EDIBLE INSECTS AS A SUBSTITUTE FOR CONVENTIONAL MEAT IN HUMAN DIET: AN APPLICATION OF NUTRITIONAL PROFILING MODELS

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

Signature …………………………………………..Date……….……………………………

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This thesis has been submitted for examination with our approval as University supervisors

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DEDICATION

I dedicate this thesis to Almighty God, the creator of heaven and earth, without whom nothing is impossible.

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Weru, J., Chege, P., & Kinyuru, J. (2021). Nutritional potential of edible insects: a systematic review of published data. *International Journal of Tropical Insect Science*, *41*(3), 2015–2037. https://doi.org/10.1007/s42690-021-00464-0

Weru, J., Chege, P., Wanjoya, A., & Kinyuru, J. (2022). Comparison of healthfulness of conventional meats and edible insects in Sub - Saharan Africa using three nutrient profiling models. *Bulletin of the National Research Centre*, *46*(43). https://doi.org/10.1186/s42269-022-00726-y

LIST OF ABBREVIATIONS

DV	Daily Value
GDA	Guideline Daily Amounts
Kcal	Kilo Calories
LIM	Nutrients to limit
MRV	Maximum Recommended Value
NRF	Nutrient Rich Foods
NVS	Nutrient Value Score
RACC	Reference Amount Customarily Consumed
RDA	Recommended Daily Allowance
RDV	Reference Daily Amount
RRR	Ratio of Recommended to Restricted
WHO	World Health Organization

DEFINITION OF TERMS

Nutritional quality	the appropriate levels of individual nutrients in a diet
Nutrient profiling	classification or categorization of foods based on their nutritional composition
Edible insects	insects that are eaten by human beings as food
Healthy	in good health or without a disease e.g., a healthy person
Healthful	promoting or bringing about good health e.g., healthful juice
Nutrient dense	having a lot of nutrients and relatively few calories
Energy dense	having high concentrations of calories per unit of measure (e.g., per gram, per serving, etc.)

ABSTRACT

The world population is steadily increasing thereby stretching food resources with devastating effects on the well-being of humanity. Protein sources are diminishing at a fast rate and the production of more animal protein to meet the increasing demand has impacted negatively on the environment. Meat and meat products have been blamed for a myriad of problems facing human kind like lifestyle illnesses, environmental degradation, and climate change. There is therefore an urgent need for alternative protein sources such as edible insects. Edible insects have been suggested as the suitable alternatives to conventional meats in order to ameliorate these drawbacks. The use of insects as food for humans has been practiced traditionally in many countries. Edible insects are a suitable source of valuable nutrients that can meet the nutritional requirements for humans. Nutrient profiling (NP) is the science of categorizing foods according to their nutritional composition to help consumers make healthful dietary choices. Healthfulness is the ability for a given food to impart health benefits to the consumer. Evidence is however scanty on the healthfulness of both the meats and edible insects in order to have grounds for replacing meats with insects in the diet. The objective of this study was to evaluate the suitability of edible insects as healthful alternatives to conventional meats in human diet by use of nutrient profiling models.

Nutritional data for edible insects were searched systematically from published research articles using Google Scholar, PubMed, Scopus, and Web of Science. A total of 483 published scientific journal articles were obtained and screened for quality based on European Food Information Resource (EuroFIR) guidelines with data from 26 articles meeting the criteria by scoring above 17.5 out of 35 points. A total of 91 insect species in 135 data lines were identified in the search.

The healthfulness of edible insects and conventional meats was carried out using data obtained from Food Composition Tables (FCTs) and the systematic review, which were applied in three nutrient profiling models: the WXYfm (Ofcom) model that was designed to regulate advertising of foods to children, the RRR (Ratio of Recommended to Restricted) model that assesses the ratio of positive to negative nutrients in foods, and the GDA (Guideline Daily Amounts) model which has been used to regulate health claims on foods. To assess the effect of replacing meat with edible insects on the nutritional quality of diets, 21 meat recipes were obtained from Kenya and 13 from Malawi FCTs, respectively. The meats in the recipes were replaced with cricket, termite, and grasshopper since they are among the most consumed edible insects in Kenya and Malawi. The healthfulness of the recipes before and after substitution was evaluated using the three NP models. For cost-effectiveness study, the prices of the recipe ingredients were obtained from the online marketplace and the cost of each recipe calculated before and after substitution. Tukey's Studentized Range (HSD) Test (The SAS System) was used to check for significance in differences of healthfulness using mean scores. The results showed a wide variety of nutrient content among different insect species, with great variation within species and regions, attributable to diet (feeding regime), sex, geographical source, and growth stage. The highest and the lowest recorded values for macronutrients were; Carbohydrates: 94.01g/100g, 0.1g/100g; Protein: 81.11g/100g, 1.11g/100g and Fat: 77.01g/100g, 2.11g/100g. The highest energy value was 762.0 Kcal/100g and the lowest was 268.3 Kcal/100g. The highest and lowest values for fatty acids were; SFA: 733.46mg/100g, 17.50mg/100g; MUFA: 165.80mg/100g, 5.67mg/100g; and PUFA: 1514.32mg/100g, 3.70mg/100g. Potassium was the highest reported value of 2515mg/100g while copper was the lowest reported value of 0.0073mg/100g. Vitamin E was the highest recorded value of 0.925mg/100g while vitamin C was the lowest recorded value of 0.0046mg/100g. The highest recorded value for amino acids was 96.02mg/g of protein for leucine and the lowest reported value was 1.19mg/g of protein for methionine+cysteine. The WXYfm model classified all foods as healthful, and *Nasutitermes spp.* was significantly more healthful than duck (P=0.001). The RRR model classified all foods as healthful, and *Nasutitermes spp* termite. was significantly more healthful than all other foods except *Macrotermes bellicosus* termite and tilapia fish (P=0.018). Duck (for women and men) and pork (for women), were classified as unhealthful by the GDA scoring system, and duck was significantly less healthful than all other foods (P<0.0001), except for pork and mutton. There were significant differences between the healthfulness of conventional meats and edible insects' recipes, and also their cost (P<0.022). Termite was the most suitable to replace meats in recipes in Kenya and Malawi to improve healthfulness. Recipes with more expensive meat ingredients, e.g., mackerel, beef liver, and omenawere less cost-effective.

In conclusion, edible insects are a good source of nutrients and can be used to fight undernutrition with some insect species providing a significant contribution to the Recommended Daily Allowance (RDA). Edible insects are promising alternatives to conventional meats, but the choice should be on a species-to-species basis. This would be significant in fighting hunger and broadening the choice of nutrients sources to cater for an ever-increasing world population.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Nutrient profiling is the science of classifying foods according to their nutritional composition (Scarborough et al., 2007) for intentions related to promoting health and preventing disease (Rayner 2013; Maillot et al., 2008). Nutrient profiles are developed using different algorithms, referred to as nutrient profile models, which use food composition data, from which a healthfulness marker or index is derived (Quinio et al., 2007). Nutrient profiling is important in the food industry and can be used in various situations, for instance, food labelling and its regulation, regulation of advertising (Scarborough et al., 2007b), regulating commercial food marketing to consumers, promoting reformulation of food products, and regulation of nutrition and health claims on foods (Maschkowski et al., 2014). Nutrient profiling can be used to differentiate foods that are healthful from those that are less healthful (Scarborough et al., 2007b). Therefore, they can assist consumers in making healthful dietary choices especially when used in food labelling (Eržen et al., 2015) and hence useful in tackling under- and over-nutrition (Payne et al., 2015).

The term ‘healthful’ refers to promoting good health, e.g., food, while the term ‘healthy’ refers to being in good health e.g., a healthy person (Drewnowski, 2005). But the term ‘healthy’ has been used for both the person and the good food (Drewnowski, 2005). It is possible for a person to fall sick and hence be unhealthy, a phenomenon that is not applicable to food. To avoid ambiguity, the term ‘healthful’ shall therefore be used in this study when referring to food. Sustainable healthful diets should be inexpensive, accessible, safe, and culturally agreeable, while being able to alleviate the risk of diet-related illnesses and fight malnutrition in addition to preserving biodiversity and keeping the planet healthy (FAO and WHO, 2020). Healthful foods or diets have a lower risk of causing diet-related conditions e.g., noncommunicable diseases (Medina et al., 2022).

Studies have shown that healthful diets are more expensive than less healthful diets (Cade et al., 1999) (FAO and WHO, 2020). This is due to the high cost of energy in nutrient-dense foods such as fish, lean meats, fruits, and vegetables, while energy-dense foods that are low in essential nutrients are the cheapest sources of dietary energy (Maillot et al., 2007). Nutrient profile models can help consumers choose cost effective diets which are of high nutritive value (Drewnowski, 2010). Therefore nutrient profiling models are useful since they help consumers to create more healthful diets (Drewnowski, 2010). The foods that are awarded the highest scores by the nutrient profiling models should be nutrient dense, appealing and affordable (Maillot et al., 2008).

Insects constitute about 76% of the known species of animals and they are the most successful group of animals (Yoloye, 1988). Insects can affect man either by destroying crops and man’s valuable materials or by being sources of his nutrients (Elet al., 2008). Many species of insects have been consumed by many people all over the world (John N Kinyuru et al., 2010). The most common insects consumed, especially in developing countries, include termites, crickets, locusts, grasshoppers, caterpillars, and can play a major role in food security (Akinnawo et al., 2006). The species used have high quality fats, proteins, vitamins and minerals and therefore are an important source of human nutrition while contributing significantly to local economies (DeFoliart, 1999).

Insects are plenty and contain many essential nutrients for humans (Ekpo et al., 2009). For instance, they have been shown to have the same amino acid requirements as man, and they therefore accumulate these amino acids during growth hence serving as a ready source of these nutrients (Gilmour, 1961; Ekpo et al., 2009). Consumption of edible insects can have huge economic prospects since insects form the largest volume of animal protein eaten by all carnivores (Ayieko & Oriaro, 2008). Defoliart (1995) observed that insects’ protein could solve the shortage of protein in the world and that insects should be considered as part of nutrition programs. Besides their nutrition value, insects have found use as source of cooking oil, food flavoring, and color (Ayieko et al., 2008).

Red meat is an important source of highly digestible protein with raw red muscle meat containing 20–25 g protein/ 100 g, having all essential amino acids and does not contain limiting amino acids; and 2–8 g fat/100 g for lean meat, with virtually no carbohydrate. Red meat is a good source of omega-3 polyunsaturated fatty acids, essential vitamins and minerals. Mutton is particularly nutrient-dense, and is a rich source of thiamin, vitamins B6 and B12, iron, phosphorus and copper (Williamson et al., 2005; Williams, 2007). Fish and shellfish are excellent sources of protein (13–22 g protein/ 100 g) but are relatively poor in fat content (1–23 g fat/ 100 g) and carbohydrate content (0–3 g carbohydrate/ 100 g) (Nurnadia et al., 2011). Chicken muscle meat provides 19–22 g protein/ 100 g and 0.3–0.9 g fat/ 100 g (Wattanachant et al., 2004). Conventional livestock production takes up to 26% of arable land with an insatiable demand for more land, and has a huge impact on the environment due to greenhouse gas (GHG) emissions and nutrient depletion in the soil, making it the biggest contributor to climate change (Sakadevan & Nguyen, 2017). Climate change due to conventional livestock is an antithesis to the delivery of Sustainable Development Goal 13 on climate action (Hawkes C, 2017).

A lot of interest is being directed towards the nutritional value of insect food with popularity growing in utilization and research on insect food (J. Kinyuru et al., 2012). In comparison, insects provide more protein (40 – 60%) than chicken, beef and pork (20%) per dry weight (Akhtar & Isman, 2017). This high protein content has made insects to be recognized to contribute to human nutrition and has been recommended for use to improve food security for people living with HIV in Kenya (NASCOP, 2006). Protein is also important in body building, repair of won-out cells, in protein turn-over, and for better performance in sports like marathons (Methenitis et al., 2021). Defoliart (1995) observed that mass rearing of insects could be a worthy venture as an alternative protein source. The world population has been increasing and so is the need for increased new food resources (Chen et al., 2009). The mass production of insects can fundamentally eradicate the problem of malnutrition in the world and also reduce the pressure on other protein sources (El et al., 2008). Therefore, insects will play a major role as a nutritional resource for humans (Chen et al., 2009).

There is a worldwide problem of malnutrition due to an acute imbalance of the rate of population growth and world food production (McKenzie & Williams, 2015). The Sustainable Development Goals (SDGs) target 2.1 and 2.2 aim to end hunger and ensure access by all people to safe, nutritious and sufficient food all year round and to end all forms of malnutrition by the year 2030 (SDG Compass, 2015). The SDG 13 addresses responsible consumption and production in which sustainable food production is envisaged (Hawkes C, 2017). New strategies are urgently needed in order to deliver on the SDGs and assure nutritional and health benefits to the population (Canavan et al., 2016). The exploitation of non-conventional food resources, e.g. utilization of insects as human food, is one of the ways of bridging the gap between present and future food production (El et al., 2008) and hence deliver on the SDGs. The poor may not afford conventional animal protein due to its high cost and this has significantly encouraged consumption of edible insects (El et al., 2008).

Consumption of insects may be very well demonstrated as a strategic idea in solving the present world's food problems (Katayama et al., 2008). In Nigeria, use of insects as food has greatly contributed to reduction in protein deficiencies in the country (Fasoranti & Ajiboye, 1993). In Zambia, insects are valuable sources of animal protein since conventional livestock and wildlife are scarce to the rural population (Mwizenge, 1993). In Western Kenya, edible insects are widely consumed and acceptable (J. Kinyuru et al., 2012). The edible insects used in Kenya include termites, crickets, grasshoppers, ants, and caterpillars. This study therefore evaluated the suitability of edible insects as healthful alternatives to conventional meats in human diet by use of nutrient profiling models. This would provide an opportunity to include the insects as part of the human diets and in community nutritional programs.

1.2 Statement of the problem

The tradition of consuming insects is widely practiced in Kenya and the world over (John N Kinyuru et al., 2010).. It has been recognized in scientific research as a valuable source of nutrients for humans and that it can solve the problem of food shortage in the world (Arnold van Huis, 2013). The world is faced with the problem of hunger, unsustainable food production, and food insecurity (Oyinloye et al., 2018). This is becoming an impediment to achievement of the SDGs 2.1 and 2.2. Despite the lack of enough food to feed the world population, insects have not been widely included as part of daily meals in most nations, including Kenya with most consumers preferring animal source foods such as meats which are expensive. This is possibly due to lack of adequate information to help consumers compare the nutritional profile of the insects to the animal source foods which are widely known and publicized. This has hindered the full utilization of insects' potential as a source of human food and for nutritional interventions despite their recognized high nutritional value.

1.3 Justification

Insects have high amounts of nutrients including fat, protein and minerals. However, they are underutilized. Studies have shown that insects are well accepted (Verbeke, 2015). And when the insects are processed into diverse products, they are easily acceptable to humans (J. N. Kinyuru & Ndung'u, 2020). There is also evidence of positive intentions to consume insect-based foods in Kenya (Pambo et al., 2018). As such, they should be included as part of the daily diet to alleviate deficiency of nutrients, for food security, and to combat world hunger. They occupy less space, convert less feed into protein and produce less waste compared to conventional livestock and hence are more economical to farm. Nutrient profiling is useful in determining the nutritional value of foods and hence can guide in choice of affordable yet nutritious diets. This would in turn contribute towards achievement of SDG 2.1 and 2.2 of access to safe, healthful, and affordable food by all people, and alleviating malnutrition. The government of Kenya would greatly benefit from the outcome of this study in policy development or improvement by adopting the nutrient models to improve the health of the population.

1.4 Objectives

1.4.1 Main objective

To model the suitability of edible insects as healthful substitutes for conventional meats in human diet

1.4.2 Specific objectives

1. To compile high quality database of edible insects' nutrient profile from analytical published data
2. To determine the healthfulness of edible insects and conventional meats using nutrient profiling models
3. To assess the overall nutritional quality of a diet in which conventional meats are replaced with insects
4. To evaluate the cost-effectiveness of replacing meat from conventional meats with insects

1.5 Hypothesis of the study

I. The nutritional quality of edible insects is superior to that of conventional meats

II. The inclusion of edible insects as food ingredients improves the healthfulness of diets

III. Replacing conventional meats with edible insects enhances the cost effectiveness of diets

1.6 Significance of the study

The outcome of this study is expected to contribute immensely to the quest for alternative food sources owing to climate change, population explosion, and diminishing food sources. This shall create demand for insects as food sources thereby opening up new frontiers in agribusiness and value addition of insect-based products. The study is also expected to inform government policy on utilization of diverse food sources and in implementation of intervention feeding programmes using insects. For the researcher, the study will help to uncover the nutritional benefits of consuming insects in Kenya plus the benefits of using nutrient profiling models to decipher the nutritional value of foods.

CHAPTER TWO

LITERATURE REVIEW

2.1 Edible insects as a source of nutrients

More than 1000 species of insects have been reported to be consumed worldwide (Illgner & Nel, 2000). The consumption of insects by humans has been considered as a primitive practice by people in tropical countries and is regarded as food meant for the poor (Shelomi, 2015a). In Western countries, insects are rarely eaten and the practice is considered culturally inappropriate (Arnold Van Huis, 2011). In Africa, insects are consumed as a source of protein and other nutrients (Hlongwane et al., 2021). All the major insect orders have been eaten in Africa including *Lepidoptera* (moths and butterflies), *Hymenoptera* (bees and ants), *lsoptera* (termites), *Coleoptera* (beetles), *Hemiptera* (true bugs), and *Orthoptera* (crickets, locusts and grasshoppers) (Ohiokpehai et al., 1996). Consumption of edible insects in Africa is purely a cultural practice (Allotey & Mpuchane, 2003) and it is not promoted by national governments who focus mainly on Western diets (DeFoliart, 1999; Yen, 2009; Bessa et al. 2020).

