in italics.

Edible insects are widely consumed in Africa, and play an important role in nutritious diets. However, the preference and consumption of insects vary with species and orders. Lepidoptera caterpillars were the most consumed order, and they are the most preferred species because of their nutritional value, they are rich in protein, fats, and essential micronutrients (Rumpold and Schlüter, 2013, 2015). In addition, several caterpillar species play an important role in income generation in rural areas in southern Africa, Uganda, and Nigeria (Agea et al., 2008; Kelemu et al., 2015; Rahman et al., 2018).

Studies from western and Central Africa indicated that *Rhynchophorus phoenicis* (palm weevil), and *Cirina forda* (pallid emperor moth) were the commonly consumed species (Agbidye and Nongo, 2009; Alamu et al., 2013; Kelemu et al., 2015). The palm weevil and pallid emperor moth are a delicacy in western and Central Africa, and, in addition, these species were of economic importance in Nigeria, Cameroon, Benin, and Ghana (Muafor et al., 2014). In southern Africa, the literature indicates that the most consumed or preferred species were *Gonimbrasia belina* (mopane worm), *Macrotermes natalensis*, *falciger*, and *bellicosus* (termites) (Teffo et al., 2007; Dube et al., 2013; Musundire et al., 2014). While in eastern Africa, the most consumed species were *Ruspolia nitidula* and *differens* (grasshoppers), (Agea et al., 2008; Kinyuru et al., 2013; Rutaro et al., 2018). Mopane worms, and termites are an important part of food culture in different ethnic groups in southern Africa (Kinyuru et al., 2013; Kelemu et al., 2015). Moreover, the trade of mopane worms and termites plays an important role in rural food security and income generation, as it provides rural people with household income (Teffo et al., 2007; Dube et al., 2013; Muafor et al., 2014; Musundire et al., 2014; Netshifhefhe et al., 2018).

Edible insects are a good source of protein content, which ranges from 12–79% of dry matter, which is consistent with studies from China, Germany, and Asia (Chen et al., 2009; Rumpold and Schlüter, 2013). The protein content reported in edible insects is higher than protein found in chicken (43%) or beef (54%) (Teffo et al., 2007; Blásquez et al., 2012). The high protein content found in edible insects could help to combat protein deficiency in Africa. Protein deficiency is a major contributor to human malnutrition (Henley et al., 2010), and, in Africa, protein deficiency is the most common form of malnutrition, which needs to be addressed to halt starvation (de Onis and Branca, 2016). Therefore, including edible insects in daily diets might help reduce malnutrition rates.

Moisture content ranged from 1–7.5%, which is relatively low, such that most edible insects have longer preservation periods, and the risk of microbial deterioration and spoilage is minimal (Jonathan, 2012; Siulapwa et al., 2012; Bhattacharyya et al., 2018). Unlike beef or chicken, which are prone to decay (unless refrigerated), edible insects can be stored for longer periods, especially during the dry season when food shortage is higher (Jonathan, 2012). However, three caterpillars (*Gonimbrasia* (Nudaurelia) *alopia*, *Anaphe panda*, and *Pseudontheraea discrepans*) had higher moisture (>60%), meaning they are prone to spoilage and their preservation period is shorter unless processed in some manner. Siulapwa et al. (2012) reported similar results, where caterpillars *Gonimbrasia belina* and *Gynanisa maja* had higher moisture content than other species. To increase shelf life, caterpillars are usually degutted, washed in boiling salt water, or roasted before drying in the sun, then packed in large sacks and containers (Mutungi et al., 2019; Nyangena et al., 2020).

Edible insects contain fat content ranging from 1–67%. The fat content of edible insects is higher in the larval stage. For example, a palm weevil, which is a beetle larva that is consumed as a delicacy in western Africa, contained the highest fat content of 67%. These results are consistent with Bukkens (1997), who reported that Lepidopteran caterpillars and palm weevil larvae contain higher fat than any other insect species. Edible insects can be used to provide essential fatty acids required by the human body (Chen et al., 2009; Kewuyemi et al., 2020). In addition, fat plays an important role in providing the human body with energy, which means that consuming insects such as *Rhynchophorus phoenicis*, *Gonimbrasia belina*, *Anaphe panda*, and *Brachytrupes membranaceus*, may help provide people with energy, thereby reducing malnutrition associated with energy deficiencies in developing countries (Chen et al., 2009; Van Huis, 2016; Akhtar and Isman, 2018).

Carbohydrates play a very important role in human nutrition as they are the primary source of energy. Carbohydrates found in edible insects varied from 5–51% (Kouřimská and Adámková, 2016; Adámková et al., 2017). Therefore, edible insects can be used as a source of carbohydrates, as they contain relatively high amounts of polysaccharides, which play an important role in enhancing the immune system of the human body (Chen et al., 2009). In addition, carbohydrates are an essential nutritive element in the human body (Siulapwa et al., 2012). Species such as *Oryctes monoceros* and *Gryllotalpa africana*, reported in the current study, contained a high amount of carbohydrates; therefore, edible insects can be included in human diets to provide a good source of carbohydrates (Siulapwa et al., 2012).

Excellent source of iron and zinc found in some edible insects indicate that edible insects could be used to combat malnutrition deficiencies such as zinc and iron deficiency anemia, which is prevalent in Africa (Christensen et al., 2006). Species such as *Zonocerus variegatus*, *Pseudacathotermes spinige*, and *Macrotermes herus* contained high iron content of 910, 332, and 161 mg/100 g respectively, which means that these species can be used as a good source of Iron. Zinc content was notably high in insects such as *Zonocerous variegatus* (29 mg/100 g) and *Rhyncophorus phoenicis* (26.5 mg/100 g) the zinc content found in these insects exceed the daily recommended intake of 3.0–14 mg/100 g. Rumpold and Schlüter, (2013) reported that iron and zinc content found in edible insects is generally higher than the zinc and iron content found in pork, beef, or chicken; therefore, edible insects might be a solution in fighting Iron and zinc deficiency. Zinc and iron deficiency are one of the health problems faced by many women of reproductive age and children in developing countries (Christensen et al., 2006). Therefore, consumption of edible insects might provide a solution to Iron deficiency health problems, such as anemia, reduced physical activity, and maternal mortality (Christensen et al., 2006; Mwangi et al., 2018)

Edible insects reported in the current study contained a low amount of Vitamin A, B2, and C. The 100 g dry matter of edible insects reported in this study did not contain enough daily recommended Vitamin A (500–600 mg) or C (45 mg). As such, Chen et al. (2009)reported that to meet the daily recommended amount of Vitamin C, insect tea derived from the excrement of insects is an option. This tea contains up to 15.04 mg of Vitamin C per 100 g, and the consumption of 300 mL of insect tea per day makes 45 mg of Vitamin C, which is the daily recommended amount of vitamin C for adults (Chen et al., 2009). Contrary to findings reported in this study, Bukkens (1997) reported that Vitamin B1, B2, and B3 content found in an edible house fly is richer than the Vitamin B1, B2, and B3 found in chicken, beef, or salmon. In addition, edible crickets contain twice more Vitamin B12 than the beef (Akhtar and Isman, 2018). Igwe et al. (2012) found that *Microtermes nigeriensis* contain a favourable high source of Niacin, Thiamine, Vitamin A, and C. Vitamins play an important role in human nutrition, as Vitamin C is important for human growth, development, and repair of various body tissues (Arigony et al., 2013). The excellent source of Vitamins found in some edible insects shows that insects have a great potential of being used as a healthy food supplement for malnourished people, or to prevent malnutrition (Alamu et al., 2013).

There were several limitations to this review, which included studies reported in English only and excluded studies published in other languages used in Africa. There were significant gaps in data available on the nutritional composition of edible insects consumed in Africa. Most publications focused on a single macronutrient content, especially protein, carbohydrates, fats and fibre, and other nutrients, especially minerals, are not included in analyses. In addition, research focused on reporting the nutritional composition of economically important species such as *Gonimbrasia belina*, *Macrotermes natalensis*, *bellicosus* and *falciger*, *Rhynchophorus phoenics*, and *Cirina forda*. Strengths of this review incudes the robust approach to combine the nutritional composition of consumed insects in Africa, previous studies have focused on documenting the nutritional composition of single, or a group of, insects that are consumed in Africa.

This review reported combined nutritional data of consumed insects in Africa; this information can be useful to policy makers in the health and nutrition sector by including insects in food and nutrition policies. Health officials need to motivate people to include insects in their daily diets, particularly the most vulnerable groups such as elderly people, women, and children, with the aim to improve the quality of life for people. In addition, farming and rearing of insects by the agricultural sector need to be adopted to ensure that insects are easily accessible and available all year even when they are out of season in nature. Insects can be included as an ingredient in other food products such as bread, maize powder, chocolate, and biscuits to overcome discomfort and fear associated with eating whole insects in some groups of people. Future studies are required to research sustainable ways of farming and rearing insects in Africa and the implication that might have on the environment.

2.4. Conclusions

Meeting global food demand and halting poverty in Africa are among the greatest challenges, and these challenges are expected to continue if sustainable and innovative measures are not put into place. In 2017, approximately 256 million people were reported to be undernourished in Africa (FAO, 2019). There is no doubt that Africa is far from achieving Sustainable Development Goal 2, which is to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture by 2030. Edible insects are widely consumed in Africa, and they play an important socio-economic role for rural communities in Africa, by providing nutritious diets (this review), and income opportunities to traders and harvesters (Agea et al., 2008; Baiyegunhi et al., 2016; Netshifhefhe et al., 2018). In addition, edible insects are a traditional delicacy, and are used as an emergency food source during times of food shortage (Muafor et al., 2014). They are rich in protein, carbohydrates, amino acids, and micronutrients such as zinc and iron. This implies that edible insects have a potential of contributing in sustainable diets, while assuring food security, and improving livelihoods of African people.

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CHAPTER 3: INDIGENOUS KNOWLEDGE ABOUT CONSUMPTION OF EDIBLE INSECTS IN SOUTH AFRICA

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Abstract

Consumption of edible insects is an indigenous practice that has played an essential role in human nutrition across Africa. The traditional use of insects forms an important part of food culture in Africa, and insects are consumed either as a delicacy, emergency, or staple source of food. However, indigenous knowledge about insect consumption is being lost because recent generations have adopted western methods and paid less attention to traditional practices. We conducted 500 questionnaires in five local municipalities in Kwazulu-Natal (KZN), and 122 questionnaires in four local municipalities in Vhembe district in Limpopo, South Africa, to document indigenous knowledge about edible insects' consumption, collection, and preparation methods used in Limpopo and KZN. Eight insect species belonging to five insect orders were used as food in Limpopo and KZN, with mopane worms (94%) and termites (70%) being the most preferred species by respondents in Limpopo and KZN, respectively. Ninety-five percent of the respondents occasionally consumed insects in Limpopo, while only 28% did so in KZN. Nutritional benefits and tradition were the main reasons for consuming insects. Edible insects are a nutritious diet and play an important role in people's livelihoods in rural areas. However, there was a notable decline in entomophagy, particularly in KZN. The decline may be related to occidental acculturation, discomfort associated with eating insects, and declining insect availability. To promote entomophagy, the authorities should encourage people to include edible insects in their diets because of their nutritional value. In addition, edible insect flour should be incorporated in food products such as biscuits, bread, energy bars, cereal, and cookies to promote acceptability.

Keywords: edible insects; entomophagy; nutritional benefits; mopane worm; termites

3.1 Introduction

Entomophagy is an ancient indigenous practice that has played a significant role in human nutrition around the world (Fasoranti and Ajiboye, 1993; Raheem et al., 2019). Edible insects are an important protein source, and their consumption plays an important role in food security and improving rural livelihoods (Fasoranti and Ajiboye, 1993; Muafor et al., 2014; Manditsera et al., 2018; Hlongwane et al., 2020). They are consumed as a traditional food in different regions, including Latin America (Costa-Neto, 2015), China (Chen et al., 2009; Feng et al., 2018), Thailand (Hanboonsong et al., 2013; Raheem et al., 2019), Mexico (Ramos-Elorduy and Pino Moreno, 2002; Hurd et al., 2019), Japan (Nonaka, 2009; Payne, 2015), and Africa (Quin, 1959; Teffo et al., 2007; Ghally, 2009; Alamu et al., 2013; Dube et al., 2013; Obopile and Seeletso, 2013; Anankware et al., 2016; Musundire et al., 2016; Niassy et al., 2016). The traditional use of insects as food in these countries is not a new practice, as it dates back as far as the history of mankind (Ramos-Elorduy and Pino Moreno, 2002; Payne, 2015; Hurd et al., 2019). However, consumption of insects is not well accepted in western countries and still remains unexplored, because of barriers such as fear and disgust associated with eating insects (Yen, 2009; Balzan et al., 2016; Sogari et al., 2017; Mancini et al., 2019). In addition, in developed countries, eating insects is considered primitive, unclean, or food of the poor (Balzan et al., 2016). In Africa, approximately 500 species of insects are used as food in different countries (Kelemu et al., 2015; Hlongwane et al., 2020). On this continent, edible insects are consumed either as a staple, an emergency food source during times of food shortage, or an important delicacy (Agea et al., 2008; Niassy et al., 2016a). Consumption and preference of edible insects differ geographically (Niassy et al., 2016a). For example, some people prefer consuming insects, either fried, roasted, or raw, and others may find eating insects disgusting (Nonaka, 2009; Hlongwane et al., 2020). In some African countries, certain species are only consumed in one region and are of traditional importance; for example, stink bugs (Hemiptera: Tessaratomidae) are only consumed and are a delicacy for the vhaVenda people in the Limpopo province of South Africa (Teffo et al., 2007).

In South Africa, edible insects have formed part of the human diet since prehistoric times; for example, Ledger (1971) reported that South Africans consumed *Trinervitermes trinervoides* (a termite) and *Apis mellifera* unicolor (a honeybee) in early 100,000 BCE. In addition, Quin (1959) and Bodenheimer, (1951) reported an ongoing consumption of edible insects for nutritional benefits by the baPedi people in South Africa in the early 1950s. Nowadays, in South Africa, edible insects are mostly consumed in Limpopo province by vhaVenda, baPedi, and

Vatsonga people (Teffo et al., 2007; Nonaka, 2009; Netshifhefhe et al., 2018). In addition, they are also consumed in Mpumalanga, KwaZulu-Natal (Shackleton et al., 2002), North West, and Gauteng (Teffo et al., 2007). The groups of edible insects consumed in South Africa are various Lepidopteran caterpillars, termites, grasshoppers, jewel beetles, ants, and stink bugs (Ledger, 1971;Teffo et al., 2007; Makhado et al., 2009; Nonaka, 2009). Edible insects are an important natural resource available to vulnerable people and provide earning opportunities to traders and harvesters (Makhado et al., 2009; van Huis, 2015; Mmari et al., 2017; Netshifhefhe et al., 2018; Sekonya et al., 2020). In addition, edible insects play an important role in food security, rural livelihoods, and poverty eradication (Makhado et al., 2009). For example, Makhado et al. (2009) reported that trading edible insects results in an income of approximately US$202,915 per trader during one season. Edible insects create seasonal employment opportunities for unemployed people across southern Africa, reducing poverty and improving human wellbeing (Makhado et al., 2014; Netshifhefhe et al., 2018).

Malnutrition and food shortage are the major challenges experienced in developing countries (Bain et al., 2013). According to Vorster (2010), most people in South Africa are food-insecure and do not have access to nutritious food to meet their daily nutrient requirements. Edible insects are consumed because they are a nutritious traditional food source that has been used to supplement diets across Africa over many years (Niassy et al., 2016a). In addition, consumption of insects is good for human wellbeing, as the nutritional value of edible insects can help promote human health, and reduce the vulnerability to malnutrition of children, pregnant women, and older people (Belluco et al., 2013). Edible insects can also improve the well-being of vulnerable people living with malnutrition, child stunting, and macronutrient deficiencies (Meyer-rochow, 1975; Tao and Li, 2018; Gahukar, 2020; Parker et al., 2020).

Over the years, there has been a notable decrease in entomophagy in developing countries, particularly in urban areas (Dube et al., 2013; Manditsera et al., 2018). The younger generation, especially in urban areas, has little or no knowledge about insects' consumption (Manditsera et al., 2018). This is thought to result from people adopting western/modern food culture and, therefore, abandoning traditional practices such as entomophagy (Manditsera et al., 2018). Globalization and westernization have influenced what people eat (Yen, 2009). As a result, people are more reliant on western food, and they are more reluctant to try traditional food such as edible insects, as they are now perceived as dirt or a taboo (Meyer-rochow, 1975; Yen, 2009; Manditsera et al., 2018). This has led to several people being wary of accepting insects as food or even distancing themselves from consuming insects (Agbidye et al., 2009; Yen, 2009;

Manditsera et al., 2018). Yet, edible insects are rich in protein, carbohydrates, amino acids, and micronutrients, such as zinc and iron (Hlongwane et al., 2020).

Little attention has been paid to documenting indigenous knowledge on insects' consumption as an important traditional practice in South Africa (Mbabazi et al., 2012; Niassy et al., 2016b; Rahman et al., 2018). The traditional understanding of entomophagy among indigenous people is rich but restricted because it is orally passed through generations, and some has been lost in translation over the years (Egan, 2013; Raheem et al., 2019). Mostly, rural communities have no tools or resources to document their indigenous knowledge about practices that play an important role in their communities. As a result, indigenous knowledge is lost because recent generations have adopted western methods and paid less attention to traditional practices (Ngulube, 2002; Manditsera et al., 2018). Combining indigenous knowledge about entomophagy with scientific research will further improve the understanding of the role of edible insects as a food resource for people (Egan, 2013). In addition, documenting indigenous knowledge about edible insects will help promote and preserve entomophagy (Manditsera et al., 2018). The current study, therefore, aims to (1) document indigenous knowledge relating to the consumption patterns, methods, or techniques used in the collection, and preparation of insects in South Africa; (2) determine the most consumed or preferred insect species; (3) access the perception of edible insects; and (3) determine the factors influencing the consumption of edible insects in South Africa.

3.2. Materials and methods

3.2.1. Study Site

The study was conducted in villages at KwaZulu-Natal and Limpopo provinces, South Africa. In KwaZulu-Natal, sampling was conducted in five villages (Swayimane, Umbumbulu, Nhlazuka, Tugela Ferry, and Kokstad) of the uMshwathi, eThekwini, Richmond, uMsinga and Greater Kokstad local Municipalities, while in Limpopo, sampling was conducted in several villages of the Mutale, Makhado, Thulamela, and Musina local Municipalities of Vhembe District Municipality (see Appendix 3.1). In the villages surveyed, the population size ranged from 86 to 4099 in Limpopo and 2000 to 7903 in KwaZulu-Natal (KZN) (StatsSA, 2019; Department of Cooperative Governance and Traditional Affairs, 2020) (Table 3. 1). These villages were selected because consumption of insects mainly forms part of their tradition.

However, we are not undermining the other nearby or known villages in South Africa where edible insects' consumption is also practiced.

Table 3. 1. Population size of local municipalities surveyed in KwaZulu-Natal (KZN) and Limpopo provinces.

Municipalities	**Population Size**
Limpopo	
Makhado	416,728
Thulamela	497,237
Mutale	91,870
Musina	32,009
KZN	
UMshwathi	10,374
Richmond	65,793
UMsinga	160,000
Greater Kokstad	51,561
EThekwini	3,702,231

Adapted from (Department of Cooperative Governance and Traditional Affairs, 2020; StatsSA, 2019).

3.2.2. Questionnaires

Questionnaires made up of closed and open-ended questions were conducted in KZN (*n* = 500) in August 2019 and Vhembe district municipality (*n* = 122) in December 2019, by visiting local peoples' households to obtain their perspective on the subject of eating insects. The respondents were chosen randomly by approaching people door to door in their households (see Appendix 3.2). The KZN sample was larger as there was more variability in answers, and the villages were more extensive and further apart. Questionnaires were conducted through face-to-face interviews. Questions assessed respondents' knowledge about edible insects, ways of assessing insects, processing and preparing, reasons for eating insects, how often they consumed insects, the benefits of eating insects, and their attitude towards eating insects. In addition, respondents were asked to list the names of the insects consumed or used as food in their villages. Respondents were provided with pictures of different edible insects taken from the guide of insects of Southern Africa (Picker et al., 2008) and from the internet, to select the species consumed, or previously consumed, in their villages. In addition, as part of a separate study, we purchased edible insects from all the traders we interviewed in markets in Vhembe district, and these were used to identify the insects consumed. Questionnaires were written and presented by a first-language-speaking author using local languages isiZulu (KZN, ZTH) and

Tshivenda (TCM) in Vhembe district of Limpopo. Demographic information of the respondents who participated in the study in both provinces are presented in (Table 3. 2 and 3. 3)

Table 3. 2. Demographic information of the respondents in five local municipalities, KwaZulu-Natal (*n* = 500), South Africa.

Demographics	**KZN Overall (%)**	**Greater Kokstad**	**Richmond**	**uMshwathi**	**uMsinga**	**eThekwini**
Age category (years)						
Under 18	8	9	8	9	9	6
18–24 years	18	13	9	24	23	23
25–34	15	19	22	10	13	11
35–44	10.6	14	9	7	11	12
45–54	11.2	10	10	12	11	13
55–64	15.8	15	23	15	15	11
65–74	11.8	12	13	13	8	13
75 years and above	9	8	6	10	10	11
Sex						
Male	40	41	40	42	40	37
Female	60	59	60	58	60	63
Level of education						
No formal education	23	20	27	14	26	30
Primary education	37	39	44	34	33	34
Secondary education	32	26	26	44	32	33
Tertiary education	8	15	3	8	9	3
Occupation						
Unemployed	32	30	35	22	28	46
Self employed	11	9	15	12	13	6
Pensioner	32	34	37	34	25	29
Employed	15	18	8	19	21	10
Student	10	9	5	13	13	9

Table 3. 3. Demographic information of the respondents in four local municipalities in the Vhembe district, Limpopo province (n = 122).

Demographics	Limpopo Overall (%)	Thulamela	Makhado	Musina	Mutale
Age category (years)					
Under 18	9	0	9	1	1
18–24 years	16	7	6	4	2
25–34	23	16	7	4	2
35–44	12	5	6		4
45–54	13	11	4		1
55–64	13	8	4		2
65–74	11	9	4		2
75 years and above	4	3			2
Sex					
Male	48	28	18	5	7
Female	52	32	19	4	9
Level of education					
No formal education	7	7	1	1	
Primary education	14	11	2		4
Secondary education	57	24	32	6	8
Tertiary education	22	6	16	1	3
Occupation					
Unemployed	60	30	25	8	10
Self employed	18	13	6		3
Pensioner	17	11	7		3
Employed	5	3	2	1	

This study has been ethically reviewed and approved by the University of KwaZulu-Natal Human and Social Sciences Research Ethics Committee (approval number HSS/0125/019D) (see Appendix A1, A2, and A3). Permission to conduct research in various villages in all the local municipalities was obtained from community leaders. All participants provided informed consent to participate in the study, and data were anonymised, treated confidentially, and stored securely.

3.2.3. Data Analysis

Data from the questionnaires were coded and entered into an excel spreadsheet. A chi-square test of independence was used to determine if there were any significant differences in consumption pattern of edible insects across local municipalities. To determine if there were significant differences in factors influencing the choice to consume insects, a Generalized Linear Model (GLM) was used. Count data of respondents are presented in percentages. The GLM and chi-square test analysis were performed using IBM SPSS Statistics version 26 (SPSS Inc. Chicago, IL, USA).

3.3. Results

3.3.1. Insect Consumption Pattern

Eight species belonging to five insect orders were consumed as food in the Vhembe district and KZN (Table 3. 4). In KZN, termites were consumed consistently ($X^2{}_4 = 2.243$, $p = 0.619$) at about 70% of respondents across the five villages, while edible locust (6–40%) and *Cirina forda* (0–19%) were consumed less, with significant differences across the villages (locust: $X^2{}_4 = 59.313$, $p < 0.001$; *Cirina forda*: $X^2{}_4 = 44.457$, $p < 0.001$) (Table 3. 5).

Mopane worms were consumed consistently ($X^2{}_3 = 1.664$, $p > 0.05$) at about 94% of the respondents across villages in Limpopo, followed by termites (85%) and edible grasshoppers (84%) with no significant differences across villages (termites $X^2{}_3 = 12.475$, df = 3, $p < 0.05$; 11.407, df = 3, $p < 0.05$; edible grasshopper $X^2{}_3 = 11.990$, df = 3, $p < 0.05$), while *Encosternum delegorguei* (stink bug) (19%), *Gynanisa* caterpillar (18%), *Carebara vidua*. (15%), and Cicadoidea (1%) were consumed less, with no significant differences across villages (stink bug: $X^2{}_3 = 3.398$, $p > 0.05$); lepidopteran caterpillar: ($X^2{}_3 = 1.406$, 3$p > 0.05$), *Carebara vidua* ($X^2{}_3 = 0.72$, $p > 0.05$), and Cicadoidea spp. ($X^2{}_3 = 5.715$, $p > 0.05$) (Table 3. 6).

Table 3. 4. Traditional collection and preparation methods of the commonly consumed insects in KZN and Limpopo provinces of South Africa.

Insects Group	**Insect Order**	**Consumption Stage**	**Seasonality**	**Method of Collection**	**Collectors**	**Processing for Preservation Method**	**Cooking Method**
Gynanisa caterpillar	Lepidoptera	Larvae	November–January	Collected from the host plant	Women	Degutted, washed, boiled in salt water, and sun-dried	Fried, roasted, or as a relish
Mopane worms (*Imbrasia belina*)	Lepidoptera	Larvae	Nov–January; April–May	Collected from *Colophospermum mopane*	Women	Degutted, washed, boiled in salt water, and sun-dried	Fried, boiled without salt, boiled with salt, roasted, or as a relish
Termites (*Macrotermes* species)	Blattodea	Winged adult	September–January	Trapped in a large bowl of water near the light source	Women	Killed with boiling water, boiled, and sun-dried	Fried and roasted
Stinkbug (*Encosternum delegorguei*)	Hemiptera	Adult	May–August	Picked from woodlands	Women	Killed with warm water, cooked, and dried	Fried, roasted
Cirina forda	Lepidoptera	Larvae	Nov–Feb	Picked from the host tree	Women	Degutted, washed, boiled in salt water, and sun-dried	Fried, boiled, boiled with salt, roasted, or as a relish
Edible grasshopper/locust (*Locustana and Zonocerous* species)	Orthoptera	Adult		Picked from grassland	Women and children	Dewinged, degutted, killed in hot water and roasted	Fried, roasted
Carebara vidua	Hymenoptera	Adult	All year round	Picked from grassland	Women and children	Eaten raw	Eaten raw
Cicadoidea spp.	Hemiptera	Adult		Picked from grasslands		Killed with warm water, cooked, and dried	Fried, roasted

Table 3. 5. Percentage of respondents that consumed insects across five municipalities in KZN, South Africa.

Insects	Greater Kokstad	Richmond	uMshwathi	uMsinga	eThekwini	Average
Termites	74	72	65	67	70	70
Edible locust	6	6	34	40	19	22
Cirina forda	0	1	13	19	2	8

Table 3. 6. Percentage of respondents that consumed insects across four municipalities in Vhembe district in Limpopo, South Africa.

Insects	Thulamela	Makhado	Musina	Mutale	Average
Mopane worm	100	97	90	97	96
Termites	97	97	83	70	86
Gynanisa caterpillar	16	13	20	10	14
Stink bug	16.6	16.6	30	13	19
Edible grasshopper	97	97	76	73	85
Carebara vidua	16.6	13.3	20	13.3	15
Cicadoidea spp.	0	0	6.6	0	2

There were no significant differences in the number of people who have never consumed insects, the people who have consumed insects in their lifetime, and the people who still consume insects ($X^2_8 = 9.041$, $p > 0.05$) in KZN. However, there were significant differences in people who have never consumed insects, the people who have consumed insects in their lifetime, and those who still consume insects ($X^2_6 = 13.395$, $p < 0.05$) in Limpopo. A greater percentage of respondents reported having consumed at least one insect species in their lifetime in Limpopo (98%) compared to KwaZulu-Natal (64%), with 95% still practicing entomophagy in Limpopo compared to only 28% in KwaZulu-Natal. Thirty-five percent of KZN respondents reported that they used to consume insects (2% who cited that they used to consume insects in the past in Limpopo; the percentage is low because of the high number who currently consume). KZN had a greater number (36%) of respondents who had never consumed insects than in Limpopo (only 3%).

There were significant differences in factors affecting the choice to eat insects in KZN ($X^2_{15} = 35.233$, $p < 0.05$) and in Limpopo ($X^2_{19} = 35.145$, $p < 0.05$). In KZN, age ($X^2_7 = 23.764$, $p < 0.05$) and educational background ($X^2_4 = 11.208$, $p < 0.05$) were the factors that influenced the choice to eat insects, while in Limpopo, employment status ($X^2_3 = 10.913$, $p < 0.05$) and gender ($X^2_1 = 3.378, p < 0.05$) were the factors that influenced the choice to eat insects (Tables 3. 7 and 3. 8).

Table 3. 7. Factors affecting choice to consume insects in KZN, South Africa.

Factors	Chi-Square	df	*p* Value
Gender	1.080	1	0.299
Age	23.765	7	0.001
Educational background	11.208	3	0.011
Occupation	4.662	4	0.324

Table 3. 8. Factors affecting choice to consume insects in Limpopo, South Africa.

Factors	Chi-Square	df	*p* Value
Gender	3.738	1	0.053
Age	6.748	7	0.456
Educational background	2.014	3	0.570
Occupation	10.913	4	0.002

3.3.2. Reasons for Consuming Insects, or Not

Nutritional benefits of insects and traditional beliefs were the primary reason for practicing entomophagy in KwaZulu-Natal (43% and 38%, respectively) and Limpopo (66% and 21%, respectively) (Figure 3. 1).

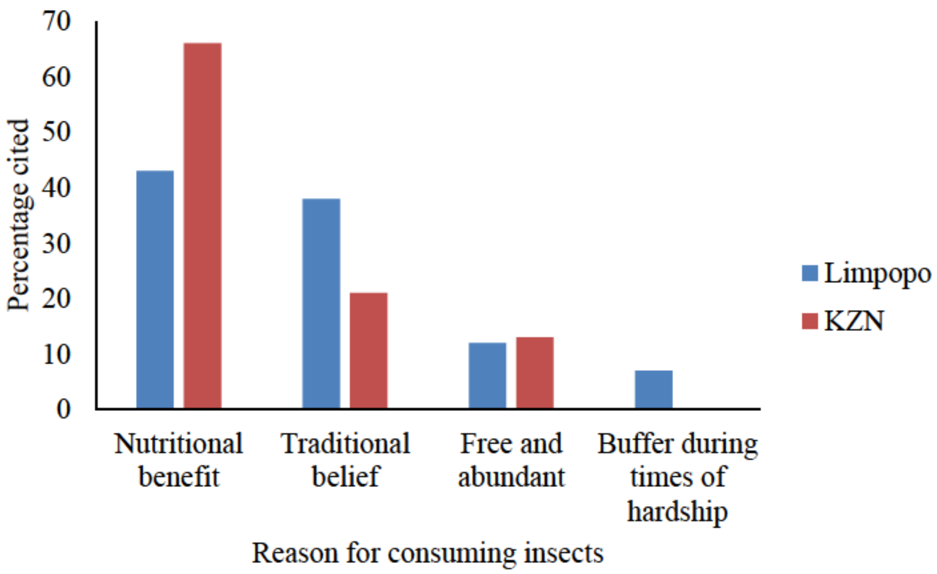

Figure 3. 1. Reasons for consuming insects in Limpopo and KZN provinces of South Africa.

The most cited reasons (36%) for not consuming insects in KZN were fear and discomfort associated with consuming insects, adoption of western food culture (27%), followed by a lack of knowledge about entomophagy (12%), and a decrease in the availability of edible insects in the wild (10%) (Appendix 3.3). In Limpopo, 3% of the respondents cited religious beliefs as a reason for not consuming insects. In comparison, only 2% cited dislike and discomfort associated with eating insects as a reason for stopping eating insects. Respondents did not include cost as a reason for not consuming insects, because in KZN, insects were collected from the wild, and in Limpopo, insects were also collected from the wild and sold for R20–R30 a cup in town.

There were significant differences in reasons for consuming edible insects among respondents of different genders (X^2_1 = 6.361, p = 0.012) and age group (X^2_7 = 78.308, p = 0.001); however, there were no significant differences in reasons for consuming edible insects among respondents with different educational backgrounds (X^2_4 = 2.567, p = 0.633) and employment status (X^2_4 = 1.635, p = 0.802) in KZN. In Limpopo, there were significant differences in reasons for consuming insects among respondents of different genders (X^2_1 = 10.215, p = 0.001), ages (X^2_1 = 44.568, p = 0.001), and employment status (X^2_3 = 30.850, p = 0.001). However, there were no significant differences in reasons for consuming insects among respondents with different educational backgrounds (X^2_3 = 4.746, p = 0.191).

There were significant differences in reasons for not consuming edible insects among different genders (X^2_1 = 5.213, p = 0.019), ages (X^2_7 = 15.967, p =0.025), and educational backgrounds (X^2_4 = 13.525, p = 0.009); however, there were no significant differences in reasons for not consuming insects among respondents with different employment status (X^2_4 = 1.366, p = 0.850) in KZN. On the other hand, there were no significant differences in reasons for not consuming edible insects among respondents of different genders (X^2_1 = 0.078, p = 0.780), ages (X^2_7 = 4.231, p = 0.753), educational backgrounds (X^2_3 = 0.559, $p > 0.906$), and employment status (X^2_3 = 2.246, $p > 0.523$).

3.3.3. Frequency of Consumption

There were no significant differences in insect consumption frequency across local municipalities in KZN (X^2_4 = 1.680, p = 0. 794). The majority (59–71%) of the respondents rarely consume insects (at least once a month), while fewer respondents (1–6%) consumed insects regularly (1–4 times a month) in KZN (Appendix 3. 4). The frequency of insect consumption did not differ significantly (X^2_9 = 15.317, p = 0.083) across local municipalities in Limpopo; 33–57% of the respondents consumed insects occasionally while only 24–40% consumed insects at least once a month (Appendix 3. 4)

There were significant differences in frequency of edible insect consumption among different genders ($X^2_1 = 6.980$, $p = 0.008$) and ages ($X^2_7 = 70.704.$, $p = 0.001$); on the other hand, there were no significant differences in frequency of edible insect consumption among respondents with different educational backgrounds ($X^2_4 = 2.970$, $p = 0.563$) and employment backgrounds ($X^2_4 = 0.748$, $p = 0.945$) in KZN. There were no significant differences in frequency of edible insect consumption among different genders ($X^2_1 = 0.020$, $p = 0.928$), ages ($X^2_7 = 0.028$, $p > 0.05$), educational backgrounds ($X^2_3 = 0.034$, $p > 0.05$), and employment status ($X^2_3 = 0.048$, $p > 0.05$) in Limpopo.

3.3.4. Preparation and Collection Methods

Seasonal availability, collection, and preparation methods of edible insects differed from one species to another (Table 3. 4). All respondents collected insects from the wild in KZN, while almost half in Limpopo bought insects from towns (46% from Elim, Sibasa, Louis Trichardt, Makhado-Biaba, and Tshakhuma markets, or Thohoyandou). All the insects consumed are collected from the wild and are not reared for consumption. *Gynanisa* caterpillars and termites were abundant in the rainy season (from October to January), while stink bugs occurred in the dry season from May to August.

Edible insects are mainly collected in the wild mainly by women and they are prepared using different methods (Table 3. 4). They are eaten either fried, boiled, roasted, sun-dried, or as a relish (Table 3. 4). A greater number of respondents preferred sun-dried (62%) edible insects in Limpopo, while fried or roasted edible insects were the most preferred (88%) cooking method in KwaZulu-Natal.

3.4. Discussion

Entomophagy is an important traditional practice in Africa’s different regions (Niassy et al., 2016b; Manditsera et al., 2018). The current study reported a greater number of respondents consuming insects in their lifetime in Limpopo (98%) and KwaZulu-Natal (64%). These results are similar to those of Shackleton et al. (2002). They reported that 96.3% of the respondents in Ha-Gondo village, 55 km east of Thohoyandou in Limpopo, used insects as food; by comparison, 67.8% of the respondents in KwaJobe village in northern KwaZulu-Natal used insects as food. These results indicate that entomophagy is a common practice in South Africa. In addition, Egan (2013) reported that 90.5% of the respondents consume insects in Blouberg

Municipality in Limpopo. According to Teffo et al. (2007), the consumption of insects in South Africa is more prevalent in Limpopo, Gauteng, North West, and Mpumalanga provinces. Across African countries, Zimbabwe (Dube et al., 2013; Manditsera et al., 2018), Angola (Lautenschläger et al., 2017), Tanzania (Mmari et al., 2017), Nigeria (Banjo et al., 2006), and Botswana (Obopile and Seeletso, 2013) have been reported to consume edible insects. However, Ethiopia is one exception, because religious beliefs prohibit the consumption of insects, and only 1% of people interviewed were prepared to accept insects as a human food (Ghosh et al., 2020).

However, the consumption of insects may be declining in some areas, as reported in the current study; only 28% still consume insects in KwaZulu-Natal. According to Dobermann et al. (2017), the consumption of insects seems to be declining because of the spread/adoption of western food choices, and the association of insects with fear and discomfort when it comes to eating them. In addition, the way of living is constantly changing, and is being influenced by modern technology and education, resulting in people neglecting traditional practices that formed part of their lifestyle in the past (Ngulube, 2002; Barennes et al., 2015). Documenting indigenous knowledge about edible insects will preserve long-standing traditional knowledge about edible insects that can help influence planning and decision-making on the sustainable use of insects as a nutritious food that can ensure food security for people in developing countries (Ngulube, 2002; Adebayo et al., 2011).

The choice not to eat insects is primarily influenced by preference, availability of insects, and consumer acceptance (Awobusuyi et al., 2020). Findings from the current study revealed that religion (for example, the "African-initiated church" such as the Zionist churches) and fear associated with consuming insects were the main reasons influencing the decision not to eat insects. According to van Huis (2013), the consumption of insects is perceived as unholy, dirty, and unhealthy by some people, particularly in developed countries. For example, Balzan et al. (2016) reported that, in Italy, respondents associated insect meals with dirt and food contamination. In addition, Netshifhefhe et al. (2018) found that 80.7% of the respondents in Limpopo cited that some religions are against the consumption of insects, especially traditional churches. Culture plays a significant role in determining acceptance and preference of edible insects. For example, *Zonocerous* spp (a grasshopper) is consumed as food in Cameroon, Nigeria, and South Africa, but the same species is considered poisonous elsewhere (Ghosh et al., 2018). In addition, cultural beliefs influence how insects should be prepared before consumption (Ghosh et al., 2018). Religious and gender-based taboos also govern the consumption of insects in some regions. For example, religion and customs prohibit women of the Baganda tribe in Uganda from consuming nsenene (*Ruspolia differens*) (Mmari et al., 2017; Ghosh et al., 2018). There is a need to educate and raise awareness about the consumption of insects through media to promote and encourage people to adopt edible insects as foods, because insects are a sustainable nutritious food which has less impact on the environment (Barennes et al., 2015). In addition, incorporating insect powder into food products such as bread, biscuits, snack bars, cereal, porridge, and shakes might promote acceptance of insects as food (Awobusuyi et al., 2020).

Sociodemographic factors play a significant role in a person's choice to consume insects (Cicatiello et al., 2016). This study found that gender, age, occupation, and educational background were the main factors influencing the choice to eat insects. These results are similar to (Anankware et al., 2017), a study which found that gender, age, educational background, and occupation significantly influenced people's choice to consume insects in Ghana. Youth, educated, urban dwellers, and middle- and upper-class earners are highly influenced by western culture (Imathiu, 2020). As a result, they are adopting western diets and ignoring traditional food such as edible insects. There is a notable shift to adopting Western diets, and a decline in consumption of edible insects, particularly by youth and educated people (Imathiu, 2020). This might be the main reason why the consumption of insects is largely practiced in rural areas where high levels of unemployment and people with no formal education are found. In addition, people who are unemployed consume edible insects more because they have to do so to meet nutritional requirement needs.

Eight insect species belonging to five insect orders were used as food in Limpopo and KZN. These results are similar to Obopile and Seeletso's (2013) findings, who reported that insects belonging in six insect orders were used as food in Botswana. Contrary to this, Makhado et al. (2009) reported that insects belonging in four insect orders were used as food in Greater Giyani Municipality, Limpopo. This suggests that the consumption pattern and preference of insects vary from place to place (Séré et al., 2018). According to Raheem et al. (2019), insects and preference consumption varies from country to country, and variations can be observed between ethnic groups in different countries. The variation in the number of insects consumed in different countries is attributed to the availability and occurrence of edible insects in the wild (Ghosh et al., 2018). Differences in geographic area and environmental conditions influence the occurrence of different species; for example, mopane worm (*Imbrasia belina*) occurs in mopane woodlands in Southern Africa and is mostly used as food in this region (Baiyegunhi et al., 2016b).

Mopane worms and termites were the most preferred and consumed insects in Limpopo and KwaZulu-Natal, respectively. Kelemu et al. (2015) reported that mopane worms and termites are the most consumed species in Southern Africa. In addition, they are a popular traditional food in many cultures in Southern Africa (Baiyegunhi et al., 2016a; Netshifhefhe et al., 2018). According to (Baiyegunhi et al., 2016a), mopane worms are occasional delicacies for different cultures in South Africa. Edible insects are valued natural resources that people collect for food and income in rural areas; they are used as a food security safety net in rural areas where poverty and malnutrition are major problems (Makhado et al., 2009; Baiyegunhi et al., 2016a, 2016b).

This study found that edible insects are consumed because of their nutritional value and they contribute to nutritional diets in rural areas. Similar results were reported by several previous studies (Teffo et al., 2007; Manditsera et al., 2018; Netshifhefhe et al., 2018). Netshifhefhe et al. (2018) conducted a study looking at the human uses and indigenous knowledge of edible termites in Vhembe district, Limpopo province, South Africa, and found that the majority of the respondents consumed edible termites for their nutrition and to enhance their health. Similarly, Manditsera et al. (2018)conducted a study on consumption patterns of edible insects in rural and urban areas in Zimbabwe and found that the primary motives for consuming insects in rural and urban areas were nutrition and taste of edible insects. Food shortage and malnutrition are prevalent challenges experienced in rural communities in Southern Africa (Bain et al., 2013). Edible insects play an important role in supplementing diets in poor communities across Africa (Niassy et al., 2016b); in addition, edible insects are used to ease food shortages and provide vulnerable communities with nutritious diets that improve human health and wellbeing (Meyer-rochow et al., 2008; Food and Argriculture Organization of the United Nations, 2013).

Climate change is a global problem that reduces precipitation and increases the extended drought in Southern Africa (Mataboge et al., 2016; Ndlovu et al., 2019). These changes have resulted in the decline of insect availability in the wild (Ayieko et al., 2010; Mataboge et al., 2016). Other factors that might affect the availability of edible insects are different land uses such as clearing of land, development, agriculture, and deforestation (Food and Argriculture Organization of the United Nations, 2013; van Huis, 2013; Ndlovu et al., 2019). Ndlovu et al. (2019)reported that 40% of the respondents in Zimbabwe cited that the cutting down of mopane trees for fuel use resulted in the decline in mopane worm yields. The decline in the availability of insects affects rural livelihoods and the well-being of the people who depend on insects for food and cash income (van Huis, 2013; Mataboge et al., 2016). In addition, this affects the nutrition security of rural populations. Interventions to increase insect yields are required. This can be done by farming and rearing to make insects easily available to people, particularly in vulnerable communities (Food and Argriculture Organization of the United Nations, 2013; van Huis, 2013; Mataboge et al., 2016). In addition, because of their nutritional value, insects can be used as nutritious food alternatives to mainstream animal protein such as pork, chicken, beef, and fish (van Huis, 2013; Food and Argriculture Organization of the United Nations, 2013; Mataboge et al., 2016; Akhtar and Isman, 2018).

Insects are mainly harvested in the wild by women. According to (Dzerefos et al., 2013; 2014) insects collection and preparation are primarily female-driven tasks, with more than 70% (in the current study) of females involved in insects harvesting in Limpopo province. Insect preparation and processing methods differ from species to species. The important step is removing unpalatable parts and degutting before washing (Narzari and Sarmah, 2015; Mutungi et al., 2019). After washing, insects are then boiled or roasted, then sundried to increase shelf life (Akullo et al., 2018; Nyangena et al., 2020). According to Agea et al. (2008), sun-drying insects extend the availability of insects and allows traders to have products for a longer period, even when the period of occurrence of insects has passed.

This study reported that edible insects are incorporated in regular diets and they are eaten fried, boiled, roasted, dried, or as a relish. Similar findings were reported by other authors (Dube et al., 2013; Netshifhefhe et al., 2018; Manditsera et al., 2018, 2019). They found that edible insects are eaten fried, boiled, dried, or as a relish. However, in some parts of Africa, edible insects are smoked or eaten raw without preparation (Kouřimská and Adámková, 2016; Séré et al., 2018). Tradition and culture influence cooking methods of edible insects. People prepare insects based on the knowledge that has been passed down from older generations; for example, in Limpopo province, South Africa, *Encosternum delergorguei* (stink bug) is eaten either fried or raw, while in Zimbabwe, the same species is eaten fried or dried but not raw (Teffo et al., 2007; Dube et al., 2013). In addition, some tribes prohibit the consumption of raw edible insects; in Uganda, the Baganda tribe customs and tradition prohibit the consumption of raw *Ruspolia differens* (Mmari et al., 2017). Cooking methods improve the sensory quality of edible insects through the formation of aromatic compounds (Melgar-Lalanne et al., 2019). According to (Ghosh et al., 2018), sensory characteristics such as taste, texture, odour, colour, and appearance play an important role in food selection, acceptability, and preference. Some cooking methods reduce foodborne and degradative enzymes, which increase the shelf life of edible insects (Melgar-Lalanne et al., 2019).

This study's limitations were that local communities refer to several species from one insect order/genus using the same common vernacular names. Therefore, there might be an underrepresentation of the total number of species consumed in the two provinces. Respondents relied on the pictures from the insect guidebook to identify the correct species they consume; species that were not represented in the book might have been left out of the survey.

3.5. Conclusions

Edible insects play a crucial role in food and nutrition security in rural communities of Limpopo and KwaZulu-Natal provinces, South Africa. This study recorded eight species belonging to five insect orders that are used as food in these provinces. Indigenous knowledge about the collection and preparation of edible insects needs to be preserved, because it can play an important role in the promotion of edible insects as food. Entomophagy is still practiced in Limpopo and KwaZulu-Natal. However, there is a notable decline in the availability of edible insects and the consumption of insects in KwaZulu-Natal. This is thought to be a result of the adoption of western food culture, religion, fear/discomfort associated with eating insects and the decline in the availability of insects in the wild.

The latter is concerning because people are losing critical traditional practices that play a major role in rural nutrition and livelihoods. Edible insects are highly nutritious and have a lower environmental impact than livestock production (Hlongwane et al., 2020). To promote entomophagy, there is an urgent need for education and awareness about edible insects and their benefits to help reduce the stigma, fear, and discomfort associated with eating insects. In addition, documenting indigenous knowledge about the consumption of edible insects in media and literature will help promote edible insects, ensure that indigenous knowledge about edible insects is preserved, and change peoples' perceptions about edible insects. In addition, indigenous knowledge about entomophagy will contribute to local, national, and global knowledge about edible insects, which might help guide the inclusion of edible insects in food policy, enabling the adoption of insects as food that will be included in daily diets and to better understand edible insects as a potential solution to food security problems, particularly in developing countries (Ngulube, 2002; Egan, 2013). Future research should focus on the nutritional content of edible insects, and the potential of farming and rearing of edible insects in South Africa to increase the availability of edible insects, and make them easily accessible to people. Government officials should encourage people, especially from vulnerable groups, to include edible insects in their daily diets. To promote acceptability, edible insects could be incorporated into food products. In addition, more research should focus on the acceptability of food products fortified with edible insects.

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CHAPTER 4: EFFECT OF GEOGRAPHICAL LOCATION, INSECT TYPE AND COOKING METHOD ON THE NUTRITIONAL COMPOSITION OF INSECTS CONSUMED IN SOUTH AFRICA

This chapter is from: Hlongwane, Z. T., Siwela, M., Slotow, R., Munyai, T. C. Effect of geographical location, insect type and cooking methods on the nutritional composition of insects consumed in South Africa. Journal of Insects as Food and Feed. (**Accepted for publication**).

Abstract

Edible insects may be a sustainable source of protein and some other nutrients, especially for low economic status communities. The current study determined the influence of insect type, geographic location and cooking method on the nutritional composition of insects. The investigation would contribute to maximal derivation of the nutritional benefits of insects. Dried samples of four insect types, *Gonimbrasia belina* (mopani worm), *Gynanisa* caterpillar, termite soldiers/workers, and termite alates, were procured from different street vendors across Vhembe district in Limpopo Province, South Africa. *G. belina* samples were cooked by frying, boiling with and without salt addition. Generally, nutrient content varied significantly with insect type and geographic location ($p<0.05$). Protein content varied from 40.97 g/100 g in termite alates to 70.08 g/100 g in termite soldiers/workers. Termite soldiers/workers had the highest iron content (range: 496.33- 690.33 mg/kg), whilst *Gynanisa* caterpillar had the highest zinc content (range: 116.67-155.67mg/kg). Similarly, *Gynanisa* caterpillar had the highest levels of lysine (range: 0.80-4.53 g/100g), threonine (range: 0.79-2.64 g/100g) and isoleucine (range: 0.63-2.33 g/100g). On the other hand termite soldiers/workers had the highest levels of valine (range: 2.20-3.47 g/100g), leucine (range: 2.49-3.87 g/100g) and phenylalanine (range: 1.38-3.55 g/100g). Cooking method significantly affected nutrient retention. Boiling with salt added resulted in the highest retention of protein and total mineral content (ash), and, therefore, seems a suitable method for cooking insects. The findings indicate that, if optimally selected and cooked, edible insects can contribute significantly to the alleviation of protein, zinc, and iron deficiencies in target communities.

Keywords: Edible insects, protein, iron, zinc, geographical location, cooking method, amino acids

4.1. Introduction

The world's population is increasing at an exponential rate, and it is projected to reach 9.6 billion people by the year 2050 (United Nations Department of Economic and Social Affairs, 2017). The increase in human population will require an increase in food production and yields (Belluco et al., 2013). Malnutrition, in its different forms is a global problem, and limited progress is being made to address it. In 2017, it was reported that 821 million people were undernourished in the world, of these, 256 million were found in Africa (Kourimska and Adamkova, 2016). Unfortunately, with the rapid growth in global population, these figures are expected to triple by the year 2050 if no efforts are made to reverse the current situation (van Huis, 2013). The increase in the demand for animal protein has caused the price of chicken, beef, fish, and grain to increase (Raheem et al., 2019). Livestock production is associated with land degradation, water, and air pollution, accounting for more than 14% of annual greenhouse gas emissions worldwide (van Huis, 2013; Rojas-Downing et al., 2017). In addition, the growing demand for animal protein will negatively impact the environment, as more greenhouse gases will be emitted, and more land and water will be required (Henchion et al., 2017), resulting in exacerbated climate change (van Huis and Oonincx, 2017). The increase in food prices will lead to increasing incidence of hunger and undernourishment especially in developing countries. The World Bank (2020), reported that approximately 501 million people in Africa live below the international poverty datum line of $1.90 a day or less, and were unable to access good quality nutritious food.

Conventional sources of protein (meat, fish, and chicken) will not be enough to feed the exponentially growing human population (Zielinska et al., 2015; Kourimska and Adamkova, 2016; van Huis, 2016; World Bank, 2020). Therefore, relatively more affordable and sustainable alternative protein sources need to be adopted (van Huis, 2013; van Huis, 2016). Edible insects have been proposed as an alternative protein source, because of their nutritional value, diversity and abundance (van Huis, 2013). In addition, insect farming and breeding can lead to the reduction in the emission of green house gases (Kourimska and Adamkova, 2016). Adoption of edible insects as an alternative protein source might be a solution that can help alleviate the environmental pressure caused by livestock production (van Huis, 2013).

Furthermore, edible insects have a potential to reduce malnutrition globally, especially in developing countries where malnutrition, particularly undernutrition, is a major challenge (van Huis, 2013; Zielinska et al., 2015; van Huis, 2016).

Edible insects are highly nutritious and considered a healthy food source (Kourimska and Adamkova, 2016; Payne et al., 2016; van Huis, 2016; Dobermann et al., 2017). They are high in energy, protein, essential amino acids, fat, and minerals, including zinc and iron (Feng et al., 2018; Kwiri et al., 2014). Thus, edible insects currently play an important role in human nutrition in the developing regions of Africa (Kelemu et al., 2015; Manditsera et al., 2018; Niassy et al., 2018; Tao and Li, 2018), Asia (Chen et al., 2009; Poshadri, 2018), and Latin America (Costa-Neto, 2015; Hurd et al., 2019), where they are a common traditional food source. As a result, consumption of edible insects should be encouraged in developed countries and used as a source of food in the future. Jongema (2017), reported that approximately 2111 insect species are consumed in the world of these, approximately 500 species are found and consumed in Africa (Kelemu et al., 2015; Manditsera et al., 2018; Niassy et al., 2018). In Africa, edible insects are consumed for their taste, nutritional value, as well as an emergency food source during times of food shortages (DeFoliart, 1997; Agea et al., 2008; Mutungi et al., 2019). The most widely consumed insects in Africa are Lepidopteran caterpillars, termites, and grasshoppers (Illgner and Nel, 2000; Kachaphulula et al., 2018; Kelemu et al., 2015; Raheem et al., 2019).

Edible insects are subjected to different processing and cooking methods before consumption (Manditsera et al., 2019). They are consumed in different forms such as stewed, dried, grilled, roasted, boiled, and as a side dish to a starchy meal, or as a snack (van Huis, 2013). Cooking edible insects changes the colour and texture of edible insects and improves sensory quality throught the formation of aromatic coumpounds (Melgar-Lalanne et al., 2019). In addition, cooking of edible insects improves taste, shelf life and safety (Manditsera et al., 2019). However, cooking methods might have a negative effect on the nutritional content of edible insects (Madibela et al., 2007; Lautenschlager et al., 2016). Kinyuru et al. (2010) found that toasting and drying grasshoppers resulted in a significant reduction in protein digestibility while no significant change was reported in toasted and dried termites. Manditsera et al. (2019) reported that boiling resulted in a decrease in protein content of edible bettle (*Eulepida mashona*) and cricket (*Henicus whellani*) consumed in Zimbabwe. Frying resulted in a decrease in zinc content of mopane worm consumed in Botswana (Madibela et al., 2007).

Mopane worms are considered a delicacy and are the most consumed and preferred insect in the Southern Africa (Thomas, 2013; Makhado et al., 2014; Baiyegunhi et al., 2016). They are processed and cooked using different methods which vary with geographic region (Mutungi et al., 2017). In South Africa mopane worms are traditionally consumed dried as a crispy snack, they can also be further boiled, fried or cooked to a tomato stew (Mpucane et al., 1996; Illgner and Nel, 2000; Hlongwane et al., 2021). Boiling, drying and frying were the most preferred and common traditional methods used to cook mopane worms in South Africa (Hlongwane et al., 2021). Traditionally mopane worms are served as a side dish to maize porridge and leafy vegetables (Illgner and Nel, 2000).

Although many insect species are consumed in Africa, the number of species consumed in the different regions, countries, and geographical locations of Africa vary. The latter is due to consumer preferences, socio-economic status, and availability of insect species, which can in turn be affected by natural ecological factors, human activities, such as agriculture and urbanisation, or trade (Nonaka, 2009; Anankware et al., 2017; Manditsera et al., 2018; Imathiu, 2019; Hlongwane et al., 2020). The nutritional composition of insects varies with insect type (genetic factors- species, etc.), life cycle stage, environmental factors like geographical location (Klunder et al., 2012; Manditsera et al., 2019; Mutungi et al., 2019; Nyangena et al., 2020), and processing and preparation methods (Kinyuru et al., 2010; Klunder et al., 2012; Nyangena et al., 2020). While several studies have been conducted to assess the nutritional composition of edible insects consumed in other African countries (Illgner et al., 2000; Banjo et al., 2006; Christensen et al., 2006; Teffo et al., 2007; El Hassan et al., 2008; Edijala et al., 2009; Mba and Elekima, 2010; Assielou et al., 2015; Manditsera et al., 2018), few have been conducted in South Africa, other than the nutritional composition of *Encosternum delegorguei* Spinola (stink bug) (Teffo et al., 2007), and *Hemijana variegate* consumed in Limpopo province (Egan, 2013). The objectives of this study were to determine (i) the nutritional composition of some major types of edible insects consumed in South Africa, (ii) the effect of geographic origin on their nutritional composition, and (iii) the effect of cooking method on their nutritional composition. The information is vital in selecting edible insect types that can contribute significantly to food and nutrition insecurity in developing regions, especially sub-Saharan Africa. Data on the potential of edible insects for use in addressing protein and mineral deficiencies in this region will be particularly useful.

4.2. Materials and Methods

4.2.1 Origin of insects and pre-preparation/cooking of insects

Dried edible insects, i.e. *Gonimbrasia belina* (mopane worm), *Gynanisa* caterpillar, termite soldiers/workers, and termite alates (Figure 4. 1) were purchased from various markets in Vhembe district, Limpopo, in December 2019. The insects were kept in a freezer approx. (-18°C) until needed for analysis. Insects bought in Vhembe markets were originally from Zimbabwe, Botswana, Zambia, and around Limpopo province of South Africa.

Traditional preparation method of edible insects

Caterpillars (*Gonimbrasia belina* and *Gynanisa* caterpillar)

Harvesters and traders mentioned that they collect live caterpillars are collected from the host tree and placed them in a bucket. They are then degutted, washed in cold water then boiled with salt water for 30 minutes, and sundried for one day (Hlongwane et al., 2021).

Termites soldiers/workers and alates

Collected termites are killed with boiling water, washed in cold water and fried with cooking oil then sun dried for one day. Dried caterpillars and termites are ready for consumption either raw or further cooked (Hlongwane et al., 2021). Dried caterpillars are ready for consumption, either raw or further cooked (Egan, 2013).

Figure 4. 1. Edible insects included in the study: (a) *Gonimbrasia belina*, (b) *Gynanisa* caterpillar, (c) termite soldiers/workers and (d) termite alates

Cooking methods

The effect of cooking method was only investigated on mopani worms (*Gonimbrasia belina)* samples, because of limited resources. Mopane worms were chosen for this experiment as they served as the best example of insects cooked using the methods investigated. Although common methods of cooking and preserving edible insects are often stated in the literature (e.g. Illgner and Nel, 2000; Manditsera et al., 2019; Hlongwane et al., 2021), *viz*. boiling, frying, salting and drying, the technical details of the methods are not provided. The cooking methods (including technical details) used in the current study were obtained from the study respondents from Vhembe district in Limpopo province of South Africa from where the edible insects were purchased. Dried caterpillars were washed with cold water and subjected to the following cooking treatments: (i) raw (sun dried), (ii) boiling in water for 30 minutes, (iii) boiling in water with additional salt added for 30 minutes, and (iv) fried with oil and salted. Each cooking treatment was performed three times (that is, three independent samples). Recipes and detailed cooking procedures are provided in (Method A, B, and C below). The cooking treatments followed traditional cooking methods described by respondents in Vhembe district, Limpopo (Hlongwane et al., 2021). The effect of cooking method was only investigated on mopani worms (*Gonimbrasia belina)* samples, because of limited resources. Mopane worms were chosen for this experiment as they served as the best example of insects cooked using the methods investigated.