Termites, crickets, grasshoppers, ants and caterpillars are commonly consumed in Kenya. They are fried lightly in their own fat over low heat with addition of little salt and the wings are sometimes removed (John N. Kinyuru et al., 2013). Termites can also be eaten raw but the fried ones are preferred since they are often sundried and hence can keep for long (John N Kinyuru et al., 2010).The sun-dried termites are packaged in different containers and sold locally in Western Kenya or transported to other markets in East Africa e.g. Kisumu, Nairobi and Kampala (Yagi, 1998).

Most insects have higher protein content with similar digestibility compared to conventional livestock (Moreki et al., 2012). The crude protein content of many insect species has been found to exceed 60%. The house cricket [*Acheta domesticus* (L.)], for instance, was shown to surpass soy protein in terms of being a protein source when fed to weaning rats (Finke et al., 1989). Chen & Akre (1994) found the weaver ant, a common insect in China, to contain 42% - 67% protein and being rich in amino acids. Some insects have been shown to have protein with superior solubility

(Omotoso, 2006) and some have been reported to have protein with high biological value (Guevara et al., 1995; Solomon et al., 2008).

Insects are rich in minerals including copper, manganese, selenium, iron, calcium, zinc, and phosphorus, with a particularly high content of iron and zinc (Barker et al., 1998; Christensen et al., 2006; Kinyuru, 2009; Rumpold & Schlüter, 2013). Most developing nations suffer deficiencies in iron and zinc due to their low bioavailability in the staple foods such as legumes and cereals which contain anti-nutrients and therefore edible insects can help solve these deficiencies (Christensen et al., 2006). Research has shown that supplementation of foods with zinc reduces morbidity related to infections in children and infants. Diarrhea, which is a major cause of death in developing countries, is decreased by adequate zinc status (Wardlaw & Kessel, 2002).

Edible insects can be a source of fat and fiber in the diet. For instance, termites contain, on average, 32% fat and 5% fiber, while crickets have 13% fat and 10% fiber based on dry matter (Rumpold & Schlüter, 2013a). Edible insects are high in monounsaturated fatty acids and polyunsaturated fatty acids as well as vitamins such as riboflavin, pantothenic acid, biotin, and in some cases folic acid (Rumpold & Schlüter, 2013a). On fresh weight basis, the energy content of insects is on average comparable to meat from conventional livestock except for pork since it has high fat content (Durst & Johnson, 2010).

Recent studies have shown that edible insects are becoming acceptable to the general population which is showing a positive gain towards adoption of these novels foods (J. N. Kinyuru & Ndung'u, 2020). There is willingness to consume edible insects in Kenya but impetus is needed by key players in the value-chain (e.g., nutritionists, health officials, and scientists) to promote these novel food items (Pambo et al., 2018). Consumer education coupled with tasting sessions would enhance acceptability and reduce aversion towards edible insects (Mancini et al., 2019). Based on their superior nutritional value, edible insects can be used as alternatives to conventional protein sources like beef, pork, chicken, etc. (Hlongwane et al., 2021).

2.2 Global insects' species consumption

Insects consumption dates back to Bible times (DeLong, 1960) in the nation of Israel as recorded in Leviticus 11:22 'You may eat any kind of locust, cricket, katydid, or grasshopper' (God's Word Translation) and Mark 1:6 'John was clothed with camel's hair and a leather belt around his waist. He ate locusts and wild honey' (World English Bible) (Kritsky, 1997). Presently, there is data on consumption of different species of insects the world over (Lenteren et al., 2006).

Ramos-Elorduy (2009) reported that 2086 insect species are eaten worldwide in 130 countries by 3071 ethnic groups. Coleoptera (beetles), which constitute 40% of all known insect species, are the most consumed globally at 31% followed by Lepidoptera (caterpillars), which are popular in Sub-Saharan Africa, at 18%, then Hymenoptera (ants, bees and wasps) at 14% and common in Latin America, followed closely at 13% by Orthoptera (crickets, locusts and grasshoppers). In fifth position is Hemiptera (leafhoppers, planthoppers, true bags, cinadas and scale insects) at 10%, then Isoptera (termites) and Odonata (dragon flies) each at 3%, then Diptera (flies) at 2%, and other orders at 5% (Cerritos, 2009; Jongema, 2015). The larvae and adult stages of Coleoptera are commonly eaten while Hymenoptera are consumed as larvae and pupa. Lepidoptera are mostly eaten as caterpillars, while the orders Hemiptera, Orthoptera and Isoptera are mainly consumed in the mature stage (Cerritos, 2009). The insects are mostly consumed as supplements to major foods e.g. maize, sorghum, rice, beans, etc., or as ingredients for other food items (Gahukar, 2011).

By and large, Africa is the leader in terms of variety of edible insects (Ramos-Elorduy, 2005). The most popular edible insect orders in Africa are Lepidoptera, Orthoptera and Coleoptera with the Central African region leading in the practice of consuming insects (Kelemu et al., 2015). The edible insects have mainly been obtained from the wild by gathering them manually or by use of nets, knives or shovels (Ramos-Elorduy, 2009). However, recently some insects are reared commercially in different countries. Some examples include Japan where edible wasps are commercially reared, the *witjuti* grubs (larvae of the moth family *Cossidae*) in Australia, mopane worms in Botswana, crickets, giant water bugs and grasshoppers in Thailand, Kenya, Uganda and caterpillars in the Democratic Republic of Congo (DRC), to name but just a few (P. Durst & Johnson, 2010).

In Tanzania, the longhorn grasshopper, known locally as senene, is a traditional delicacy and provides adequate nutrient requirement of proteins, zinc, iron, and vitamin A for children below 5 years of age Mmari et al. 2017a). In South Africa, edible insects have been consumed since time immemorial with records of *Apis mellifera* unicolor (a honeybee) and *Trinervitermes trinervoides* (a termite) being eaten in early times. But currently, termites, grasshoppers, various Lepidopteran caterpillars, ants, jewel beetles, and stink bugs are consumed in South Africa (Hlongwane et al., 2021).

2.3 Need for alternative protein sources

The world population is expected to reach 9 billion people by the year 2050. The current food production will need to almost double for this population to be fed. Land is a scarce resource and it is not possible to expand the area devoted to farming so as to increase food production (FAO, 2013). To improve food production various methods have been employed including intensive farming policies, genetic selection, development of genetically modified organisms (GMOs), and extending the shelf-life of foods. Little focus has been given to widening sources for food of animal origin (Belluco et al., 2013a). Rapid urbanization and increasing incomes in developing countries have created changes in the composition of global food demand (Msangi & Rosegrant, 2011) and wealth is a major determinant in the increase in global meat consumption (Tilman et al., 2011)).

Increase in meat consumption increases demand for grain and protein-rich feeds (Trostle, 2008). Livestock are fed about 6 kg of plant protein for every kilogram of high-quality animal protein produced (Pimentel & Pimentel, 2003). As a consequence, there will be an increase in demand and prices for coarse grain to feed livestock as demand for meat increases (Msangi & Rosegrant, 2011). An increase in prices for the most important agricultural crops will cause an increase in prices for beef, pork, and poultry by more than 30% by 2050 compared to 2000 (Nelson et al., 2009). This situation may be worsened by climate change, causing prices to escalate by an additional 18-21% (Nelson et al., 2009). The upsurge in food and feed prices in the coming years will prompt the quest for alternative protein sources, for instance, mini-livestock (Paoletti, 2005), seaweed (Fleurence, 1999), vegetables & fungi (Asgar, 2010), and cultured meat (Bhat & Fayaz, 2011).

2.4 Advantages of insects as mini-livestock compared to conventional livestock

Mini-livestock are domesticated, small animals, including insects, reared as food and nutrient (Arnold Van Huis, 2011). The activities of rearing and/or gathering insects as mini-livestock require minimal land, technical skills or capital expenditure, and can directly improve diets and incomes of the poor since they can also be collected freely from nature (FAO, 2013). Since they are easily accessible, simple to rear, and have quick growth rates insects can offer an inexpensive and resourceful opportunity to fight hunger (FAO, 2013).

Insects are efficient feed converters. The feed conversion ratios (FCRs) are particularly important, because the upsurge of meat demand will lead to a non-proportional demand for grain and high-protein feeds (Arnold Van Huis, 2011). FCRs depend on the class of animal and the method of production used to produce the meat. Some figures from literature report as follows: 2.5 for chicken, 5 for pork, and 10 for beef (Smil, 2002a). The proportion of edible weight varies substantially between insects and conventional livestock (Arnold Van Huis, 2011). The percentage of edible portion for chicken and pork is both 55% of live weight which is higher than that of beef (40%) (Flachowsky 2002; Smil 2002b). Crickets, for instance, have a FCR of 1.7 and hence they are twice as efficient as chickens, 4 times more efficient than pigs and 12 times more than cattle (Arnold Van Huis, 2011).

Greenhouse gas (GHG) emissions from conventional livestock production account for about 18% of global emissions induced by humans (Steinfeld et al., 2006). Studies show that 1 kg of beef has the highest environmental impact when measured in CO_2 equivalents (14.8 kg), followed by pork at 3.8 kg, and chicken at 1.1 kg (Fiala, 2008). Almost all ammonia emissions into the atmosphere is from the agricultural sector, of which almost two-thirds is by livestock (Steinfeld et al., 2006). Insects can also produce GHG and ammonia, for example, tropical species of cockroaches (Blaberidae & Blattinae), termites (Isoptera), and scarab beetles (Scarabidae) have bacteria in their hindguts that produce methane (Hackstein & Stumm, 1994). Nevertheless, most of the commercially reared edible insect species, e.g., the yellow mealworm (*Tenebrio molitor*), the house cricket (*Acheta domesticus*), and the migratory locust (*Locusta migratoria*) are better than conventional livestock in terms of ammonia production and direct GHG emissions (Oonincx et al., 2010).

The amount of water used to raise conventional livestock is very high compared to that of cereal crops, specifically, that of beef at 22, 000 liters/kg produced (Oki & Kanae, 2003). Some literature mentions higher amounts of 43, 000 liters, mainly due to indirect water use such as forage and grain feed crops. The amounts of water used to rear edible insects is expected to be lower, since, for instance, some insects are drought resistant and can be reared on organic side streams, e.g., the yellow mealworm and the lesser mealworm (Ramos-Elorduy et al., 2002), and have efficient FCRs.

Diseases like avian influenza (H5N1), foot-and-mouth, bovine spongiform encephalopathy (BSE), and classical swine fever are infectious sicknesses that affect conventional livestock and cost billions of monies every year to control. They occur mostly due to high-density animal production operations where animals are reared close together in a bid to maximize on limited space (Brownlie et al., 2006). It has been reported that consumption of meat in high-income countries has been associated with human illnesses such as BSE (Brownlie et al., 2006), cardiovascular diseases and cancer (Pan et al., 2012). Zoonotic infections are on the rise and they pose a threat to human health (Tomley & Shirley, 2009). Insects are taxonomically far more distant from humans than the conventional livestock and hence such infections are expected to be very low (Arnold Van Huis, 2011).

2.5 Acceptability of edible insects as human food

Edible insects are accepted and consumed the world over by more than 2 billion people due to their nutritive value, especially their protein content, and for environmental sustainability (Imathiu, 2020; John N Kinyuru et al., 2015). In Tanzania, the longhorn grasshopper (*Ruspolia differens*) is a highly regarded delicacy and is even used a symbol of respect and acceptance when served to guests in a family (M. W. Mmari et al., 2017). Edible insects have further been used as healthful ingredients in food products like complementary foods in Kenya and Tanzania as a way of boosting the nutritional profiles of the staple foods which are mostly deficient of essential nutrients (Kipkoech, 2019; M. Mmari et al., 2017).

One of the major challenges of universal adoption of edible insects as a regular food item is related to acceptability (Dagevos, 2021). In Africa, edible insects have been eaten traditionally as an indigenous diet and entomophagy is accepted culturally (Pambo et al., 2018). The Western world is mainly lagging behind in accepting insects as a modern diet (Shelomi, 2015a) and most cultures in the developed world consider eating of insects as taboo (Shelomi, 2015b). The main barrier to consumption of insects by the majority is the 'disgust factor', which is an emotional view of insects as being dirty, dangerous, unsightly, and disgusting (Dagevos, 2021). Developed nations are averse to insects as human food since they consider entomophagy as primitive and view edible insects as food for the poor (Hlongwane et al., 2021). In Africa, the western culture influence pervades the middle- and upper-class earners, urban-dwellers, and the educated youth leading to their rejection of insects as human food (Hlongwane et al., 2021; Pambo et al., 2018). Lack of information on edible insects, their unavailability (as opposed to other food items), indifference among non-traditional insects consumers, legislative hurdles, are among the key impediments to adoption of edible insects as a regular diet (J. N. Kinyuru & Ndung'u, 2020; Pambo et al., 2018). A study on indigenous knowledge on consumption of edible insects reported religion as a barrier to entomophagy in Ethiopia (Hlongwane et al., 2021).

Since culture plays a pivotal role in adoption of novel foods, influencing culture would go a long way in ensuring the promotion and adoption of edible insects to non-traditional insect eaters (J. N. Kinyuru & Ndung'u, 2020). A starting point is indirect entomophagy in which insects are used as animal feed to increase food production or when insects are used to make compost for crop production for human food (J. N. Kinyuru & Ndung'u, 2020; Mancini et al., 2022). Due to their sustainability to the environment, insects are suitable for feed production and also for human food (Mancini et al., 2022). In order to influence culture and promote consumption of edible insects, there needs to be tailor-made consumer education, presentation of edible insects as ordinary food as opposed to being novel, making insects constantly available and affordably, innovating flavorful edible insects-based products, and incorporation of insects in familiar products (Kim et al. 2019; Kinyuru and Ndung'u 2020; Bessa et al. 2020). In Kenya, the rural population has willingness to consume insect-based foods but the information from government or policer-makers and the food industry is an impetus to enhance acceptability of these novel foods (Pambo et al., 2018). Additionally, intention to consume insects is influenced by taste, price, convenience, and healthfulness (nutritiousness) of the edible insects (Pambo et al., 2016). Issues to do with safety and quality need to be addressed by the edible insects value chain (Jantzen da Silva Lucas et al., 2020).

Other strategies to promote entomophagy is by powdering insects for use in food products like porridge, bread, snack bars, etc. or by extracting insect proteins and oils for use as food ingredients for nutritional and functional roles (Hlongwane et al., 2021; Jantzen da Silva Lucas et al., 2020; Kipkoech, 2019). Edible insects are comparable to nuts in terms of their flavor, texture, and even micronutrient composition, and as such they can be promoted as suitable alternatives to nuts (Shelomi, 2015b). Repeated exposure to new foods creates preference and acceptability of edible insects can therefore be expanded by making them readily available and accessible (Monterrosa et al., 2020).

2.6 Nutrient profiling to enhance nutrition

Nutrient profiling is the science of characterizing foods according to their nutrient composition (Drewnowski & Fulgoni, 2008). A nutrient profiling system/model is a scoring tool based on the nutrient composition of a food according to scientific and reasonable standards (Townsend, 2010). Nutrient profiling filters a huge quantity of nutritional data into a single convenient index or indicator (Arvaniti & Panagiotakos, 2008). Nutrient profile models are mostly based on 1) qualifying nutrients known to be beneficial to health (positive nutrients), mostly vitamins and minerals, 2) disqualifying nutrients (negative nutrients), mostly fats, added sugars, and sodium, or 3) the combination of both (Drewnowski & Fulgoni, 2008). Some models, for example, the WXYfm model, use a simple scoring system where negative points are assigned for beneficial nutrients and positive points are assigned for negative nutrients based on the nutritional content of 100 g of food or drink, and the points are summed up (Rayner, 2005). Certain cutoff points are determined and foods or drinks that score above the cutoffs are categorized as ‘less healthful’ (Miller et al., 2009).

The general ‘building blocks’ for the models include: nutrients selection, reference amount, food category declination, and cut-off use. Nutrient selection is concerned about the balance between positive nutrients and negative nutrients and how many are to be included; reference amount is the basis for comparison, e.g. per 100 g, per 100 kcal, per serving. Food category declination is concerned about the likelihood of applying the same nutritional criteria (nutrient scores and/or thresholds) for all foods (across the board model) or specific criteria according to food category (category-wise model). And cut-off use suggest the likelihood of either allocating scores based on the nutrient composition or using threshold values for each nutrient (Garsetti et al., 2007).

One application of nutrient profiling is to help consumers make more healthful food choices (Drewnowski & Fulgoni, 2008). Nutrient-dense foods were described by the Dietary Guidelines for Americans (GDA) as those that provide healthful food components like vitamins and minerals and relatively low or no sodium, added sugars, and saturated fat (UNESCO, 2016). The idea of nutrient density was used by GDA and MyPyramid (USDA Food Guide Pyramid) to promote the consumption of nutrient-rich foods across and within food groups (Drewnowski & Fulgoni, 2008). The Nutrient Rich Foods Index (NRF) gives an authenticated metric to evaluate nutrient density of individual foods (Drewnowski & Fulgoni, 2008; Fulgoni et al., 2009). The variant of NRF, known as NRF9.3, was based on the total percentage of daily values (DV) for 9 nutrients to encourage minus the total percentage of maximum recommended values (MRV) for 3 nutrients to limit, with all DV computed per 100 kcal and capped at 100% (Fulgoni et al., 2009). The 9 nutrients to encourage were based on foods' amount of protein, fiber, vitamins A and C, calcium, and iron, according to FDA's definition of "healthful foods", plus vitamin E, potassium, and magnesium, according to GDA (Drewnowski, 2005; Drewnowski & Fulgoni, 2008). Saturated fat, added sugar, and sodium were the 3 nutrients to limit (**Table 2.1**) (Drewnowski, 2010).

Health nutrition programs promote healthful eating through educational programs in the population (Lachat et al., 2005). Multimedia campaigns can be used to relay messages concerning food groups whose consumption should be encouraged, e.g., "five fruits and vegetables a day", and foods whose consumption should be limited, e.g., "eat fewer sugary, fatty, and salty foods" (Hercberg, 2008). These messages are delivered by nutritional labelling on the food packaging, which is not easily understood by the consumer in a way that they are able to identify healthful foods, and especially so for those in the population whose literacy levels are low (Cowburn & Stockley, 2005). Simplified front-of-package nutritional labels, derived from nutrient profiling models, have been shown as potential tools to assist consumers to select healthful foods at the point of purchase (Campos et al., 2011).