Scientific laboratory procedures

Method A: Recipe for cooking boiled *Gonimbrasia belina* samples

479 g of *Gonimbrasia belina* samples were washed in cold water and set aside after draining water. Washed *Gonimbrasia belina* samples were added in a pot with 500 ml of water and then boiled for 30 minutes under medium heat.. After 30 minutes *Gonimbrasia belina* were removed and allowed to cool in a container.

Method B: Recipe for cooking boiled and salted *Gonimbrasia belina* samples

479 g of *Gonimbrasia belina* samples were washed in cold water and set aside after draining water. Washed *Gonimbrasia belina* samples were added in a pot, 500 ml of water and 5 g of salt were added in the pot and then boiled for 30 minutes under medium heat. After 30 minutes *Gonimbrasia belina* were removed and allowed to cool in a container.

Method C: Recipe for cooking fried *Gonimbrasia belina* samples

479 g of *Gonimbrasia belina* samples were washed in cold water and soaked in 500 ml of water for 20 minutes. After 20 minutes water was drained from *Gonimbrasia belina* samples and set aside in a clean container. 54 g of cooking oil was heated a medium cooking pan under medium heat. *Gonimbrasia belina* samples and 5g of salt were added in a pan and fried for 20 minutes

Average portion size

A sub sample (10 persons) of the study participants (insect traders who were also insect consumers) were asked to dish out (using a cup) the typical amount of the dried insect they would consume in one meal. For simplicity, it was assumed that the typical portion consumed was the same for an adult and child. The mass of each of the 10 portion sizes was determined and the average portion size calculated. This was done for each insect type of the study.

4.2.2 Nutritional composition of edible insects

The nutritional composition of edible insect samples was determined using standard methods. Before nutritional analysis, cooked *Gonimbrasia belina* samples were oven dried (60°C) for 24 hours to reduce moisture content. Dried samples were then milled into fine meal with a hammer mill (model SK1, manufactured by Retsch KG, Haan, Germany). Three samples were replicated three times for each cooking method.

Protein content

To determine protein content of edible insects, samples were measured with a LECO Truspec Nitrogen Analyser (LECO Corporation, St Joseph, Michigan, USA) using the Association of Official Analytical Chemists (AOAC) Official Method 990.03 (AOAC, 2003). Samples were measured in triplicates, and placed into a combustion chamber at 950 °C with an autoloader. The following equation (AOAC, 2003) was used to calculate the percentage of protein:

$$\% \, \boldsymbol{crude\ protein} = \% \, \boldsymbol{N} \times \mathbf{6.25}$$

Ash content

The total mineral content of the samples was measured using the AOAC Official Method 942.05 (AOAC, 2003). The samples were weighed and placed in a furnace at 550 °C for 24 hours. The minerals remained as a residue of ash in the crucibles after the volatilisation of the organic matter from the samples. To determine the percentage of ash content the following equation (AOAC, 2003) was used:

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

Fat content

The fat content of the samples was determined following the Soxhlet procedure. The Büchi 810 Soxhlet Fat extractor (Büchi, Flawil, Switzerland) was used for the analysis according to the AOAC Official Method 920.39 (AOAC, 2003). Petroleum ether was used for extraction, and the percentage of crude fat was calculated using the following equation (AOAC, 2003):

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

Amino Acids

Amino acids were determined by the hierarchical clustering linear combination (HCLC) method after HCl hydrolysis and derivatization. The method was according to the International Analytical Group (ALASA, 1998; AOAC, 2003; International Analytical Group, 2016) and is briefly described below. The freeze-dried sample was added to a glass vial and 6 N HCl was added. Thereafter, the vial was flushed with argon or nitrogen gas to eliminate oxygen, before the lid was closed. The vial was placed in an oven at 110 °C for 18-24 hours. The vial was removed from the oven and allowed to cool. The hydrolysate was filtered using centrifuge tube filters (Corning® Costar® Spin-X tubes, Sigma-Aldrich, St. Louis, MO, USA). The filtrate was transferred to Eppendorf tubes and allowed to dry using a speedvac. The speedvac used is a manual system manufactured by the North West University Engineering workshop in Potchefstroom, South Africa, and thereafter reconstituted in borate buffer for derivatization. The borate buffer was transferred into a 200 µl glass insert in a 2 ml glass vial, and 10 µl of either standard solution or diluted sample was added. The 6-aminoquinolyl-N-hydroxysccinimidyl carbamate (AQC) reagent was added, and then the vial was placed in a vortex to ensure that the sample was mixed properly. The vial was then placed in an oven at 55 °C for 10 minutes, and then loaded into the autosampler tray for analysis. An H-class Waters Acquity ultra performance liquid chromatography (UPLC) linked to a Waters photodiode array detector (Waters, Milford, MA, USA), was used for high-resolution UPLC-UV analysis. The separation was achieved on an Acquity UPLC BEH C18 (2.1 × 150 mm; 1.7 µm particle size) column at 60 °C and a flow rate of 0.4 ml/min. Data were collected at a wavelength of 254 nm. An injection volume of 1 µl was used, and gradient separation was performed using Solvents A and B from the Waters Accutag kit. The standard dynode, phosphor, and photomultiplier detection system, was used.

Gross energy

Gross energy was determined by combusting 1g of the sample in a bomb calorimeter according to the (AOAC, 2003). The initial temperature of the calorimeter was recorded (Ti), the sample was ignited, and the final temperature recorded (Tf). The energy value of the sample was computed as: Gross energy (Kcal/g) = (ΔT×Cs)-length of wire burnt (Wt ×1000). Where ΔT = Temperature change (Tf - Ti), Wt = Weight of sample, Cs = Energy equivalent of the bomb system (10316.2 J/g).

Minerals

Zinc, Iron, Phosphorus, Calcium, Sodium, Magnesium, Potassium, Copper, and Manganese were analysed using the Agricultural Laboratory Association of Southern Africa (ALASA) Method 6.1.1 (ALASA, 1998). The first step of this process was to freeze-dry the samples in a freeze drier (Edwards, High vacuum international, Sussex, England). Samples were ashed for 24 hours at 550 °C in a furnace. The samples were dissolved in HCl and then HNO_3 was added. The samples were analysed using an atomic absorption spectrophotometer. Calcium and phosphorus were determined using the Analytik Jena Spekol 1300 spectrophotometer (Analytik Jena AG, Achtung, Germany). Iron was determined with the Varian SpectrAA atomic absorption spectrophotometer (Varian Australia Pty Ltd, Mulgrave, Victoria), and zinc with the GBC 905AA spectrophotometer (GBC Scientific Equipment Pty Ltd., Dandenong, Victoria, Australia). Only zinc and iron were included in the results. Other minerals (phosphorus, calcium, sodium, magnesium, potassium, manganese and copper) were excluded from the results because the focus was only on the problematic minerals i.e. zinc and iron, which are generally deficient in the diets of a large proportion of populations in the Sub-Saharan African countries, including South Africa.

Estimated Average Requirements (EARs)

Estimated Average Requirements (EARs) is one of the four Dietary Reference Intakes (DRIs). The EAR is the recommended DRI for assessing the nutritional status of population groups, defined by demographic profiles, including age, gender and lifecycle stage (Institute of Medicine, 2006). The EAR is the amount of a nutrient that is estimated to meet the needs of 50% of people in a defined population group and can be used to estimate the prevalence of inadequate nutrient intakes (EAR cut-point method). The EAR cut-point method can be used for most nutrients, but cannot be used for energy, as energy intake and expenditure are highly related (Murphy, Guenther & Kretsch, 2006; Institute of Medicine, 2001).

In the current study, the formula below was used to calculate the % contribution of insect meal portions to the EARs of the different age categories:

% EAR met= Protein content in usual insect meal portion size/(EAR) x100

The usual insect meal portion size was determined as described in section 2.1. The same procedure was used to determine the % contribution to EARs for the other nutrients, i.e. zinc and iron.

4.2.5. Statistical analysis

One Way ANOVA was performed to determine if insect type, geographic location and cooking methods had an effect on the nutrient content of the edible insects. If there was significant effect, the Tukey HSD test was performed to separate means. The analysis was performed using IBM SPPS version 25 software (SPSS Inc. Chicago, IL, USA). To determine the effect of insect type and geographic location on nutrient content, six replicate samples were analyzed, whilst nine replicates were analyzed for each cooking method.

Ethical clearance

This study has been ethically reviewed and approved by the University of KwaZulu-Natal Human and Social Sciences Research Ethics Committee (approval number HSS/0125/019D). Permission to conduct research in various towns was obtained from the Vhembe district municipality.

4.3. Results

4.3.1 Nutritional composition of the insects

Proximate composition

Table 4. 1 shows proximate nutritional composition of edible insects collected from different countries. Overall, *Gonimbrasia belina* samples from South Africa, had the highest levels of protein, fat, and energy content compared with *Gonimbrasia belina* samples from other countries (Table 4. 1). Cross border trade of edible insects in the Southern Africa is primarily an informal activity with no proper storage and transportation facilities. This might result in microbiological contamination of edible insects which might have a negative effect on the sensory quality and nutritional value of edible insects.

There were significant differences ($p< 0.05$) in the nutrient content of different insect types found in the same geographic location. For example, for, in SA, the four types of insect studied had different levels of protein and ash (total mineral content) and similar trends were observed in Botswana and Zimbabwe (Table 4. 1). The results are similar to the findings of several previous studies (Christensen et al., 2006; Mba and Elekima, 2010; Siulapwa et al., 2012; Kim et al., 2016; Musundire et al., 2016; Kuntadi et al., 2018). Siulapwa et al. (2012) investigated the nutritional composition of edible insects consumed in Ndola district, Zambia, the insects studied included *Gonimbrasia belina* (mopane worm), *Gynanisa maja*, *Ruspolia differens* (katydid), and *Macrotermes falciger* (termite), and found that *Gonimbrasia belina* contained higher protein content, whereas *Gynanisa maja* contained higher mineral content compared with other species. Similarly, Musundire et al. (2016) investigated the nutritional composition of fourteen edible insects consumed in Zimbabwe, and found that *Gonimbrasia belina* contained the highest protein content compared with other species. However, Kim et al. (2019) studied the proximate composition and mineral content of five edible insect types consumed in Chungnam, South Korea, and found that there were variations in the nutritional composition of the insects, with *Oxya chinensis* containing the highest protein content. In contrast, *Verlarifictorus aspersus* contained the highest zinc and iron content compared with other species. It is noted that variations in the nutritional composition of different insect types from the same geographic location may be caused by diet, genetic differences, sex, and life cycle stages (Imathiu, 2019; Kim et al., 2019). Different insects feed on different materials, which may vary in nutritional composition. Liu et al. (2017) reported variations in nutritional composition of the black soldier during different phases of the life cycle. As higher nutrient content was reported in the larvae stage compared to the adult stage (Liu et al., 2017). These results suggest that insects can be selected and recommended for consumption in terms of their high nutrient content, which is affected by insect type. In this study, termite soldiers/workers from South Africa would be recommended for consumption compared to other insects, because they were higher in protein relative to the other insect types.

Furthermore, there were significant differences in the proximate composition of edible insects across the four countries (Zimbabwe, Zambia, Botswana and South Africa) included in the current study (Table 4. 1). This is the first study comparing the proximate composition of the same insect types found in these countries. The protein content of *Gonimbrasia belina* samples collected from SA were significantly higher (64.37-64.57 g/100 g) than samples collected from other countries i.e. Zimbabwe (64.22-64.30 g/100 g), Botswana (62.41-62.57 g/100 g) and Zambia (62.22 -63.22 g/100 g). On the other hand, the protein content of *Gynanisa* caterpillar samples collected from Zimbabwe was significantly higher (60.52-60.71 g/100 g) than that of *Gynanisa* caterpillar samples collected from other countries. Samples of termite soldiers/workers from SA had significantly higher protein content (69.42-70.08 g/100 g) compared with termite soldiers/workers samples from Zimbabwe. Similarly, the protein content of termite alates samples from SA was significantly higher (41.65-42.88 g/100 g) than that of termite alates (40.97-41.10 g/100 g) samples from Zimbabwe. The protein content of *Gonimbrasia belina* samples from SA reported in this study (64.37-64.57 g/100 g) is similar to the protein content that was reported by Dreyer (1982), (62 g/100 g) for *Gonimbrasia belina* samples from the same country (SA). However, the protein content (40.49- 69.64 g/100 g) of Zimbabwe insect samples reported in this study are within range with the protein content (54 - 58 g/100 g) of Zimbabwe insects reported by Dube et al. (2013). On the other hand, we found that the protein content of *Gonimbrasia belina* samples from SA were higher than the protein content of *Gonimbrasia belina* from Botswana (Madibela et al., 2007) and Zambia Siulapwa et al., (2012).

The differences in the proximate composition of edible insects from different countries might be caused partly by different processing methods including drying used. For example, Dube et al. (2013) reported that *Gonimbrasia belina* samples were degutted and heated in oven at 280°C for 20 minutes before boiling for a 1 hour and further drying in the sun. While, Madibela et al. (2007) roasted the *Gonimbrasia belina* samples inside hot ash for seven minutes before boiling them for 1 hour and, lastly, sun drying for two days. The different processing methods can have different effects on nutrient retention as described and discussed later (Section 3.2). The *Gonimbrasia belina* samples from the current study were degutted, boiled for 1 hour, and then sundried for 3 hours. In addition, environmental factors like climate, and soil and vegetation type likely contributed significantly to the observed differences in the nutritional composition of the same insects obtained from different countries (geographic location). Most insects utilise different types of vegetation as feed, and the differences in the chemical composition of the vegetation types would result in differences in the nutritional composition of the insects. For example, there were no significant differences in the protein content between *G. Belina* sourced in Zambia and Botswana likely due to differences in the chemical composition of feed utilised by the insects in the different countries. The feed of this insect types could be the same in the two countries, but different in chemical composition due to differences in environmental actors (for example soil type) in the different specific ecological locations. Some insect types, e.g. termites, derive nutrients from soil and, therefore, differences in soil chemical composition across different geographical locations may affect the nutrition composition of insects, especially their mineral composition. These results suggest that, to ensure higher protein contant intake, termite alates and *Gonimbrasia belina* samples from South Africa would be recommended for consumption, because they contained a higher protein and energy content compared with other insect types. As will be discussed later (amino acid section), in addition to having a high protein concentration, samples of these insect types sourced in South Africa had a good amino acid profile, including appreciable concentrations of lysine (lysine is deficient in cereal grains, the predominant staples in sub-Saharan African countries). It is noted that termite soldiers had a low fat content compared to the other insect type. The low fat content was compensated by a high protein content (Table 1), which would be of nutritional advantage in addressing protein deficiency, which is prevalent among the majority of population groups in sub-Saharan Africa.

Table 4. 1. Proximate nutritional composition of edible insects harvested from different localities (g/100 g, dry mass basis)[1]

Treatments	**Moisture**	**Protein**	**Fat**	**Ash**	**Energy (MJ/kg)**
Gonimbrasia belina -SA1	6.93^{e} ±0.48	64.57^{g} ±0.44	14.91^{d}±0.97	11.44^{d}±0.67	20.64^{b}±0.08
Gonimbrasia belina -SA2	6.29^{d} ±0.02	64.37^{g} ±0.09	14.06^{d}±0.68	12.06^{d}±0.25	20.16^{b}±0.26
Gonimbrasia belina - Botswana1	6.63^{e} ±0.02	62.41^{f} ±0.25	11.86^{b}±0.59	15.64^{f}±0.13	19.11^{e}±0.10
Gonimbrasia belina - Botswana2	6.42^{d} ±0.11	62.57^{f} ±0.11	12.35^{c}±0.48	15.73^{f}±0.11	19.59^{d}±0.11
Gonimbrasia belina - Zambia1	6.85^{e} ±1.25	63.22^{f} ±0.26	12.76^{c}±0.18	13.41^{e}±0.14	19.61^{d}±0.36
Gonimbrasia belina - Zambia2	7.01±0.08	62.77^{f} ±0.31	12.20^{c}±0.65	13.87^{e}±0.15	19.54^{d}±0.09
Gonimbrasia belina - Zimbabwe1	7.02±0.05	64.30^{h} ±0.22	12.39^{c}±0.10	11.78^{d}±0.12	19.93^{c}±0.30
Gonimbrasia belina - Zimbabwe2	6.72^{e} ±0.23	64.22^{h} ±0.15	12.59^{c}±0.11	11.88^{d}±0.20	19.79^{c}±0.09
Gynanisa caterpillar - SA1	6.43^{d} ±0.15	60.31^{d} ±0.02	11.69^{b}±1.28	16.61^{g}±0.34	19.21^{e}±0.06
Gynanisa caterpillar - SA2	6.29^{d} ±0.02	60.42^{d} ±0.16	11.55^{b}±0.10	16.21^{g}±0.36	19.43^{e}±0.14
Gynanisa caterpillar - Botswana1	5.72^{c} ±0.18	59.29^{c} ±0.44	11.92^{b}±0.44	16.59^{g}±0.56	19.63^{d}±0.09
Gynanisa caterpillar - Botswana2	5.78^{c} ±0.10	59.92^{c} ±0.63	11.62^{b}±0.54	14.65^{e}±0.38	19.55^{d}±0.02
Gynanisa caterpillar - Zimbabwe1	6.25^{d} ±0.19	60.71^{e} ±0.24	12.13^{c}±0.28	14.66^{e}±0.29	19.53^{d}±0.27
Gynanisa caterpillar - Zimbabwe2	5.95^{c} ±0.19	60.52^{e} ±0.30	12.08^{c}±0.17	15.03^{e}±0.14	19.69^{d}±0.04
Termite soldiers/ workers - SA1	3.91^{b} ±0.10	69.42^{i} ±0.34	7.76^{a}±0.45	7.52^{c}±0.18	20.14^{b}±0.31
Termite soldiers/ workers - SA2	3.85^{b} ±0.08	70.08^{i} ±0.27	8.18^{a}±0.25	7.49^{c}±0.10	20.43^{b}±0.07
Termite soldiers/ workers - Zimbabwe1	3.10^{a} ±0.18	69.32^{j} ±0.48	7.84^{a}±0.21	8.21^{c} ±0.05	20.35^{b}±0.07
Termite soldiers/ workers - Zimbabwe2	3.05^{a} ±0.06	69.64^{j} ±0.23	7.14^{a}±0.17	7.74^{c} ±0.16	20.47^{b}±0.04
Termite alates - SA1	6.82^{e} ±0.24	42.88^{b} ±1.94	50.03^{e}±2.22	5.36^{b}±0.46	28.06^{a}±0.15
Termite alates - SA2	7.05^{f} ±0.05	41.65^{b} ±0.52	48.97^{e}±1.29	5.71^{b}±0.57	28.10^{a}±0.30
Termite alates - Zimbabwe1	6.69^{e} ±0.11	41.10^{a} ±0.14	51.77^{f}±1.20	4.44^{a} ±0.25	28.65^{f}±0.22
Termite alates - Zimbabwe2	7.09^{f} ±0.29	40.97^{a} ±1.76	52.06^{f}±0.28	4.28^{a}±0.45	28.50^{f}±0.30
p values	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

[1]Mean±SD, mean of six replicates; Means marked by different letters in the same column are significantly different, according to the Tukey HSD test ($p<0.05$). SA=South Africa. The numbers 1 and 2 indicate independent samples of the same insect type

Estimated Average Requirement (EAR) met for protein

Table 4. 2 shows percentage of the Estimated Average Requirement (EAR) met for protein, for different age groups, from the consumption of usual portions of dried edible insects from different countries. The ranges of the percentage contribution of the insects studied relative to the Estimated Average Requirement (EAR) met for protein amongst different age groups (Table 4. 2), indicated that the insects would contribute significantly to addressing protein deficiencies, 89.5-160.4% for 4-8 years and 29.9-53.6% for childbearing women (19-50) years (Table 4. 2). Protein deficiency is a major health problem in developing countries particularly Southern Africa (Muller and Krawinkel, 2005). Diets of most people in Southern Africa are generally deficient in protein, zinc and iron leading to protein, zinc and iron deficiencies. These insects would have a huge positive health impact in the Southern Africa, especially the low economic status rural communities who are highly vulnerable to malnutrition, including protein deficiency (Voster, 2010; Govender et al., 2017; Modjadji and Madiba, 2019). *Gonimbrasia belina* have quite a high protein content (62.49-64.47 g/100 g), and are consumed in relatively higher portion sizes than the other insects, therefore they would be more effective in addressing protein deficiency than the other insects, including termite spp. (termites soldiers/workers and alates), which despite having a higher protein content than *Gonimbrasia belina*, are consumed in smaller portion sizes (Table 4. 2).

Table 4. 2. Percentage of the Estimated Average Requirement met for protein for different age groups from the consumption of usual portions of dried edible insects from different countries

	4-8 years old children					**19-30 years child-bearing women**					**31-50 years child-bearing women**				
Insect samples	Protein g/100 g	Average portion size (g)	Protein in meal portion(g)	EAR (g/day)	% of EAR met	Protein g/100 g	Average portion size (g)	Protein in meal portion(g)	EAR (g/day)	% of EAR met	Protein g/100 g	Average portion size (g)	Protein in meal portion(g)	EAR (g/day)	% of EAR met
Gonimbrasia belina - SA	64.47	45.39	29.26	18.24	160.4	64.47	45.39	29.26	54.56	53.6	64.47	45.39	29.26	54.56	53.6
Gonimbrasia belina - Zimbabwe	64.26	45.39	29.17	18.24	159.9	64.26	45.39	29.17	54.56	53.5	64.26	45.39	29.17	54.56	53.5
Gonimbrasia belina - Zambia	62.99	45.39	28.56	18.24	156.7	62.99	45.39	28.56	54.56	52.4	62.99	45.39	28.59	54.56	52.4
Gonimbrasia belina - Botswana	62.49	45.39	28.36	18.24	155.5	62.49	45.39	28.36	54.56	52.0	62.49	45.39	28.36	54.56	52.0
Gynanisa caterpillar - SA	60.37	40.49	24.44	18.24	134.0	60.37	40.49	24.44	54.56	44.8	60.37	40.49	24.44	54.56	44.8
Gynanisa caterpillar - Zimbabwe	60.61	40.49	24.54	18.24	134.5	60.61	40.49	24.54	54.56	45.0	60.61	40.49	24.54	54.56	45.0
Gynanisa caterpillar - Botswana	59.61	40.49	24.14	18.24	132.3	59.61	40.49	24.14	54.56	44.2	59.61	40.49	24.14	54.56	44.2
Termite soldiers/workers - SA	69.75	15.27	10.65	18.24	58.4	69.75	15.27	10.65	54.56	19.5	69.75	15.27	10.65	54.56	19.5
Termite soldiers/workers - Zimbabwe	69.48	15.27	10.61	18.24	58.2	69.48	15.27	10.61	54.56	19.4	69.48	15.27	10.61	54.56	19.4
Termite alates - SA	42.27	39.77	16.81	18.24	92.2	42.27	39.77	16.81	54.56	30.8	42.27	39.77	16.81	54.56	30.8
Termite alates - Zimbabwe	41.04	39.77	16.32	18.24	89.5	41.04	39.77	16.32	54.56	29.9	41.04	39.77	16.32	54.56	29.9

Amino acids

The essential amino acid content of edible insects collected from different countries (Table 4.3) showed significant differences. The results show that *Gynanisa* caterpillar obtained from Zimbabwe had the highest lysine content followed by the different termite types obtained from Zimbabwe and SA, whereas *Gonimbrasia belina* samples obtained from all the three countries had the lowest lysine content. The different types of termites sourced in SA and Zimbabwe had higher levels of methionine relative to *Gynanisa* caterpillar and *Gonimbrasia belina*, which generally had similar levels of methionine. *Gynanisa* caterpillar and termite workers/soldiers sourced in Zimbabwe had the highest total essential amino acids content followed by termite alates from SA and termite alates from Zimbabwe whilst *Gonimbrasia belina* samples from all the four countries had the lowest total essential amino acid content.

There are no studies in literature that compared the influence of geographic location on the essential amino acid composition of African edible insects. However, Siulapwa et al. (2012), studied essential amino acids of four edible insect species in Zambia and found that amino acid content varied significantly among species, and insects contained a considerable amount of amino acids. The influence of geographical location on the amino acid profile of insects observed in this study can be attributed to environmental factors and differences in preparation and processing methods (including drying and cooking methods) used in the different geographical regions. For example, differences in the mineral composition of soils of from different geographical region would affect the amino acid profile and minerals. High sulphur soil content will result in high concentrations of sulphur containing amino acids, such as methionine and cysteine. Similarly, the amino acid composition of insects is dependent on the chemical composition of vegetation consumed.

Cereal and legume grains are leading food sources in the diets of the majority of populations in most of the sub-regions of sub-Saharan Africa, including southern Africa, yet, they are generally deficient in lysine and tryptophan and methionine, respectively (van Huis et al., 2013). Cereal-legume composite foods are usually used so that the two grain types (cereals and legumes) complement each other with regard to amino acid profile. However, legumes are not as available and accessible as cereal grains, as a result, monotonous cereal-based diets are popular. From the current results, it is clear that edible insects contain a considerable amount of amino acids, including lysine and tryptophan and methionine. Therefore, supplementing the diets of the populations mentioned above with edible insects would significantly address deficiencies in essential amino acids, such as lysine and methionine, as similarly suggested by Ebenebe et al. (2017) and Igwe et al. (2012). The insect types can be ranked in nutritional superiority with respect to total essential amino acid content as *Gynanisa* caterpillar from Zimbabwe>termite soldiers/worker from Zimbabwe> termite alates from SA>termite alates from Zimbabwe> *Gonimbrasia belina*. *Gynanisa* caterpillar and termite soldiers/workers from Zimbabwe should be prioritised in human diets for higher lysine and methionine content intake.

Table 4.3a. Essential amino acids of edible insects from different localities (g/100 g, dry mass basis)[1]

Treatments	**Histidine**	**Threonine**	**Lysine**	**Methionine**	**Valine**	**Isoleucine**	**Leucine**	**Phenylalanine**	**Sum of essential amino acids**
Gonimbrasia belina – Zambia	0.67^{b} ±0.02	1.00^{a} ±0.13	1.19^{a} ±0.06	0.49^{a} ±0.08	1.09^{a} ±0.17	0.80^{a} ±0.11	1.21^{a} ± 0.16	1.10^{a} ±0.18	7.55
Gonimbrasia belina – Botswana	0.60^{a} ±0.48	1.44^{b} ±0.08	2.09^{c} ±0.07	0.70^{a} ±0.02	1.62^{b} ±0.06	1.18^{b} ±0.01	1.75^{b} ± 0.04	1.43^{b} ± 0.11	10.81
Gonimbrasia belina – Zimbabwe	0.51^{a} ±0.07	1.05^{a} ±0.02	1.23^{a} ±0.01	0.55^{a} ±0.01	1.12^{a} ± 0.07	0.83^{a} ± 0.02	1.24^{a} ± 0.05	1.03^{a} ± 0.07	7.56
Gonimbrasia belina – SA	0.67^{b} ±0.17	1.02^{a} ±0.33	1.02^{a} ±0.22	0.46^{a} ±0.09	1.06^{a} ±0.21	0.78^{a} ±0.14	1.16^{a} ±0.21	1.09^{a} ±0.27	7.26
Gynanisa caterpillar – Botswana	0.44^{a} ± 0.10	1.27^{b} ± 0.34	1.72^{d} ±0.06	0.44^{a} ±0.17	1.17^{b} ±0.02	0.83^{a} ±0.08	1.29^{a} ±0.06	1.09^{a} ±0.01	8.25
Gynanisa caterpillar - SA	0.55^{a} ±0.06	0.79^{a} ±0.07	0.80^{a} ±0.13	0.36^{a} ±0.10	0.79^{a} ±0.00	0.63^{a} ±0.02	0.90^{a} ±0.01	0.83^{a} ±0.05	5.65
Gynanisa caterpillar – Zimbabwe	1.25^{d} ± 0.01	2.64^{d} ±0.26	4.53^{a} ± 0.10	1.15^{b} ±0.17	3.30^{d} ±0.36	2.33^{c} ±0.14	3.50^{d} ±0.20	3.51^{d} ± 0.04	22.21
Termite soldiers/workers – Zimbabwe	1.22^{d} ±0.16	2.30^{d} ±0.11	2.77^{b} ±0.66	1.78^{c} ±0.06	3.47^{d} ±0.02	2.16^{c} ±0.03	3.87^{d} ±0.05	3.55^{d} ±0.04	21.12
Termite soldiers/workers – SA	0.96^{c} ±0.47	1.61^{d} ± 0.54	2.06^{c} ±0.08	1.17^{b} ±0.58	2.20^{c} ±0.83	1.38^{b} ±0.50	2.46^{b} ±0.88	1.38^{b} ±0.72	13.22
Termite alates – Zimbabwe 1	0.87^{c} ±0.02	1.54^{c} ± 0.31	2.59^{b} ±0.09	1.86^{d} ±0.07	1.94^{c} ±0.38	1.40^{b} ±0.24	2.54^{b} ±0.40	2.57^{c} ±0.22	15.31
Termite alates –- Zimbabwe 2	1.35^{d} ± 0.02	1.50^{c} ±0.06	1.70^{d} ± 0.02	1.86^{d} ±0.02	2.09^{c} ±0.06	1.49^{c} ±0.03	2.77^{c} ±0.05	3.06^{d} ± 0.04	15.82
Termite alates – SA 1	1.16^{d} ±0.17	1.63^{d} ±0.13	1.97^{d} ± 0.15	2.02^{e} ±0.08	2.11^{c} ±0.26	1.61^{b} ±0.03	2.95^{c} ± 0.02	3.09^{d} ±0.09	16.54
Termite alates – SA 2	0.98^{c} ±0.07	1.70^{d} ±0.23	2.60^{b} ± 0.69	1.81^{c} ±0.11	2.13^{c} ±0.18	1.52^{c} ±0.02	2.81^{c} ±0.04	2.70^{c} ±0.41	16.25
p values	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	

[1]Mean±SD, mean of six replicates; Means marked by different letters in the same column are significantly different, according to the Tukey HSD test ($p<0.05$).