Table 2. 1: Reference daily values and maximum recommended values for nutrients based on a 2000-kcal diet*

Nutrient	RDV	MRV
Protein (g)	50	-
Fiber (g)	25	-
Vitamin A (IU)	5000	10000
Vitamin C (mg)	60	2000
Vitamin E [IU (mg)]	30 (20)	(1000)
Calcium (mg)	1000	2500
Iron (mg)	18	45
Potassium (mg)	3500	4700
Magnesium (mg)	400	400
Saturated fat (g)	-	20
Added sugar (g)	-	50
Sodium (mg)	-	2400

*RDV, reference daily value; MRV, maximum recommended value
Source: (Drewnowski 2010; Public Health England 2016).

2.6.1 Cost and choice of a nutritious diet

Food cost is a major influence on food choices. Nutrient profiles, combined with food-price data, can assist consumers to identify affordable nutrient-rich foods across food groups, and therefore make smarter food purchases (Drewnowski, 2010). Atwater (1894), distinguished between cheap and “economical” foods. The cheapest food was that which supplied the most nutrients for the least money, whereas the most economical food was the cheapest and at the same time the best adapted to the needs, wants, and resources of the consumer. Based on those principles, modern consumers choose foods in relation to taste, cost, convenience, social norms, and nutritional value (Drewnowski, 1997; Glanz et al., 1998).

2.7 Approaches to nutrient profiling

There are many nutrient profiling models that have been developed and which differ in their purpose and the way they are constructed (Eržen et al., 2015). Despite the diversity of their objectives, the models should follow certain agreeable standards. For instance, the algorithm used need to be scientifically right, independent, applicable, and transparent (Drewnowski, 2005; Scarborough et al., 2007; Drewnowski, 2007). Some model approaches tend to classify foods as "good" or "bad" thereby penalizing whole food categories, e.g., the " traffic light" system (Tetens et al., 2007). The "traffic light" system expresses food's content of fat, sugars, and sodium (i.e., 'negative' nutrients or nutrients to limit) regardless of the amount of positive nutrients (or the total nutrient package) in the food. Since this system is a food labeling model, it can convey misinformation leading to consumer confusion, although it has been widely adopted by supermarkets in the UK (Miller et al., 2009).

Therefore, it is paramount that any model is simple and user friendly for the consumer to pick the best options within a food group (Needs, 2007). Scarborough et al., (2007) proposed a seven step approach to developing nutrient profile models: 1) determine the purpose for which the model is to be used; 2) determine the group or population to which the purpose is applicable; 3) determine whether to use food-category-specific or across-the-board criteria; 4) determine which nutrients or other food components to use; 5) determine which base or combination of bases to use for calculation (e.g., 100g, 100kcal, etc.); 6) determine which type of model to use i.e. continuous or categorical; and 7) choose the numbers to use (e.g., based on dietary recommendations).

Various models have been developed by academic researchers, the food industry, and regulatory bodies and are based either on nutrients to encourage only, nutrients to limit (LIM) only, or on a combination of both (**Table 2.2**) (Fulgoni et al., 2009). In order for the models to be acceptable, they need to be validated against some independent measures of a healthful diet (Arambepola et al., 2008). As observed by Fulgoni et al. (2009), the nutritional quality guides used to construct the models need to be based on up-to-date scientific information about diet and health, and they should consider nutrients valuable to health and also LIM on the premise of scientifically agreed or authoritative data.

Table 2. 2: Summary of the beneficial nutrients and nutrients to limit used to construct selected nutrient profile models

Score/Model	Macronutrients	Vitamins	Minerals	Nutrients to limits (LIM)
Nutritional Quality Index (NQI)	Protein, Fiber, MUFA, Carbs	Vit A, C, thiamin, riboflavin, B6, B12, niacin	Ca, Fe	Fat, saturated fat, cholesterol
Calories for Nutrients (CFN)	Protein	Vit. A, C, thiamin, riboflavin, niacin, B6, B12, folate	Ca, Fe, Zn, Mg	
Nutritious Food Index	Fiber	Vit. A, C, thiamin, riboflavin, niacin, folate	Ca, Fe, Zn, Mg, K, Ph	Total fat, saturated fat, cholesterol, Na
Ratio of Recommended to Restricted Food Components (RRR)	Protein, Fiber	Vit. A, C	Ca, Fe	Energy, saturated fat, total sugar, cholesterol, Na
Naturally Nutrient Rich (NNR)	Protein, Fiber, MUFA	Vit. A, C, D, E, thiamin, riboflavin, B12, folate	Ca, Fe, Zn, K	
Nutrient for Calorie (NFC)	Protein, Fiber	Vit. A, C, E, B12	Ca, Fe, Zn, Mg, K, Ph	Saturated fat, Na
Nutrient Density Score NDS 16	Protein, Fiber	Vit. A, C, D, E, thiamin, riboflavin, niacin, panthotenic acid, B6, B12, folate	Ca, Fe, Mg	

Score/Model	**Macronutrients**	**Vitamins**	**Minerals**	**Nutrients to limits (LIM)**
Nutrient Density Score NDS 23	Protein, Fiber, linoleic, linolenic acids	Vit. A, C, D, E, thiamin, riboflavin, niacin, B6, B12, folate	Ca, Fe, Zn, K, Cu, I, Se	
Nutrient Density Score NDS 5	Protein, Fiber	Vit. C	Ca, Fe	
Nutrient Density Score NDS 6	Protein, Fiber	Vit. A, C	Ca, Fe	
Nutrient Density Score NDS 9	Protein, Fiber	Vit. A, C, E	Ca, Fe, Mg, K	
Limited Nutrients (LIM) Score				Saturated fat, added sugar, Na,
Limited Nutrients (LIMtot) Score				Total fat, total sugar, Na
Smart Spot	Protein, Fiber	Vit A, C	Fe	Total fat, saturated fat, trans fat, added sugar, Na
Unilever Nutrition Score				Saturated fat, trans fat, sugar (total and added), Na
FSA Model SSC3d	n-3 fatty acids, F+V (g)		Ca, Fe	Energy, saturated fat, added sugar, Na
FSA Model WXYfm	Protein, Fiber, F+V+nuts (g)			Energy, saturated fat, total sugar, Na

Abbreviations: DHA, docohexanoic acid, F+V, Fruit and Vegetables, MUFA, Monounsaturated fatty acids

Source: (Drewnowski & Fulgoni, 2008)

2.7.1 Nutrient Value Score and Omega Value

The Nutrient Value Score (NVS) evaluates nutritional value of foods based on 100g (or food basket-specific quantity) of food based on amounts of energy, protein, fat and 8 micronutrients (namely: calcium, iron, iodine, thiamine, vitamin C, vitamin A, riboflavin, and niacin). NVS was developed for use in food assistance programs in populations with high risk of under-nutrition and micronutrient deficiencies (Ryckembusch et al., 2013; Payne et al 2015).

The Omega Value calculates the cost effectiveness of nutrient delivery particularly in food assistance programs based on different food baskets. It is defined as the ratio of an in-kind food basket (NVS/full delivery cost) over that same ratio for a food basket delivered via a commodity-based voucher (NVS/full delivery cost) (Ryckembusch et al., 2013). Assuming that A represents one food basket and B represents the alternative food basket, then the Omega Value will be computed as follows:

$(NVS\ for\frac{A}{Full}Costs\ forA\ \div(NVS\ for\frac{B}{Full}Costs\ for\ B)$ ……………………………… Eq 2.1

If the Omega Value is greater than 1, then food basket A is more nutritionally cost-effective and if the Omega Value is less than 1, then food basket B is more nutritionally cost-effective. So, when delivering food assistance, one would therefore choose which method of delivery is more cos-effective based on the Omega Value (Ryckembusch et al., 2013). The incorporation of cheaper but more nutritious food items, e.g., fortified ingredients, in a food basket would make it more cost-effective (Lentz et al., 2013).

Consumers have difficulty using food package labels to derive nutritional information and they need refined support in making dietary choices. Nutrient profile (NP) models can therefore furnish consumers with instant data on the levels or amounts of nutrients in individual foods and hence the ability to make quick decisions on food choice (Lobstein & Davies, 2008). A good example is the UK Food Standards Agency (FSA) system for front-of-pack labelling using color-coded signals called “Traffic Light Labelling”. Traffic Lights judge the nutritional quality of food based on the levels of salt, sugar, fat and saturated fat (per 100 g or 100 ml) in the food via of highly visible red, amber and green flags on the front of the pack in a simple way that makes it more useful for more healthful decision making in real-time, in the aisles of supermarkets and other stores (Magnusson, 2010).

The traffic lights system is based on GDA (Guideline Daily Amounts). For instance, high or ‘red’ signals indicate amounts of a nutrient above 25% of the GDA for that nutrient. An advantage of the front-of-pack color coding system is that it motivates retailers to utilize technology and reformulate their products in order to get favorable color signals in order to meet the demand by customers for more healthful products (Lobstein & Davies, 2008). A case in point is the Sainsbury’s Chicken and Bacon Pasta Bake product which was reformulated by increasing the amount of chicken and decreasing the quantity of sauce thereby changing the product profile from three ‘red’ signals to one red signal. As a consequence, this reformulation reduced the amount of salt and fat in the product (Lobstein et al., 2007).

Lobstein & Davies (2008) suggested that NP, e.g. the traffic light signals, could be used in food outlets whereby diners choose more healthful options from menus before making food orders. They also noted that the presence of red, amber or green signals are easy attention catchers since most consumers pay little consideration to the nutritional information on package labels, and the signals can be understood promptly by children and people with little or no nutritional know-how. Various algorithms are used in constructing NPs. As previously discussed, and depending on the objective of each NP, different nutrients are included.

2.7.2 Types of models

Firstly, the models can either be categorical or continuous (Scarborough et al., 2007a). Categorical models split foods into two or more groupings, e.g., based on the amount of negative nutrients, a model could classify foods as ‘high in fat’, without showing which food(s) contain more fat (Scarborough et al., 2007a). This is the basis for health claims carried on food labels since categorical models classify foods as ‘healthful’ or ‘more healthful’ since the categories are based on whether the foods have nutrient levels below or above certain set thresholds, hence they are also called threshold models (Scarborough et al., 2007b; Lobstein & Davies, 2008).

Continuous models rank foods based on a scoring system and are more intricate than categorical models (Scarborough et al., 2007a). Foods are assigned points on the basis of the amounts of positive or negative nutrients, as previously discussed. Continuous models can be transformed into categorical models by setting certain threshold criteria, for instance, a food can be described as ‘less healthful’ if it scores a certain number of points or less (Scarborough et al., 2007a).

Secondly, NPs can either be across-the-board or category-specific. Across-the-board models rank foods relative to all other foods whereas the latter classifies foods in relation to foods in the same category e.g. bread, dairy, etc. (Scarborough et al., 2007b).

Therefore, algorithms used in categorical models usually use ratio-based scores (Fulgoni et al., 2009b), e.g. the healthfulness of a food may be determined using the following equation, based on LIM only (Scarborough et al., 2007a).

$$SCORE = \frac{Total\ fat\ (g)/100g}{Total\ fat\ (g)GDA} + \frac{Total\ sugar\ (g)/100g}{Total\ sugar\ (g)GDA} + \frac{Total\ salt\ (g)/100g}{Total\ salt\ (g)GDA}$$

………. Eq 2.2

GDA = Guideline Daily Amounts

The reference values on the numerator and denominator can change depending on the base or combination of base used (per 100g, per serving, per Kcal), but most NPs use ‘per 100g’ perhaps because it is the base used in food composition tables and it is the format used in the EU for nutrition labelling (Scarborough et al., 2007a). The denominator can be GDA (Guideline Daily Amounts), DV (Daily Value), MRV (Maximum Recommended Value), RDA (Recommended Daily Allowance), etc., depending on the objective of the model (Scarborough et al., 2007a; Drewnowski & Fulgoni, 2008; Drewnowski, 2010).

An example of a categorical NP model is the Ratio of Recommended to Restricted (RRR) which scores foods (across-the-board) based on serving size using the following algorithm:

$$RRR = \Sigma(\frac{Nutrient_{\text{recommended}}}{6})/\Sigma\left(\frac{\text{Nutrient}_{\text{restricted}}}{5}\right)$$
……………………………………..…..Eq 2.3

(Scheidt & Daniel, 2004)

The scores are calculated by dividing mean percent DVs for six positive nutrients by mean %DV for four negative nutrients and energy. The RRR model uses only the nutrients found on the food label and generates ratio-based scores (Drewnowski & Fulgoni, 2008).

The Nutritional Quality Index (NQI) was developed based on 1000 kcal and profiles foods nutrient-by-nutrient, covering 18 nutrients calculated separately for each nutrient (so not a total score) (Eq 2.4). It was based on US RDA, measuring the ratio of amount of a nutrient in a portion of food that meets the energy needs to the recommended daily allowance for that nutrient (Drewnowski, 2005; Drewnowski & Fulgoni, 2008).

$$NQI = (\frac{N}{RDA_n}) \div (\frac{Kcal}{1000}) \qquad \text{Eq 2.4}$$

(Hansen et al., 1979)

N = Nutrient

Algorithms for continuous models are usually based on sums or means of scores as exemplified in **Table 2.3** (Drewnowski & Fulgoni, 2008).

As previously discussed, insects have been shown to contain high amounts of nutrients. Despite this fact, data is lacking on whether insects are nutritionally superior to conventional meats. NP models can be used to demonstrate that a product is nutritionally better than another similar product, or to compare between foods from the same category to show that one type contains higher amounts of a given nutrient than another (Lobstein & Davies, 2008).

Table 2. 3: Examples of algorithms used for selected nutrient profiling models

Model	Algorithm	Reference amount	Remarks
Calories for Nutrient (CFN)	$CFN = ED/ \Sigma_{1\text{–}3} (\%DV)/13$	100 g	Energy density (ED) divided by mean of percent DVs for 13 nutrients, based on 100 g of food.
Nutritious Food Index (NFI)	$NFI = \Sigma (wDFC/RDI + wLDFC/RDI)$	Serving	Sum of weighted (w) desirable (DFC) and less desirable (LDFC) food components; each divided by RDI.
Naturally Nutrient Rich, (NNR)	$NNR = \Sigma_{1\text{–}15} ((Nutrient/DV) \times 100)/15$	2,000 kcal	Unweighted arithmetic mean of % DVs for 15 nutrients. DVs based on 2000 kcal and capped at 2000%DV.
Nutrient Rich Food, NRFn	$NRFn = (\Sigma_{1\text{–}n} ((Nutrient/DV) \times 100)/n)/ED$	100 kcal	Unweighted arithmetic mean of %DVs for n nutrients.
Nutrient Rich Food NRFn.3	NRFn—LIM	RACC	Calculated by subtracting LIM from NRFn. Calculations based on RACC
Nutrient for Calorie (NFC)	$NFC = \Sigma_{1\text{–}11} (\%DV)/11 - \Sigma_{1\text{–}3} (\%DV)/3$		Sum of 11 positive nutrients minus sum of 3 negative nutrients
FSA-SSCf3d and WXYfm	Point system: see (Peter Scarborough, Boxer, et al., 2007)	100g	Total score = C (negative nutrients)—A (positive nutrients) unless C>11. Complex score for nut, vegetable and fruit content
Nutrient Adequacy Ratio (NAR) SAIN16, SAIN23	$NAR_n = \Sigma_{1\text{–}n}((Nutrient/DV) \times 100)/n$	100 g	NAR based on nutrients (n) and 100 g of food
Nutrient Density Score, NDS16, NDS23	$NDS_n = (NAR_n/ED) \times 100$	100 kcal	NDS calculated by dividing NAR by energy density (ED)

Source: (Drewnowski & Fulgoni, 2008)

This study shall therefore employ the NP tools to evaluate 1) the overall nutritional value of edible insects, 2) the ‘healthfulness’ of insects relative to conventional meats, and 3) the nutrient and/or energy density of edible insects.

Firstly, the Nutrient Value Score (NVS) is a continuous model that was developed to calculate the macro- and micronutrient content, including the energy, value of different food baskets intended for nutrition intervention. It is therefore a model that is used to fight malnutrition (Ryckembusch et al., 2013; Payne et al., 2015). It is hence suitable for evaluating the overall nutritional value of edible insects to determine their suitability in combating malnutrition.

Secondly, the WXYfm model was designed to regulate advertising of foods to children, and being a categorical model, it classifies foods based on their ‘healthfulness’. The presence of energy, fat, sugar, and sodium has a negative effect on the final score (Scarborough et al., 2007c; Drewnowski & Fulgoni, 2008; Miller et al., 2009). Negative points are awarded for nutrients to encourage while positive points are awarded negative points and then summed up to give a composite index (Miller et al., 2009). In addition to regulating advertising of foods on TV, this model can be applied to food vending in schools (Masset, 2012) Thus, this model is appropriate for evaluating the ‘healthfulness’ of edible insects.

Thirdly, the Nutrients Rich Foods (NRFn.3) model evaluates the nutrient density of foods on a continuous scale. The total score is calculated by summing up sub scores of variable number n of nutrients to encourage (NRn) and subtracting the total sum of LIM sub scores (LIMt) of 3 nutrients to limit (saturated fat, sodium, and total or added sugar) (Drewnowski & Fulgoni, 2008; Fulgoni et al., 2009; Drewnowski, 2010). The nutrients to encourage are based on percent DVs truncated at 100% while the LIMt sub scores are calculated using MRVs per 100 g (Drewnowski et al., 2021) It is hence fit for use in assessing the nutrient density of edible insects to determine whether insects are nutrient dense or energy dense.

The cost of energy in foods can be estimated by calculating the energy cost per reference amount (kcal, 100g, serving, etc.), e.g., cost/100 kcal, cost/serving, etc. The NRF index score can be divided by the price of food per reference amount (per serving or per 100 kcal) to estimate the amount of nutrients per unit of cost (e.g. dollar, shilling, etc.), hence identify the most affordable nutrient-rich foods (Drewnowski, 2010). The Omega Value is used to compare the cost effectiveness of two modes of delivering different food baskets in nutrition programs by combining NVS with full cost of delivery, e.g., comparing an in-kind versus a commodity-based voucher transfer methods (Ryckembusch et al., 2013). When edible insects are used to replace animal source foods in food baskets, the Omega Value can aptly be applied to evaluate the cost-effectiveness of such substitution.

2.8 Food cost and culture as influencers of food choice and healthfulness

Food choice is influenced by psychological processes that include hunger signals from the brain and a desire to eat certain nutrients, accompanied by the prize gained from the experience of eating that food (Leng et al., 2017). Consumers' understanding of healthfulness is a major determinant of food choice, but the choice is also affected by culture, social pressures, and the cost of food (Cade et al., 1999; Grunert, 2002; Leng et al., 2017). There is evidence that cost is a barrier to a healthful diet since nutrient-dense (healthful) foods cost more than energy-dense foods (with fewer nutrients) (Cade et al., 1999; Monterrosa et al., 2020). People who are poor and those with low incomes are more likely to eat unhealthful diets and, resultantly, the modern food supply is awash with low-cost tasty energy-dense foods to meet the market demand (Cade et al., 1999; Monterrosa et al., 2020). Therefore, it is clear that food prices and cost of diets limit the access of healthful diets by the poor who can't purchase the expensive nutrient-dense foods (Maillot et al., 2007). Food choice is a function of food cost (Monterrosa et al., 2020).

Culture is expressed as values that people or a community hold dear and that are encapsulated in ideas, customs, traditions, and social behavior (Monterrosa et al., 2020). Food preferences are created through repeated exposure to specific foods and exposure is for the most part an outcome of culture (Monterrosa et al., 2020; Rozin, 2004). Food choice is a form of cultural identity that the members of the society carry along with them wherever they go, including when visiting a different community in a foreign country (Chowdhury et al., 2000). Cultural values help in negotiating food choices or making those choices easier and the cultural valuation of foods has an effect on food cost (Monterrosa et al., 2020; Rozin, 2004). The modern food culture has been associated with metabolic disorders like obesity and diabetes due to the appetizing nature of energy-dense (unhealthful) foods available in the market (Leng et al., 2017). Children are most affected when it comes to the delectable energy-dense foods since their food choices are based on social acceptance as opposed to the foods being healthful (Freedman, 2016). Governments worldwide are applying interventions to move their people into more healthier lifestyles by changing their choices into a culture of healthful foods (Leng et al., 2017).

Most culinary cultures are local in nature since most of the cooks and chefs are locally sourced, but communication technology has led to globalization of cuisines in the society (Lane, 2011). There is cultural shift towards consumption of edible insects owing to the concerted efforts of stakeholders in the edible-insects value chain in promoting entomophagy (Alemu et al., 2015; Hlongwane et al., 2021; J. N. Kinyuru & Ndung'u, 2020; M. Mmari et al., 2017; M. W. Mmari et al., 2017; Pambo et al., 2016, 2018). And since edible insects are famed for their nutrient density and healthfulness (Hlongwane et al. 2020; Weru et al. 2021), it is expected that the shift to entomophagy culture shall improve the health outcomes of the population

CHAPTER THREE

SYSTEMATIC REVIEW OF THE NUTRITIONAL VALUE OF EDIBLE INSECTS[1]

3.1 Introduction

The world population has increased tremendously in the recent past with undernutrition being on the rise (Barennes et al. 2015) Edible insects have been suggested as alternative sources of high-value nutrients (Van Huis 2020; Rumpold and Schlüter 2013; Shadung and Given 2012). As a result, the use of edible insects as human food and livestock feed has increased in the recent past worldwide (Ssepuuya et al. 2017). Insects have been consumed traditionally by more than 2 billion people in over 113 countries in the world; but in most cases, the consumption of insects is purely a cultural practice and by choice based on the palatability of specific insects (Van Huis et al. 2013; Barennes et al. 2015; Ohiokpehai et al. 1996; Van Huis 2013). Even with the advent of technology, the harvesting, and processing of edible insects are still largely traditional with the use of simple equipment that are locally available (M. W. Mmari et al., 2017), and the insects are mostly obtained from the wild by traditional experts (J. Kinyuru et al., 2012).

Edible insects have high amounts of quality nutrients including proteins, fat, essential fatty acids, vitamins, fiber, and minerals (Barennes et al. 2015; Rothman et al. 2014) and could potentially be used to enhance food security and alleviate the problem of undernutrition, if adopted by non-insect eating communities. In Africa, Asia, and Latin America, edible insects constitute a considerable part of diets and they are processed minimally before consumption or sale in the local markets (Kamau et al., 2018). Similarly, the longhorn grasshopper (*Ruspolia differens*), known as *senene* in Tanzania, has been used to make complementary foods for children (M. Mmari et al., 2017).

The consumption of wild harvested insects has remained a cultural practice for long (Belluco et al., 2013b). Recently though, there is emerging effort to promote their consumption in regular diets and their acceptance as a valuable source of nutrients (Belluco et al., 2013b). In Asia, e.g. in Thailand and Lao People's Democratic Republic, commercial farming, production, and marketing of edible insects (cricket and palm weevil) has not only created a demand for these insects but also increased farmers' incomes massively (P. B. Durst & Hanboonsong, 2015). Insects have been sold

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[1] Weru et al., 2021

in supermarkets and convenience stores as ready-to-eat processed products (P. B. Durst & Hanboonsong, 2015). In restaurants, cooked insects and dishes with insect ingredients have been sold, but the most preferred are insect snacks sold by street vendors on mobile carts particularly at night to accompany beer consumption (Durst and Hanboonsong 2015; Yupa and Tasanee 2013). In Kenya, meatloaf, sausages, muffins, and crackers have been produced from termites and lake flies (Ayieko et al. 2010). There are also efforts to test the viability of edible insects as potential ingredients in making meat analogues (Kiiru et al., 2019) which could increase their acceptability in the modern diet.

Information on the nutritional value of edible insects is a vital pillar in propelling the insects onto dinner tables, and to address food and nutrition insecurity (Mancini et al., 2019). Currently, consolidated data is lacking, e.g. in food composition databases, on the nutritional value of edible insects (Varelas, 2019) and therefore consumers have no clear guide on the nutritional benefits of consuming insects. Studies have been done on the nutritional composition of various edible insects, however, the publications from the studies depict a huge variation in the nutrient content values (Manditsera et al. 2019; Van Huis 2013). This scenario has been reported in a study reviewing the nutritional content of edible insects showing wide ranging values of fat, protein, energy, and minerals (Charlotte L R Payne et al., 2016). This variation in data from the studies may arise from differences in food description, food identification, sampling plans, number of analytical samples, sample handling, analytical methods, and analytical quality control (Ifr et al. 2009; Castanheira et al. 2007). For instance, on a sampling plan, a statistically developed sampling plan may have a different objective from that intended for use in food composition tables, e.g. the sampling plan may cover foods consumed by sports persons thereby creating a bias against the general population (Ifr et al., 2009). There is a need to evaluate the data for quality and be able to give an opinion on the nutrient potential of the insects.

This study focused on the systematic review of the nutritional composition of edible insects to determine if they have adequate nutrients for human nourishment, especially in Africa. In assembling data on the nutrient composition of these commonly consumed insect species, and reporting on the quality of published data, it is hoped that the consideration of the potential of edible insects as a food source will be simplified.

3.2 Materials and methods

3.2.1 Selection of insect species

The following species of edible insects were selected for the search in the study as they are the most commonly consumed in Africa (Van Huis 2003): *Acanthacris ruficornis, Acheta domesticus, Anacridium melanorhodon, Apis mellifera, Bombyx mori, Brachytrupes membranaceus, Encosternum delegorguei, Gastrimargus africanus, Gonimbrasia belina, Gryllus bimaculatus, Hermetia illucens, Locusta migratoria migratorioides, Locustana pardalina, Macrotermes spp, Nomadacris septemfasciata, Oecophylla smaragdina, Oxya spp, Paracinema tricolor, Phymateus viridipes brunneri, Rhynchophorus phoenicis, Ruspolia differens, Schistocerca gregaria, Tenebrio molitor, Vespula spp, Zonocerus variegatus,*. The species selected for inclusion ranged from those harvested from the wild in farms and forested areas to those species that are commercially produced on an industrial scale. The scientific names were adopted, as opposed to common names, due to the universality of scientific names in identifying living organisms, and to reduce the confusion associated with the use of common names in scientific nomenclature (Peruzzi 2020).

3.2.2 Identification of primary studies and search strategy

To identify research articles with nutritional data on edible insects, a syntax was developed with agreed search terms which we applied to Google Scholar, PubMed, Scopus, and Web of Science databases:

(Species Name) AND (Edible Insects OR Food OR Feed OR Entomophagy) AND (Proximate Composition OR Proximate Analysis Data OR Proximate Data OR Proximate Composition Data OR Chemical Analysis OR Chemical Analysis Data OR Chemical Composition OR Proximate Composition OR Nutrient Composition) AND (Nutrition* OR Protein* OR Fat* OR Energy* OR Mineral* OR Vitamin* OR Carbohydrate*)

The search was intended to obtain original research articles, written in English, and thus excluded conference papers, book chapters, and editorial material.

3.2.3 Screening of the primary studies

A systematic review of published nutritional composition data of edible insects up to the year 2020 was conducted using guidelines by Kitchenham (2004), Higgins et al. (2020), and Popay et al. (2006). The European Food Information Resource (EuroFIR) guidelines were used to evaluate the quality of individual values for food components when extracting data from original published sources (Ifr et al., 2009). The guidelines provide a step by step procedure of how to assess the quality of data and to attribute quality index to data from scientific literature (Ifr et al., 2009). They are applied to original data on nutrient composition before this data is accumulated to compile nutrient composition tables. The guidelines ensure that certain standards are observed concerning the quality of included data namely; appropriate descriptions and identifications of foods, sampling plan, handling, and quality of analysis (Ifr et al., 2009). Mendeley Desktop (Version 1.19.2) reference manager was used to pool and manage all the primary studies obtained from the online databases. The studies were then screened for relevance (Kitchenham, 2004) and assessed for quality based on EuroFIR guidelines (Ifr et al., 2009) (**Figure 3.1**).

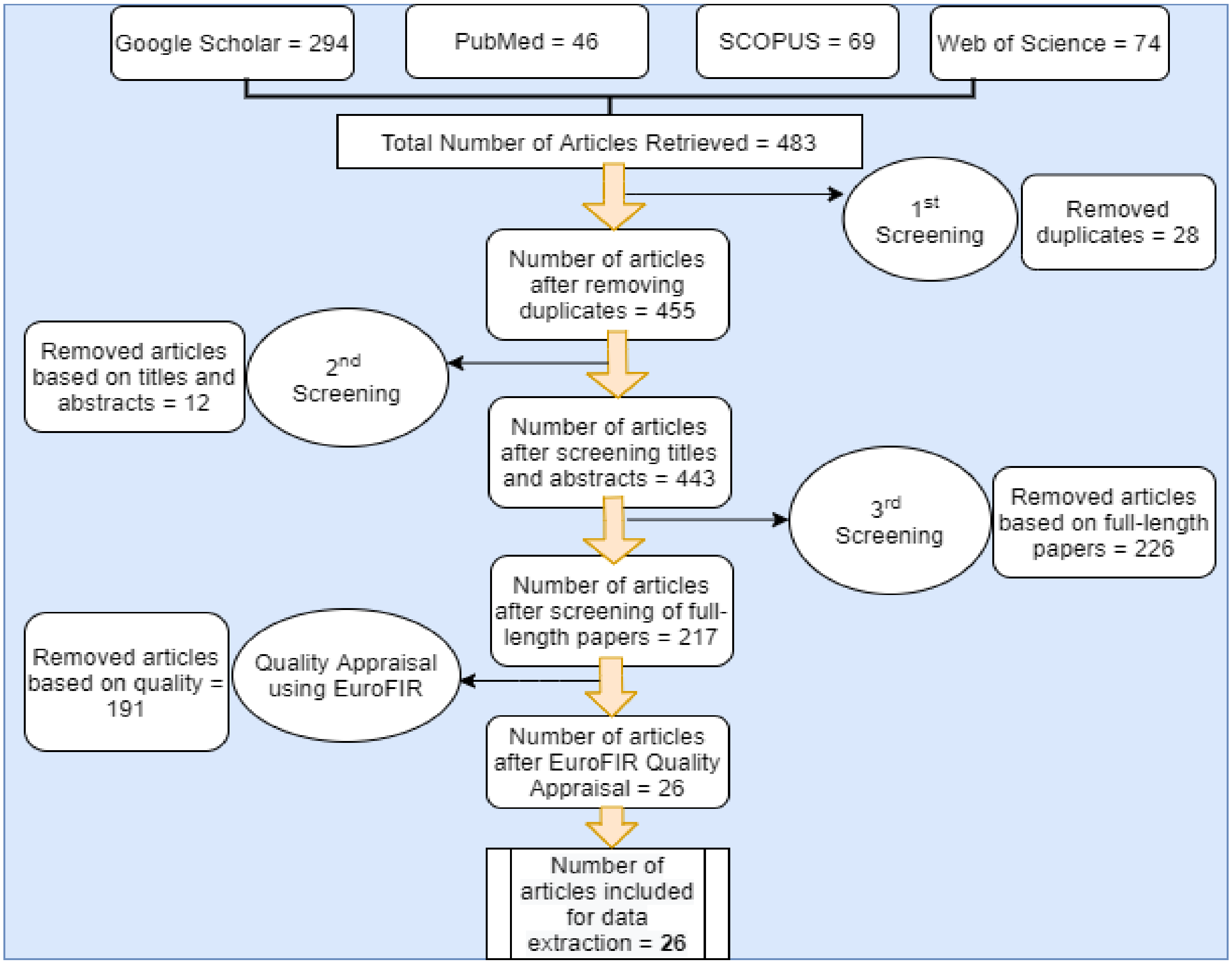

Figure 3. 1: Screening of primary articles for relevance and quality

To start, all the primary studies obtained from the search were grouped into folders based on the database they were recovered from. Then the screening process began by eliminating the double entries. The second screening process removed articles based on titles and abstracts. Those studies that did not focus on the study area and the ones having abstracts only, without full-length articles, were removed. Thirdly, full-length article screening was carried out to remove articles that did not have direct evidence of the study topic. The quality of the remaining articles was then assessed using EuroFIR guidelines (**Table 3.1**) (Payne et al. 2016; Ifr et al. 2009; Westenbrink et al., 2009). Articles that scored more than 17.5 points (50% of the total score) after the quality appraisal qualified to be included in the current review (Achimugu et al., 2014). Nutritional data of edible insects were then extracted from these articles and tabulated.

Table 3. 1: Categories for assessing the quality of published articles

Category	Summarized Criteria
Food Description	Are the food group (e.g., beverage), a food source (e.g., variety/cultivar), and part of the plant or animal provided? Is the analyzed portion clearly described? If relevant, are methods of treatment, processing, preservation, cooking, and packaging provided? Was moisture measured and recorded? Is the geographical origin of the food and season/month, if relevant, given?
Component Identification	Is the component described unequivocally? Is the unit unambiguous? Is the matrix unit unambiguous?
Sampling Plan	Is the sampling plan representative of the country where the study was done? Was the number of primary samples greater than 9? If relevant, were the samples taken from more than one geographical location? If relevant, were the samples taken during more than one season of the year?

	If relevant, were the samples taken from the most important sales outlets (e.g., local market, grocery store, etc.)? If relevant, was more than one subspecies sampled?
Number of Analytical Samples	Is the number of analytical samples 1, 2, 3, 4, or ≥5?
Sample Handling	If relevant, were appropriate treatments applied to stabilize the sample (e.g., protection from heat, microbial or enzymatic activity, air, etc.)? Were the samples homogenized?
Analytical Method	Is the analytical method used appropriate according to EuroFIR guidelines for analytical methods? Are the key steps appropriate for the method described? Were analytical portion replicates tested?
Analytical Quality Control	Was the laboratory used accredited for the method or was the method validated by performance testing? If available, was an appropriate reference material or a standard reference material used?

(Ifr et al., 2009)

3.2.4 Quality index scores of published articles

There were seven categories in the EuroFIR guidelines, each of which has a criterion for assessing the quality of the published articles (**Table 3.1**). Each article was evaluated for each category and awarded a Quality Score ranging from 1 to 5 (1 = low quality, 5 = high quality). The total score (Quality Index) was arrived at by multiplying the Quality Score by 7. Therefore, if an article was awarded 5 (high quality) for every category, the Total Quality Index would be 35 (5 × 7). A low-quality paper would have a Quality Index of 7 (1×7) (Ifr et al., 2009)

For each category criteria, the criterion was answered Yes, No, or Not Applicable (N/A) after assessing the level of information available in the article. If a criterion was evaluated and given YES, then the score was 5 while NO would get a score of 1. Criteria with N/A are not used for calculating the final score for the category. The number of criteria with YES are multiplied by 5 and then divided by the total number of criteria with Yes or No. Using ‘Sampling Plan’ as an example, if 3 criteria are Yes, 1 is NO, and 2 are N/A, the quality score is (3×5)/4 = 4, after rounding off to the nearest integer.

Each category, however, has its specific guidelines on the scoring system to ensure that an appropriate final score is arrived at. For instance, in the category ‘Component Identification’, all the criteria must get a YES for it to be high quality. If one of the criteria is NO, then this category scores 1 = low quality. And for ‘Number of Analytical Samples’, the scoring system is based on the number of analytical samples given, i.e., the score should be equal to the number of samples if between 1 to 4, and the score should be 5 if the number of samples is ≥5. If the number of analytical samples is not provided in the article, the score selected is 1. The specific details of the criteria used to assess each category can be found here (Ifr et al., 2009).