Table 4.3b. Non-essential amino acids of edible insects from different localities (g/100 g, dry mass basis)

Treatments	**Arginine**	**Serine**	**Glycine**	**Aspartate**	**Glutamate**	**Alanine**	**Proline**	**Tyrosine**
Gonimbrasia belina - Zambia	1.19 ±0.13	0.89± 0.11	0.91 ±0.11	1.54 ±0.10	2.15 ±0.14	1.23± 0.08	0.45± 0.05	1.64 ±0.30
Gonimbrasia belina – Botswana	1.56± 0.29	1.20 ±0.07	1.27 ±0.03	2.93 ±0.11	3.62 ±0.11	1.72 ±0.10	0.65 ±0.01	2.30 ±0.07
Gonimbrasia belina – Zimbabwe	1.23 ±0.03	1.09 ±0.14	0.99 ±0.05	1.74 ±0.09	2.33± 0.12	1.20 ±0.03	0.47 ±0.03	1.56 ±0.03
Gonimbrasia belina - SA	1.21 ±0.34	0.90±0.22	0.98 ±0.26	1.56 ± 0.39	2.14 ±0.49	1.10 ±0.21	0.44 ±0.08	1.63 ±0.42
Gynanisa caterpillar – Botswana	1.11 ±0.07	0.70 ±0.28	0.89 ±0.01	2.06 ±0.01	2.39 ±0.36	1.51 ±0.10	0.50 ±0.02	1.70 ±0.19
Gynanisa caterpillar - SA	0.88 ±0.04	0.68 ±0.03	0.73 ±0.03	1.15±0.14	1.59 ± 0.08	0.95 ±0.10	0.31±0.05	1.15 ±0.02
Gynanisa caterpillar – Zimbabwe	2.66 ±0.02	2.49 ±0.09	2.59 ±0.03	5.60 ±0.36	7.16 ± 0.04	4.60±0.07	3.30±0.39	4.45± 0.49
Termite soldiers/workers – Zimbabwe	2.40 ±0.30	1.89 ±0.23	2.82 ±0.00	4.24 ±0.38	6.70 ±0.45	6.22 ± 0.21	3.81 ±0.05	5.38 ±0.00
Termite soldiers/workers – SA	2.04 ±0.76	1.37 ±0.54	1.84 ±0.91	2.91 ±0.83	4.22 ±1.24	4.19 ± 1.57	2.31 ±1.01	2.66 ±1.46
Termite alates – Zimbabwe 1	1.62 ±0.06	1.25 ±0.12	1.68 ±0.18	3.10 ±0.66	4.05 ±1.00	3.13 ±0.08	1.72 ±0.25	3.55±0.30
Termite alates – Zimbabwe 2	1.93 ±0.04	1.35 ±0.08	1.76 ± 0.11	3.06 ±0.12	3.87 ± 0.20	2.29 ±0.24	2.02 ±0.12	4.58 ±0.13
Termite alates – SA 1	2.00± 0.18	1.44 ±0.11	1.90 ±0.05	3.26 ±0.30	4.38 ±0.43	3.10± 0.42	2.01 ±0.12	4.15 ±0.01
Termite alates – SA 2	0.98 ±0.07	1.74 ±0.18	1.37 ±0.27	1.57± 0.04	3.61 ±0.58	1.70 ±0.23	2.71±0.35	2.60 ±0.69

Mineral element composition

Table 4.4 shows mineral element composition of insects from the four countries included in the current study. The zinc content of *Gonimbrasia belina* samples (150.33 mg/kg) from South Africa reported in this study is similar to zinc content (140 mg/kg) reported by Dreyer and Wehmeyer (1982) for *Gonimbrasia belina* samples obtained from the same country. Similarly, the zinc content of *Gonimbrasia belina* samples (108.3 mg/kg) from Zimbabwe reported in this study was lower than zinc content (142 mg/kg) reported by Glew et al. (1999) for *Gonimbrasia belina* samples from the same country. On the other hand, zinc content of *Gonimbrasia belina* samples (133.3 mg/kg) from Zambia reported in this study was lower than the zinc content of *Gonimbrasia belina* samples (260.7 mg/kg) reported by Siulapwa et al. (2012) in the same country. Differences in zinc content of *Gonimbrasia belina* samples from Zambia could be due to a difference in the processing methods used to prepare samples before analysis. *Gonimbrasia belina* samples from Zambia are degutted and boiled for 1 hour and smoked on a grill above the fire or directly deposited in hot coal for one day (Cloutier, 2015). Boiling mopane worm samples for longer period of time might result in minerals leaching in a cooking medium (Manditsera et al., 2019) All the insect types studied also contained appreciable levels of other mineral elements, sodium, phosphorus, calcium, magnesium, potassium, copper and manganese (Table 4.4). The current report seems the first on the mineral composition of termites and *Gynanisa* caterpillar from Zimbabwe, South Africa, and Botswana. However, termites and caterpillars consumed in Africa have been found to contain high zinc levels. For example, Madibela et al. (2007), Mbah and Elekima (2010), Siulapwa et al. (2012), Kinyuru et al. (2013), Adepoju and Ajayi (2016), reported that zinc content of termite and caterpillar ranged from 8-16.9 mg/100 g and 8-14 mg/100 g respectively.

The results in Table 4.4 show that there are significant differences in the mineral element composition of different insect types found in the same geographic region. For example, in SA the four types of insects studied, i.e. *Gonimbrasia belina*, *Gynanisa* caterpillar, termite soldiers/workers, and termite alates, had different levels of minerals including zinc and iron. Similar trends were observed for the insects obtained from Zimbabwe and Botswana. Similar results were reported in several previous studies (Siulapwa et al., 2012; Payne et al., 2015; Kim et al., 2016; Kuntadi et al., 2018;). Payne et al., (2015) conducted a study of mineral composition of five edible insects consumed in Zimbabwe (*Gonimbrasia belina*, *Gynanisa maia*, *Macrotermes* spp., *Cirina forda*, and *Encosternum delegorguei*), and found that *Gonimbrasia belina* contained the highest iron content, whereas *Encosternum delegorguei* had the highest zinc content. On the other hand, Akullo et al. (2018) investigated the nutritional composition of three insects commonly consumed in Lango region, northern Uganda, and found that *Macrotermes bellicosus* (termite) contained the highest iron content, whereas the African cricket *Brachytrupes spp.* contained the highest zinc content. As discussed earlier for proximate composition, including total mineral content (ash) (Section 3.1), the factors that likely contributed to differences in the mineral element content of different insect types found in the same geographic region are diet, genetic factors, life cycle states, specific growth environment (niche), and sex (Imathiu, 2019; Kim et al., 2019).

The results in Table 4.4 also indicate a variation in the mineral composition of the same insect type across the countries included in the study. The zinc content of *Gonimbrasia belina* samples collected from South Africa was significantly higher than that of the *Gonimbrasia belina* samples collected from the other countries included in the study. Similarly, the zinc content of *Gynanisa* caterpillar samples collected from South Africa was significantly higher than that of the same insect collected from other countries. Termite soldiers/workers samples from South Africa (142.66 mg/kg) had significantly higher zinc content than termite soldiers/workers samples from Zimbabwe (131.16 mg/kg). On the other hand, there were no significant differences ($p > 0.05$) in zinc content of termite alates samples collected from South Africa and Zimbabwe. The iron content of *Gonimbrasia belina* samples collected from Zimbabwe was significantly ($p<0.05$) higher than that of *Gonimbrasia belina* samples collected from other countries. However, the iron content of *Gynanisa* caterpillar samples from South Africa was significantly higher than that of *Gynanisa c*aterpillar samples from other countries. Termite soldiers/workers samples from Zimbabwe (629.5 mg/kg) had significantly ($p<0.05$) higher iron content compared with termite soldiers/workers samples from South Africa (545 mg/kg). Similarly, the iron content of termite alates samples collected from South Africa (307.67 mg/kg) was significantly higher than that of termite alates samples from Zimbabwe (177.17 mg/kg). As was discussed for the other nutrients environmental factors such as climate, soil and vegetation type likely were significant contributors to the differences in the mineral element content of the same insects obtained from different countries (geographic location). In addition, as already discussed, differences in the processing methods used to process the same insect types in the different countries probably contributed to the varied mineral element content of the same insect type obtained from the four countries considered.

The iron and zinc contents of the insects of this study agree with the trends stated in the literature, which show that edible insects are high in several mineral elements, including zinc and iron. In fact, the literature indicates that, generally, insects are higher in iron compared to chicken and beef, the popular, but expensive protein sources (Rumpold and Schluter, 2013; Hlongwane et al., 2020). Zinc and iron deficiencies are common health problem in many low income countries (Siwela et al., 2020). Zinc and iron are lacking in human diets of many South African (Motadi et al., 2015). In addition, diets are made up of mainly carbohydrate rich food, with a low intake of animal protein, dairy products, and fruits, which contribute less iron, protein, and zinc intake (Mamabolo et al., 2006; Motadi et al., 2015). Therefore, edible insects should be recommended for intake to combat iron and zinc deficiencies, which are prevalent and of health concern in South Africa, as stated earlier. Furthermore, the current study results suggest that, when insects are used to address iron and zinc deficiencies in specific geographic regions (e.g. in different countries), specific insect types that are high in the mineral element of interest should be determined for the specific country. According to the result from this study (Table 4.4), termite soldiers/workers should be recommended for consumption in Zimbabwe and Gynanisa caterpillar in SA, *Gynanisa* caterpillar should be recommended. Furthermore, the trends of variation of mineral element content of the same insect across geographical location (countries in the current study) suggest that geographic regions can be mapped for obtaining maximal levels of target mineral elements (zinc and iron in the current study) specific insect types..

Table 4.4. Mineral composition of edible insects from different localities (dry mass basis)[1]

	g/100 g					mg/kg			
Insect sample	**Sodium**	**Phosphorus**	**Calcium**	**Magnesium**	**Potassium**	**Iron**	**Copper**	**Zinc**	**Manganese**
Gonimbrasia belina - SA1	$1.77^{c}\pm0.04$	$0.51^{c}\pm0.01$	$0.09^{d}\pm0.00$	$0.16^{e}\pm0.00$	$1.21^{d}\pm0.01$	$96.67^{g}\pm17.03$	$5.67^{c}\pm0.57$	$139.67^{b}\pm24.66$	$36.67^{h}\pm1.52$
Gonimbrasia belina - SA2	$2.09^{c}\pm0.08$	$0.49^{c}\pm0.02$	$0.11^{d}\pm0.01$	$0.17^{e}\pm0.01$	$1.24^{d}\pm0.02$	$97.33^{g}\pm15.01$	$5.67^{c}\pm0.57$	$111.67^{e}\pm6.35$	$34.67^{h}\pm2.08$
Gonimbrasia belina - Bots1	$3.85^{a}\pm0.03$	$0.67^{b}\pm0.00$	$0.13^{c}\pm0.01$	$0.22^{c}\pm0.01$	$1.42^{c}\pm0.02$	$228.00^{h}\pm97.00$	$3.33^{d}\pm0.57$	$132.67^{c}\pm8.02$	$35.67^{h}\pm1.15$
Gonimbrasia belina - Bots2	$3.50^{a}\pm0.34$	$0.63^{b}\pm0.03$	$0.14^{c}\pm0.01$	$0.23^{c}\pm0.0.$	$1.36^{c}\pm0.06$	$174.33^{i}\pm10.69$	$3.67^{d}\pm0.57$	$125.33^{d}\pm8.03$	$36.00^{h}\pm1.00$
Gonimbrasia belina - Zambia1	$2.94^{b}\pm0.29$	$0.58^{b}\pm0.00$	$0.20^{b}\pm0.01$	$0.23^{c}\pm0.01$	$1.51^{b}\pm0.02$	$174.67^{i}\pm3.78$	$3.67^{d}\pm0.57$	$137.33^{b}\pm18.50$	$41.33^{g}\pm1.15$
Gonimbrasia belina - Zambia2	$3.13^{a}\pm0.08$	$0.61^{b}\pm0.06$	$0.18^{b}\pm0.02$	$0.24^{c}\pm0.01$	$1.51^{b}\pm0.02$	$167.00^{j}\pm14.79$	$3.33^{d}\pm0.57$	$129.67^{d}\pm14.97$	$40.33^{g}\pm3.05$
Gonimbrasia belina - Zim1	$1.69^{c}\pm1.43$	$0.47^{c}\pm0.18$	$0.23^{a}\pm0.02$	$0.20^{d}\pm0.02$	$2.08^{a}\pm1.05$	$413.00^{d}\pm409.00$	$2.67^{d}\pm1.15$	$83.00^{f}\pm63.3$	$52.00^{f}\pm21.65$
Gonimbrasia belina - Zim2	$2.59^{b}\pm0.10$	$0.56^{b}\pm0.01$	$0.20^{b}\pm0.02$	$0.21^{d}\pm0.00$	$1.44^{c}\pm0.01$	$168.33^{j}\pm18.55$	$3.67^{d}\pm0.57$	$133.67^{b}\pm19.3$	$41.00^{g}\pm1.73$
Gynanisa caterpillar - SA1	$3.34^{a}\pm0.04$	$0.75^{a}\pm0.02$	$0.24^{a}\pm0.00$	$0.37^{a}\pm0.00$	$1.72^{a}\pm0.09$	$438.00^{d}\pm250.3$	$5.00^{c}\pm1.00$	$155.67^{a}\pm10.69$	$31.00^{i}\pm2.00$
Gynanisa caterpillar - SA2	$3.09^{a}\pm0.27$	$0.74^{a}\pm0.01$	$0.23^{a}\pm0.01$	$0.35^{a}\pm0.02$	$1.73^{a}\pm0.02$	$279.67^{g}\pm28.57$	$3.67^{d}\pm0.57$	$145.00^{a}\pm9.53$	$30.00^{i}\pm0.00$
Gynanisa caterpillar - Bots1	$2.92^{b}\pm0.01$	$0.73^{a}\pm0.01$	$0.20^{b}\pm0.01$	$0.27^{b}\pm0.01$	$1.61^{b}\pm0.01$	$258.33^{e}\pm7.57$	$2.00^{d}\pm0.00$	$127.67^{d}\pm13.76$	$27.00^{j}\pm1.00$
Gynanisa caterpillar - Bots2	$2.64^{b}\pm0.17$	$0.69^{b}\pm0.02$	$0.16^{c}\pm0.00$	$0.28^{b}\pm0.01$	$1.58^{b}\pm0.04$	$202.00^{e}\pm21.63$	$5.33^{c}\pm0.57$	$116.67^{e}\pm3.78$	$22.67^{j}\pm2.08$
Gynanisa caterpillar - Zim1	$2.72^{b}\pm0.09$	$0.77^{e}\pm0.04$	$0.25^{a}\pm0.02$	$0.36^{a}\pm0.02$	$1.86^{a}\pm0.08$	$249.00^{h}\pm12.12$	$3.67^{d}\pm1.15$	$155.00^{c}\pm10.53$	$31.67^{i}\pm3.05$
Gynanisa caterpillar - Zim2	$2.40^{b}\pm0.15$	$0.78^{e}\pm0.03$	$0.22^{a}\pm0.01$	$0.32^{a}\pm0.02$	$1.72^{a}\pm0.01$	$233.67^{h}\pm4.72$	$3.33^{d}\pm1.15$	$142.67^{b}\pm12.58$	$29.67^{i}\pm0.57$
Termite soldiers/workers - SA1	$1.08^{d}\pm0.04$	$0.39^{d}\pm0.01$	$0.20^{b}\pm0.01$	$0.12^{f}\pm0.01$	$0.73^{e}\pm0.01$	$496.33^{c}\pm27.97$	$65.00^{a}\pm1.00$	$145.00^{a}\pm1.00$	$325.6^{e}\pm12.42$
Termite soldiers/workers - SA2	$1.12^{d}\pm0.14$	$0.40^{d}\pm0.01$	$0.22^{a}\pm0.00$	$0.12^{f}\pm0.01$	$0.74^{e}\pm0.00$	$593.67^{b}\pm27.97$	$79.33^{a}\pm20.5$	$140.33^{b}\pm2.08$	$349.0^{e}\pm10.3$
Termite soldiers/workers - Zim1	$1.13^{d}\pm0.04$	$0.39^{d}\pm0.01$	$0.20^{b}\pm0.01$	$0.11^{f}\pm0.01$	$0.74^{e}\pm0.01$	$690.33^{a}\pm29.14$	$68.00^{a}\pm1.00$	$131.00^{c}\pm2.64$	$366.3^{e}\pm21.22$
Termite soldiers/workers - Zim2	$1.05^{d}\pm0.06$	$0.41^{d}\pm0.02$	$0.20^{b}\pm0.02$	$0.11^{f}\pm0.01$	$0.71^{e}\pm0.01$	$568.67^{b}\pm23.96$	$61.67^{a}\pm1.52$	$131.33^{c}\pm4.61$	$349.6^{e}\pm32.03$
Termite alates - SA1	$0.60^{e}\pm0.11$	$0.42^{d}\pm0.02$	$0.07^{e}\pm0.01$	$0.08^{g}\pm0.01$	$0.59^{f}\pm0.04$	$297.67^{g}\pm140.67$	$36.00^{b}\pm4.35$	$102.33^{e}\pm6.65$	$3884^{d}\pm354.3$
Termite alates - SA2	$0.52^{e}\pm0.09$	$0.45^{c}\pm0.06$	$0.07^{e}\pm0.01$	$0.09^{g}\pm0.01$	$0.55^{f}\pm0.02$	$317.67^{f}\pm180.18$	$42.67^{b}\pm7.63$	$117.00^{e}\pm7.00$	$5338^{b}\pm561.0$
Termite alates - Zim1	$0.36^{e}\pm0.08$	$0.48^{c}\pm0.05$	$0.09^{d}\pm0.01$	$0.09^{g}\pm0.01$	$0.60^{f}\pm0.01$	$180.67^{i}\pm63.06$	$36.00^{b}\pm4.58$	$111.00^{e}\pm11.0$	$4505^{c}\pm940.4$
Termite alates - Zim2	$0.31^{e}\pm0.03$	$0.43^{d}\pm0.02$	$0.09^{d}\pm0.00$	$0.08^{g}\pm0.01$	$0.58^{f}\pm0.02$	$173.67^{i}\pm14.15$	$40.33^{b}\pm10.21$	$107.67^{e}\pm4.93$	$5129^{a}\pm1939$
p value	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

[1]Mean±SD, mean of six replicates; [a] DW: dry weight basis; Different letters in columns show significant difference according to Tukey HSD test ($p<0.05$). Bots= Botswana; Zim= Zimbabwe

Estimated Average Requirement (EAR) met for iron and zinc

Table 4. 5 shows the percentage of the Estimated Average Requirement (EAR) met for iron and zinc for different age groups from the consumption of the usual portions of dried edible insects from different countries. The results indicate that all insect types from different countries would contribute a significant high percentage of EAR for iron (107.7-381%) for 4-8 years old children, but would have a lower percentage contribution to percentage EAR (30-71%) for iron for the groups of childbearing women ages (19-30) and (31-50) (Christensen et al., 2006; Mwangi et al., 2018). Child bearing women have a high demand for dietary iron because of loss of this mineral through menstruation. Therefore, insects would not be an effective food source to address iron deficiencies among the two population groups. All the insect type from different country similarly would contribute a high percentage of EAR for zinc for 4-8 years old children (108- 152%), except for termite soldiers/workers, which would contribute a much lower percentage of EAR (50.3-54.5%). The usual portion size of the termite soldiers/workers was much lower in weight than the weight of the usual portion size of other insect type, hence it contributed much less zinc intake (Table 4. 5). For the same reason as iron, child bearing women have a high demand for other minerals including zinc and therefore the usual portion of different insect type would contribute a much lower percentage for zinc (Table 4. 5).

Protein and mineral deficiency lead to several health conditions which are common in developing countries. Mineral deficiency result in the high proportion of unhealthy, morbid and less productive people in the population of these regions. The affected developing countries need alternative sustainable and economically accessible food sources to address the health problems in challenges caused by nutrient deficiencies. The current study results clearly show that insects would be suitable alternative food sources to address protein and mineral deficiencies in developing regions and thereby improve the health and well-being of the population.

Table 4.5. Percentage of the Estimated Average Requirement met for Iron and Zinc for different age groups from the consumption of usual portions of dried edible insects from different countries

	4-8 years old children					**19-30 years child-bearing women**					**31-50 years child-bearing women**				
Insect samples	Iron in insect (100/kg)	Usual portion size (kg)	Iron in meal portion (mg)	EAR (mg/day)	% of EAR met	Iron in insect (mg/kg)	Usual portion size (kg)	Iron in meal portion (mg)	EAR (mg/day)	% of EAR met	Iron in insect (mg/kg)	Usual portion size (kg)	Iron in meal portion (mg)	EAR (mg/day)	% of EAR met
Gonimbrasia belina - SA	97.0	0.045	4.40	4.1	107.4	97.0	0.045	4.40	22	20.0	97.0	0.045	4.40	22	20.1
Gonimbrasia belina - Zimbabwe	290.7	0.045	13.19	4.1	321.8	290.7	0.045	13.19	22	60.0	290.7	0.045	13.19	22	60.0
Gonimbrasia belina – Zambia	170.8	0.045	7.75	4.1	189.1	170.8	0.045	7.75	22	35.3	170.8	0.045	7.75	22	35.3
Gonimbrasia belina - Botswana	201.2	0.045	9.13	4.1	222.7	201.2	0.045	9.13	22	41.5	201.2	0.045	9.13	22	41.5
Gynanisa caterpillar - SA	385.8	0.040	15.62	4.1	381.0	385.8	0.040	15.62	22	71.0	385.8	0.040	15.62	22	71.0
Gynanisa caterpillar - Zimbabwe	241.3	0.040	9.77	4.1	238.3	241.3	0.040	9.77	22	44.4	241.3	0.040	9.77	22	44.4
Gynanisa caterpillar - Botswana	230.2	0.040	9.32	4.1	227.3	230.1	0.040	9.32	22	42.4	230.2	0.040	9.32	22	42.4
Termite soldiers/workers - SA	545.0	0.015	8.32	4.1	203.0	545.0	0.015	8.32	22	37.8	545.0	0.015	8.32	22	37.8
Termite soldiers/workers - Zimbabwe	629.5	0.015	9.61	4.1	234.5	629.5	0.015	9.61	22	43.7	629.5	0.015	9.61	22	43.7
Termite alates - SA	307.7	0.040	12.24	4.1	298.4	307.7	0.040	12.24	22	55.6	307.7	0.040	12.24	22	55.6
Termite alates - Zimbabwe	177.2	0.040	7.05	4.1	171.9	177.2	0.040	7.05	22	32.0	177.2	0.040	7.05	22	32.0

Insect samples	Zinc in insect (mg/kg)	Usual portion size (kg)	Zinc in meal portion (mg)	EAR (mg/day)	% of EAR met	Zinc in insect (mg/kg)	Usual portion size (kg)	Zinc in meal portion (mg)	EAR (mg/day)	% of EAR met	Zinc in insect (mg/kg)	Usual portion size (kg)	Zinc in meal in portion (mg)	EAR (mg/day)	% of EAR met
Gonimbrasia belina - SA	125.67	0.045	5.70	4	142.6	125.7	0.045	5.70	9.5	60.0	125.7	0.045	5.70	9.5	60.0
Gonimbrasia belina - Zimbabwe	108.34	0.045	4.92	4	122.9	108.3	0.045	4.92	9.5	51.8	108.3	0.045	4.92	9.5	51.8
Gonimbrasia belina – Zambia	133.50	0.045	6.06	4	151.5	133.5	0.045	6.06	9.5	63.8	133.5	0.045	6.06	9.5	63.8
Gonimbrasia belina - Botswana	129.00	0.045	5.86	4	146.4	129.0	0.045	5.86	9.5	61.6	129.0	0.045	5.86	9.5	61.6
Gynanisa caterpillar - SA	150.34	0.040	6.09	4	152.2	150.3	0.040	6.09	9.5	64.1	150.3	0.040	6.09	9.5	64.1
Gynanisa caterpillar - Zimbabwe	148.83	0.040	6.03	4	150.6	148.8	0.040	6.03	9.5	63.4	148.8	0.040	6.03	9.5	63.4
Gynanisa caterpillar - Botswana	122.17	0.040	4.59	4	123.7	122.2	0.040	4.95	9.5	52.1	122.1	0.040	4.95	9.5	52.1
Termite soldiers/workers - SA	142.67	0.015	2.18	4	54.5	142.7	0.015	2.18	9.5	22.9	142.7	0.015	2.18	9.5	22.9

Termite soldiers/workers - Zimbabwe	131.84	0.015	2.01	4	50.3	131.8	0.015	2.01	9.5	21.2	131.8	0.015	2.01	9.5	21.2
Termite alates - SA	109.67	0.040	4.36	4	109.0	109.7	0.040	4.36	9.5	45.9	109.7	0.040	4.36	9.5	45.9
Termite alates - Zimbabwe	109.34	0.040	4.35	4	108.7	109.3	0.040	4.35	9.5	45.8	109.3	0.040	4.35	9.5	45.8

4.3.2. Effect of cooking methods on the nutritional composition of insects

Figure 4. 2 is comprised of pictures representing uncooked, dried *Gonimbrasia belina* (control), and *Gonimbrasia belina* samples cooked using different methods. The *Gonimbrasia belina* samples that were boiled in water alone (Figure 4. 2 (b)) appear as light as the control, but are swollen, obviously due to water absorbed during boiling. In contrast, samples of *Gonimbrasia belina* samples that were boiled in water with salt added (Figure 4. 2 (c)) and the fried samples (Figure 4. 2 (d)) look darker, but almost the same size and shape as the control, which is likely due to the fact that they absorbed little water during cooking. Further cooking dried *Gonimbrasia belina* improves sensory characteristics such as odour, taste, colour, texture and appearance of *Gonimbrasia belina* samples and play an essential role in food selection, preference and consumer acceptability of *Gonimbrasia belina* (Melgar-Lalanne et al., 2019; Hlongwane et al., 2021). In Southern Africa dried *Gonimbrasia belina* are further cooked using different cooking methods (frying, boiling, stew, roasted) so that they can be consumed as a side dish to a starchy staple e.g. maize meal stiff porridge (pap) (van Huis, 2013), a very popular staple food in Southern Africa. On the other hand, dried *Gonimbrasia belina* are consumed a snack.

Figure 4. 2. Pictures representing uncooked, dried *Gonimbrasia belina* (control) and *Gonimbrasia belina* samples cooked using different methods: (a) dried (uncooked), (b) boiled (c) boiled and salted, and (d) fried.

Effect of cooking methods on proximate composition

Results from One way ANOVA show that cooking method had a significant effect on the nutrient content of insects. Table 4.6 shows the effect of different cooking methods on the proximate composition of *Gonimbrasia belina* samples obtained from South Africa. For all three samples of *Gonimbrasia belina* boiling, resulted in a significant increase ($p<0.05$) in their protein content compared with the controls (dried *Gonimbrasia belina* samples). Similarly, boiling with addition of salt resulted in a significant increase in the protein content of *Gonimbrasia belina*. On the other hand, frying resulted in a significant decrease in the protein content of the *Gonimbrasia belina* samples compared with the controls.

Some workers (Medigo et al., 2018; Nyangena et al., 2020) found that boiling resulted in a significant increase in protein content of *Tenebrio molitor*, *Ruspolia differens*, *Spodoptera littoralis* and *Acheta domesticus*. On the other hand, frying resulted in a significant increase in protein content of edible insects (Medigo et al., 2018; Nyangena et al., 2020). Other workers found that boiling with or without salt as well as frying resulted in a significant decrease in protein content of *Eulepida mashona*, *Hemijana variegata* and *Henicus whellani* (Madibela et al., 2007; Klunder et al., 2012; Egan, 2013; Manditsera et al., 2019). Differences in protein content as a result of cooking can be ascribed to differences in boiling and frying time. For example, in the current study, insects were boiled for 30 minutes and fried for 15 minutes, whilst in other studies the insects were boiled for an hour (Madibela et al., 2007; Egan, 2013). An increase in protein content during boiling in water alone or with salt added in this study could be attributed to the observed decrease in other nutrients during cooking. Therefore, there is a proportionate increase in protein. In a similar study, Nyangena et al. (2020) gave the same reason for an increase in protein content due to the observed decrease in fat content. On the other hand, the decrease in protein content during frying could be attributed to the protein oxidation which result which changes colour, texture and nutrient content of meat products. These results suggest that, to increase protein intake per unit weight of cooked insects, boiling with salt added should be recommended. Generally, frying increased energy content of *Gonimbrisia belina* samples, whilst, boiling resulted in a decrease in the energy level of the insects samples. During frying the samples absorbed fat, increasing energy level. The decrease in energy content during boiling can be attributed to loss of fat (Table 4.6).