3.2.5 Criteria for data extraction from included articles

For each of the selected publications, important data were extracted and documented for systematic review in the current study. The data on the nutrient composition of edible insects was included if the following criteria were satisfied:

- The data source was in English or translatable into English
- The sample analyzed was unprocessed or minimally processed to allow for standard comparisons
- The insects are edible and data was from commonly consumed life stages for the species
- The original full-text publication was available
- Data were extracted independently by at least two researchers and results compared
- Nutrients composition was reported per 100g of edible portion (Peter Scarborough, Rayner, et al., 2007)

3.3 Results and Discussion

3.3.1 Quality scores of published articles

Table 3.2 provides the quality scores for the included studies. The Total Quality Index ranged from 21 to 28 (average = 23.54) out of a possible maximum of 35 scores. All the papers scored a maximum of 5 points under the component identification category. This is because food components were clearly described based on EuroFIR thesauri (Macháčková et al., 2017) and the unit and matrix unit were unambiguous. The lowest-scoring category was the ‘number of analytical samples’ with an average of 1.38 since most of the publications did not have more than one analytical sample. It is possible that analytical samples used in the studies were more than one, but the lack of expressly reporting it in the articles attracted a low score.

Table 3. 2: Quality index scores of the published articles included in the review

Article	Quality Index Category							
	Food Description	**Component Identification**	**Sampling Plan**	**No. of Analytical Samples**	**Sample Handling**	**Analytical Method**	**Analytical Quality Control**	**Total Quality Index***
Bosch et al. 2014	4	5	2	1	4	5	3	**25**
Oyarzun and Crawshaw 1996	4	5	2	1	2	5	4	**23**
Adámková et al. 2017	4	5	3	1	5	5	1	**24**
Zhenjun et al. 2013	4	5	2	1	4	5	3	**24**
Ramos-Elorduy et al. 1997	5	5	4	3	3	5	3	**28**
Zielińska et al. 2015	4	5	2	1	3	4	4	**23**
Ghosh et al. 2017	5	5	2	1	2	4	3	**22**
Bhattacharyya et al. 2018	5	5	3	1	5	1	1	**21**
Kim et al. 2016	5	5	2	1	2	3	1	**19**
Dauda et al. 2014	5	5	2	1	4	5	1	**23**
Assielou et al. 2015	4	5	2	1	2	5	3	**22**
Oranut et al. 2010	4	5	3	1	2	5	3	**23**
Kulma et al. 2020	4	5	3	1	5	5	1	**24**
Raksakantong et al. 2010	4	5	4	1	2	5	3	**24**
Kulma et al. 2019	4	5	3	3	5	5	1	**26**
Adeyeye and Olaleye 2016b	5	5	3	1	3	5	1	**23**
Musundire et al.2014	5	5	2	2	3	5	3	**25**
Kim et al. 2017	4	5	3	1	2	5	3	**23**
Longvah et al. 2011	4	5	2	1	1	5	3	**21**
Womeni et al. 2012	5	5	1	1	2	5	3	**22**

Article	Food Description	Component Identification	Sampling Plan	No. of Analytical Samples	Sample Handling	Analytical Method	Analytical Quality Control	Total Quality Index*
Afiukwa and Okereke 2013	5	5	2	1	1	5	2	**21**
Zhou and Han 2006	5	5	1	3	3	5	3	**25**
Omotoso and Adedire 2007	5	5	1	3	3	5	3	**25**
Ntukuyoh et al. 2012	5	5	2	1	3	5	2	**23**
Adeyeye and Olaleye 2016a	5	5	3	2	3	5	3	**26**
Kinyuru et al. 2013	5	5	4	1	5	5	2	**27**
Average	**4.54**	**5**	**2.42**	**1.38**	**3.04**	**4.69**	**2.42**	**23.54**

*Total Quality Index - Maximum was 35

The categories ‘sample handling’ and ‘analytical quality control’ had the same average score of 2.42. Samples were homogenized where appropriate, but sample replicates were mostly not tested and a few laboratories were not reported as ‘accredited’, and hence the low scores. The methods of analysis used were appropriate for most of the articles and hence the average score of 4.82 under the ‘analytical method’ category. A total of 91 species of edible insects were identified from the 26 published articles, with 135 data lines.

3.3.2 Energy and macronutrients

Table 3.3 shows data for energy, fat, protein, carbohydrates, ash, and fibre of edible insects on a dry weight basis. The mean value for energy was 458.62±85.66 kcal/100g with the lowest energy recorded being that of *Henicus whellani* (Ground Cricket) (268.3 kcal/100g) and the highest being that of *Phasus triangularis* (Butterfly) (762 kcal/100g). No single insect would provide the daily adult requirements for energy (2300–2900 (Males), 1900–2200 (Females) in 100g based on data reported here. It is worth noting that the energy levels of edible insects are high and only a small quantity is needed to meet the daily requirements for adults. The Butterfly (*P. triangularis*), which had the highest recorded value for energy at 762 kcal/100g, provides 26.27% and 34.64% of the maximum daily energy needs for males and females, respectively (National Research Council 1989; Medicine 2005; Food and Nutrition Board 2011). The variation in levels of energy reported could be attributed to species-specific differences in nutrient profiles. The diet fed to the insects could also contribute to the differences in quantities of energy. Owing to the low amounts of energy, edible insects are thus not energy-dense and hence they can provide a balance of nutrients in the diet without oversupplying energy.

The mean fat content was 23.72±16.08g/100g with the lowest value recorded being 2.1g/100g for winged termites - workers (*Macrotermes bellicosus*) and the highest being 77g/100g recorded for Butterfly (*P. triangularis*). The stage of development affects the amount of fat with the larval stages having more fat than adult stages (Kouřimská & Adámková, 2016). Sex also affects the nutrient content, where females tend to have more fat than protein compared to males (Kulma et al., 2019).

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Table 3. 3: Energy and proximate components of identified insect species, expressed in 100g edible portion

Scientific name	**Common name**	**Energy (Kcal)**	**Fat (g)**	**Protein (g)**	**CHO^1 (g)**	**Ash (g)**	**Fiber (g)**	**Source**
Scyphophorus acupunctatus	Agave weevil	555.00	52.90	36.80	13.00	1.60	-	Ramos-Elorduy et al. 1997
Blaptica dubia	Argentinean cockroach	-	24.50	64.40	-	4.40	-	Bosch et al. 2014
Apis mellifera	Bee brood	566.00	51.21	19.54	14.60	9.18	5.45	Adeyeye and Olaleye 2016a
Oileus rimator	Bess beetle	547.00	47.40	21.30	32.30	2.70	-	Ramos-Elorduy et al. 1997
Ascalapha odorata	Black witch moth	419.00	15.20	56.00	16.60	6.90	-	Ramos-Elorduy et al. 1997
Xylotrupes gideon (Linnaeus*)*	Brown rhinoceros beetle	375.5	4.08	80.98	5.66	0.81	8.45	Bhattacharyya et al. 2018
Hermetia illucens	BSF larvae	-	12.80	56.10	-	12.60	-	Bosch et al. 2014
Phasus triangularis	Butterfly	762.00	77.00	15.80	6.20	2.90	-	Ramos-Elorduy et al. 1997
Bunaea alcinoe	Cabbage tree emperor moth	365.00	11.42	46.57	23.33	6.23	12.42	Dauda et al. 2014
Oxya chinensis sinuosa	Chinese rice grasshopper	396.40	3.03	74.28	18.29	4.40	-	Kim et al. 2017
Meimuna opalifera Walker	Cicada	-	8.53	47.23	15.98	9.04	19.22	Raksakantong et al. 2010
Proarna hilaris	Cicadas	401.00	4.00	72.20	21.60	3.70	-	Ramos-Elorduy et al. 1997
Heliothis zea	Corn earworm	513.00	29.80	42.30	25.90	4.40	-	Ramos-Elorduy et al. 1997
Verlarifictorus asperses	Cricket	530.20	28.52	46.31	22.11	3.06	-	Kim et al. 2017
Blaberus craniifer	Death's head cockroach	499.30	23.15	65.80	-	2.65	-	Bosch et al.2014; Kulma et al. 2020

Scientific name	Common name	Energy (Kcal)	Fat (g)	Protein (g)	CHO^1 (g)	Ash (g)	Fiber (g)	Source
Schistocerca gregaria	Desert locust	429.50	15.04	69.05	9.82	3.97	2.20	Zielińska et al. 2015
Copris nevinsoni Waterhouse	Dung beetle	-	13.61	54.43	7.63	9.18	15.15	Raksakantong et al. 2010
Eisenia foetida	Earthworm	299.00	12.03	70.19	-	8.90	-	Zhenjun et al. 2013
Polyrhachis vicina Roger	Edible Chinese ant	-	9.00	56.60	-	6.20	-	Ntukuyoh et al. 2012
Taleogryllus emma	Emma field cricket	-	25.14	55.65	-	8.17	10.37	Ghosh et al. 2017
Samia ricinii	Eri silkworm (pupae)	459.00	27.41	60.09	3.92	4.61	3.97	Longvah et al. 2011
Apis mellifera	European honey bee (L&P)	475.00	21.50	50.60	25.40	4.60	-	Ramos-Elorduy et al. 1997
Apis mellifera	European honey bee (L)	475.00	19.80	42.40	36.40	3.30	-	Ramos-Elorduy et al. 1997
Apis mellifera	European honey bee (P)	476.00	20.60	49.10	27.60	4.00	-	Ramos-Elorduy et al. 1997
Gryllus bimaculatus	Field cricket	-	11.88	58.32	-	6.96	9.53	Ghosh et al. 2017
Gryllus assimilis	Field cricket nymph	-	32.00	56.00	-	-	-	Adámková et al. 2017
Callipogon barbatus	Flat-faced longhorn beetle	474.00	34.80	41.50	24.00	2.10	-	Ramos-Elorduy et al. 1997
Copestylum haggi & anna	Flower flies	460.00	31.20	37.10	24.20	8.80	-	Ramos-Elorduy et al. 1997
Arsenura armida	Giant silk moth	356.00	8.40	52.20	33.00	8.40	-	Ramos-Elorduy et al. 1997
Hylesia frigida	Giant silk moth	372.00	10.10	42.50	41.00	7.90	-	Ramos-Elorduy et al. 1997
Latebraria amphipyroides	Giant silk moth	293.00	7.00	57.30	30.60	6.10	-	Ramos-Elorduy et al. 1997

Scientific name	**Common name**	**Energy (Kcal)**	**Fat (g)**	**Protein (g)**	**CHO^1 (g)**	**Ash (g)**	**Fiber (g)**	**Source**
Catasticta teutila	Golden dartwhite butterfly	438.00	19.90	60.20	15.00	7.60	-	Ramos-Elorduy et al. 1997
Mischocyttarus basimacula	Golden paper wasp	-	-	75.00	-	-	-	Ramos-Elorduy et al. 1997
Protaetia brevitarsis seulensis	Grub (beetle larvae)	417.90	10.41	57.44	23.71	8.45	-	Kim et al. 2017
Polyrhachis vicina Roger	Guizhou black ant	-	15.20	-	-	-	-	Oranut et al., 2010
Carcinops pumilio	Hister beetles	410.00	18.10	54.00	23.70	7.60	-	Ramos-Elorduy et al. 1997
Myrmecosystus melliger	Honey ant	401.00	6.90	4.90	81.20	4.10	-	Ramos-Elorduy et al. 1997
Apis mellifera	Honey bee	-	5.90	16.86	67.44	6.09	3.91	Adeyeye and Olaleye 2016b
Acheta domesticus	House cricket	434.8	17.24	69.30	5.33	4.64	-	Bosch et al. 2014; Kulma et al. 2019
Musca domestica	Housefly pupae	-	19.20	62.50	-	5.60	-	Bosch et al. 2014
Allomyrina dichotoma	Japanese rhinoceros beetle	-	20.24	54.18	-	3.88	4.03	Ghosh et al. 2017
Holotrichia serrata	June beetle	-	5.41	51.74	11.20	12.34	19.31	Raksakantong et al. 2010
Atta cephalotes	Leaf-cutter ant	391.00	31.40	43.40	25.00	2.80	-	Ramos-Elorduy et al. 1997
Atta Mexicana	Leaf-cutter ant	555.00	39.00	46.00	11.80	4.30	-	Ramos-Elorduy et al. 1997
Acanthocephala declivis	Leaf-footed bugs	547.00	45.80	35.30	18.10	1.30	-	Ramos-Elorduy et al. 1997
Pachilis gigas	Leaf-footed bugs -adults	445.00	19.00	65.00	3.00	3.10	-	Ramos-Elorduy et al. 1997

Scientific name	**Common name**	**Energy (Kcal)**	**Fat (g)**	**Protein (g)**	**CHO^1 (g)**	**Ash (g)**	**Fiber (g)**	**Source**
Pachilis gigas	Leaf-footed bugs (nymphs)	498.00	26.40	63.00	7.90	4.10	-	Ramos-Elorduy et al. 1997
Alphitobius diaperinus	Lesser mealworm	-	22.20	64.80	-	4.10	-	Bosch et al. 2014
Melanoplus mexicanus	Lesser migratory grasshopper	377.00	7.80	71.10	20.30	2.00	-	Ramos-Elorduy et al. 1997
Tessaratoma papillosa	Longan stink bug	-	23.55	50.54	6.71	5.35	13.85	Raksakantong et al. 2010
Aplagiognathus spinosus	Long-horned beetle	508.00	36.80	26.20	34.90	3.50	-	Ramos-Elorduy et al. 1997
Sitophilus zeamais	Maize weevil	-	6.70	16.49	64.80	8.16	3.88	Adeyeye and Olaleye 2016b
Tenebrio molitor	Mealworm beetle	444.00	24.70	52.35	2.20	3.62	1.97	Zielińska et al. 2015
Tenebrio molitor	Mealworm larvae	-	31.93	52.72	-	5.38	6.37	Kim et al. 2016; Ghosh et al. 2017; Adámková et al. 2017
*Catharsius molossus (*Linnaeus*)*	Molossus dung beetle	375.19	4.71	80.08	5.40	2.43	7.35	Bhattacharyya et al. 2018
Imbrasia belina	Mopane worm	-	3.73	17.87	70.09	4.66	3.68	Adeyeye and Olaleye 2016b
Zophobas morio	Morio worm	549.48	36.20	47.03	-	1.85	-	Bosch et al. 2014; Kulma et al. 2020; Adámková et al. 2017
Tetragonula carbonaria	Native stingless bee	593.00	41.20	28.10	28.10	3.00	-	Ramos-Elorduy et al. 1997

Scientific name	**Common name**	**Energy (Kcal)**	**Fat (g)**	**Protein (g)**	**CHO^1 (g)**	**Ash (g)**	**Fiber (g)**	**Source**
Rhynchophorus phoenicis	Palm weevil (adult)	-	52.40	8.43	15.97	1.43	21.80	Omotoso and Adedire 2007
Rhynchophorus phoenicis	Palm weevil (ELS)	-	61.45	9.10	4.93	2.37	22.14	Omotoso and Adedire 2007
Rhynchophorus phoenicis	Palm weevil (LLS)	-	62.13	10.51	7.82	2.33	17.22	Omotoso and Adedire 2007
Rhynchophorus phoenicis	Palm weevil larvae	596.63	49.21	18.48	7.63	5.76	-	Womeni et al. 2012
Parachartegus apicalis	Paper wasp	-	62.40	43.05	5.20	2.11	-	Ramos-Elorduy et al. 1997
Hoplophorion monograma	Parakeet of the aguacate	394.00	14.20	64.90	9.10	3.70	-	Ramos-Elorduy et al. 1997
Passalus af. punctiger	Passalid beetle	552.00	44.80	26.30	27.81	3.30	-	Ramos-Elorduy et al. 1997
Oecophylla smaragdina Fabricius	Queen caste	-	36.87	37.46	14.43	2.98	8.26	Raksakantong et al. 2010
Xyleutes redtenbacheri	Red agave worm	614.00	48.30	43.10	7.30	2.50	-	Ramos-Elorduy et al. 1997
Oryctes owariensis	Rhinoceros beetle (larvae)	417.00	20.61	55.28	15.64	8.43	-	Assielou et al. 2015

Scientific name	Common name	Energy (Kcal)	Fat (g)	Protein (g)	CHO^1 (g)	Ash (g)	Fiber (g)	Source
Oecophylla smaragdina Fabricius	Queen caste	-	36.87	37.46	14.43	2.98	8.26	Raksakantong et al. 2010
Xyleutes redtenbacheri	Red agave worm	614.00	48.30	43.10	7.30	2.50	-	Ramos-Elorduy et al. 1997
Oryctes owariensis	Rhinoceros beetle (larvae)	417.00	20.61	55.28	15.64	8.43	-	Assielou et al. 2015
*Sophrops iridipennis (*Brenske*)*	Scarab beetle	361.50	4.86	72.03	9.64	5.10	8.35	Bhattacharyya et al. 2018
Oryctes boas	Scarab beetle larva	-	3.14	14.74	75.61	2.79	3.68	Adeyeye and Olaleye 2016b
Brachytrupes portentosus Lichtenstein	Short tailed cricket	-	20.60	48.69	9.74	9.36	11.61	Raksakantong et al. 2010
Sphenarium histrio	Short-horned grasshopper	363.00	4.80	77.40	16.44	2.00	-	Ramos-Elorduy et al. 1997
Sphenarium purpurascens	Short-horned grasshopper	385.33	9.37	67.43	21.20	3.44	-	Ramos-Elorduy et al. 1997
Bombyx mori	Silkworm	515.15	27.11	55.74	13.61	4.55	-	Ramos-Elorduy et al. 1997; Kim et al. 2017
Bombyx mori	Silkworm larva	422.00	27.06	22.89	35.40	9.35	5.23	Adeyeye and Olaleye 2016a
Antheraea pernyi	Silkworm pupae	-	21.75	77.80	-	4.32	-	Zhou and Han 2006
Bombyx mori	Silkworm pupae	443.00	30.82	35.95	19.81	7.43	6.21	Kim et al. 2016; Adeyeye and Olaleye 2016a