Table 4.6.. Proximate composition of *Gonimbrasia belina* samples cooked by different cooking methods (g/100 g, dry mass basis)[1]

Treatments	**Moisture**	**Protein**	**Fat**	**Ash**	**Energy (MJ/kg)**
Dried *Gonimbrasia belina* 1 (control)	6.21^{a} ±0.22	64.87^{b}±0.21	14.84^{c}±1.21	9.11^{a} ±0.01	18.89^{c}±2.22
Dried *Gonimbrasia belina* 2 (control)	6.46^{a} ±0.18	64.76^{b}±0.39	13.51^{b}±0.42	11.03^{c}±0.69	18.89^{c}±2.22
Dried *Gonimbrasia belina* 3 (control)	6.77^{a} ±0.19	65.44^{c}±0.53	13.96^{c}±0.41	9.58^{a}±0.22	18.89^{c}±2.22
Boiled *Gonimbrasia belina* 1	14.54±0.61	66.15^{d}±0.35	12.69^{a}±0.20	11.66^{c}±0.23	18.88^{c}±0.15
Boiled *Gonimbrasia belina* 2	11.92^{b} ±1.16	65.59^{d}±0.02	13.05^{a}±0.48	10.90^{b}±0.44	18.89^{c}±0.03
Boiled *Gonimbrasia belina* 3	11.68^{b} ±0.27	65.69^{d}±0.19	13.46^{a}±0.24	10.62^{b}±0.08	18.99^{c}±0.12
Boiled, salted *Gonimbrasia belina* 1	16.40^{d} ±0.36	65.89^{c}±0.52	13.23^{a}±0.93	11.87^{d}±0.73	18.08^{d}±0.08

Boiled, salted *Gonimbrasia belina* 2	16.69^{d} ±0.30	66.37^{d}±0.13	13.60^{b}±0.27	11.78^{d}±0.19	18.12^{d}±0.11
Boiled, salted *Gonimbrasia belina* 3	16.66^{d} ±0.35	66.17^{d}±0.48	13.65^{b}±0.39	11.80^{d}±0.18	18.08^{d}±0.03
Fried *Gonimbrasia belina* 1	10.89^{b} ±1.07	59.77^{a}±0.43	21.40^{d}±1.35	11.42^{c}±0.52	20.01^{a}±0.54
Fried *Gonimbrasia belina* 2	12.27^{c} ±0.58	61.32^{a}±1.14	20.15^{d}±1.36	11.53^{c}±0.16	19.81^{b}±0.28
Fried *Gonimbrasia belina* 3	11.93^{b} ±0.31	61.13^{a}±0.35	20.71^{d}±1.39	11.55^{c}±0.30	19.49^{a}±0.64
p value	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

[1]Mean±SD, mean of nine replicates; means marked by different letters in the same column are significantly different, according to the Tukey HSD test ($p<0.05$).

Effect of cooking methods on amino acid profile

Table 4.7a shows the effect of different cooking methods on essential amino acids of *Gonimbrasia belina* samples obtained from South Africa. Overall, the results show that boiling in water alone or in water with salt added decreased most essential amino acids (histidine, threonine, lysine and valine) compared with frying. However, boiling in water alone and boiling in salt it resulted in a significant increase in methionine content. On the other hand, frying resulted in decrease in threonine, lysine, and valine content, but resulted in an increase in histidine and methionine content.

Previous studies on the effect of cooking methods on amino acid composition of edible insects could not be found in the literature. However, studies have shown that different cooking methods such as boiling with or without salt added, and frying resulted in a significant decrease or increase in amino acid content in meat and fish (Erkan et al., 2010; Oluwaniyi et al., 2010; Zhang et al., 2014; El-Lahamy et al., 2019). For example, Zhang et al. (2014) found that boiling rabbit meat resulted in a significant increase in all essential amino acids whilst, frying resulted in a significant decrease in lysine, threonine, isoleucine and valine content. A decrease in some amino acids mentioned above can be attributed to several chemical reactions occurring during cooking, such as transamination, and the Maillard reaction, deamination, racemisation, hydrolysis, and desulfuration (Medigo et al., 2018; Nyangena et al., 2020). The current study indicates that frying or boiling with or without salt would reduce the potential of insects for addressing deficiencies of some essential amino acids in the diets of the populations that are vulnerable to nutrient deficiencies. It is particularly of concern that both frying in fat and boiling in water with or without salt added result in a decrease in the lysine content of the insect samples. In sub-Saharan Africa, diets based on cereal grains are generally the most popular, yet, cereal grains are deficient in lysine. Several studies have shown that supplementing food products with insect flour increase nutritional composition (e.g. Ayensu et al., 2019; Kowalczewski et al., 2021; Zielinska and Pankiewicz, 2020). For example Awobusuyi et al. (2020) found that supplementing wheat biscuits with termite flour resulted in a significant increase in lysine content and other essential amino acids. Therefore, to increase lysine intake, dried insects should be ground and incorporated as an ingredient in food products such as bread, biscuits, maize meal and cereal grain porridges. Therefore, to increase lysine intake, dried insects should be ground up and incorporated as an ingredient in food products such as bread, biscuits, maize meal and cereal.

Overall, boiling without or with salt added and frying resulted in a significant increase in ash content of all samples of *Gonimbrasia belina* compared with the corresponding controls. Similar results were reported previously (Dreyer and Wehmeyer, 1982; Nonaka, 2009; Edijala et al., 2009; Klunder et al., 2012). An increase in the ash content during boiling was likely due to the concentration effect proportionate to the decreasing concentration of the other nutrients. For example, fat content decreased in boiled *Gonimbrasia belina* samples, whilst their ash content increased. The same reason, i.e. concentration effect, for an increase in ash content was suggested by Nyangena et al. (2020) In addition, for the samples where salt was added, an increase in ash content was partly due to the fact that salt is a mineral. These results suggest that to maximise mineral intake from the consumption of insects, they should be boiled with an addition of salt added.

Table 4.7.a**.** Essential amino acids of cooked *Gonimbrasia belina* samples using different cooking techniques (g/100 g, dry mass basis)

Treatments	**Histidine**	**Threonine**	**Lysine**	**Methionine**	**Valine**	**Isoleucine**	**Leucine**	**Phenylalanine**
Dried *Gonimbrasia belina* 1 (control)	2.09[a] ±0.74	2.89[c] ±0.09	3.69[e]±0.03	1.43[c] ±0.28	3.47[b] ±0.02	2.22 ±0.04	3.42 ±0.07	3.82± 0.07
Dried *Gonimbrasia belina* 2 (control)	1.75[a] ±0.09	3.08[c] ±0.13	6.23 [b]±0.43	1.20[e]± 0.10	3.36[b] ±0.22	2.49 ±0.39	3.76 ±0.62	3.54 ±0.65
Dried *Gonimbrasia belina* 3 (control)	2.11[a] ± 0.13	3.03[c] ±0.11	5.28 [c]±2.85	1.23[e] ±0.14	3.32[b] ±0.11	2.45 ±0.26	3.79 ±0.42	3.71 ±0.72
Boiled *Gonimbrasia belina* 1	1.56[b] ±0.14	2.73[b] ± 0.26	6.92 [a]±0.48	2.32[a]± 0.24	3.38[b] ± 0.08	2.45 ±0.39	3.73 ±0.60	3.55± 0.20
Boiled *Gonimbrasia belina* 2	1.23[b] ± 0.42	2.62[a] ±0.00	3.99[e]±0.17	1.32[d]±0.06	2.82[c] ± 0.05	2.14 ±0.03	3.29 ±0.05	3.83± 0.32
Boiled *Gonimbrasia belina* 3	1.72[a] ±0.08	2.55[a] ±0.04	3.20[f]±0.49	1.33[d] ±0.11	3.03[c] ±0.02	2.18 ±0.05	3.32 ±0.09	3.93± 0.05
Boiled, salted *Gonimbrasia belina* 1	1.09[b] ±0.05	2.69[a] ±0.02	4.58 [d]±0.13	1.42[c] ±0.14	2.68[a] ±0.02	1.96 ±0.06	3.06 ±0.12	3.10 ±0.27
Boiled, salted *Gonimbrasia belina* 2	1.38[b] ±0.07	2.69[a] ±0.23	4.32[d]±1.45	1.23[e] ±0.04	2.94[a] ±0.01	2.10 ±0.06	3.21 ±0.08	3.37±0.67
Boiled, salted *Gonimbrasia belina* 3	1.33[b] ±0.28	2.76[b] ±0.11	4.04[e]±0.99	1.55[b] ±0.41	3.05[a] ±0.16	2.19 ±0.20	3.33 ± 0.37	3.67 ±0.84
Fried *Gonimbrasia belina* 1	2.29[a] ± 0.02	2.48[a] ±0.01	2.66[g]±0.11	1.57[b]±0.11	2.98[a] ±0.01	2.00 ±0.01	3.18 ±0.00	3.81 ±0.013
Fried *Gonimbrasia belina* 2	2.28[a] ±0.05	2.52[a] ± 0.07	3.04[g]±0.18	1.44[c] ± 0.04	3.02[a] ±0.08	1.97 ±0.03	3.14 ±0.07	3.56± 0.03
Fried *Gonimbrasia belina* 3	2.15[a] ± 0.27	2.61[a] ± 0.03	3.12[g]±0.77	1.37[d] ± 0.03	3.07[a]±0.01	1.91 ±0.02	2.98 ±0.03	3.32± 0.42
p values	**0.006**	**0.005**	**0.025**	**0.004**	**0.001**	0.091	0.204	0.824

[1]Mean±SD, mean of nine replicates; Means marked by different letters in the same column are significantly different, according to the Tukey HSD test ($p<0.05$)

Table 4.7b. Non-essential amino acids cooked *Gonimbrasia belina* samples using different cooking techniques (g/100 g, dry mass basis)

Treatments	**Arginine**	**Serine**	**Glycine**	**Aspartate**	**Glutamate**	**Alanine**	**Proline**	**Tyrosine**
Dried *Gonimbrasia belina* 1 (control)	2.97 ±0.50	2.73 ±0.30	2.84 ±0.01	5.52 ±0.44	7.79 ±0.62	3.65 ±0.19	3.03 ±0.01	4.92 ±0.31
Dried *Gonimbrasia belina* 2 (control)	2.83 ±0.46	3.07 ±0.69	2.91 ±0.19	5.72 ±0.22	7.83 ±0.31	3.79 ±0.31	3.17 ±0.03	4.74 ±0.68
Dried *Gonimbrasia belina* 3 (control)	3.14 ±0.17	3.32 ±0.59	2.90 ±0.22	5.45 ±0.22	7.66 ±0.36	3.70 ±0.17	3.28 ±0.13	5.06 ±0.45
Boiled *Gonimbrasia belina* 1	2.74 ±0.09	2.83 ±0.65	2.61 ±0.05	4.95 ±0.31	6.75 ±0.23	3.47 ±0.26	3.03 ±0.30	4.60 ±0.17
Boiled *Gonimbrasia belina* 2	2.71 ±0.13	2.21 ±0.26	2.54 ±0.18	4.96 ±0.03	6.69 ±0.15	3.77 ±0.19	2.95± 0.10	4.77 ±0.21
Boiled *Gonimbrasia belina* 3	2.75 ±0.02	2.34 ±0.07	2.61 ±0.19	4.76 ±0.30	6.57 ± 0.36	3.37 ±0.25	2.93 ±0.07	4.96 ±0.02
Boiled, salted *Gonimbrasia belina* 1	2.00±0.16	2.19± 0.00	2.39 ±0.01	5.28 ±0.01	6.86 ±0.07	3.75 ±0.27	2.70 ±0.02	3.91 ±0.16
Boiled, salted *Gonimbrasia belina* 2	2.55 ±0.01	2.26 ±0.37	2.58 ±0.24	5.13 ±0.55	6.88 ±0.90	3.83 ±0.11	2.89 ±0.33	4.26 ±0.83
Boiled, salted *Gonimbrasia belina* 3	2.41 ±0.29	2.31 ±0.06	2.63 ±0.12	5.34 ±0.67	7.26 ±0.42	3.80 ±0.35	2.94 ±0.21	4.50 ±0.94
Fried *Gonimbrasia belina* 1	2.94 ±0.00	2.50 ±0.01	2.59 ±0.04	4.35 ±0.04	6.02 ±0.06	3.22 ±0.12	2.76±0.01	4.67 ±0.12
Fried *Gonimbrasia belina* 2	2.96 ±0.02	2.57 ± 0.09	2.59 ±0.01	4.53 ±0.26	6.17 ±0.34	3.15 ±0.05	2.75 ±0.01	4.38 ±0.01
Fried *Gonimbrasia belina* 3	2.85 ±0.17	2.60 ±0.02	2.53 ±0.05	4.97 ±0.19	6.70 ±0.09	3.24 ±0.07	2.63 ± 0.02	4.16 ±0.54

Effect of cooking methods on mineral element composition

Table 4. 8 shows the effect of different cooking techniques in mineral composition of *Gonimbrasia belina* samples obtained from South Africa. Boiling resulted in a significant increase in zinc (121.0-151.6 g/100 g) and iron (146.0-155.3 g/100 g) content of *Gonimbrasia belina* samples compared with the corresponding controls. The same trends of change in mineral content due to boiling was observed in sodium, phosphorus, calcium, and magnesium. Boiling in combination with addition of salt resulted in a significant increase in zinc content (131.6 g/ 100 g) and iron (184.3 - 167.3 g/100 g) content of *Gonimbrasia belina* samples compared with the corresponding controls. Similarly, frying resulted in a significant increase in zinc (129.0 - 147.0 g/100 g) and iron (187.0 -194 g/100 g) content of *Gonimbrasia belina* samples compared with the corresponding controls. The same trends of change in mineral content because of boiling with addition of salt and frying was observed for sodium, phosphorus, calcium and magnesium. Generally, boiling with or without salt and frying resulted in a significant increase in iron, zinc, sodium, phosphorus, calcium, and magnesium content of *Gonimbrasia belina* samples. Boiling with or without addition of salt and frying resulted in a significant decrease in potassium content of *Gonimbrasia belina*.

Results reported by other authors (Madibela et al., 2007; Manditsera et al., 2019), found that boiling and frying result in an increase or decrease of mineral content of edible insects. For example, Manditsera et al. (2019) investigated the effect of domestic cooking on protein and mineral content of wild harvested edible insects and found that boiling and frying edible insects resulted in an increase in iron content, however boiling and frying resulted in a decrease in zinc content of edible insect. Similarly, Madibela et al. (2007) found that frying resulted in a significant decrease in zinc content of *Gonimbrasia belina* consumed in Botswana. However, El-Lahamy et al. (2019) reported that boiling and frying did not affect zinc and iron content of Sudanese tree locust. There were no reports of previous studies on the effect of boiling with an addition of salt in mineral content of edible insects. The increase in zinc and iron during frying and boiling without salt corresponds to an increase in ash content, the reasons for an increase in ash were explained earlier. Salt is a mineral; therefore, addition of salt will result in an increase in total mineral content of *Gonimbrasia belina* samples. These results suggest that, to maximize intake of zinc and iron per unit weight of *Gonimbrasia belina* samples boiling and frying would be the recommended cooking methods

Table 4.8. Mineral composition of cooked *Gonimbrasia belina* samples using different cooking techniques

	g/100 g					mg/kg			
Treatments	**Sodium**	**Phosphorus**	**Calcium**	**Magnesium**	**Potassium**	**Iron**	**Zinc**	**Copper**	**Manganese**
Dried *Gonimbrasia* belina 1 (control)	1.96^{d}±0.06	0.50^{d}±0.04	0.09^{e}±0.01	0.17^{e}±0.17	1.25^{a}±0.05	81.33^{e} ±4.51	118.0^{d}±17.34	6.00±0.00	36.3±1.53
Dried *Gonimbrasia* belina 2 (control)	2.47^{c}±0.12	0.48^{d}±0.02	0.10^{d}±0.01	0.19^{c} ±0.01	1.28^{a}±0.03	110.0^{e} ±9.54	107.3^{e}±11.15	3.67±1.53	37.0±2.65
Dried *Gonimbrasia belina* 3 (control)	2.01^{d}±0.14	0.46^{d}±0.01	0.09^{e}±0.02	0.17^{e}±0.02	1.27^{a}±0.05	94.67^{e} ±18.93	99.6^{e}±3.06	5.67±1.16	36.6±3.79
Boiled *Gonimbrasia belina* 1	2.60^{c}±0.03	0.57 ^{c}±0.07	0.12^{b}±0.01	0.22^{b} ±0.01	1.22^{a}±0.02	155.33^{c}±11.68	135.3^{b} ±6.66	3.67±0.58	39.3±2.89
Boiled *Gonimbrasia* be*lina* 2	2.53^{b}±0.23	0.59^{a}±0.01	0.11^{c}±0.01	0.21^{b} ±0.01	1.22^{a}±0.03	148.00^{d}±28.62	151.6^{a}±23.03	4.00±0.00	41.0±1.00
Boiled *Gonimbrasia* be*lina* 3	2.30^{c}±0.02	0.57^{c}±0.01	0.11^{c}±0.00	0.20^{a} ±0.00	1.22^{a}±0.02	146.00^{d}±16.01	121.6^{d}±13.01	4.00±0.00	40.0±2.00
Boiled, salted *Gonimbrasia belina* 1	2.75^{a}±0.03	0.56^{b} ±0.01	0.13^{a}±0.01	0.20^{a} ±0.00	0.99^{b} ±0.01	185.00^{b}±9.54	144.3^{a}±14.64	4.00±0.00	36.3±0.58
Boiled, salted *Gonimbrasia belina* 2	2.72^{b}±0.47	0.61^{a}±0.00	0.12^{b}±0.01	0.20^{a} ±0.00	1.06 ^{b}±0.02	184.33^{b}±33.29	131.6^{b}±3.79	3.67±0.58	37.6±0.58
Boiled, salted *Gonimbrasia belina* 3	2.72^{b}±0.03	0.62^{a}±0.02	0.12^{b}±0.00	0.20^{a} ±0.01	1.07 ^{b}±0.06	167.33^{c} ±5.51	127.0^{c}±1.00	4.33±0.58	36.6±1.16
Fried *Gonimbrasia belina* 1	2.69^{b}±0.01	0.53^{b}±0.02	0.13^{a}±0.01	0.18^{d}±0.01	0.86^{d}±0.01	194.67^{a}±2.52	147.0^{a}±11.53	6.33±4.04	37.3±0.58
Fried *Gonimbrasia belina* 2	2.74^{a}±0.05	0.55^{b} ±0.02	0.13^{a}±0.01	0.19^{c}±0.01	0.91^{c}±0.04	187.00^{b}±2.00	124.6^{c} ±9.07	4.00±0.00	37.3±0.58
Fried *Gonimbrasia belina* 3	2.71^{b}±0.03	0.55^{b} ±0.02	0.14^{a}±0.00	0.18^{d}±0.01	0.92^{c}±0.08	192.67^{a}±4.73	129.0^{c}±10.58	3.67±0.58	35.6±0.58
p values	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	0.150	0.053

[1]Mean±SD, mean of nine replicates. Means marked by different letters in the same column are significantly different, according to the Tukey HSD test (p<0.05)

4.4. Conclusions

The nutritional composition of the edible insects studied varied with insect type. Among the insect types studied, samples of the termite soldiers/workers were found the most nutritious in protein and iron content, whilst *Gynanisa* caterpillar had the highest zinc content. Therefore, edible insects have a potential of alleviating protein, zinc and iron deficiencies around the world. In addition, edible insects consumption contributes to food and nutrition security in developing countries. This is directly linked to United Nations SDG goal 2: end hunger, achieve food and nutrition security and promote sustainable agriculture. Thus, consumption of insects should be broadened beyond the traditional population groups. Alternatively, it would be beneficial to recommend the consumption of different types of insects to leverage their different advantages in terms of concentration of specific nutrients. The study further demonstrated that the nutritional composition of the same insect type can vary with geographical location, which suggests the need to identify and map geographic areas that are superior sources of highly nutritive specific insect types.

Cooking methods were found to have different effects on the concentrations of different nutrients in *Gonimbrasia belina* samples. For the cooking methods investigated in the current study, it was found that boiling with or without salt added had the highest retention of protein, whereas boiling resulted in the highest retention of minerals. Overall, the results indicate that boiling with salt added would be the most recommended method for cooking insects as it retained the highest levels of protein and a significant percentage of total mineral content (ash). Our results showed that insects are a good source of protein, zinc and iron. However, climate and land use changes are a major threat, and result in the decline in the abundance and diversity of edible insects in South Africa (Teffo et al., 2007; Hlongwane et al., 2021). As a result, the decline in the availability of insects would affect the well-being of the communities who depend on them for food and nutrition security. Therefore, edible insects could potentially be farmed to increase their availability and accessibility.

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CHAPTER 5: THE ROLE OF EDIBLE INSECTS IN RURAL LIVELIHOODS AND CHALLENGES IDENTIFIED, IN VHEMBE DISTRICT, LIMPOPO, SOUTH AFRICA

This chapter is from: Hlongwane, Z. T., Siwela, M., Slotow, R., Munyai, T. C. The role of edible insects in rural livelihoods and challenges identified, in Vhembe district, Limpopo, South Africa. Diversity. (**Under review**).

Abstract

Edible insects are an important natural commodity in rural areas, used for household consumption and to generate income through trade. As a result, edible insect trading is a profitable business that provides employment, and improves the livelihoods of impoverished rural people. This study aimed at determining the socio-economic benefits of, and reasons for, trading insects, and to assess if edible insects are included in economic development strategies, in the Vhembe district of Limpopo province, South Africa. Using closed and open ended questions 72 insect traders were interviewed in five towns across the district. Five insect groups, belonging to four insect orders, were traded in informal markets of the district. Mopane worms (*Gonimbrasia belina*) were the most traded (42%) edible insects. Unemployment (45%) and demand for edible insects (34%) were the major reasons for trading in insects. Insect trading had numerous benefits, however provision of income (60%) and financial support (35%) were the primary benefits. Despite several benefits associated with trading in insects, there were many challenges with trading, such as insect spoilage and a decline in the availability of insects from the wild. Edible insects play an important role in food security and the rural economy by generating employment opportunities for unemployed traders. Insect trading is a traditional practice based on indigenous knowledge, which has persisted as an economic practice, that improves rural livelihoods in reducing poverty, and increases the human dignity of rural citizens. Few (four) governmental organization in Limpopo included edible insects in economic development strategies. Trading insects is primarily an informal activity, government could stimulate the activity, and broaden and deepen the community benefits, by providing infrastructure, access to harvest areas, financial support, and business training, as part of a rural empowerment strategy to end hunger and poverty, while creating employment opportunities in rural areas.

Keywords: Rural livelihoods, food security, income, employment opportunity.

5.1. Introduction

The majority of rural populations in southern and eastern Africa are food insecure and are susceptible to malnutrition (Kalaba et al., 2009). In addition, rural communities in Africa often experience high poverty levels, which exacerbate malnutrition and food insecurity problems (Kalaba, 2009; Kalaba et al., 2009; Govender et al., 2017). Rural areas in South Africa are underdeveloped, and job opportunities are scarce (Ofoegbu et al., 2017). As a result, most rural populations are poor, and depend on cash handouts from government in form of social grants, and the subsistence use of natural resources for survival (Ofoegbu et al., 2017). The use of wild natural resources, such as edible insects, is a rural safety net strategy against poverty and hunger (Dovie et al., 2010).

Rural communities in developing countries are greatly dependent on indigenous natural resources, such as wild fruits and edible insects, to sustain their livelihoods (Twine et al., 2003; Kalaba, 2009; Kalaba et al., 2009; Makhado et al., 2009; Dovie et al., 2010; Sekonya et al., 2020). Natural resources from the wild play an essential role in rural livelihoods in various communities in South Africa (Twine et al., 2009). These natural resources are primarily used for household consumption, and to generate income through trading (Kalaba, 2009; Makhado et al., 2009; Dovie et al., 2010). As a result, wild fruits and edible insects play an important role in food security in rural areas (Twine et al., 2003; Kalaba, 2009). Also, they are used as an alternative source of nutrition (Kalaba, 2009; Hlongwane et al., 2020).

Consumption of insects is a common practice in South Africa, particularly in Limpopo, Mpumalanga, Gauteng, and North West provinces (Teffo et al., 2007; Hlongwane et al., 2021). Edible insects are consumed because they play a significant traditional role in nutritious diets in various parts of South Africa (Teffo et al., 2007; Netshifhefhe et al., 2018), being an important source of protein, vitamins, fats, amino acids, and minerals (Teffo et al., 2007; Egan, 2013; Egan et al., 2014; Kelemu et al., 2015; Sogari et al., 2017; Netshifhefhe et al., 2018; Sekonya et al., 2020a; Hlongwane et al., 2020). As a result, edible insects are consumed regularly, or are used to supplement diets during times of hardship and when staple food is scarce (Raheem et al., 2019; Gahukar, 2020).

Edible insects trading is a good business that generates income and improves livelihoods in rural communities (Makhado et al., 2014; Muafor et al., 2014; Van Huis, 2016). The income generated from edible insects varies from species to species. For instance, *Gonimbrasia belina* (mopane worm) is an economically important caterpillar in southern Africa, which plays a vital role in rural income generation (Gardiner and Ghazoul, 2006; Nonaka, 2009; Anankware et al., 2015). Approximately 16 000 metric tons of mopane worms are traded per year, resulting in an income generation of about US$39 million to US$59 million a year in southern Africa (Potgieter et al. 2012). Mopane worm traders in the town of Thohoyandou in the Limpopo province of South Africa can each generate an income of approximately US$ 1393 (about R21 060) per year (Baiyegunhi et al., 2016). Other economically important species include termites that are widely consumed across Africa, creating earning opportunities for rural traders and harvesters (Dube et al., 2013; Kelemu et al., 2015; Netshifhefhe et al., 2018).

Despite the significant role of edible insects in improving rural livelihoods, there is still no clear policy and legislation that governs edible insect trading and consumption in South Africa. There is also limited information on policy documents and regulations that support and promote the use of insects as food. Therefore, this study aims to determine socio-economic benefits of trading insects in the Vhembe district, South Africa, and the associated reasons for trading insects, by: (1) assessing if edible insects are included in economic development strategies in the Vhembe district; (2) identifying economically important edible insect groups; and (3) determining the benefits and monetary value associated with trading edible insects. Based on our results, we provide policy recommendations to improve rural livelihoods and wellbeing.

5.2. Materials and Methods

5.2.1. Study site

The study was conducted in December 2019 across six towns in the Vhembe district of Limpopo province in South Africa: Elim (23.1561° S 30.0554° E), Makhado (23.0462° S, 29.9047° E), Sibasa (22.9325° S, 30.4674° E), Thohoyandou (22.8785° S, 30.4818° E), Musina (22.3813° S, 30.0319° E), and Biaba (22.540° S, 30.0319° E).

Questionnaires

A questionnaire comprising of open-ended and closed questions was used to source information from traders in each town, selected based on our observations of people buying and selling insects in the markets, bus terminals, taxi ranks, and along roadsides. The number surveyed in each town was based on the scale of the trade we observed, and we interviewed as many as possible. Traders were asked to list the number of species that they were selling, and where they harvested or bought their insects for trading. Also, to describe how they processed the insects, the reason for selling insects, preparation and storage methods, socio-economic benefits, challenges associated with selling insects, and season of availability of different species that they were selling (Appendix 5. 2). Assessment of trading conditions, considering food safety, hygiene, trading structure, shelter, storage, safety, sanitation and water availability, was conducted across trading places in Vhembe district.

This study has been ethically reviewed and approved by the University of KwaZulu-Natal Human and Social Sciences Research Ethics Committee (approval number HSS/0125/019D). Permission to conduct research in various towns was obtained from the Vhembe district municipality. All participants provided informed consent to participate in the study, and data were anonymised, treated confidentially, and stored securely.

5.2.2. Data analysis

Data from the questionnaires were coded and entered into a Microsoft Excel spreadsheet. A chi-square test of independence was used to determine if there were any significant differences in the number of insects harvested and sold across small towns. Count data of respondents were presented in percentages. The chi-square test analysis was performed using IBM SPSS Statistics version 26 (SPSS Inc., Chicago, IL, USA)

5.3. Results

A total of 72 informal street vendors selling one or more species of edible insects were surveyed in Vhembe district, Limpopo. These traders were from the towns Thohoyandou (27), Tshakhuma (14), Sibasa (10), Musina (7), Louis Trichardt (6), Elim (6) and Biaba (2). The majority of traders were women (94%) between the ages of 18 to 74 years, while only 6% of traders were males, between the ages of 35 and 65 years (Appendix 5.1). Most traders (30%) were between 35 to 44 years old, followed by 45 to 54 years (22%), and the least number of traders (8%) were the youth, between the ages of 18 to 24 years (Appendix 5.1).

Education background of the traders ranged from no formal education to tertiary education, with the majority of the traders (65%) obtaining secondary education, followed by primary education (22%), and the fewest (3%) traders having tertiary education. The majority of the traders (98%) were unemployed and made a living by selling edible insects, while only 2% of the traders were employed and selling insects part-time. In addition, 97% of the traders were breadwinners in their households.

Forty-two percent of the traders sold mopane worms only, followed by traders that sold a combination of termites (13%), and traders that sold a combination of mopani worm and termites (10%). In contrast, fewer traders (2%) sold *Gynanisa* caterpillars only (Figure 5. 1). There were significant differences in the number of traders who sold mopane worms (X^2_7= 23.996, p<0.05), termites soldiers/workers (X^2_7 = 60.484, p<0.05), termites alates (X^2_7 = 41.203, p<0.05), *Gynanisa* caterpillar (X^2_7 = 15.707, p<0.05) across towns, but there were no significant differences in the number of traders who sold stink bugs (X^2_7 = 22.242, p>0.05) or grasshoppers (X^2_7 = 6.105, p>0.05).

Stinkbugs and grasshoppers were out of season and not seen in the markets during the survey. However, our analysis was based on the responses of the traders who sell stinkbugs and grasshopper when they are in season. Ninety-four percent of the traders bought insects from middlemen, with only 6% involved in insects harvesting from the wild.

Insect trading took place in the informal markets along the street, pavements, and on table stalls made of cardboard and wood. The majority of trading stalls had no protection from the sun (Figure 5. 2). Some traders were sitting down on pavements along roadsides. Safety and hygiene were the major issues of concern stated by the respondents in Vhembe district. The informal markets were untidy with few garbage disposal units. There were no traders' dedicated sanitation services (including running water, toilets). Majority of the traders had no secure storage units in which to put their stock; as a result, several traders were forced to travel with their stock every day because of the high theft rate.

The retail price of edible insects per steel cup (200 grams) varied (caterpillars: (R30 (US$1.85) per cup; termites: R20 ($1.23) per cup (see Figure 5.3)). We noted that traders in the area usually buy a 5 kg bucket of the caterpillars costing R300 ($18.5) from the middleman, which generates between R2000-R3000 ($123-$185) for the trader. In addition, a 50 kg sack of caterpillars costs R3000 ($185) and generates a total of R15000 ($923). On the other hand, 5 kg bucket of termites cost R200 ($12.3) from the middleman and generates an income of R1500 ($92.3).