Scientific name	Common name	Energy (Kcal)	Fat (g)	Protein (g)	CHO^1 (g)	Ash (g)	Fiber (g)	Source
Eublaberus distanti	Six sport roach	-	25.10	66.30	-	3.60	-	Bosch et al. 2014
Aegiale hesperiaris	Skipper butterfly	593.00	30.00	40.70	26.00	3.00	-	Ramos-Elorduy et al. 1997
Vespula squamosa	Southern yellowjacket wasp	490.00	22.90	63.00	13.60	3.40	-	Ramos-Elorduy et al. 1997
Melipona beeckei	Stingless bee	569.00	41.20	29.20	27.00	3.90	-	Ramos-Elorduy et al. 1997
Edessa petersii	Stink bugs	576.00	48.30	35.65	14.90	1.60	-	Ramos-Elorduy et al. 1997
Euschistus egglestoni	Stink bugs/jumiles	548.00	45.80	35.60	20.10	1.10	-	Ramos-Elorduy et al. 1997
Pseudacanthotermes militaris	Sugarcane termite	-	46.59	33.51	8.73	4.58	6.59	Kinyuru et al. 2013
Lepidiota mansueta Burmeister	Sugarcane white grub	379.29	4.19	78.11	9.38	3.04	5.27	Bhattacharyya et al. 2018
Lepidiota albistigma Burmeister	Sugarcane white grub beetle	371.04	5.64	70.33	12.14	4.95	6.90	Bhattacharyya et al. 2018
Nasutitermes spp.	Termite	-	15.04	58.20	-	4.11	30.56	Oyarzun and Crawshaw 1996
Pseudacanthotermes spiniger	Termite	-	47.31	37.54	0.72	7.22	7.21	Kinyuru et al. 2013
Trinervitermes germinatus	Termite	395.50	26.57	26.49	33.50	5.64	8.39	Raksakantong et al. 2010; Afiukwa and Okereke 2013
Nasutitermes spp	Termite soldier	384.00	13.27	20.58	56.92	4.56	4.75	Adeyeye and Olaleye 2016a

Scientific name	**Common name**	**Energy (Kcal)**	**Fat (g)**	**Protein (g)**	**CHO[1] (g)**	**Ash (g)**	**Fiber (g)**	**Source**
Oecophylla smaragdina	Thai red ant	-	9.30	-	-	-	-	Oranut et al. 2010
Eucheria socialis	The madrone caterpillar	439.00	16.30	47.30	32.00	7.80	-	Ramos-Elorduy et al. 1997
Umbonia reclinata	Treehoppers	470.00	33.00	29.00	26.21	11.80	-	Ramos-Elorduy et al. 1997
Gryllodes sigillatus	Tropical house cricket	452.00	18.23	70.70	0.10	4.74	3.65	Zielińska et al. 2015
Brachygastra azteca	Wasp	481.00	22.50	63.40	12.90	3.90	-	Ramos-Elorduy et al. 1997
Brachygastra mellifica	Wasp	522.00	30.30	53.70	14.80	3.60	-	Ramos-Elorduy et al. 1997
Polybia accidentalis bohemani	Wasp	466.00	19.10	62.00	17.20	3.30	-	Ramos-Elorduy et al. 1997
Polybia accidentalis nigratella	Wasp	445.00	28.30	61.10	13.90	3.30	-	Ramos-Elorduy et al. 1997
Polybia parvulina	Wasp (adults)	467.50	17.10	62.35	17.05	5.19	-	Ramos-Elorduy et al. 1997
Polybia parvulina	Wasp (larvae)	-	-	81.10	-	-	-	Ramos-Elorduy et al. 1997
Corisella decolor	Water boatmen (adults)	347.00	9.70	58.80	15.20	18.90	-	Ramos-Elorduy et al. 1997
Corisella decolor	Water boatmen (eggs)	329.00	7.00	62.40	13.00	19.20	-	Ramos-Elorduy et al. 1997
Oecophylla smaragdina Fabricius	Weaver ant	-	12.13	32.13	11.50	5.03	15.38	Raksakantong et al. 2010
Polyrhachis vicina Roger	Wenzhou black ant	-	6.30	-	-	-	-	Oranut et al. 2010
Protaetia brevitarsis	White-spotted flower beetle	-	15.36	44.23	-	6.90	11.06	Ghosh et al. 2017

Scientific name	Common name	Energy (Kcal)	Fat (g)	Protein (g)	CHO[1] (g)	Ash (g)	Fiber (g)	Source
Macrotermes bellicosus	Winged termite	-	25.50	29.00	34.74	4.83	5.93	Kinyuru et al. 2013; Adeyeye and Olaleye 2016b
Macrotermes subylanus	Winged termite	-	44.82	39.34	1.89	7.58	6.37	Kinyuru et al. 2013
Macrotermes bellicosus	Winged termite (queen)	-	-	32.16	-	1.00	-	Ntukuyoh et al. 2012
Macrotermes bellicosus	Winged termite (soldiers)	389.75	2.71	55.57	35.78	4.10	2.00	Ntukuyoh et al. 2012
Macrotermes bellicosus	Winged termite (workers)	392.00	2.10	27.57	65.14	3.55	1.70	Ntukuyoh et al. 2012
Terebrio molitor	Yellow mealworm	568.40	35.50	50.90	9.60	3.70	-	Bosch et al. 2014; Kim et al. 2017
Median		**445**	**20.61**	**50.9**	**15.97**	**4.31**	**7.055**	
SD		*85.66*	*16.08*	*18.68*	*17.12*	*3.18*	*6.52*	
Range		*268.30 – 762.00*	*2.10 – 77.00*	*4.90 - 81.10*	*0.10 - 81.20*	*1.00 - 19.20*	*1.70 - 30.56*	
n		*72*	*108*	*108*	*88*	*105*	*41*	

[1] Column Abbreviations: CHO: Carbohydrates

Recommended Dietary Allowances (RDAs) for adults between 19 to 70 years: Energy (Kcal): 2300–2900 (M), 1900–2200 (F); Fat: 30–35%E; Protein: 56 (M), 46 (F); CHO: 130 (National Research Council 1989; Medicine 2005; Food and Nutrition Board 2011)
Adequate Intakes (AIs) for adults aged 19 to 50 years: Fiber: 38 (M), 25 (F) (Food and Nutrition Board, 2011)
M = Males; F = Females; %E = percent of Daily Energy Intake, representing the maximum total fat intakes for adults (WHO, 2003; Burlingame *et al.*, 2009).

Despite the bad vibes about fat, it has many nutritional and functional uses in the body. It provides, for instance, 9 Kcal of energy, raw materials for cell membranes and hormones, insulation of the body against variations in environmental temperature, cushion for body organs against mechanical shocks, and it assists in the absorption of fat-soluble vitamins (A, D, E, & K) from food (Pinheiro & Wilson, 2017). Fat is also used in frying food as a means of heat transfer, and the fat present in edible insects has been demonstrated to be useful in this regard, avoiding the addition of external cooking oil or fat, as reported by Kinyuru (2009) who stated that the insects "are fried lightly in their fat over low heat".

The protein content for the insects was quite high relative to other macronutrients. Despite having a recorded protein value of as low as 4.9g/100g for honey ant (*Myrmecosystus melliger*), the data indicates that insects are a good source of protein based on the Recommended Dietary Allowances (RDAs). Protein values were recorded for a total of 108 data lines, out of which 42 (38.88%) insects would provide the RDA for males (56g/day) and 65 (60.19%) insects would supply the RDA for females (46g/day). This data portrays insects as a valuable source of dietary protein.

The lowest recorded value for macronutrients was in carbohydrate content of 0.1g/100g recorded for tropical house cricket (*Gryllodes sigillatus*) and the highest value was also in carbohydrate at 81.2g/100g for honey ant (*M. melliger*). Ash values ranged from 1 – 19.2g/100g with a mean of 5.14±3.18g/100g. Fibre values varied from 1.7g/100g which was recorded for winged termites - workers (*M. bellicosus*) to 30.56g/100g for termite – (*Nasutitermes* spp.) with a mean of 9.06±6.52g/100g. Termites, which had the highest recorded value for fibre (30.56g/100g), would meet 80.42% and 122.24% of Adequate Intake (AI) for males and females, respectively. With proper selection of the insects, incorporation of the edible insects in diets can boost the fibre content of foods. Going by the sample numbers, fat and protein were the most studied macronutrients (n=108) while fibre was the least studied (n=41) in the selected publications

3.3.3 Minerals

Table 3.4 shows data for selected minerals of edible insects. The highest value for a specific mineral was recorded for potassium at 2515mg/100g for mopane worm (*Imbrasia belina*) and the least was copper at 0.0073mg/100g for silkworm pupae (*Antheraea pernyi*). The data for minerals was wide ranging across the edible insects reviewed. For instance, phosphorus values ranged from 2.74 to 1443mg/100g while magnesium varied from 1.54 to 1009.26mg/100g.

Table 3. 4: Mineral content (mg/100g) of identified insect species

Scientific name	Common name	Minerals[1]									Source
		Ca	P	Mg	K	Mn	Cu	Na	Fe	Zn	
Xylotrupes gideon (Linnaeus*)*	Brown rhinoceros beetle	29.30	-	-	53.68	5.60	14.99	31.47	22.73	15.86	Bhattacharyya et al. 2018
Bunaea alcinoe	Cabbage tree emperor moth	27.00	128.50	19.53	91.25	16.93	1.13	125.90	38.67	24.73	Dauda et al. 2014
Oxya chinensis sinuosa	Chinese Rice grasshopper	108.60	651.30	102.50	-	4.82	2.72	-	9.97	11.00	Kim et al. 2017
Verlarifictorus aspersus	Cricket	114.90	510.50	5.02	-	3.70	2.73	-	7.14	18.90	Kim et al. 2017
Taleogryllus emma	Emma field cricket	193.54	1085.40	152.48	895.50	5.86	2.19	278.23	10.75	18.47	Ghosh et al. 2017
Samia ricinii	Eri silkworm (pupae)	-	-	187.00	-	2.61	1.80	-	23.40	7.02	Longvah et al. 2011
Gryllus bimaculatus	Field cricket	240.17	1169.60	143.65	1079.9	10.36	4.55	452.99	9.66	22.43	Ghosh et al. 2017
Latebraria amphipyroides	Giant silk moth	19.50	864.00	-	-	-	-	-	-	-	Ramos-Elorduy et al. 1997
Protaetia brevitarsis seulensis	Grub (beetle larvae)	228.20	887.50	242.40	-	3.86	1.39	-	9.25	7.56	Kim et al. 2017
Apis mellifera	Honey Bee	18.00	618.00	56.80	198.00	1.08	0.18	369.00	11.20	30.00	Adeyeye and Olaleye 2016b
Allomyrina dichotoma	Japanese rhinoceros beetle	12.34	860.69	283.56	1249.10	8.64	1.43	148.38	14.26	10.26	Ghosh et al. 2017

Scientific name	Common name	Minerals[1]									Source
		Ca	P	Mg	K	Mn	Cu	Na	Fe	Zn	
Sitophilus zeamais	Maize Weevil	17.60	1198.00	105.00	710.00	4.25	0.177	140.00	22.50	45.20	Adeyeye and Olaleye 2016b
Tenebrio molitor	Mealworm larvae	78.42	1039.20	315.23	737.00	1.50	2.00	108.82	10.02	11.74	Ghosh et al. 2017
*Catharsius molossus (*Linnaeus*)*	*Molossus dung beetle*	23.33	-	-	58.06	19.66	15.93	35.91	37.05	15.64	Bhattacharyya et al. 2018
Imbrasia belina	Mopane Worm	-	-	61.20	2515.00	2.35	0.097	370.00	12.70	34.60	Adeyeye and Olaleye 2016b
Rhynchophorus phoenicis	Palm Weevil (ELS)	0.28	4.89	60.96	455.00	0.49	-	17.00	6.50	0.47	Omotoso and Adedire 2007
Rhynchophorus phoenicis	Palm Weevil (Adult)	2.63	4.71	53.31	372.50	0.50	-	13.67	22.90	0.56	Omotoso and Adedire 2007
Rhynchophorus phoenicis	Palm Weevil (LLS)	0.27	6.52	43.52	457.50	0.30	-	15.67	6.00	0.31	Omotoso and Adedire 2007
Rhynchophorus phoenicis	Palm Weevil Larvae	36.10	-	-	-	-	-	147.00	11.80	4.63	Womeni et al. 2012
Xyleutes redtenbacheri	Red agave worm	71.20	570.00	-	-	-	-	-	-	-	Ramos-Elorduy et al. 1997
Oryctes owariensis	Rhinoceros Beetle (larvae)	54.51	142.17	369.75	1610.00	7.88	0.91	102.25	20.26	7.89	Assielou et al. 2015
*Sophrops iridipennis (*Brenske*)*	Scarab beetle	33.37	-	-	64.32	2.63	16.13	23.16	19.86	15.38	Bhattacharyya et al. 2018

Scientific name	Common name	Minerals[1]									Source
		Ca	P	Mg	K	Mn	Cu	Na	Fe	Zn	
Oryctes boas	Scarab Beetle Larva	9.39	1443.00	17.40	782.00	2.94	0.196	273.00	13.70	15.30	Adeyeye and Olaleye 2016b
Bombyx mori	Silkworm	95.70	870.90	252.30	-	1.68	0.94	-	4.95	14.70	Kim et al. 2017
Antheraea pernyi	Silkworm pupae	0.63	2.72	1.54	34.00	-	0.0073	2.81	0.04	0.036	Zhou and Han 2006
Pseudacanthotermes militaris	Sugarcane termite	48.31	-	-	-	-	-	-	60.29	12.86	Kinyuru et al. 2013
Lepidiota mansueta Burmeister	Sugarcane white grub	33.33	-	-	14.20	1.30	6.52	27.76	1.64	15.55	Bhattacharyya et al. 2018
Lepidiota albistigma Burmeister	Sugarcane white grub beetle	29.94	-	-	144.33	1.09	2.01	29.57	1.41	2.38	Bhattacharyya et al. 2018
Nasutitermes spp.	Termite	26.00	38.00	14.00	54.00	5.70	3.80	17.00	65.20	16.30	Oyarzun and Crawshaw 1996
Pseudacanthotermes spiniger	Termite	42.89	-	-	-	-	-	-	64.77	7.10	Kinyuru et al. 2013
Trinervitermes germinatus	Termite	410.41	-	1009.26	-	-	0.11	53.70	62.12	1.77	Raksakantong et al. 2010; Afiukwa and Okereke 2013
Oecophylla smaragdina Fabricius	Weaver Ant	35.50	-	-	-	-	-	71.50	81.50	4.90	Raksakantong et al. 2010
Protaetia brevitarsis	White-spotted flower beetle	258.56	1140.40	327.60	2001.40	5.89	1.82	211.60	16.20	11.89	Ghosh et al. 2017

Scientific name	Common name	Minerals[1]									Source
		Ca	**P**	**Mg**	**K**	**Mn**	**Cu**	**Na**	**Fe**	**Zn**	
Macrotermes bellicosus	Winged termite	43.20	710.00	54.90	209.00	2.35	-	402.00	62.73	19.03	Kinyuru et al. 2013; Adeyeye and Olaleye 2016b
Macrotermes subylanus	Winged termite	58.72	-	-	-	-	-	-	53.33	8.10	Kinyuru et al. 2013
Macrotermes bellicosus	winged termite (queen)	54.64	-	47.85	-	21.70	18.27	69.10	39.33	25.21	Ntukuyoh et al. 2012
Macrotermes bellicosus	winged termite (soldiers)	20.26	-	16.40	-	1.34	4.09	39.40	22.71	8.35	Ntukuyoh et al. 2012
Macrotermes bellicosus	winged termite (workers)	58.30	-	43.02	-	22.44	18.82	67.92	54.27	21.21	Ntukuyoh et al. 2012
Terebrio molitor	Yellow Mealworm	39.40	567.70	137.60	-	0.70	11.40	-	62.80	98.70	Kim et al. 2017
Median		**36.1**	**651.3**	**61.2**	**413.75**	**3.32**	**2.005**	**70.3**	**19.86**	**12.86**	
SD		*88.08*	*456.02*	*203.63*	*695.34*	*6.36*	*6.36*	*134.43*	*23.05*	*17.18*	
Range		*0.27-410.41*	*2.72-1443.00*	*1.54-1009.26*	*34.00-2515.00*	*0.30-22.44*	*0.0073-18.82*	*2.81-452.99*	*0.04-81.50*	*0.036-98.70*	
n		*37*	*23*	*27*	*22*	*30*	*30*	*28*	*37*	*37*	

[1] Column Abbreviations: Ca: Calcium; P: Phosphorus; Mg: Magnesium; K: Potassium; Mn: Manganese; Cu: Copper; Na: Sodium; Fe: Iron; Zn: Zinc

Recommended Dietary Allowances (RDAs) for adults aged 19 – 70 years: Ca: 1000; P: 700; Mg: 415 (M[2]), 315 (F[2]); Mn: 2.3 (M), 1.8 (F); Cu: 0.9; Fe: 8 (M), 18 (F); Zn: 11 (M); 8 (F) (Food and Nutrition Board, 2011)

Adequate Intakes (AIs) for adults aged between 19 to 70 years: K: 4700; Na: 1500 (Food and Nutrition Board, 2011)

The wide ranges in mineral content reported could be associated with source of the insects, whether wild or farmed. Insects that are reared domestically are fed on diets with specific nutrient contents relative to those harvested in the wild. It is possible to manipulate the mineral content of the insects using their feed (Nadeau et al., 2014).

Despite some very low values of the recorded minerals, the mean values are indicative that insects are a suitable source of minerals, in respect of RDAs and AIs. The lowest recorded value for calcium was 0.27mg/100g in palm weevil (*Rhynchophorus phoenicis*) – late larval stage, which is a meagre 0.027% of the RDA. The highest value for calcium which was recorded for termite (*Trinervitermes germinates)* would meet 41.04% of the RDA. The highest value of magnesium of 1009.26mg/100g recorded for winged termites (*Trinervitermes germinatus*), provides 243.19% and 320.4% of RDA for males and females, respectively. But the lowest value (1.54mg/100g), recorded for silkworm pupae (*A. pernyi*), provides a paltry 0.37% and 0.49% of RDA for males and females, respectively. The lowest and the highest amounts of potassium (34, 2515mg/100g) recorded were for silkworm pupae (*A. pernyi*) and mopane worm (*I. belina*) representing 0.72% and 53.51% of AI, respectively. The RDA for Manganese for males and females can be met by 66.67% of the edible insects reported.