Forty-five percent of the traders indicated that unemployment was the primary reason for selling edible insects. The second (34%) primary reason for trading was increased demand for edible insects by consumers, while 14% cited poverty. Few (1%) traders indicated that they sold insects because of their health benefits (Figure 5.4a).

Most traders (60%) cited that trading insects provided financial support, while 35% cited that they use money generated from trading insects to pay school fees, buy electricity, and some household items. However, 5% mentioned that they don't benefit much from selling insects. Three percent of the traders made above R2000 ($123) per week in large towns, while only one percent of the traders made above R2000 ($123) per week in small towns (Figure 5. 4b).

A total of 36 policy documents from various governmental organizations in Limpopo were reviewed, and only four policy documents included edible insects in economic development strategies. Also, only mopane worm was included in economic development strategies, while other insects were not included (Table 5. 1). Interventions were aimed at providing infrastructure for processing, packaging, storage, etc.; however, only one plan provided a budget for this (Table 5. 1).

Table 5. 1. Policy documents that included edible insects in economic development strategies in various governmental organisations in Limpopo province

Municipality	Policy document	Year	Edible insects included	Action/ explanation	Budget allocation
Limpopo (Economic Development Agency)	Strategic plan	2020-2025	None	No action	
Limpopo (Provincial treasury)	Strategic plan	2020-2025	None	No action	
Vhembe district Municipality	IDP	2020-2021	None	No action	
Musina local municipality	IDP	2020-2021	None	No action	
Musina local Municipality	IDP	2015-2016	Mopani worm	No action	
Musina local Municipality	IDP	2013 -2014	Mopani worm	No Action	
Musina local Municipality	LED	2018	Mopani worm	Planned to establish mopani worm production facility for processing and packaging of mopani worm	

Collins Chabane local Municipality	IDP	2017-2018	None	No action
Collins Chabane local Municipality	IDP	2018-2019	None	No action
Collins Chabane local Municipality	IDP	2019-2020	None	No action
Collins Chabane local Municipality	IDP	2020-2021	None	No action
Thulamela local Municipality	IDP	2020-2021	None	No action
Makhado local Municipality	LED	2013	None	No action
Mopani District Municipality	IDP	2016-2021	None	Recognises mopani worm as an important economic activity in the district
Mopani District Municipality	IDP	2006-2012	None	No action
Greater Giyani local Municipality	IDP	2020	Mopani worm	The municipality recognizes mopani worms trading as an important economic activity. Dzumeri Processing centre used

				by insect traders and harvesters to process, store and trade mopani worm	
Greater Giyani local Municipality	LED	2014-2016	Mopani worm	Greater Giyani Natural Resource program aimed at expanding mopani worm business. The municipality proposed building a processing center used by local traders to store large quantities of mopani worms and expand mopani worm value chains to the neighboring SADC countries.	R11.6 million ($801104.97)
Greater Tzaneen Municipality	LED	2018	None	No action	
Greater Tzaneen Municipality	IDP	2015-2016	None	No action	
Greater Tzaneen Municipality	IDP	2019-2020	None	No action	
Capricon District Municipality	IDP	2016-2021	None	No action	

Blouberg local Municipality	IDP	2015-2016	None	No action
Blouberg local Municipality	IDP	2019-2020	None	No action
Blouberg local Municipality	IDP	2018-2019	None	No action
Blouberg local Municipality	IDP	2020-2021	None	No action
Molemole local Municipality	LED	2012	None	No action
Molemole local Municipality	LED	2019-2024	None	No action
Lepelle-Nkumpi local Municipality	IDP	2015-2016	None	No action
Lepelle-Nkumpi local Municipality	IDP	2016-2021	None	No action
Lepelle-Nkumpi local Municipality	IDP	2017-2018	None	No action
Lepelle-Nkumpi local Municipality	IDP	2015-2016	None	No action

Lepelle-Nkumpi local Municipality	IDP	2020-2021	None	No action
Lepelle-Nkumpi local Municipality	LED	2019	None	No action
Aganang local Municipality	LED	2013	None	No action
Aganang local Municipality	IDP	2009-2010	None	No action
Polokwane local Municipality	IDP	2019-2020	None	No action
Polokwane local Municipality	IDP	2021-2021	None	No action

IDP-Integrated Development Plan; LED- Local Economic Development strategy. Makhado and Musina local municipalities fall under Vhembe District Municipality, and Blouberg under Capricorn District Municipality, and Greater Giyani and Greater Tzaneen under Mopani District Municipality.

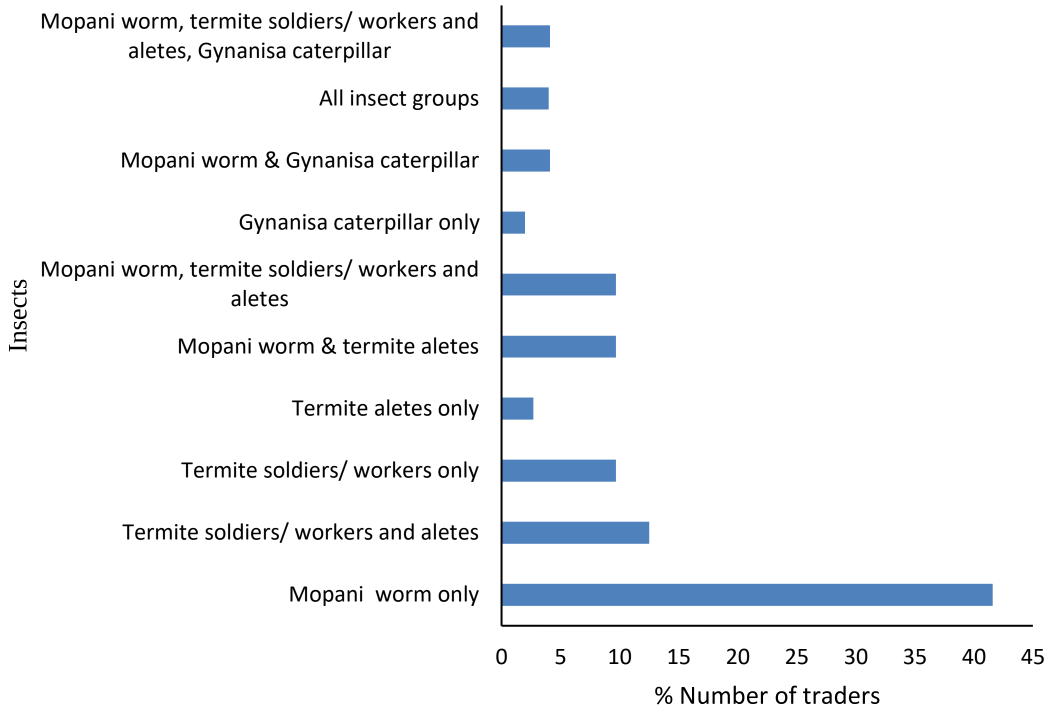

Figure 5. 1. Edible insects sold in various towns of the Vhembe district, Limpopo province, South Africa (n=72). *All species refers to mopani worm, termite soldiers/workers and alates, *Gynanisa* caterpillar, grasshopper, and stinkbug

Figure 5. 2. Photos showing the condition of informal markets where edible insect are sold in towns of Vhembe District, South Africa: (a) Thohoyandou, (b) Makhado, (c) Elim and (d) Sibasa

Figure 5. 3. Steel cup (200 g) used to measure single serving of insects, in this case termites.

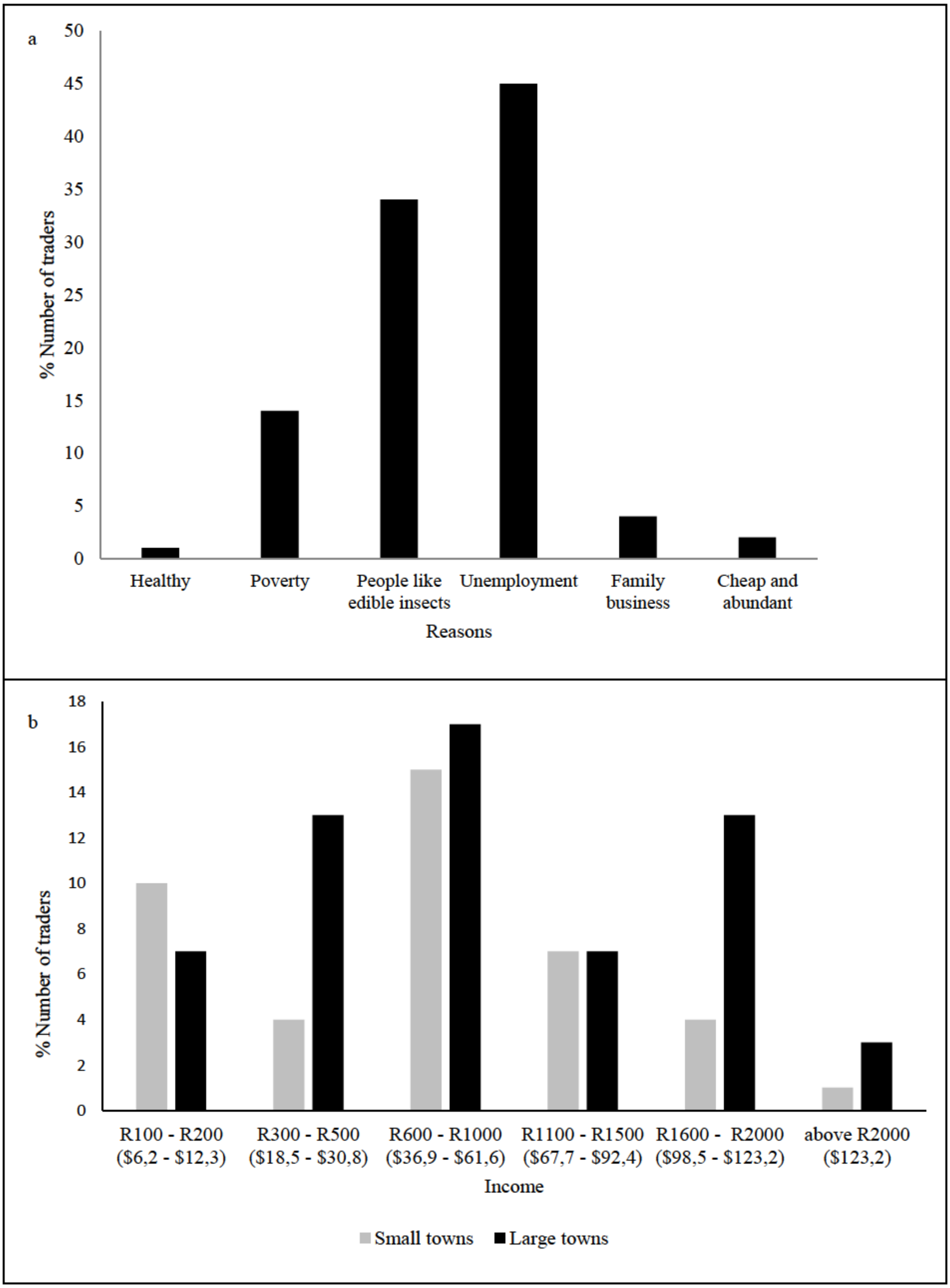
a
50
45
40
35
30
25
20
15
10
5
0
% Number of traders
Healthy
Poverty
People like edible insects
Unemployment
Family business
Cheap and abundant
Reasons
b
18
16
14
12
10
8
6
4
2
0
% Number of traders
R100 - R200 ($6,2 - $12,3)
R300 - R500 ($18,5 - $30,8)
R600 - R1000 ($36,9 - $61,6)
R1100 - R1500 ($67,7 - $92,4)
R1600 - R2000 ($98,5 - $123,2)
above R2000 ($123,2)
Income
Small towns
Large towns

Figure 5. 4. (a) Reason for trading insects and (b) the weekly profit generated by traders from selling edible insects, across small towns (i.e. Elim, Sibasa, Tshakuma, Biaba and Halambani) and large towns (i.e. Thohoyandou, Makhado and Musina) in Vhembe district (n=72 traders).

5.4. Discussion

Edible insect trading is an everyday activity that provides seasonal employment for unemployed communities in Vhembe district, particularly for females (Netshifhefhe et al., 2018). This study found that almost all of the traders were women, and when men did trade, they were over 35 years of age. Insect trading is primarily female driven in most countries in Africa (Dzerefos et al., 2009; Adeoye et al., 2014; Netshifhefhe et al., 2018; Imathiu, 2020). These results indicate that women play an essential role in rural livelihoods, and they are the backbone of subsistence household food security. Women depend on edible insects to generate cash income that reduces poverty and improves household food security (Shackleton et al., 2011; Food and Argriculture Organization of the United Nations, 2013; Van Huis, 2016). As a result, edible insect trading creates opportunities for women to participate in economic development in rural areas, thus empowering them with income opportunities and improving their livelihoods (Naughton et al., 2017; Shackleton et al., 2011; Imathiu, 2020). This directly contributes to SDG 1, 2 and 5, no poverty, zero hunger and to achieve gender equality and empower all women and girls respectively (Imathiu, 2020). The National Development Plan of South Africa's goal is to eradicate poverty and to reduce inequality by year 2030. Therefore, expanding edible insects markets can contribute to realizing this goal. Edible insects should be adopted as an economic development strategy to end poverty in developing countries, and empower women by providing earning opportunities.

Edible insects are an important natural resource used as food and cash income in southern Africa (Hope et al., 2009; Makhado et al., 2009; Baiyegunhi et al., 2016). This study found that mopane worms were the most sold insects across towns in the Vhembe district. Mopane worms are a popular food source and delicacy that is widely consumed in southern Africa (Makhado et al., 2014; Baiyegunhi et al., 2016;). The sale of mopane worms results in an income of approximately US$39 million to US$59 million per annum across South Africa, Zimbabwe, and Botswana (Potgieter et al., 2012; Makhado et al., 2014). Edible insects provide earning opportunities that play a crucial role in improving livelihoods and reducing poverty in rural areas (Makhado et al., 2014; Netshifhefhe et al., 2018; Van Huis, 2016). Consumption and trading of edible insects are essential coping strategies contributing to household food security and nutrition (Makhado et al., 2014).

Natural resources provide many benefits to people in rural areas. As a result, edible insects play an important role in sustaining rural livelihoods (Timko et al., 2010; Gahukar, 2016). Harvesting and selling insects improve rural livelihoods by providing cash income that is used for basic needs such as paying school fees, buying food, and paying electricity bills (Agea et al., 2008; Gahukar, 2010). Trading edible insects provide seasonal employment, and creates earning opportunities in rural communities in Southern Africa (Makhado et al., 2009; Thomas, 2013).This study found that income generated from trading insects in Vhembe district, Limpopo ranged from R100 – R200 per week, to over R2000 per week. These findings are in range with the findings of Netshifhefhe et al. (2018) who reported that, on average, the amount made from selling termites in Limpopo was estimated to be R292 ($18) a day, R2395 ($147) a month, and R20400 ($1256) a year. On the other hand, in Namibia and Cameroon, income from selling insects was estimated to be $71-4800 per season (Adeoye et al., 2014; Muafor et al., 2014). Traders said the income from selling insects had improved their standard of living (Agea et al., 2008).

South Africa remains one of the countries with the highest unemployment rate globally (Harmse et al., 2009; Klasen and Woolard, 2009; Davies and Thurlow, 2010), and unemployment is one of the significant socio-economic issues facing this country. According to Statistics South Africa (2020), the unemployment rate in South Africa was estimated at 30.1% in the first quarter of the year 2020, and approximately 7.1 million South African were unemployed in this quarter. Most of the unemployed population in South Africa is found in rural areas (Klasen and Woolard, 2009), and the majority of the population in Limpopo live in rural areas (De Cock et al., 2013). This study reported that unemployment and poverty were the primary reasons for trading insects in the Vhembe district. According to Makhado et al. (2009), 82% of the respondents in six villages of Greater Giyani Municipality, Limpopo were unemployed and dependent on woodlands natural resources such as edible insects and wild fruits and herbs, medicinal plants, and fuelwood for household nutrition and income generation. In addition, high poverty rate resulted to rural people selling insects to sustain their livelihoods (Muafor et al., 2015)

Edible insects are a traditional food source that has been consumed in South Africa over centuries (Bodenheimer, 1951; Quin, 1959). However, edible insects are still not included in food policies and legislation that governs the use of insects as food (Niassy et al., 2018). Edible insects are not regulated in terms of food safety and quality even though they are widely consumed in Limpopo, and in some parts of Mpumalanga, Gauteng, North West and KwaZulu-Natal province (Shackleton et al., 2002; Teffo et al., 2007; Hlongwane et al., 2021). Both government and non-governmental organization are not doing enough to protect, promote and encourage the culture of consuming insects in South Africa. Edible insects are seen as food for the poor people, dirty and undignified food (Egan, 2013). For example, edible insects are mostly (rarely anywhere else) sold in informal markets where selling conditions do not meet the food standard requirements approved by the Department of Health, the Department of Agriculture, Forestry and Fisheries and the Department of Trade and Industry (Niassy et al., 2018). The informal markets where insects are sold had no proper sanitation facilities (running water and toilets), no proper storage facilities, were fundamentally unhygienic, and not safe.

Little is being done to improve the conditions where edible insects are sold, as indicated by our assessment of the municipal development plans. This shows a lack of respect and human dignity, which is unconstitutional given Section 10 of the South African constitution: "Everyone has inherent dignity and the right to have their dignity respected and protected" (Constitution of the Republic of South Africa 1996). Important cultural practices should be celebrated and embraced by the government (in terms of Sections 30 and 31 of the Constitution), by offering support such as infrastructure, proper storage facilities, and funding to improve trading conditions of edible insects. This would also ensure that food safety and hygienic practices are being met. The personal circumstances and needs of the traders and their clients are accorded the necessary dignity and respect.

Edible insects are rarely included in rural development strategies. As a result, resources and budget to develop and expand the edible insects sector is limited (Shackleton and Pandey, 2014). The lack of clear legislation and regulatory guidelines that govern trading and the use of insects as food in South Africa might be the primary barrier that prevents local authorities from including edible insects in rural economic development plans (Niassy et al., 2018). There are no clear guidelines on the use of insects as food in South Africa. There are no standards on the use of insects for human consumption (Niassy et al., 2018). Food laws, such as the Meat Safety Act (2000), and policies in South Africa have not included insects, and insects have not been tested and approved for human consumption (Niassy et al., 2018). This may be the reason for not including edible insects in economic development strategies. The National Biodiversity Economy Strategy (2016) does not include developing the use of insects in rural areas. In addition, this might be the major barrier that preventing the expansion of edible insect food sector in South Africa, and other parts of the world (Halloran et al., 2015).

Government and local authorities are well aware of the potential of edible insects in addressing food insecurity and poverty in South Africa. For example, the Intergrated Development Plan 2020/2021 of Greater Giyani local municipality recognised mopani worms trading as an important local economic development activity that contributes to livelihoods in this municipality. Furthermore, the Greater Giyani Municipality Local Economic Development Strategy of year 2014-2016 had plans to establish a mopane worm processing center used by traders to sell and store large quantities of mopani worm traders in a hygienic place (Greater Giyani Municipality LED, 2014-2016). This municipality also wanted to expand mopani worm value chain to neighbouring SADC countries. This initiative will provide job opportunities to local people in Giyani, South Africa (Greater Giyani Municipality LED, 2014-2016). Musina Local Municipality also wanted to establish mopani worm production facility that will be used for storing and processing of mopani worms by local traders and harvesters (Musina Local Municipality LED, 2018). The Greater Giyani and Musina local municipalities are moving in the right direction by including mopani worm in their local economic development strategies, but these strategies need to translate into implementation on the ground, which will require allocation of the necessary budget. The focus should not be on mopani worms; other edible insects (for example, termites, stink bugs and grasshoppers) that are consumed in these municipalities should be prioritized. Other municipalities should also include edible insects in their local economic development strategies, because edible insects can create earning opportunities for rural communities.

Edible insects are collected in the wild and their availability is affected by climate change, uncontrolled harvesting, land use changes such as clearing of land and agriculture (Niassy et al., 2018; Hlongwane et al., 2021). The decline in the availability of insects affects rural communities who depend on edible insects trading for making a living. As a result, edible insects could be farmed to ensure long term availability and accessibility when the natural supply is limited. (Stull et al., 2018; Stull and Patz, 2020). Edible insects have been farmed successfully in Thailand, Kenya, Uganda, Ghana, and Zimbabwe (Halloran et al., 2015; Stull et al., 2018). The Flying Food project in Kenya and Uganda are small scale insect farming projects that have successfully farmed edible crickets (Flying Food Project, 2013), whilst, the Aspire Food Group project specializes in farming palm weevils in Ghana (Aspire Food Group, 2016). Mopane Worm Enterprises from Zimbabwe specializes in farming mopane worms (Mopani Worm Enterprises, 2017). These small scale insect farms are good examples of successful insect farming that can be adopted in South Africa, thereby creating localised value chains. Farming edible insects will reduce overharvesting pressure and ensure that edible insects contribute to rural development, job creation, and social wellbeing, without putting pressure on the species in the wild. However, there must be clear legislation and regulatory frameworks governing the farming of edible insects to ensure that proper standards and guidelines are followed (Halloran et al., 2015). Insect farming in South Africa can provide training opportunities and skills that will empower rural communities.

5.5. Conclusion

Edible insects are a traditional food source that plays a vital role in rural food security. Traditional food contributes primarily to rural livelihood improvement as a source of income and nutrition. As a result, edible insect trading plays an important role in elleviating poverty for unemployed rural people in the Vhembe district. This study revealed that edible insect trading is an economic activity that creates earning opportunities for unemployed people in rural areas, especially women. Mopane worms were the most sold insect in various towns across the district. Edible insects generate income for many more people in rural areas. Therefore, edible insects should be included in food policies and prioritised as a nutritious food source that can improve food and nutrition security in South Africa. The associated education and awareness interventions are necessary to promote their use. Edible insect trading can be adopted as rural development and poverty eradication strategy to improve rural livelihoods and create job opportunities. However, traders should be provided with infrastructure and funding for insect farming as part of the rural development program to create job opportunities while empowering rural communities, thus contributing to food security. Edible insect farming will ensure accessibility and grow the edible insect markets in rural areas. In addition, this will provide stable earning opportunities for insect traders and farmers. Edible insects can generate revenue that can contribute to the rural economy, thereby reducing poverty in rural areas. Government officials should invest in expanding the sale of edible insects in the Vhembe district, because they play an important role in generating income for traders in this district.

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Vhembe district Municipality Intergrated Development Plan 22020-2021

CHAPTER 6: GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

Edible insects are a good source of essential nutrients such as protein, zinc, iron and essential amino acids. As a result, they have a potential of addressing food and nutrition security worldwide particularly in developing countries. This study investigates diversity, distribution, nutritional composition, economic and cultural benefits of edible insects consumed in South Africa. Questionnaires were administered to collect indigenous knowledge about consumption, collection and preparation of edible insects in KwaZulu-Natal and Limpopo provinces. In addition, edible insect traders were interviewed to collect information about socio economic and cultural benefits of trading in insects in Vhembe district in Limpopo province, South Africa. The nutritional composition of edible insect consumed in South Africa was determined using the standard methods of the Association of Official Analytical Chemists. Based on the results, the study will provide policy recommendations and suggest areas for future research.

Summary of results

6.2. Nutritional composition of edible insects consumed in Africa: A systematic review

Systematic review of extant literatures revealed that 212 edible insect species from nine insect orders are potentially used as food in Africa. Of these, Lepidoptera was found to contain the highest number of species, while Mantodea and Diptera contributed less than 1%. These insects provided an excellent source of protein, fats, and fibre. However, the proximate composition varied with insect orders. For instance, the highest protein and fat content were recorded in order Lepidoptera whilst, order Coleoptera contained the highest fibre content.

Iron and zinc are minerals lacking in diets of many Africans thus, many people in Africa suffer from iron and zinc deficiencies. In chapter 2, species such as *Zonocerus variegatus*, *Pseudacathotermes spinige*, and *Macrotermes herus* were found to contained high iron content of 910, 332, 161 mg/100 g respectively, while, *Zonocerous variegatus* (29 mg/100 g) and *Rhyncophorus phoenicis* (26.5 mg/100 g) had adequate zinc content. Findings from chapter 2 revealed that *Gonimbrasia belina* (mopane worm), *Macrotermes falciger*, *natalensis* and *bellicosus* (termites) were the most consumed species in southern Africa while, *Rhynchophorus* *phoenicis* (palm weevil), and *Cirina forda* (pallid emperor moth) were the most consumed species in western and central Africa. Furthermore, *Ruspolia nitidula* and *R. differens* (grasshoppers) were the most consumed species in eastern Africa.

6.3. Indigenous knowledge about the consumption of edible insects in South Africa

This study found that entomophagy is an important traditional practice contributing to nutrition security in Limpopo and KwaZulu-Natal provinces. The consumption of insects is still a common practice in Limpopo province; however, this practice is declining in KwaZulu-Natal due to the adoption of western diets.

This study found that mopane worms and termites were the most preferred edible insect in Limpopo and KwaZulu-Natal, respectively. These insects were consumed because they are a traditional food source that plays an important role in nutrition security in households in Limpopo and KwaZulu-Natal. This study reported that religion and discomfort associated with consuming insects were the main reasons for not consuming insects. Religion influences what people eat, and certain foods are deemed unholy by particular religious groups. Some people, particularly youth, perceive edible insects as unclean, dirty, and fear consuming insects These barriers, or food taboos, contribute to the decline in entomophagy As a result, there is a need to promote and encourage the consumption of insects to ensure that people benefit from their nutritional benefits.

Edible insects are collected in the wild primarily by women, and they are consumed fried, boiled, roasted, or as a relish. Edible insects are collected and cooked using traditional methods. Therefore, culture influences the way insects are cooked. Traditional knowledge provides vital information about when and how to harvest insect species. It also includes information about how insects are prepared (cleaned) and cooked for human consumption. This information is passed down through generations by demonstration, storytelling, and observations.

6.4. Nutritional composition of insect species commonly consumed in South Africa, and the effect of cooking methods on their nutritional composition

Chapter 4 revealed that edible insects contained a considerable amount of protein, iron, and zinc content. However, nutritional composition varied with insect species and geographic type. Termite workers/ soldiers had the highest protein and iron content compared with other edible insects groups, whilst *Gynanisa* caterpillar had the highest zinc content. Generally, mopani worms, termites, and *Gynanisa* caterpillar from South Africa had the highest protein, iron, and zinc content relative to insect species from other countries, i.e., Zimbabwe, Zambia, and Botswana. Even though edible insects studied have considerable amounts of iron and zinc, studies have shown that these micronutrients may not be bio-assimilated in the body when eaten (Skau et al., 2015; Konyole et al., 2019). Therefore, to improve iron and zinc absorption and utilization food products need to be fortified with these micronutrients.

Findings in chapter 4 revealed that cooking methods had a significant effect on the nutritional composition of mopani worms. Boiling, with or without salt added, resulted in a significant increase in the percentage of protein content compared with controls. On the other hand, frying resulted in a significant decrease in protein content of mopani worm samples compared with controls. Frying or boiling with or without salt resulted in a significant increase in zinc and iron content compared with controls. Therefore, to maximise mineral intake from consumption of edible insects, they should be boiled before consumption.

Edible insect species studied made a significant contribution to Estimated Average Requirement (EAR) for protein, iron, and zinc. Mopani worm contributed significantly to addressing protein deficiencies, with 156.7 – 160.4% EAR for children between 4 -8 years old and 52.4 – 53.6% EAR for both 19-30 years child bearing women and 31 -50 years child bearing women. On the other hand, all insect types would contribute a significant percentage of EAR for iron (107.7 -381%) and zinc (108- 152%) for children between 4- 8 years old, but would have lower percentage contribution for iron (20 -70%) and zinc (21.2 – 64.1%) for both 19-30 years child bearing women and 31-50 years child bearing women.

6.5. The role of edible insects in rural livelihoods in Vhembe district, Limpopo, South Africa

This study revealed that edible insects play an important role in income generation in Vhembe district, Limpopo. Mopane worms, termites, grasshoppers, stinkbug, and *Gynanisa* caterpillars were sold in various markets in Vhembe district. Traders sold at least one to four insect orders. However, the majority of the traders sold mopani worms only, followed by traders that sold a combination of mopani worms and termite soldiers or alates.

Unemployment and poverty were the main reasons for trading in insects. Trading insects creates earning opportunities and provides financial support to traders in rural areas. Money generated from trading insects ranged from as little as R100 - 200 per week to over R2000 per week. Income generated from trading insects is used to pay school fees, buy electricity and few household items. The current study indicates that edible insect trade plays a crucial role in rural livelihoods.

Findings from chapter 5 show that edible insects contribute to rural livelihoods and food security by providing earning opportunities and seasonal employment. However, edible insects are not included in food policy and legislation in South Africa. As a result, few municipalities in Limpopo have included edible insects in economic development strategies. This hinders the growth and expansion of trading on edible insects.

Availability of edible insects is one of the major challenges affecting insect trade in the Vhembe district. As a result, edible insects should be farmed to ensure availability and accessibility when the natural supply is limited. Therefore, governmental and non-governmental organizations should provide infrastructure, farming resources, and financial support to train local people to farm insects. This will provide skills development, and job, career, and business opportunities that will improve rural livelihoods. In addition, insect farming will reduce the overharvesting pressure in a wild population of edible insects.

6.6. Limitations of the study

- Some species that respondents listed were out of season during the period of data collection. As a result, the nutritional composition was only analysed for the insects that were in the season. This excluded several groups, such as the stink bug, grasshoppers and locusts.
- The number of traders interviewed was based on the number of the traders we observed in each town; however, a few traders refused to be interviewed.
- As the majority of traders cited that they purchased edible insects from middleman from Zimbabwe, it would have been beneficial to interview the middlemaen to understand edible insect value chains before they reach South Africa; however, during the time of data collection the middlemen were not available.

- The small sample size of harvesters during data collection resulted in the exclusion of the role of harvesting edible insect from the study
- This study did not assess assimilation of micronutrients, for future research it is important to investigate opportunities for increased bioavailability through fortification processes.

6.7. Future studies

Most edible insect availability is seasonal which implies that access is limited when insects are out of season. This negatively affects traders and consumers who use edible insects to supplement their diets, and for income generation. As a result , edible insects should be farmed to increase availability. Future studies should focus on studying the feasibility and technologies required for insect farming and rearing in South Africa. In addition, more research should focus on developing regulatory frameworks governing the consumption, farming, harvesting, transportation and trade of edible insects in South Africa.

Edible insects are harvested in the wild and processed using traditional methods that increase shelflife. Therefore future research should investigate innovative methods to increase shelf life of edible insects. In addition, The effect of storage methods or conditions should be determined in future studies as it may affect the nutritional composition of edible insects. Edible insects are harvested and traded in informal markets with poor hygiene conditions therefore, research should focus on investigating health and safety of edible insects, particularly within informal trading environments. In addition, future studies should focus on investigating the risk of potential mycotoxins, heavy metals, insect allergies, and pathogens from consuming edible insects.

6.8. Recommendations and implications of research findings

Based on the results of the study that revealed that edible insects contain high percentage of essential nutrients such as zinc, iron, amino acids and proteins. This implies that edible insects can contribute to improved diets in many rural communities. Therefore, it is suggested that edible insects should be prioritised in communities of low economic status where malnutrition and poverty are prevalent. Government officials should encourage and promote the consumption of indigenous food sources such as edible insects that contribute in improving rural diets. This can be done by recognising edible insects as essential traditional food.

Insects are prepared using indigenous knowledge that has been passed down from older generations. Knowledge about indigenous methods and skills can play an important role in stimulating the development of technologies that can be used to improve harvesting, preservation, storage, and preparation methods used in rural areas. Government authorities should merge traditional knowledge with modern science to establish innovative technologies that can be used to establish and scale up farming and rearing technologies in South Africa. In addition, edible insects need to be farmed to increase availability when the natural supply is limited.

This study reported that trading in edible insects provide employment and earning opportunities for rural people. In addition, the income generated from trading in edible insects ranged from (R100- R200) to over R2000 per week in Vhembe district. As a result, trading in edible insects generates high income levels, greater than minimal wage labour, in rural areas in South Africa.. Therefore, government authorities should expand the edible insect industry by maximizing the production of edible insects. Mass rearing and farming of edible insects are strategies that can be used to grow the edible insect sector. In addition, mass rearing and farming of edible insects can contribute to the development of edible insect value chains that can contribute to the economy of South Africa. Government authorities should look into commercialization of edible insects, this will include development of value-added products (biscuits, bread, cereal, protein snack bars, and protein shakes) derived from edible insects. To capitalize on the economic benefits of edible insects, government authorities need to develop policy and legislation that governs production of insect based products, farming, and trading of edible insects. This will ensure that proper standards and regulations are in place, but there has to be follow-up to ensure implementation.

Edible insects are a good source of nutrients and they are considered a healthy food source. Based on the result of this study that revealed that the nutritional value of edible insect varies greatly with insect type, geographic location, and cooking method. This implies that for higher nutrient intake insects with high percentage of essential nutrients such as zinc, iron, protein and essential amino acids should be selected and prioritised for consumption in communities where nutrient deficiencies are a problem . In addition, cooking method that result in higher retention of nutrients should be selected and used. In addition, interventions to educate rural communities on cooking methods that result in higher retention of nutrients are required. Based on the results of this study fear and discomfort associated with consuming edible insects and adoption of western food culture were the main reasons for not consuming insects in KwaZulu-Natal. Therefore, innovative technologies to increase the acceptability of edible insects are required. In addition, to broaden consumer interest and consumption of edible insects beyond traditional groups edible insect flour should be included as an ingredient in a variety of food products such as ice cream, biscuit, protein shakes, porridge, cereal and bread. In addition, government authorities need to find ways to encourage and promote the consumption of insects. Consumption of edible insects should be promoted through awareness campaigns in various social media platforms and television.

6.9. Conclusion

The consumption of insects is an important traditional practice that plays an important role in sustaining rural livelihoods in Limpopo and KwaZulu-Natal. Edible insects are consumed for their nutritional value and to supplement diets in rural areas. They are rich in protein, zinc, and iron. As a result, their consumption contributes to household food and nutrition security in Limpopo and KwaZulu-Natal. Edible insects are a valued natural resource, they are not only used as a source of food, but they are also traded to generate cash income in rural areas. Income generated from trading insects is used to improve rural livelihoods, and to provide earning opportunities to unemployed people in rural areas. Edible insect need to be prioritised for consumption and trade, because they play an important role in improving diets and sustaining livelihoods in poor communities. In addition, edible insect contributes significantly to address protein, zinc, and iron deficiencies in poor communities.

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Appendices

Appendix A. 1. Ethics approval from the humanities and social science ethics committee, University of KwaZulu-Natal

UNIVERSITY OF ™
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

25 June 2019

Ms Zabentungwa Thakasile Hlongwane (211521338)
School of Life Science
Pietermaritzburg Campus

Dear Ms Hlongwane,

Protocol reference number: HSS/0125/019D
Project title: Diversity of edible insects and their related indigenous Knowledge by human in Limpopo and KwaZulu-Natal Province, South Africa

Approval Notification – Expedited Application

In response to your application received on 14 January 2019, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 1 year from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

[redacted]..................
[redacted]uty Chair)

/ms

Cc Supervisor: Dr Caswell Munyai
cc Academic Leader Research: Professor G Kana
cc School Administrator: Ms Tanya Karalic

Humanities & Social Sciences Research Ethics Committee
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Westville Campus, Govan Mbeki Building
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1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE

Founding Campuses ■ Edgewood ■ Howard College ■ Medical School ■ Pietermaritzburg ■ Westville

Appendix A. 2. Ethics approval from the humanities and social science ethics committee, University of KwaZulu-Natal

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

06 November 2019

Ms Zabentungwa Thakasile Hlongwane (211521338)
School of Life Science
Pietermaritzburg Campus

Dear Ms Hlongwane,

Protocol reference number: HSS/0125/019D
Project title: Diversity of edible insects and their related Indigenous Knowledge by human in Limpopo and KwaZulu-Natal Province, South Africa

Approval Notification – Amendment Application

This letter serves to notify you that your application and request for an amendment received on 03 October 2019 has now been approved as follows:

- Inclusion of additional research sites

Any alterations to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form; Title of the Project, Location of the Study must be reviewed and approved through an amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

Best wishes for the successful completion of your research protocol.

Yours faithfully

[redacted]

....

Professor Urmilla Bob
University Dean of Research

/ms

Cc Supervisor: Dr Caswell Munyai
cc Academic Leader Research: Professor G Kana
cc School Administrator: Ms Tanya Karalic

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1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE

Founding Campuses: Edgewood, Howard College, Medical School, Pietermaritzburg, Westville

Appendix A. 3. Ethics approval from the animal research ethics committee, University of KwaZulu-Natal

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

15 November 2019

Ms Zabentungwa Thakasile Hlongwane (211521338)
School of Life Sciences
Pietermaritzburg Campus

Dear Ms Hlongwane,

Protocol reference number: AREC/050/019M
Project title: Diversity of edible insects and their related indigenous knowledge by humans in Limpopo and KwaZulu-Natal province, South Africa.

Full Approval – Research Application

With regards to your revised application received on 04 July 2019. The documents submitted have been accepted by the Animal Research Ethics Committee and **FULL APPROVAL** for the protocol has been granted.

Any alteration/s to the approved research protocol, i.e Title of Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.

Please note: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of one year from the date of issue. Renewal for the study must be applied for before 03 July 2020.

Attached to the Approval letter is a template of the Progress Report that is required at the end of the study, or when applying for Renewal (whichever comes first). An Adverse Event Reporting form has also been attached in the event of any unanticipated event involving the animals' health / wellbeing.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

[redacted]

....

Dr Sanil D Singh, PhD
Chair: Animal Research Ethics Committee

/kr

cc Supervisor: Dr Caswell Munyai
cc BRU Manager: Dr Jaca

Animal Research Ethics Committee (AREC)
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Appendix 2. 1. Edible insects consumed in different African countries

Order	Scientific Name/Morpho Species	Common Name	Country	Consumption stage	References
Blattodea	*Periplaneta americana*	Common cockroach	Nigeria	Adult	(Mbah and Elekima, 2010)
Coleoptera	*Analeptes trifasciata*	Stem girdler	Nigeria	Larvae	(Banjo et al., 2006; Alamu et al., 2013; Adeoye et al., 2014)
Coleoptera	*Oryctes boas Fabr*	Rhinoceros beetle	Nigeria, Ivory Coast, Sierra Leone, Liberia, Democratic Republic of Congo, South Africa, Botswana, Namibia, Guinea Bissau	Larvae	(Illgner and Nel, 2000; Banjo et al., 2006; Obopile and Seeletso, 2013;Alamu et al., 2013; Kelemu et al., 2015; Ebenebe et al., 2017)
Coleoptera	*Oryctes monoceros*	Rhinoceros beetle	Nigeria	Larvae	(Illgner and Nel, 2000; Banjo et al., 2006; Agbidye and Nongo, 2009; Edijala et al., 2009; Alamu et al., 2013; Ebenebe et al., 2017)
Coleoptera	*Aphodius rufipes*	Dung beetle	Nigeria	Larvae	(Banjo et al., 2006; Paiko et al., 2012; Alamu et al., 2013)
Coleoptera	*Rhynchophorus phoenicis*	Palm weevil	Nigeria, Angola, Burkina Faso, Cameroon; Ghana, Cote D'ivioire, Democratic Republic of Congo, Liberia, Niger, Sao Tome, Togo, Benin, Guinea Bissau	Larvae, pupa and adult	(Illgner and Nel, 2000; Edijala, 2005; Onyeike et al., 2005; Banjo et al., 2006; Omotoso and Adedire, 2007; Ekpo and Onigbinde, 2007; Edijala et al., 2009; Agbidye and Nongo, 2009; Ekpo et al., 2009;Womeni et al., 2009; Idolo, 2010; Braide and Nwaoguikpe, 2011; Ogbuagu et al., 2011; Elemo et al., 2011; Jonathan, 2012; Womeni et al., 2012; Alamu et al., 2013; Okore et al., 2014; Muafor et al., 2014;Adeoye et al., 2014; Kelemu et al., 2015; Anankware et al., 2016; Muafor et al., 2016; Meutchieye et al., 2016;Ebenebe et al., 2017; Laar et al., 2017; Lautenschläger et al., 2017b; Séré et al., 2018; Quaye et al., 2018)
Coleoptera	*Heteroligus meles*	Yam beetle	Nigeria	Larvae, pupa, adult	(Banjo et al., 2006; Agbidye et al., 2009; Tobih, 2011; Jonathan, 2012; Alamu et al., 2013; Adeoye et al., 2014; Okore et al., 2014; Ebenebe et al., 2017)
Coleoptera	*Eulepida mashona*	Beetle	Zimbabwe	Larvae/adult	(Dube et al., 2013; Manditsera et al., 2019)
Coleoptera	*Carbula marginella*	Beetle	Burkina Faso	Adult	(Séré et al., 2018)
Coleoptera	*oryctes sp.*	Beetle	Burkina Faso	Larvae	(Séré et al., 2018)
Coleoptera	*Oryctes rhinoceros* larva	Beetle	Nigeria; Cote D'ivoire	Larvae	(Onyeike et al., 2005;Agbidye et al., 2009; Okaraonye and Ikewuchi, 2009; Ebenebe et al., 2017; Ehounou et al., 2018)
Coleoptera	*Stenorcera orissa* Buq	Giant jewel beetle	Botswana, Zimbabwe	Winged adult	(Dube et al., 2013; Obopile and Seeletso, 2013)
Coleoptera	*Eulepida anatine*	Beetle	Zimbabwe	Larvae	(Dube et al., 2013)
Coleoptera	*Eulepida nitidicollis*	Beetle	Zimbabwe	Larvae	(Dube et al., 2013)
Coleoptera	*Apomecyna parumpunctata*	African longhorned beetle	Nigeria	Larvae	(Thomas, 2018)

Coleoptera	*Oryctes owariensis*	Beetle	Cote D'ivioire, Democratic Republic of Congo, South Africa, Angola, Malawi, Botswana, Mozambique, Zambia, Zimbabwe Nigeria, Ivory Coast, Sierra Leona, Guinea, Ghana, Equatorial Guinea, Guinea Bissau	Adult	(Illgner and Nel, 2000; Assielou et al., 2015; Kelemu et al., 2015)
Coleoptera	*Rhinoceros oryctes*	Beetle	Nigeria	Larvae, pupa, adult	(Okore et al., 2014)
Coleoptera	*Sitophilus oryzae*	Rice weevil	Nigeria	Larvae, pupa, adult	(Okore et al., 2014)
Coleoptera	*Callosobruchus maculatus*	Bean beetle	Nigeria	Larvae, pupa, adult	(Okore et al., 2014)
Coleoptera	*Dermestes maculatus*	Beetle	Nigeria	Larvae, pupa, adult	(Okore et al., 2014)
Coleoptera	*Cotinis nitida*	Beetle	Nigeria	Adult/larvae	(Ebenebe et al., 2017)
Coleoptera	*Eulopida mashona*	Beetle	Zimbabwe	Adult/larvae	(Musundire et al., 2016)
Coleoptera	*Sternocera funebris*	Beetle	Zimbabwe	Adult/larvae	(Musundire et al., 2016)
Coleoptera	*Oryctes* spp Oliver	Beetle	Nigeria	Larvae	(Adeoye et al., 2014)
Coleoptera	*Augosoma centaurus*	Beetle	Cameroon	Adult, larvae	(Muafor et al., 2014)
Coleoptera	*Phyllophaga nebulosa* (Harris)	Beetle larvae	Ghana	Larvae	(Anankware et al., 2015, 2016)
Coleoptera	*Sitophilus zeamais*	Beetle	Ghana	Larvae, adult	(Aydoğan et al., 2016)
Coleoptera	*Polycleis equestris*	Weevil	South Africa	Adult	(Illgner and Nel, 2000)
Coleoptera	*Polycleis plumbeus*	Weevil	South Africa	Adult	(Illgner and Nel, 2000)
Coleoptera	*Sipalus aloysii-sabaudiae*	Beetle	South Africa	Larvae	(Illgner and Nel, 2000)
Coleoptera	*Teralobus flabellicornis*	Beetle	South Africa	Larvae	(Illgner and Nel, 2000)
Coleoptera	*Sternocera orissa*	Beetle	South Africa	Larvae	(Illgner and Nel, 2000)
Diptera	*Chaoborus edulis*		Malawi	Adult	(Illgner and Nel, 2000)
Hemiptera	*Nezara viridula*	Southern green stink bug	Nigeria	Adult	(Agbidye et al., 2009; Alamu et al., 2013; Banjo et al., 2006)

Hemiptera	*Encosternum delegorgui* Spinola	Stink bug	South Africa, Zimbabwe, Swaziland, Malawi, Botswana, Namibia, Mozambique	Adult	(Illgner and Nel, 2000; Teffo et al., 2007; Dzerefos et al., 2009; Dube et al., 2013; Kelemu et al., 2015; Musundire et al., 2016)
Hemiptera	*Monomatapa insingnis* Distant	Cicada	Botswana	Adult	(Obopile and Seeletso, 2013)
Hemiptera	*Aspongubus viduatus*	Melon bug	Sudan	Adult	(Mariod et al., 2011)
Hemiptera	*Agonoscelis pubescens*	Sorghum bug	Sudan	Adult	(Mariod et al., 2011)
Hemiptera	*Rhynchophorus spp.*	May bug	Nigeria, Cameroon	Larvae	(Tamesse et al., 2016; Ebenebe et al., 2017)
Hemiptera	*Brevisana brevis*	African cicada	Zimbabwe	Ault	(Musundire et al., 2016)
Hemiptera	*Ugada limbalis*	Cicada	Uganda		(Okia et al., 2017)
Hemiptera	*Pediculus capitata*		Angola, Malawi, South Africa, Zambia, Zimbabwe, Mozambique, Namibia, Botswana		(Illgner and Nel, 2000)
Hymenoptera	*Apis mellifera*	Honey bee	Nigeria, Botswana, Cote D'ivioire, Cameroon, Zambia, Zimbabwe, Botswana, Angola, Mozambique, Tanzania, Senegal, Ghana, Lesotho, Benin, South Africa	Egg, larva, pupa	(Illgner and Nel, 2000;Banjo et al., 2006; Ekpo and Onigbinde, 2007; Okore et al., 2014; Kelemu et al., 2015; Verbeke, 2015; Tamesse et al., 2016; Adeoye, 2016; Akullo et al., 2017, 2018)
Hymenoptera	*Carebara vidua*	African thief ant	Botswana, Zimbabwe; Kenya Burundi, South Africa, Malawi, Zambia, Sudan, Namibia, Mozambique	Winged adult	(Illgner and Nel, 2000; Onyeike et al., 2005;Ayieko et al., 2012; Dube et al., 2013; Obopile and Seeletso, 2013; Kelemu et al., 2015; Musundire et al., 2016; Okia et al., 2017)
Hymenoptera	*Plebeina hildebrandti* Friese	Stingless bee	Botswana	Adult	(Obopile and Seeletso, 2013)
Hymenoptera	*Hypotrigona gribodoi* Magretti	Stingless bee	Botswana	Adult	(Obopile and Seeletso, 2013)
Hymenoptera	*Cossus cossus*	Capenter ant	Cote D'ivioire	Adult	(Ehounou et al., 2018)
Hymenoptera	*Componotus spp.*	Ant	Nigeria	Adult	(Mbah and Elekima, 2010)
Hymenoptera	*Oecophylla longinoda*	African weaver ant	Nigeria, Cameroon	Adult	(Mbah and Elekima, 2010; Meutchieye et al., 2016; Tamesse et al., 2016)
Hymenoptera	*Carebara lignata*	Ant	Zambia, South Africa, Democratic Republic of Congo, Zimbabwe, Botswana, Mozambique, Namibia, Sudan	Adult	(Kelemu et al., 2015)
Blattodea	*Macrotermes nigeriensis*	Termite	Nigeria	Winged adult, queen	(Illgner and Nel, 2000; Banjo et al., 2006; Mbah and Elekima, 2010; Ntukuyoh et al., 2012; Igwe et al., 2012;Alamu et al., 2013; Inje et al., 2018)

Blattodea	*Macrotermes bellicosus*	Termite	Nigeria, Kenya, Uganda, Democratic Republic of Congo, Cameroon, Cote D'ivioire, Sao Tome, Togo, Liberia, Burundi, Ghana, Zimbabwe,	Winged adult, queen	(Illgner and Nel, 2000; Ekpo and Onigbinde, 2005; Banjo et al., 2006; Ntukuyoh et al., 2012; Alamu et al., 2013; Kinyuru et al., 2013; Adeoye et al., 2014; Adepoju, 2014; Kelemu et al., 2015; Adepoju and Ajayi, 2016; Ebenebe et al., 2017; Odongo et al., 2018)
Blattodea	*Macrotermes natalensis*	Termite	Nigeria, South Africa, Zimbabwe, Cameroon, Democratic Republic of Congo, Burundi, Malawi	Winged adult, queen	(Illgner and el, 2000; Banjo et al., 2006; Agbidye et al., 2009; Alamu et al., 2013; Dube et al., 2013; N Musundire et al., 2016; Netshifhefhe et al., 2018)
Blattodea	*Macrotermes falciger*	Termite	Democratic Republic of Congo; South Africa, Zimbabwe, Burundi, Zambia, Burkina Faso, Benin	Winged adult	(Illgner and Nel, 2000; Ajai et al., 2013; Dube et al., 2013; Kelemu et al., 2015; Bomolo et al., 2017; Netshifhefhe et al., 2018; Odongo and Jean, 2018)
Blattodea	*Macrotermes michaelseni*	Termite	South Africa	Winged adult	(Netshifhefhe et al., 2018)
Blattodea	*Macrotermes subhyalinus*	Termite	Burkina Faso Zimbabwe, Cote D'ivioire, Rwanda, Uganda, Angola, Togo, Kenya	Adult	(Illgner and Nel, 2000; Dube et al., 2013; Kelemu et al., 2015; Okia et al., 2017; Rémy et al., 2018; Ehounou et al., 2018;Séré et al., 2018)
Blattodea	*Hodotermes mossambicus* (Hagen)	Harvester termite	Botswana	Larvae	(Obopile and Seeletso, 2013)
Blattodea	*Macrotermes sp.*	Termite	Nigeria, Uganda	Adult queen, soldiers	(Mbah and Elekima, 2010; Okore et al., 2014; Akullo et al., 2018)
Blattodea	*Syntermes soldiers*	Termite	Uganda	Adult	(Akullo et al., 2018)
Blattodea	*Pseudacanthotermes militaris*	Termite	Kenya, Uganda	Winged adult	(Kinyuru et al., 2013; Okia et al., 2017; Odongo and Jean, 2018)
Blattodea	*Pseudacanthotermes spiniger*	Termite	Kenya, Uganda, Burundi	Winged adult	(Kinyuru et al., 2013; Okia et al., 2017; Odongo and Jean, 2018)
Blattodea	*Odontotermes kibarensis*	Termite	Uganda	Winged adult	(Okia et al., 2017)
Blattodea	*Pseudacanthotermes* sp.1	Termite	Uganda	Winged adult	(Okia et al., 2017)
Blattodea	*Pseudacanthotermes* sp.2	Termite	Uganda	Winged adult	(Okia et al., 2017)
Blattodea	*Odontotermes* spp.	Termite	Uganda	Winged adult	(Okia et al., 2017)
Blattodea	*Pseudacanthotermes* sp.5	Termite	Uganda	Winged adult	(Okia et al., 2017)

Blattodea	*Pseudacanthotermes* sp. 4	Termite	Burundi	Adult	(Okia et al., 2017)
Blattodea	*Macrotermes* spp.	Termite	Rwanda, Cameroon	Winged adult	(Meutchieye et al., 2016; Tamesse et al., 2016; Okia et al., 2017)
Blattodea	*Macrotermes swaziae*	Termite	Zimbabwe		(Illgner and Nel, 2000)
Blattodea	*Microhodotermes viator*	Termite	South Africa		(Illgner and Nel, 2000)
Blattodea	*Termes badius*	Termite	South Africa	Winged adult	(Illgner and Nel, 2000)
Lepidoptera	*Anaphe venata*	African silkworm	Nigeria, Zambia, Cote D'ivioire, Sierra Leona, Guinea, Liberia, Guinea Bissau, Angola	Larvae	(Illgner and Nel, 2000; Banjo et al., 2006; Alamu et al., 2013; Kelemu et al., 2015; Adeoye, 2016; Lautenschläger et al., 2017b)
Lepidoptera	*Anaphe infracta*	African silkworm	Nigeria	Larvae	(Illgner and Nel, 2000;Alamu et al., 2013)
Lepidoptera	*Anaphe recticulata*	African silkworm	Nigeria	Larvae	(Illgner and Nel, 2000; Banjo et al., 2006; Alamu et al., 2013)
Lepidoptera	*Bunaea alcinoe*	Emperor moth	Nigeria; Democratic Republic of Congo, Botswana, Zimbabwe, Cameroon, Zambia, South Africa, Democratic Republic of Congo, Tanzania	Larvae, pupa and adult	(Banjo et al., 2006;Agbidye et al., 2009; Braide and Nwaoguikpe, 2011; Alamu et al., 2013; Dube et al., 2013; Obopile and Seeletso, 2013; Kelemu et al., 2015; Meutchieye et al., 2016; Adeoye, 2016; Bomolo et al., 2017; Ebenebe et al., 2017)
Lepidoptera	*Lepidoptara litoralia*	Caterpillar	Nigeria	Larvae	(Banjo et al., 2006; Solomon and Prisca, 2012; Alamu et al., 2013)
Lepidoptera	*Cirina forda*	Pallid emperor	Nigeria, Angola, Democratic Republic of Congo, Botswana, Zimbabwe; Togo, Zambia, Mozambique, Ghana, Namibia	Larvae	(Illgner and Nel, 2000; Akinnawo and Ketiku, 2000;Ande and Sciences, 2003;Banjo et al., 2006; Omotoso, 2006; Oyegoke et al., 2006;Agbidye and Nongo, 2009; Osasona and Olaofe, 2010;Adepoju and Daboh, 2013; Alamu et al., 2013; Obopile and Seeletso, 2013; Dube et al., 2013; Badanaro et al., 2014;Kelemu et al., 2015; Lautenschläger et al., 2017b; Bomolo et al., 2017; Inje et al., 2018)
Lepidoptera	*Imbrasia epimethea*	Caterpillar	Angola, Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Kelemu et al., 2015; Lautenschläger et al., 2017a)
Lepidoptera	*Imbrasia obscura*	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Imbrasia truncata*	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Gonimbrasia* (*Nudaurelia*) *alopia*	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Gonimbrasia* (*Nudaurelia*) *dione*	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Pseudantheraea discrepans*	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Micragone cana*	Caterpillar	Angola, Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Lautenschläger et al., 2017b)

Lepidoptera	*Anaphe panda*	Bagnest moth	Angola, Zimbabwe, Zambia, Cameroon, Democratic Republic of Congo, Nigeria, Tanzania	Larvae	(Illgner and Nel, 2000; Morris, 2008; Dube et al., 2013; Kelemu et al., 2015; Musundire et al., 2016)
Lepidoptera	*Notodontidae* sp. 1	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Notodontidae* sp. 2	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Notodontidae* sp. 3	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Notodontidae* sp. 4	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Gastroplakaeis rubroanalis*	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Sciatta inconcisa*	Caterpillar	Angola	Larvae	(Lautenschläger et al., 2017b)
Lepidoptera	*Elaphrodes lactea* Gaede	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Bomolo et al., 2017)
Lepidoptera	*Lobobunaea saturnus* Fabricius	Caterpillar	Democratic Republic of Congo, Zimbabwe	Larvae	(Illgner and Nel, 2000;Dube et al., 2013; Bomolo et al., 2017)
Lepidoptera	*Cinabra hyperbius* (Westwood)	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Bomolo et al., 2017)
Lepidoptera	*Gonimbrasia richelmanni* Weymer	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Bomolo et al., 2017)
Lepidoptera	*Antheua insignata*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Bomolo et al., 2017)
Lepidoptera	*Imbrasia rubra*	Caterpillar	Democratic Republic of Congo	Larvae	(Bomolo et al., 2017)
Lepidoptera	*Athletes semialba* (Sonthonnax)	Caterpillar	Democratic Republic of Congo, Zimbabwe, Zambia, South Africa, Namibia, Mozambique	Larvae	(Illgner and Nel, 2000;Dube et al., 2013; Bomolo et al., 2017)
Lepidoptera	*Cirina butyrospermi*	Caterpillar	Burkina Faso, Cote D'ivioire, Zambia, Zimbabwe, South Africa, Nigeria, Mali, Ghana	Larvae	(Anankware et al., 2015; Kelemu et al., 2015;Anvo et al., 2016; Bama et al., 2018; Ehounou et al., 2018; Rémy et al., 2018)
Lepidoptera	*Hemijana variegata*	Caterpillar	South Africa	Larvae	(Egan et al., 2014)
Lepidoptera	*Gonimbrasia belina*	Mopane worm	Nigeria; Botswana; Zimbabwe, Namibia, South Africa, Malawi, Zambia, Angola, Mozambique	Larvae	(Illgner and Nel, 2000; Mpuchane et al., 2000; Pharithi et al., 2004; Madibela et al., 2007; Ekpo and Onigbinde, 2007; Ghally, 2009; Elemo et al., 2011; Dube et al., 2013; Obopile and Seeletso, 2013; Thomas, 2013; Kelemu et al., 2015; Musundire et al., 2016; Baiyegunhi et al., 2016)
Lepidoptera	*Isoberlina paniculata*	Caterpillar	Zambia	Larvae	(Ghally, 2009)
Lepidoptera	*Urota sinope*	Caterpillar	Zambia, Botswana	Larvae	(Mbata et al., 2002; Obopile and Seeletso, 2013)

Lepidoptera	*Gonimbrasia zambesina*	Caterpillar	Zambia; Zimbabwe, Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Mbata et al., 2002; Dube et al., 2013)
Lepidoptera	*Lophostethus dumolinii* Angas	Arrow sphinx	Botswana	Larvae	(Obopile and Seeletso, 2013)
Lepidoptera	*Daphnis nerii L*	Oleander hawk moth	Botswana	Larvae	(Obopile and Seeletso, 2013)
Lepidoptera	*Heniocha* spp.	Marbled emperor moth	Botswana	Larvae	(Obopile and Seeletso, 2013)
Lepidoptera	*Imbrasia tyrrhea*	Willow emperor moth	Botswana	Larvae	(Obopile and Seeletso, 2013)
Lepidoptera	*Sphingomorpha chlorea*	Sundown emperor moth	Botswana	Larvae	(Obopile and Seeletso, 2013)
Lepidoptera	*Hippotion celerio* L.	Silver striped hawk	Botswana	Adult	(Obopile and Seeletso, 2013)
Lepidoptera	*Agrius convolvuli* L.	Convolvulus hawk moth.	Botswana, South Africa, Angola, Zimbabwe, Zambia, Malawi, Mozambique, Namibia	Larvae	(Obopile and Seeletso, 2013)
Lepidoptera	*Gonanisa maia*	Caterpillar	Zimbabwe, Botswana, Malawi, Democratic Republic of Congo, South Africa	Larvae	(Illgner and Nel, 2000; Dube et al., 2013; Musundire et al., 2016)
Lepidoptera	*Anthoaera zambezina*	Caterpillar	Zimbabwe, Botswana, Malawi, Namibia, Zambia, South Africa, Mozambique, Angola	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Athletes gigas*	Caterpillar	Zimbabwe, Botswana, Malawi, Namibia, Zambia, South Africa, Mozambique, Angola	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Bombycomorpha pallida*	Moth	Zimbabwe, South Africa	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Bunaea caffra*	Moth	Zimbabwe, Zambia, South Africa, Namibia, Botswana, Mozambique, Angola	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Bunaeopsis aurantica*	Moth	Zimbabwe, Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Gonometa postica*	Moth	Zimbabwe, South Africa	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)