Copper has the lowest RDA among the minerals reported. From the data set, RDA for copper is met at a meagre 0.81% from the lowest recorded value of 0.0073mg for silkworm pupae (*A. pernyi*) while the highest value of 18.82mg for winged termite (*Macrotermes bellicosus)* – workers, oversupplies the RDA at a whopping 2091.11%.

Sodium data shows relatively low amounts with the highest amount recorded being 452.99mg/100g for field cricket (*Gryllus bimaculatus*) and only providing 30.19% of AI. There is no clear benefit of consuming sodium in large amounts and it has actually been associated with cardiovascular events (National Research Council 1989). Sodium is considered a nutrient to limit (LIM) in addition to fat (more so saturated fat), cholesterol, total sugars and energy (Rayner et al., 2005; Drewnowski and Fulgoni 2008). The current data for sodium suggests that insects are safe at the reported quantities of 100g in which the highest recorded value contributed only 30.19% of AI. Edible insects are therefore suitable for use in low-sodium diets (Rumpold and Schlüter 2013).

Iron amounts ranged from 0.04mg/100g for silkworm pupae (*A. pernyi*) to 81.5mg/100g for weaver ant (*Oecophylla smaragdina* Fabricius) representing 0.5% and 0.22% of RDA for the lower value, and 1018.75% and 452.78% of RDA for the higher value for males and females, respectively. Overall, 81.08% of the insects reported provides the RDA of iron for males, while 51.35% provides the RDA of iron for females. The reported values for zinc ranged from 0.036mg/100g for Silkworm pupae (*A. pernyi*) to 98.7mg/100g for yellow mealworm (*Terebrio molitor*). From the zinc data, 59.46% and 67.57% of the reported insects would provide the RDA of zinc for males and females, respectively. Overall, silkworm pupae (*A. pernyi*) had the lowest recorded values for most (77.78%) of the minerals reported.

Iron and zinc are involved in tissue synthesis together with other nutrients like protein and vitamin C and therefore help reduce incidences of degenerative diseases (MoH, 2010). Iron deficiency is a big problem in both developed and developing nations. To cite a few examples, epidemiological studies have reported prevalence of anaemia as follows in developing countries: 39% in children below 5 years, 48% in children aged 5 to 14 years, 42% in all women, and 52% in pregnant women with half of these cases being iron deficiency anaemia. In the UK, iron deficiency in female teenagers aged 11 to 18 years was 21% while in women aged 16 - 64 years it was 18%, whereas in USA data showed 9 – 11% of non-pregnant women of age 16 – 49 years were anaemic of which 2 – 5% was iron deficiency anaemia (Zimmermann & Hurrell, 2007). In a study in Africa, iron deficiency was reported to range from 21.7% to 41.9%, affecting about 35% of children in Kenya, Uganda and Burkina Faso. The prevalence of anaemia was reported as follows; Burkina Faso: 87.0%, Kenya: 70.0%, The Gambia: 60.1%, and Uganda: 49.7% (Muriuki et al., 2020).

The current data indicate adequate amounts of iron and zinc are present in edible insects, with most (>50%) of them meeting the RDAs for males and females. With this attendant prevalence and considering the iron amounts recorded in this review, it would not be too far-fetched to suggest that edible insects would be invaluable in combating deficiencies in zinc and iron, and iron deficiency anaemia.

Magnesium is an important element in the body and it is involved in many functions including protein synthesis, blood glucose control, regulation of blood pressure, signal transduction, muscle and nerve transmission, neuromuscular conduction, and in DNA and RNA synthesis among many other roles (Gröber et al. 2015). The high amounts of magnesium recorded in this review therefore suggests that insects are a reliable source of this important mineral element. However, selection of edible insects is key to meeting the daily requirements for the micronutrients since some are very poor sources of minerals like is the case with silkworm pupae (*A. pernyi)*.

3.3.4 Vitamins

Table 3.5 provides data for vitamins that were reported in the selected publications. Only four vitamins were reported for five species of edible insects. The data depicts very minute quantities of vitamins with data having narrow ranges. Vitamin E had the highest reported value of 0.925mg/100g for termite (*Nasutitermes* spp.), representing a meagre 0.62% of RDA, while the lowest reported value was for vitamin C at 0.0046mg/100g for termite soldiers (*Macrotermes bellicosus)* which would meet a paltry 0.00051% of RDA for males and 0.00066% of RDA for females. The diet eaten by insects, e.g. food wastes, commercial feeds, etc. can affect the quantities of vitamins in edible insects (Baiano, 2020). None of the reported insects would meet the daily requirements for vitamins. The data was very scanty with vitamin A having the greatest number of reported values (n=4) and vitamin E having the least (n=1). In this review, edible insects are not depicted as a suitable source of vitamins. Most studies seem to be biased towards assessing macronutrients and minerals while ignoring vitamins. It is not clear why this is the case. The paucity of data on vitamins in edible insects has also been reported elsewhere (Halloran et al. 2018; Rumpold and Schlüter 2013). There should be more effort to include vitamins in analysis nutritional value of edible insects to fill this data gap.

Table 3. 5: Vitamin content (mg/100g) of identified insect species

Scientific Name	**Common Name**	**Vitamins**				**Source**
		Vit A	**Vit C**	**Vit B2**	**Vit E**	
Rhynchophorus phoenicis	Palm Weevil Larvae	-	-	0.2210	-	Womeni et al. 2012
Nasutitermes spp.	Termite	0.0742	-	-	0.925	Oyarzun and Crawshaw, 1996
Trinervitermes germinatus	Termite	-	-	0.1830	-	Raksakantong et al. 2010; Afiukwa and Okereke 2013
Oecophylla smaragdina Fabricius	Weaver Ant	-	-	0.0675	-	Raksakantong et al. 2010
Macrotermes bellicosus	Winged termite (queen)	0.0700	0.0063	-	-	Ntukuyoh et al. 2012
Macrotermes bellicosus	Winged termite (soldiers)	0.0250	0.0046	-	-	Ntukuyoh et al. 2012
Macrotermes bellicosus	Winged termite (workers)	0.0170	0.0113	-	-	Ntukuyoh et al. 2012
Median		**0.0475**	**0.0063**	**0.183**		
SD		*0.0290*	*0.0030*	*0.0790*	-	
Range		*0.0170 – 0.0742*	*0.0046 – 0.0113*	*0.0675 – 0.2210*	-	
n		*4*	*3*	*3*	*1*	

Recommended Dietary Allowances (RDAs) for adults aged 19 – 70 years: Vit A: 900(M), 700(F); Vit C: 90(M), 75(F); Vit B2: 1.29(M), 1.1(F); Vit E: 15 (Food and Nutrition Board, 2011)

3.3.5 Essential amino acids

Amino acids are needed for protein metabolic balance in the body, and essential amino acids must be obtained from diet since the body cannot synthesize them (WHO 2007). The quality of protein in terms of its essential amino acid composition, among other factors like digestibility, has been associated with commonness of stunting in children, especially in Africa, where staple foods consist mostly of maize and cassava in which there is deficiency of these essential amino acids (Shibani et al. 2013).

Table 3.6 shows data for essential amino acids in selected edible insects. The data reported was wide ranging. In reference to Estimated Adult Requirements (EAR), the data set for amino acids depicts low to moderate values. The mean values are also low relative to EAR. The highest mean was 10.05±9.1mg/g of protein (phenylalanine+tyrosine) which is 33.5% of EAR while the lowest mean was 3.85±3.42mg/g (methionine+cysteine) providing only 17.5% of EAR. The lowest reported value was 1.19mg/g (methionine+cysteine) for Chinese edible ant (*Polyrhachis vicina* Roger) which is 5.41% of EAR, while the highest recorded value was 96.02 mg/g (leucine) for palm weevil larvae (*Rhynchophorus phoenicis*) providing 162.75% of EAR. Amino acid data for palm weevil larvae (*R. phoenicis*) is strikingly unique in that it meets the EAR for all the reported amino acids except valine. Silkworm pupae (*Antheraea pernyi*) meets the EAR for histidine at 196%. In this study, only one insect - Chinese edible ant (*P. vicina* Roger) - had data obtained for tryptophan. It is clear that the stage of development of the insect has an influence on the amount of amino acids present (Kulma et al., 2020). The growth stage is therefore an important factor in choosing edible insects to meet various human nutritional needs.

It is notable here that insects contain essential amino acids in varied quantities with palm weevil larvae (*R. phoenicis*) providing more than the EAR for most of the essential amino acids. But, as stated earlier, there was no data for tryptophan, except for Chinese edible ant (*P. vicina* Roger), in the articles that were reviewed in this study. This is the same essential amino acid that is deficient together with lysine in maize, the staple in most African nations (Semba, 2016). Therefore, tryptophan seems to be a limiting amino acid in edible insects. But the absence of tryptophan in the studies reviewed could be associated with the method of analysis used, in which case tryptophan was hydrolysed by acid and therefore rendered unavailable (Kulma et al. 2020, 2019).

New methods of analysis of tryptophan need to be explored to avoid loss, e.g., chromatography (Sadok et al., 2017)

Table 3. 6: Essential amino acids (mg/g) of identified insect species

Scientific name	**Common name**	**Amino Acids[1]**									**Source**
		Ile	**Leu**	**Lys**	**Met+Cys**	**Phe+Tyr**	**Thr**	**Val**	**Hist**	**Trp**	
Scyphophorus acupunctatus	Agave weevil	4.80	7.80	5.50	4.20	11.00	4.00	6.20	1.50	-	Ramos-Elorduy et al. 1997
Blaptica dubia	Argentinean Cockroach	3.20	5.30	40	1.30	2.70	3.10	5.40	4.50	-	Bosch et al. 2014
Ascalapha odorata	Black witch moth	4.10	6.90	6.30	4.40	13.90	4.00	4.80	2.80	-	Ramos-Elorduy et al. 1997
Hermetia illucens	BSF Larvae	4.00	6.10	5.40	1.40	3.10	3.60	5.50	4.40	-	Bosch *et al*., 2014
Phasus triangularis	Butterfly	4.60	8.00	5.70	3.50	16.70	3.80	5.70	2.50	-	Ramos-Elorduy et al. 1997
Blaberus craniifer	Death's Head cockroach	3.70	5.90	4.70	1.20	2.70	3.30	6.10	4.60	-	Bosch et al. 2014
Polyrhachis vicina Roger	Edible Chinese Ant	-	3.92	2.20	1.19	1.76	2.26	3.43	3.39	1.12	Ntukuyoh et al. 2012
Taleogryllus emma	Emma field cricket	2.15	3.96	2.61	3.81	4.40	1.92	2.92	2.41	-	Ramos-Elorduy et al. 1997
Gryllus bimaculatus	Field cricket	2.16	3.97	2.42	5.37	4.56	2.00	3.20	2.50	-	Ghosh et al. 2017
Callipogon barbatus	Flat-faced longhorn beetle	5.80	10.00	5.70	4.00	4.90	4.00	7.00	2.20	-	Ramos-Elorduy et al. 1997
Copestylum haggi & anna	Flower flies	4.00	7.40	5.50	3.70	12.00	4.90	6.10	2.90	-	Ramos-Elorduy et al. 1997
Arsenura armida	Giant silk moth	4.30	6.90	5.40	4.30	14.50	4.20	4.80	2.90	-	Ramos-Elorduy et al. 1997
Hylesia frigida	Giant silk moth	4.40	7.10	5.70	8.00	11.60	4.10	4.90	2.00	-	Ramos-Elorduy et al. 1997
Acheta domesticus	House Cricket	4.00	6.60	5.80	1.60	3.20	3.60	5.70	3.40	-	Bosch et al. 2014
Musca domestica	housefly pupae	4.00	6.10	6.20	2.60	5.20	3.80	5.00	4.80	-	Bosch et al. 2014
Allomyrina dichotoma	Japanese rhinoceros beetle	2.21	3.21	2.42	4.35	5.52	1.87	2.72	2.35	-	Ghosh et al. 2017
Atta mexicana	Leaf-cutter ant	5.30	8.00	4.90	4.90	13.50	4.30	6.40	2.50	-	Ramos-Elorduy et al. 1997

Scientific name	Common name	Amino Acids[1]									Source
		Ile	Leu	Lys	Met+Cys	Phe+Tyr	Thr	Val	Hist	Trp	
Pachilis gigas	Leaf-footed bugs (Nymphs)	4.20	6.90	4.50	6.00	20.20	3.60	6.20	2.00	-	Ramos-Elorduy et al. 1997
Alphitobius diaperinus	Lesser Mealworm	4.60	6.70	6.50	1.30	3.90	4.00	5.90	4.90	-	Bosch et al. 2014
Tenebrio molitor	Mealworm larvae	1.98	3.37	2.01	3.16	5.21	1.83	2.94	2.80	-	Kim et al. 2016;
Zophobas morio	Morio Worm	5.00	7.20	5.30	1.60	3.70	4.10	6.50	4.80	-	Bosch et al. 2014
Tetragonula carbonaria	Native Stingless bee	4.80	7.30	7.30	3.60	13.90	4.80	5.30	2.20	-	Ramos-Elorduy et al. 1997
Rhynchophorus phoenicis	Palm Weevil Larvae	67.33	96.02	54.84	22.97	56.74	23.91	27.64	24.00	-	Womeni et al. 2012
Parachartegus apicalis	Paper wasp	5.30	9.30	5.05	4.10	11.10	4.80	6.20	2.55	-	Ramos-Elorduy et al. 1997
Hoplophorion monograma	Parakeet of the aguacate	4.10	7.70	5.30	4.00	13.70	4.50	7.40	1.50	-	Ramos-Elorduy et al. 1997
Xyleutes redtenbacheri	Red agave worm	5.10	7.90	4.90	3.40	14.60	4.70	6.10	1.60	-	Ramos-Elorduy et al. 1997
Sphenarium histrio	Short-horned Grasshopper	5.30	8.70	5.70	3.30	19.00	4.00	5.10	1.90	-	Ramos-Elorduy et al. 1997
Antheraea pernyi	Silkworm pupae	7.95	3.24	4.54	2.97	10.16	4.64	6.63	29.40	-	Zhou and Han 2006
Eublaberus distanti	Six Sport Roach	3.40	5.40	4.30	1.30	2.60	3.10	5.60	4.30	-	Bosch et al. 2014
Vespula squamosa	Southern yellowjacket wasp	4.90	6.30	5.10	4.50	11.20	4.40	5.70	3.00	-	Ramos-Elorduy et al. 1997
Edessa petersii	Stink bugs	4.00	7.10	4.00	3.70	18.20	4.50	6.40	2.30	-	Ramos-Elorduy et al. 1997
Euschistus egglestoni	Stink bugs/Jumiles	4.40	7.00	3.00	3.80	8.10	4.80	6.10	3.20	-	Ramos-Elorduy et al. 1997

Scientific name	**Common name**	**Amino Acids[1]**									**Source**
		Ile	**Leu**	**Lys**	**Met+Cys**	**Phe+Tyr**	**Thr**	**Val**	**Hist**	**Trp**	
Nasutitermes spp.	Termite	1.69	3.21	2.82	0.65	1.92	1.67	2.26	1.28	-	Oyarzun and Crawshaw 1996
Umbonia reclinata	Treehoppers	3.80	6.80	5.70	3.30	12.70	4.70	4.00	3.70	-	Ramos-Elorduy et al. 1997
Brachygastra azteca	Wasp	5.10	8.50	6.10	3.00	10.60	4.40	6.40	2.80	-	Ramos-Elorduy et al. 1997
Brachygastra mellifica	Wasp	4.40	7.80	3.60	3.80	11.50	4.40	5.40	3.60	-	Ramos-Elorduy et al. 1997
Polybia accidentalis bohemani	Wasp	4.50	7.80	7.40	5.00	8.90	4.00	5.90	3.00	-	Ramos-Elorduy et al. 1997
Polybia parvulina	Wasp (adults)	4.70	7.80	7.30	5.30	9.30	4.10	6.10	3.40	-	Ramos-Elorduy et al. 1997
Protaetia brevitarsis	White-spotted flower beetle	2.62	2.31	1.75	2.94	4.92	1.55	2.49	1.82	-	Ghosh et al. 2017
Terebrio molitor	Yellow Mealworm	4.60	7.30	5.50	1.40	3.40	4.00	6.30	5.10	-	Bosch et al. 2014;
Median		**4.4**	**6.95**	**5.35**	**3.65**	**9.73**	**4**	**5.7**	**2.85**		
SD		*10.05*	*41.10*	*7.95*	*3.42*	*9.10*	*3.29*	*3.73*	*5.31*	-	
Range		*1.69 – 67.33*	*2.13 – 96.02*	*1.75 – 54.84*	*0.65 – 22.97*	*1.76 – 56.74*	*1.55– 23.91*	*2.20– 27.64*	*1.28 – 29.40*	-	
n		*39*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*1*	

[1] Column Abbreviations: Ile: Isoleucine; Leu: Leucine; Lys: Lysine; Met+Cys: Methionine and Cysteine combined; Phe+Tyr: Phenylalanine and Tyrosine combined; Thr: Threonine; Val: Valine; Hist: Histidine; Trp: Tryptophan

EAR, based on protein requirements of 0.66g/kg body weight per day: Ile: 30; Leu: 59; Lys: 45; Met+Cys: 22; Phe+Tyr: 30; Thr: 23; Val: 39; Hist: 15; Trp: 6 (WHO, 2007)

3.3.6 Fatty acids

Fatty acids play various important roles in the body including biological, functional, and structural roles (Tiuca and Nagy 2016). The human body can synthesize most of the fatty acids except some essential PUFAs like the omega-6 linoleic acid (LA) and the omega-3 α-linolenic acid (ALA) (Tiuca and Nagy 2016). **Table 3.7** depicts the various amounts of fatty acids for edible insects that were reported in the selected publications.