Lepidoptera	*Heniocha dyops*	Moth	Zimbabwe, South Africa, Botswana, Zambia, Malawi, Namibia, Mozambique, Angola	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Imbrasia epimethea*	Moth	Zimbabwe, Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Imbrasia ertli*	Caterpillar	Zimbabwe, South Africa, Cameroon, Democratic Republic of Congo, Angola, Zimbabwe, Botswana, Angola	Larvae	(Illgner and Nel, 2000; Dube et al., 2013; Kelemu et al., 2015)
Lepidoptera	*Nudaurelia belina*	Moth	Zimbabwe, Malawi, Botswana, Mozambique, Namibia, Zambia, South Africa	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Pseudobunaea irius*	Moth	Zimbabwe, South Africa, Zambia, Angola, Malawi, Namibia,	Larvae	(Illgner and Nel, 2000; Dube et al., 2013)
Lepidoptera	*Loba leopardina*	Moth	Zimbabwe	Larvae	(Dube et al., 2013)
Lepidoptera	*Imbrasia oyemensis*	Caterpillar	Cote D'ivioire	Adult	(Ehounou et al., 2018)
Lepidoptera	*Imbrasia* spp.	Caterpillar	Cameroon	Larvae	(Meutchieye et al., 2016)
Lepidoptera	*Eumeta* spp.	Caterpillar	Cameroon	Larvae	(Tamesse et al., 2016)
Lepidoptera	*Anaphe* spp.	Caterpillar	Cameroon	Larvae	(Tamesse et al., 2016)
Lepidoptera	*Dactyloceras* spp.	Caterpillar	Cameroon	Larvae	(Tamesse et al., 2016)
Lepidoptera	*Bunaea* spp.	Caterpillar	Cameroon	Larvae	(Tamesse et al., 2016)
Lepidoptera	*Dactyloceras lucina*	Caterpillar	Democratic Republic of Congo, Zambia, South Africa, Cameroon, Angola, Gabon, Sierra Leone, Equatorial Guinea, Sao Tome,	Larvae	(Kelemu et al., 2015)
Lepidoptera	*Platysphinx stigmatica*	Caterpillar	Zambia, Democratic Republic of Congo, Sierra Leone, Rwanda, Burundi, Equatorial Guinea, Sao Tome,	Larvae	(Kelemu et al., 2015)
Lepidoptera	*Epanaphe carteri*	Caterpillar	Democratic Republic of Congo, Angola, Gabon, Sierra Leone, Sao Tome, Equatorial Guinea	Larvae	(Kelemu et al., 2015)
Lepidoptera	*Gynanisa ata*	Caterpillar	Democratic Republic of Congo, Zambia, Malawi, Sudan	Larvae	(Kelemu et al., 2015)

Lepidoptera	*Eumeta cervina*	Caterpillar	Democratic Republic of Congo, Cameroon, Angola, Gabon, Sierra Leone, Sao Tome, Equatorial Guinea, Rwanda, Burundi, Liberia	Larvae	(Kelemu et al., 2015)
Lepidoptera	*Urota sinope*	Caterpillar	Democratic Republic of Congo, South Africa, Zimbabwe, Zimbabwe, Botswana, Gabon, Mozambique, Namibia	Larvae	(Illgner and Nel, 2000; Kelemu et al., 2015)
Lepidoptera	*Anthoaera caffraria*	Caterpillar	Angola, Malawi, South Africa, Zambia, Zimbabwe, Mozambique, Namibia, Botswana	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Anthoaera menippe*	Caterpillar	Angola, Malawi, South Africa, Zambia, Zimbabwe, Mozambique, Namibia, Botswana	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Bunaea caffraria*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Drapetides uniformis*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Gonimbrasia hecate*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Goodia kuntzei*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Heniocha apollonia*	Caterpillar	Angola, Malawi, South Africa, Zambia, Zimbabwe, Mozambique, Namibia, Botswana	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Heniocha marnois*	Caterpillar	Angola, Malawi, South Africa, Zambia, Zimbabwe, Mozambique, Namibia, Botswana	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Herse convolvuli*	Caterpillar	South Africa	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Imbrasia dione*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Imbrasia macrothyris*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Imbrasia rubra*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Lobobunaea phaedusa*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Melanocera parva*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Microgene cana*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Nudaurelia macrothyrus*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Nyodes prasinodes*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)

Lepidoptera	*Rohaniella pygmaea*	Caterpillar	Angola, Malawi, South Africa, Zambia, Zimbabwe, Mozambique, Namibia, Botswana	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Rheneae mediata*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Tagoropsis flavinata*	Caterpillar	Democratic Republic of Congo	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Usta terpisichore*	Caterpillar	Angola	Larvae	(Illgner and Nel, 2000)
Lepidoptera	*Usta wallengreni*	Caterpillar	Angola, Malawi, South Africa, Zambia, Zimbabwe, Mozambique, Namibia, Botswana	Larvae	(Illgner and Nel, 2000)
Mantodea	*Mantis religiosa*	African mantis	Nigeria, South Africa	Adult	(Illgner and Nel, 2000; Ebenebe et al., 2017)
Orthoptera	*Brachytrupes membranaceus*	Giant African cricket	Nigeria, Angola; Zimbabwe, Uganda; Cameroon, Democratic Republic of Congo, Burkina Faso, Tanzania, Angola, Togo, Benin; Malawi	Adult	(Illgner and Nel, 2000; Banjo et al., 2006; Morris, 2008; Agbidye et al., 2009; Adeyeye and Awokunmi, 2010; Alamu et al., 2013; Dube et al., 2013; Okore et al., 2014; Kelemu et al., 2015; Adeoye, 2016; Meutchieye et al., 2016;Ebenebe et al., 2017; Lautenschläger et al., 2017a, 2017b; Okia et al., 2017)
Orthoptera	*Gymnogryllus lucens*	Cricket	Nigeria	Adult	(Banjo et al., 2006; Ajai et al., 2013; Alamu et al., 2013)
Orthoptera	*Cytacanthacris naeruginosus*	Short horned grasshopper	Nigeria	Adult	(Banjo et al., 2006; Alamu et al., 2013)
Orthoptera	*Zonocerus variegatus*	Grasshopper	Nigeria, Cameroon, Uganda, Democratic Republic of Congo, Cote D'ivioire, Ghana, Guinea, Liberia, Sao Tome, Liberia, Guinea Bissau	Adult	(Adeyeye, 2005; Banjo et al., 2006; Womeni et al., 2009; Mbah and Elekima, 2010;Ajai et al., 2013; Alamu et al., 2013; Adeoye et al., 2014; Kelemu et al., 2015; Anankware et al., 2016; Ebenebe et al., 2017; Akullo et al., 2017, 2018)
Orthoptera	*Gryllotalpa africana*	Mole cricket	Nigeria; Zimbabwe; Malawi	Adult	(Illgner and Nel, 2000; Banjo et al., 2006; Morris, 2008; Agbidye et al., 2009; Alamu et al., 2013;Adeoye et al., 2014; Musundire et al., 2016)
Orthoptera	*Ruspolia differens*	Grasshopper	Kenya, Tanzania, Democratic Republic of Congo, Uganda, Zimbabwe, Rwanda, Cameroon, Uganda, Malawi, South Africa	Adult	(Illgner and Nel, 2000; Dube et al., 2013; Kinyuru et al., 2013; Bomolo et al., 2017; Okia et al., 2017; Mmari et al., 2017; Odongo et al., 2018; Rutaro et al., 2018)
Orthoptera	*Melanoplus foedus*	Grasshopper	Nigeria	Adult	(Inje et al., 2018)
Orthoptera	*Gryllus assimilis*	Cricket	Nigeria; Ghana	Adult	(Anankware et al., 2016; Inje et al., 2018)
Orthoptera	*Henicus whellani*	Cricket	Zimbabwe	Adult	(Musundire et al., 2014;Manditsera et al., 2019)
Orthoptera	*Kraussaria ongulifera*	Grasshopper	Burkina Faso	Adult	(Rémy et al., 2018; Séré et al., 2018)
Orthoptera	*Gryllus campestris*	Field cricket	Burkina Faso; Cameroon, Malawi	Adult	(Morris, 2008; Tamesse et al., 2016 Séré et al., 2018)

Orthoptera	*Ruspolia nitidula*	Grasshopper	Uganda	Larvae and adult	(Agea et al., 2008; Ssepuuya et al., 2017)
Orthoptera	*Normadacris septemfasciata*	Red locust	Botswana; Uganda, Zambia, South Africa, Democratic Republic of Congo, Zimbabwe, Botswana, Nigeria, Uganda, Tanzania, Malawi, Mozambique	Adult	(Obopile and Seeletso, 2013;Kelemu et al., 2015; Okia et al., 2017)
Orthoptera	*Locustana pardalina*	Brown locust	Botswana, South Africa, Zimbabwe, Malawi, Libya	Adult	(Illgner and Nel, 2000; Obopile and Seeletso, 2013; Kelemu et al., 2015)
Orthoptera	*Schistocerca gregaria*	Desert locust	Botswana, Zambia, South Africa, Cameroon, Democratic Republic of Congo, Zimbabwe, Burkina, Faso, Malawi, Mali, Niger, Togo, Benin	Adult	(Ajai et al., 2013; Obopile and Seeletso, 2013;Kelemu et al., 2015)
Orthoptera	*Cyrtacanthacris tatarica* L	Brown-spotted locust	Botswana	Adult	(Obopile and Seeletso, 2013)
Orthoptera	*Acrida acuminata*	Common stick grasshopper	Botswana	Adult	(Obopile and Seeletso, 2013)
Orthoptera	*Zonocerus elegans*	Elegant grasshopper	Botswana, South Africa	Adult	(Illgner and Nel, 2000; Obopile and Seeletso, 2013)
Orthoptera	*Acrotylus* spp.	Burrowing grasshopper	Botswana	Adult	(Obopile and Seeletso, 2013)
Orthoptera	*Homorocoryphus nitidulus*	Cricket	Cameroon	Larvae	(Womeni et al., 2009;Tamesse et al., 2016)
Orthoptera	*Gynanisa maia*	Cricket	Zimbabwe, Malawi, South Africa	Larvae	(Illgner and Nel, 2000;Dube et al., 2013)
Orthoptera	*Locusta migratoria*	migratory locust	Zimbabwe, Cote D'ivioire; Nigeria; Sudan, Zambia, Democratic Republic of Congo, Sudan, Ghana	Adult	(Illgner and Nel, 2000; Kelemu et al., 2015; Mohamed, 2015;Anankware et al., 2016; Ebenebe et al., 2017; Ehounou et al., 2018)
Orthoptera	*Acheta domesticus*	Cricket	Cote D'ivioire; Nigeria, Ghana	Adult	(Anankware et al., 2016; Ebenebe et al., 2017; Ehounou et al., 2018)
Orthoptera	*Cartarrtopsilus taeniolatus*	Grasshopper	Nigeria	Adult	(Mbah and Elekima, 2010)
Orthoptera	*Zulua cyanoptera*	Grasshopper	Nigeria	Adult	(Mbah and Elekima, 2010)
Orthoptera	*Brachytrupes spp.*	Cricket	Uganda, Cameroon	Adult	(Akullo et al., 2017; Tamesse et al., 2016)
Orthoptera	*Cyrtacanthacris aeruginosa* unicolor	Grasshopper	Uganda	Adult	(Akullo et al., 2017)

Orthoptera	*Zonocerus sp.*	Grasshopper	Nigeria	Adult	(Okore et al., 2014)
Orthoptera	*Daraba* (Sceloides) *laisalis*	Locust	Nigeria	Larvae, pupa, adult	(Okore et al., 2014)
Orthoptera	*Ornithacris turbida*	Grasshopper	Zimbabwe	Adult	(Musundire et al., 2016)
Orthoptera	*Acanthoplus discoidalis*	Cricket	Zimbabwe	Adult	(Musundire et al., 2016)
Orthoptera	*Acanthacris ruficornis*	Garden locust	Uganda, Zambia, South Africa, Cameroon, Democratic Republic of Congo, Zimbabwe, Burkina Faso, Malawi, Mali, Niger, Togo, Benin	Adult	(Kelemu et al., 2015; Okia et al., 2017)
Orthoptera	*Schistocerca* spp.	Grasshopper	Cameroon	Adult	(Tamesse et al., 2016)
Orthoptera	*Acanthacris* spp.	Grasshopper	Cameroon	Adult	(Tamesse et al., 2016)
Orthoptera	*Gastrimargus* spp.	Locust	Cameroon	Adult	(Tamesse et al., 2016)
Orthoptera	*Phymateus* spp.	Locust	Cameroon	Adult	(Tamesse et al., 2016)
Orthoptera	*Anacridium* spp.	Locust	Cameroon	Adult	(Tamesse et al., 2016)
Orthoptera	*Pyrgomorpha* spp.	Locust	Cameroon	Adult	(Tamesse et al., 2016)
Orthoptera	*Gastrimargus africanus*	Locust	Cameroon, Democratic Republic of Congo, Niger, Lesotho, Liberia	Adult	(Kelemu et al., 2015)
Orthoptera	*Phymateus viridipes brunneri* Bolivar	Locust	Zambia, South Africa, Democratic Republic of Congo, Zimbabwe, Botswana, Mozambique, Namibia	Adult	(Kelemu et al., 2015)
Orthoptera	*Gryllus bimaculatus*	Cricket	Togo, Nigeria, Guinea Bissau, Sierra Leone, Liberia, Benin, Democratic Republic of Congo, Kenya, Sudan, Zambia	Adult	(Kelemu et al., 2015)
Orthoptera	*Anacridium melanorhodon melanorhodon*	Cricket	Cameroon, Sudan, Niger	Adult	(El Hassan et al., 2008; Kelemu et al., 2015)
Orthoptera	*Paracinema tricolor*	Cricket	Cameroon, Malawi, Lesotho	Adult	(Kelemu et al., 2015)
Orthoptera	*Acheta* spp.	Cricket	Zambia, Zimbabwe, Kenya	Adult	(Kelemu et al., 2015)
Orthoptera	*Scapteriscus vicinus*	Field cricket	Ghana	Adult	(Anankware et al., 2016, 2015)
Orthoptera	*Gryllotalpa gryllotalpa*	Mole cricket	Malawi	Adult	(Morris, 2008)
Orthoptera	*Homorocoryphus vicinus*	Cricket	Uganda	Adult	(Illgner and Nel, 2000)

Orthoptera	*Nomadacris septumfasciata*	Cricket	South Africa	Adult	(Illgner and Nel, 2000)
Orthoptera	*Schistocerca gregaria*	Cricket	Zimbabwe	Adult	(Illgner and Nel, 2000)
Blattodea	*Pseudacathotermes spinige*	Termite	Kenya	Adult	(Christensen et al., 2006)
Blattodea	*Macrotermes* spp.	Termite	Kenya	Adult	(Christensen et al., 2006)
Blattodea	*Macrotermes subhylanus*	Termite	Kenya	Adult	(Christensen et al., 2006)
Hymenoptera	*Crematogaster mimosae*	Ant	Kenya	Adult	(Christensen et al., 2006)

Appendix 3. 1. Number of villages sampled in different local municipalities in Limpopo and KwaZulu-Natal.

Village	**Local Municipality**	**GPS Coordinates**
	Limpopo province	
Muwaweni	Makhado	23.3283° S, 30.1113° E
Elim	Makhado	23.1561° S, 30.0554° E
Biaba	Makhado	22.5344° S, 30.1126° E
Tshikuwi	Makhado	22.9013° S, 29.9480° E
Tshiozwi	Makhado	23.0855° S, 29.7860° E
Ha Mashau Doli	Makhado	23.1583° S, 30.1897° E
Ha mashau Mathothe	Makhado	23.1462° S, 30.1979° E
Masia	Makhado	23.2170° S, 30.3299° E
Tshikota	Makhado	23.0492° S, 29.8772° E
Mashamba	Makhado	23.0538° S, 30.3527° E
Mulima-Lambani	Makhado	22.430° S, 30.500° E
Nancefield	Musina	22.3813° S, 30.0319° E
Mbodi tshafhasi	Mutale	22.5433° S, 30.7451° E
Shakadza	Mutale	22.6160° S, 30.5711° E
Tshipise	Mutale	22.5349° S, 30.6703° E
Mukondeni	Makhado	23.2559° S, 30.1041° E
Tshivhulani	Thulamela	23.1316° S, 30.4386° E
Vhurivhuri	Thulamela	22.7008° S, 30.8056° E
Halambani	Thulamela	22.7108° S, 30.8442° E
Ha-Lambani	Thulamela	22.7108° S 30.8442° E
Mushiru	Thulamela	22.7662° S, 30.8431° E
Mukula	Thulamela	22.8628° S, 30.5754° E
Vyeboom	Makhado	23.1488° S, 30.3861° E
	KwaZulu-Natal province	
Umbumbulu	eThekwini	29.5902° S, 30.4207° E
Nhlazuka	Richmond	29.3759° S, 30.100° E
Swayimane	uMshwathi	29.4878° S, 30.6603° E

Tugela Ferry	Umsinga	28.7416° S, 30.4617° E
Kokstad	Greater Kokstad	30.5096° S, 29.4063° E

Appendix 3. 2. Questionnaire Used to Source Information in Limpopo and KwaZulu-Natal

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Project Tittle: Diversity of Edible Insects and Their Related Indigenous Knowledge by Human in Limpopo and KwaZulu-Natal Province, South Africa

You are being invited to consider participating in a study that involves research on the consumption of edible insects using indigenous knowledge in South Africa, we would like to get insight on the socio-economic benefits, drivers of consuming edible insects and the attitude people have towards edible insects. The aim of this research is to determine diversity and distribution of edible insects using indigenous knowledge in South Africa. Please note that your participation in this research is voluntary and you may choose not to participate or you may discontinue your participation at any time without penalty or disadvantage to yourself.

In case there are questions considering the survey, please contact Zabentungwa Hlongwane (0737076460 or email nolwazihlongwane20@gmail.com)

Awareness and perception

Date: ____________________________________

Questionnaire number: ____________

Location:__________________________________

Has the informed consent being signed by the participant Yes [ ]/No [ ]

Questionnaires

1. Gender Male [ ] Female [ ]

2. Age category

- Under 18 years [ ]

- 18–24 years [ ]
- 25–34 years [ ]
- 35–44 years [ ]
- 45–54 years [ ]
- 55–64 years [ ]
- 65–74 years [ ]
- 75 or older [ ]

3. Level of education

- Level 0 [ ]
- Primary school[ ]
- High school [ ]
- Undergraduate[ ]
- Post graduate [ ]

4. Employment status: unemployed [ ] self-employed [ ] pensioner [ ] employed [ ]

5. Have you ever eaten insects? Yes [ ] or No [ ] if No go to question number 15

6. If yes how often do you consume insects?

- Rarely [ ]
- Occasionally[ ]
- Regularly [ ]

7. How do you prepare and eat edible insects

- Dried [ ]
- Fried [ ]
- Stew (socked in clean water for 30 min, drain water, fried with onions, tomatoes, chili, curry powder and salt) [ ]
- Please share your recipe of how you cook edible insects for consumption

____

____

____

____

____

____

- How did your mother cook edible insects when you were growing up

____
____
____
____
____
____
____

8. Where do you buy or harvest edible insect

- Local markets [ ]
- City markets (Thohoyandou, Sibasa, Elim, Makhado or _________________________
- Harvest from the wild [ ]

9. Why do you consume insects?

- Nutritious benefits [ ]
- Cultural beliefs [ ]
- Cheap and abundantly available [ ]
- Buffer during times of food shortage [ ]
- All of the above [ ]

10. How long have you been consuming insects ___________________________

11. How many orders of insects are edible in your area ________________________

12. What season are edible insects mostly available

- Spring [ ]
- Summer [ ]
- Autumn [ ]
- Winter [ ]
- Available all year [ ]

13. There are many benefits of consuming insects, which of the following interest you the most?

- Environmental friendly [ ]
- Nutritional value [ ]
- Cheaper [ ]
- Taste [ ]

- None of the above [ ]

14. Would you ever consider eating insects? Yes [ ] or No [ ]

15. Do you know anything about edible insects. Yes[ ]or No [ ]

16. What can be done to promote eating of insects.

- Research [ ]
- Public awareness [ ]
- Sell them in shops [ ]
- Newspapers [ ]
- Radio and television [ ]
- Education and awareness [ ]

17. Are you aware of the nutritional benefits of eating insects yes [ ] or no [ ]

18. Would you be more comfortable eating insects if there were hidden in food? (covered in chocolate, cookies) yes [ ] or no [ ]

19. Which insect do you consume or would you consider eating

- Mopane worms [ ]
- Crickets [ ]
- Termites [ ]
- Locusts [ ]
- Grasshoppers [ ]
- Ants [ ]
- Beetles [ ]
- Mealworms [ ]
- Stink bug

20. Why did you stop eating insects?

____

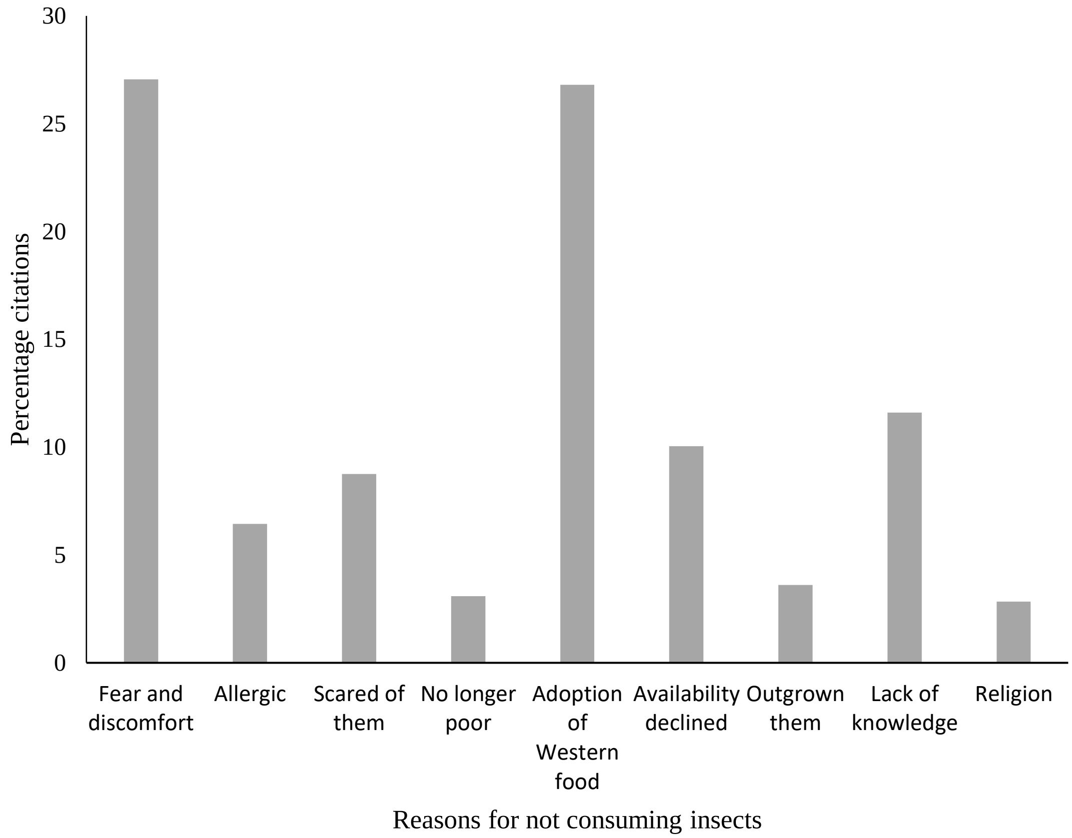
____

____

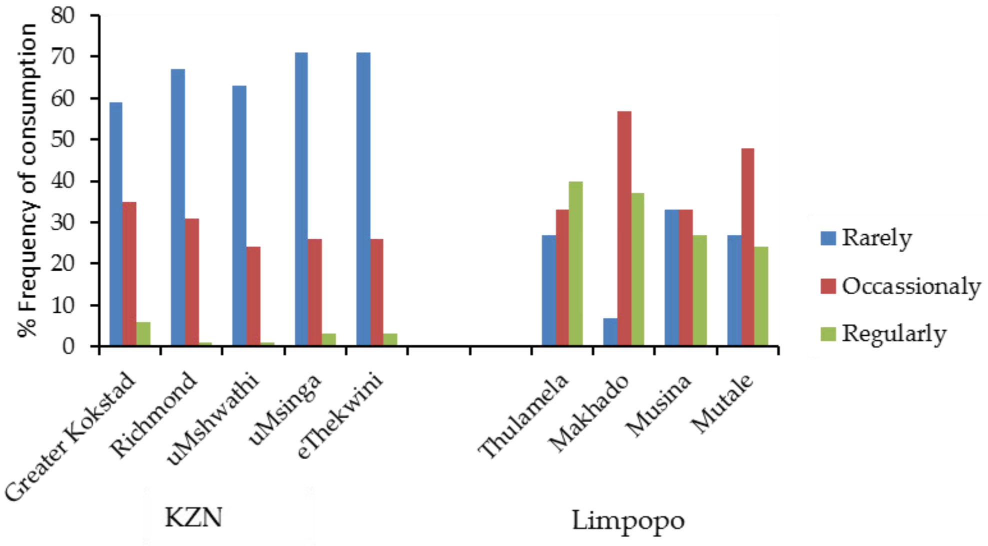
21. Is there anything you would like to tell us regarding the eating of insects by human?

____

____



Appendix 3. 3. Cited reasons for not consuming insects in KwaZulu-Natal province (*n* = 356).



Appendix 3. 4. Frequency of insect consumption per week and month across municipalities in KwaZulu-Natal and Vhembe district, Limpopo. Rarely consume insects (at least once a month), occasionally (1–4 times a month), regularly (1–4 times a week).

Appendix 5. 1. Demographic information of the traders across towns in Vhembe district (n= 72)

Demographics	Elim	Louis Trichardt	Musina	Sibasa	Thohoyandou	Tshakhuma
Age category (years)						
Under 18	0	0	0	0	0	0
18 -24 years	4	0	0	0	2	0
25 -34	0	0	0	1	3	3
35 - 44	2	1	4	2	7	6
45 - 54	0	4	2	1	5	4
55 - 64	1	1	1	5	6	1
65 - 74	3	0	1	0	4	0
75 years and above						
Sex						
Male	1	0	1	1	1	0

Female	7	6	7	8	26	14
Level of education						
No formal education	1	0	0	0	0	0
Primary education	1	3	2	1	9	0
Secondary education	4	3	6	6	17	14
Tertiary education	0	0	0	2	0	0
Occupation						
Unemployed	0	0	0	0	1	0
Self employed	5	6	8	8	25	14
Pensioner	3	0	0	0	1	0
Employed	0	0	0	0	0	0
Student	0	0	0	0	0	0

Appendix 5. 2. Questionnaire to source information from traders in Vhembe district, Limpopo

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Project tittle: Diversity of edible insects and their related indigenous knowledge by human in Limpopo and KwaZulu-Natal province, South Africa.

You are being invited to consider participating in a study that involves research on the consumption of edible insects using indigenous knowledge in South Africa, we would like to get insight on the socio-economic benefits, drivers of consuming edible insects and the attitude people have towards edible insects. The aim of this research is to determine diversity and distribution of edible insects using indigenous knowledge in South Africa. Please note that your participation in this research is voluntary and you may choose not to participate or you may discontinue your participation at any time without penalty or disadvantage to yourself.

In case there are questions considering the survey, please contact Zabentungwa Hlongwane (0737076460 or email nolwazihlongwane20@gmail.com)

Traders

Date: ____

Questionnaire number: _____________

Location: ______________________________

Has the informed consent being signed by the participant Yes [ ]/ No [ ]

1. 1. Gender   Male [ ] Female [ ]
2. What is your age
- Under 18 [ ]
- 18 – 24 years [ ]
- 25-34 years [ ]
- 35-44 years [ ]
- 45-54 years [ ]
- 55- 64 years [ ]
- 65-74 years [ ]
- 75 or older [ ]
3. Level of education
- Level zero [ ]
- Primary school [ ]
- High school [ ]
- Post graduate [ ]
4. Employment status: unemployed [ ] self-employed [ ] pensioner [ ] employed [ ] sell insects for a living [ ]
5. Where do you buy or harvest insects for trading
- Harvest them from the wild [ ]

- Locally [ ]
- Neighboring villages…..if so provide names______________________________
- In the city…. If so provide names_______________________________________
- Neighboring provinces….if so provide names___________________________________
- Neighboring countries……. if so provide names________________________________

6. How do you prepare edible insects for selling

- Degutted, cleaned and dried [ ]
- Fried [ ]
- Roasted [ ]
- Boiled
- Stew
- Other specify____________________________

7. Are you a family breadwinner Yes [ ] or No [ ], if yes how many are you in your family ___________

8. How long have you been selling edible insects? _____________________

- Less than a year [ ]
- 1- 5 years [ ]
- 6- 10 years [ ]
- 11- 15 years [ ]
- 16- 20 years [ ]
- 21- 30 years [ ]
- Above 30 years [ ]

9. What are the challenges of selling insects?

____

____

____

____

____

11. Do you and your family consume insects? Yes [ ] or No [ ]

12. If yes what do you consume insects with? Pap [ ], rice [ ] or bread [ ]

13. Who are your regular customers?

- Males [ ]
- Females [ ]

- Children [ ]
- Teenagers [ ]
- Older people [ ]

14. How many orders of insects do you sell? ________________________________

15. How does insect availability differ with season?

____

____

16. How do you store insects?

____

____

____

____

17. How much profit do you make from selling insects?

- R100-R200 per week [ ]
- R300-R500 per week [ ]
- R600-R1000 per week [ ]
- R1100- R1500 per week [ ]
- R1600-R2000 per week [ ]
- Above R2000 per week [ ]

18. How did you get into the business of selling insects?

____

____

____

____

19. Are you aware of the nutritional benefits of consuming insects? Yes [ ] or No [ ]