The amounts of fatty acids reported were wide ranging. The highest recorded value for polyunsaturated fatty acid was 1514.32mg/100g for dung beetle (*Copris nevinson*i Waterhouse). The highest mean was 257.99±418.69mg/100g for polyunsaturated fatty acid (PUFA) and the lowest mean was 4.13±9.02mg/100g for α-linolenic acid (ALA). Saturated fatty acid (SFA) was the most studied based on the number of insects reported (n=26) while EPA+DHA had the lowest number (n=7) of insects studied in the selected publications. The high amounts of SFA in some insects reported here e.g., *Copris nevinsoni* (dung beetle) and *Oecophylla smaragdina* Fabricius (queen caste) (SFA = 733.46 mg/100g and 576.96 mg/100g, respectively) agrees with other studies indicating that some species of edible insects contain elevated amounts of SFA (Bessa et al. 2020). However, fatty acid profiles of edible insects generally contain more PUFAs relative to SFAs (T.-K. Kim et al., 2019). But the composition of the fatty acids can be changed using the feed/diet given to (or eaten by) the insects and therefore the fatty acid profiles can be manipulated to reduce the SFA using diet (Roos & van Huis, 2017).

In the present review study, the amounts of essential fatty acids were very low relative to AIs per day. But a closer look at other studies shows that edible insects' fatty acid profiles, when compared to poultry and fish, contain more of the desirable mono and polyunsaturated fatty acids including linoleic (omega 6) and alpha linolenic (omega 3) acids (Roos and van Huis 2017; Bessa et al. 2020). These essential fatty acids are important in cardiovascular protection and shielding the body against cancer, in addition to acting as precursors for synthesis of EPA and DHA. EPA and DHA are important in brain function, maintenance of cell membrane, and in transmission of nerve impulses (Jantzen da Silva Lucas et al., 2020). Data on EPA and DHA were scanty in this study which concurs with another study which averred that EPA and DHA are seldom detected in edible insects (Roos & van Huis, 2017). No single insect would meet the daily requirements for any of the essential fatty acids at 100g in the present study. But since insects are ordinarily consumed with other diets, it would be expected that they would contribute their essential fatty acids to the diet.

Table 3. 7: Fatty acids (mg/100g) of edible insect

Scientific Name	Common Name	Fatty Acids[1]							Source
		SFA	MUFA	PUFA	LA (18:2)	ALA (18:3)	AA (20:4)	EPA+DHA	
Bunaea alcinoe	Cabbage tree emperor moth	33.66	-	19.51	4.25	3.35	-	-	Dauda et al. 2014
Meimuna opalifera Walker	Cicada	279.50	5.67	213.15	-	-	16.137	-	Raksakantong et al. 2010
Schistocerca gregaria	Desert Locust	25.30	39.35	26.28	14.04	11.35	-	-	Zielińska et al. 2015
Copris nevinsoni Waterhouse	Dung Beetle	733.46	85.65	1514.32	-	39.82	934.95	300.55	Raksakantong et al. 2010
Taleogryllus emma	Emma field cricket	36.10	80.20	101.50	96.10	2.20	2.70	-	Ghosh et al. 2017
Gryllus bimaculatus	Field cricket	32.50	31.30	43.30	41.50	0.80	0.10	-	Ghosh et al. 2017
Polyrhachis vicina Roger	Guizhou black ant	23.90	72.40	3.70	2.10	1.00	0.20	0.10	Oranut et al. 2010
Allomyrina dichotoma	Japanese rhinoceros beetle	69.30	93.00	8.10	6.90	0.10	0.80	0.10	Raksakantong et al. 2010
Holotrichia serrata	June Beetle	235.37	49.44	516.73	-	-	378.83	26.15	Raksakantong et al. 2010
Tessaratoma papillosa	Longan Stink Bug	338.92	59.56	420.84	-	-	382.47	-	Raksakantong et al. 2010

Scientific Name	**Common Name**	**Fatty Acids[1]**							**Source**
		SFA	**MUFA**	**PUFA**	**LA (18:2)**	**ALA (18:3)**	**AA (20:4)**	**EPA+DHA**	
Tenebrio molitor	Mealworm beetle	25.32	42.27	31.37	29.68	1.61	-	-	Zielińska et al. 2015
Tenebrio molitor	Mealworm larvae	69.40	165.80	77.80	75.70	1.10	-	-	Kim et al. 2016; Ghosh et al., 2017
Rhynchophorus phoenicis	Palm Weevil Larvae	17.50	-	-	-	-	-	-	Womeni et al. 2012
Oecophylla smaragdina Fabricius	Queen Caste	576.96	32.39	1060.96	-	-	9.64	-	Raksakantong et al. 2010
Brachytrupes portentosus Lichtenstein	Short Tailed Cricket	496.17	54.33	771.63	-	-	6.67	-	Raksakantong et al. 2010
Pseudacanthotermes militaris	Sugarcane termite	32.17	56.10	11.73	11.54	0.20	-	-	Kinyuru et al. 2013
Nasutitermes spp.	Termite	33.44	49.91	16.25	11.90	2.59	1.77	-	Oyarzun and Crawshaw 1996
Pseudacanthotermes spiniger	Termite	35.84	52.90	11.26	10.48	0.78	-	-	Kinyuru et al. 2013
Trinervitermes germinatus	Termite	123.94	14.52	465.06	-	2.46	399.20	-	Afiukwa and Okereke 2013
Oecophylla smaragdina	Thai red ant	31.90	58.70	9.40	7.00	0.70	1.00	0.30	Oranut et al. 2010

Scientific Name	**Common Name**	**Fatty Acids[1]**							**Source**
		SFA	**MUFA**	**PUFA**	**LA (18:2)**	**ALA (18:3)**	**AA (20:4)**	**EPA+DHA**	
Gryllodes sigillatus	Tropical house cricket	33.74	34.33	31.91	29.78	2.13	-	-	Zielińska et al. 2015
Oecophylla smaragdina Fabricius	Weaver Ant	451.24	36.56	1062.42	-	5.59	8.93	11.50	Raksakantong et al. 2010
Polyrhachis vicina Roger	Wenzhou black ant	22.90	73.10	4.00	2.40	0.80	0.10	0.40	Oranut et al. 2010
Protaetia brevitarsis	White-spotted flower beetle	23.60	95.20	10.40	9.10	0.40	0.70	-	Ghosh et al. 2017
Macrotermes bellicosus	Winged termite	49.46	44.64	5.90	5.03	-	-	-	Kinyuru et al. 2013; Adeyeye and Olaleye 2016b
Macrotermes subylanus	Winged termite	35.05	52.77	12.18	10.75	1.43	-	-	Kinyuru et al. 2013
Median		**35.445**	**52.835**	**31.37**	**10.75**	**1.43**	**4.685**	**0.4**	
SD		*203.47*	*32.25*	*418.69*	*26.7*	*9.02*	*262.86*	*111.61*	
Range		*17.50-733.46*	*5.67-165.80*	*3.70-1514.32*	*2.20-96.10*	*0.10-39.82*	*0.10-934.95*	*0.10-300.55*	
n		*26*	*24*	*25*	*17*	*19*	*16*	*7*	

[1] Column abbreviations: SFA: Saturated Fatty Acid; MUFA: Mono Unsaturated Fatty Acid; PUFA: Poly Unsaturated Fatty Acid; LA: Linoleic Acid; ALA: α-Linolenic Acid; AA; Arachidonic Acid; EPA: Eicosapentaenoic Acid; DHA: Docosahexaenoic Acid

Adequate intake for adults above 19 years: LA: 13g (M), 8g (F)/day; ALA: 1.3g (M), 0.8g (F)/day (NHMRC, 2006)

Adequate intake for adults: PUFA: 6 – 11%E; EPA+DHA: 0.25 – 2g/day (Burlingame et al., 2009)

3.3.7 Antinutrients

A few publications reported antinutrients for three insect species only. Antinutrients can exert negative outcome on the digestion and/or assimilation of nutrients in the human body. For instance, oxalates reduce the absorption of calcium and magnesium and also form complexes with protein thereby affecting metabolism, while phytates bind to proteins and minerals hence reducing their bioavailability with zinc being the most affected mineral (Akande et al. 2010).

Table 3.8 indicates the various antinutrients reported in the selected publications. Oxalate was the most reported (n=5) with a mean of 3.07±3.54mg/100g while tannins, saponins, alkaloids, and cyanide were the least reported (n=1). Ground cricket (*Henicus whellani)* had the highest content of reported antinutrients in terms of quantities and number of antinutrients (4 out of 7). By and large, very few studies focused on antinutrients as depicted by the data set. Antinutrients can have a negative effect on the bioavailability of nutrients and they can also be toxic (Akande et al., 2010). It is important to select edible insects that do not compromise on bioavailability of nutrients due to antinutrients.

One study reported that antinutrients in edible insects are non-toxic for the most part, but the risks should not be ignored (Arnold Van Huis et al., 2021). A review on safety of edible insects revealed that antinutrients in high amounts were mostly found in unprocessed insects and that processes like boiling, drying, heat treatment, and degutting reduced the amounts of antinutrients (Murefu et al., 2019). Additionally, only wild-harvested edible insects had antinutrients (Murefu et al., 2019), clearly suggesting that rearing insects would be the safe option.

Table 3. 8: Antinutrients (mg/100g) in edible insects

Scientific Name	**Common Name**	**Antinutrients**							**Source**
		Hydrocyanic acid	**Oxalate**	**Phytates**	**Tannins**	**Saponins**	**Alkaloids**	**Cyanide**	
Bunaea alcinoe	Cabbage tree emperor moth	-	1.5500	1.8200	-	-	-	0.1700	Dauda et al. 2014
Henicus whellani	Ground Cricket	-	9.3100	-	1.700	5.3300	5.2300	-	Musundire et al. 2014
Macrotermes bellicosus	Winged termite (queen)	0.0239	0.5500	0.0102	-	-	-	-	Ntukuyoh et al. 2012
Macrotermes bellicosus	Winged termite (soldiers)	0.0054	2.3100	0.0102	-	-	-	-	Ntukuyoh et al. 2012
Macrotermes bellicosus	Winged termite (workers)	0.0177	1.6500	0.0101	-	-	-	-	Ntukuyoh et al. 2012
Median		**0.0177**	**1.65**	**0.0102**	***n/a***	***n/a***	***n/a***	***n/a***	
SD		*0.0090*	*3.5400*	*0.9100*	-	-	-	-	
Range		*0.0054 - 0.0239*	*0.5500 - 9.3100*	*0.0101 - 1.8200*	*n/a*	*n/a*	*n/a*	*n/a*	
n		*3*	*5*	*4*	*1*	*1*	*1*	*1*	

3.4 Discussion

There were wide ranging values for specific nutrients across the reported edible insects, which indicate that the data was widely spread. This variability in data may result from the differences in species presented, the location the insects were sourced from geographically, feeding regimens, stage of development, and if domestically reared or grown in the wild. It has been shown that the fatty acid content of *Ruspolia differens* can be manipulated by altering the nutrients in their diet (Lehtovaara et al., 2017). The variation may also have arisen from factors related to analysis as depicted, for instance, by the 'number of analytical samples'. Nutritional value of edible insects is greatly affected by the species of the insect and to a lesser extent to the order they belong to. XiaoMing et al. (2010) observed that some insect orders are nutritionally superior to others.

There seems to be no established serving size for edible insects as observed in the articles reviewed. All nutrient data was presented per 100g, because it is the base used in food composition tables and it is the format used in the EU for nutrition labelling (Scarborough et al. 2007). The Food and Drug Administration (FDA) of the USA has established recommendations for serving sizes referred to as Reference Amounts Customarily Consumed (RACC) that is expressed in a common household measure that is suitable for the food (FDA 2018). For edible insects, it would be appropriate to have a serving size to guide consumers, nutritionists, manufacturers, caterers, and other players in the insects' value chain, in order to avoid over nutrition or under nutrition. It was noted in this study that insects can provide the daily requirements for most nutrients with only a very small quantity of the insects being consumed. There are recorded values that oversupplied the RDA requirement as seen, for instance, with magnesium, copper and iron. Therefore, it is likely that any established serving size would comprise very small amounts of edible insects. This would have a benefit in that consumers can be encouraged to include on their plate, substantial amounts of vegetables and fruits, resulting in more healthful diets.

It was noted that most studies focused on macronutrients as depicted by the scanty data available for other nutrients, e.g., vitamins, and in terms of number of reported insects (n) in the reviewed articles. Fat and protein were the most studied nutrients while vitamins were the least studied in the selected publications. The nutrient values were wide ranging, possibly due to factors associated with the quality and methods of analysis, sources of the insects, the type of diet eaten by the insects, sex, and the growth stages of the insects.

Edible insects can meet the nutritional needs of communities where nutritional gaps abound. The butterfly (*Phasus triangularis),* for instance, can be used in food assistance programmes as part of nutritional intervention where communities suffer from energy malnutrition. Such communities can also be assisted and encouraged to rear the butterflies for their nutrition security. Edible insects can also be incorporated in foods to boost their nutritional value. For instance, palm weevil larvae (*Rhynchophorus phoenicis*) can be incorporated into foods and food products to improve their protein content. Another example is the mopane worm (*Imbrasia belina*), which can be used to mitigate potassium deficiency in diets. It is clear from this review that edible insects are suitable candidates for fighting iron and zinc deficiencies that have ravaged many communities in Africa.

3.5 Conclusions and recommendations

A lot of research articles on nutritional potential of edible insects are available, but the quality of the data is a major drawback to the otherwise noble efforts leading to only 26 articles qualifying for data extraction. Researchers therefore need to be well versed with the food composition data quality requirements in order to maximize on their efforts in the body of science. Edible insects can be a valuable source of nutrients for human nutrition. Edible insects can meet nutritional gaps in many situations, especially cases of malnutrition.

Due to the variability of the amounts of nutrients in edible insects, a blend of edible insects may be needed to provide crucial nutrients in a diet. This review reiterates what many studies have reported that insects are a valuable source of macronutrients and mineral elements for human health. Protein is a key macronutrient present in adequate amounts and thus insects can accurately be referred to as protein-rich foods, with the wasp larvae (*Polybia parvulina*) being the best source of protein. Iron, zinc, and magnesium are the micronutrients present in suitable quantities in edible insects. Edible insects can therefore be appropriate for alleviating micronutrient deficiencies associated with Fe, Zn, and Mg.

Due to their nutrient density, insects could be used to fight undernutrition and reduce incidences of non-communicable diseases that are associated with overconsumption of calories in energy dense foods. However, more studies need to be carried out on the antinutritional aspects of edible insects to ascertain the bioavailability of these valuable nutrients. Additionally, there is need for culinary and dietary studies to determine the serving sizes of edible insects so as to understand their contribution to the nutritional value of diets during meal planning.

CHAPTER FOUR

EVALUATING THE HEALTHFULNESS OF EDIBLE INSECTS AND CONVENTIONAL MEATS USING THREE NUTRIENT PROFILING MODELS[2]

4.1 Introduction

Meat is defined as the flesh (skeletal muscle) of animals that is eaten as food. This definition may include connective tissue and the fat attached to the muscle (Williams, 2007). In culinary terms, meat is divided majorly into two categories; red meat and white meat. Red meat refers to meat from cattle, sheep, and goat (Williams, 2007) while white meat is mainly from poultry (Cosgrove et al., 2005). The term "fish" denotes all aquatic invertebrates and finfish that are caught in marine and freshwaters in the course of fishing operations (Vianna et al., 2020). The importance of fish in human diet cannot be underestimated due to their high nutritional value as exemplified by their content of omega 3 & omega 6 fatty acids and almost all the minerals needed in our bodies (Pal et al., 2018). Consumption of terrestrial wildlife e.g., bush meat is important in human nutrition and has been associated with higher hemoglobin concentrations thus reducing the incidence of anemia (Golden et al., 2011). For the purposes of this study, all animal-source foods, including fish and wildlife, shall be covered under 'conventional meats'.

Meat remains an important part of the human diet especially in the developed world (McAfee et al., 2010). Meat is nutrient dense (Cosgrove et al., 2005) with substantial amounts of protein, B vitamins, zinc, iron, and essential amino acids, and these nutrients are easily absorbed in the body (Avery, 2004). But even with this encouraging data on nutrient composition, there have been reports of association of red meat consumption with incidences of colon cancer and cardiovascular diseases, thereby creating a negative vibe towards meat consumption (McAfee et al., 2010).

Edible insects have been consumed by humans since time immemorial and this tradition is still practiced presently in the world, particularly in Africa, Asia and Latin America (Pali-Schöll et al., 2019). Insects are ubiquitous and are the most diverse group of organisms in life's history (Raheem et al., 2019). More than 1000 species of insects are consumed worldwide, providing nutrition and economic lifeline to many communities (Raheem et al., 2019).

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[2] Weru et al., 2022

A different approach of looking at the nutritional value of foods, referred to as nutrient profiling, has been developed in the recent past. Nutrient profiling is defined as “the science of categorizing foods according to their nutritional composition” in order to obtain an unbiased measure of the healthfulness of a food item or diet (Rayner et al., 2004). Nutrient profiling models filter large amounts of nutritional data into a single convenient marker or indicator, which represents healthfulness status of the food being evaluated (Arvaniti & Panagiotakos, 2008). Healthfulness of a food is the ability of a food to impart positive health outcomes to the consumer, e.g., improving the individual’s health status or reducing the risk of chronic diseases (Masset, 2012). Nutrient profiling can be applied in the regulation of health claims on foods (Maschkowski et al., 2014), controlling the advertising of foods in the media, control of labelling of packaged foods, and can assist consumers to make informed choices of healthful foods (Iberoamerican Nutrition Foundation (FINUT)., 2017). Nutrient profiling schemes are suitable in encouraging food manufacturers to reformulate their products so as to meet the set healthful standards, as opposed to being punitive, hence achieving public health objectives (Garsetti et al., 2007).

Three models have been used in nutrient profiling namely WXYfm, RRR, and GDA. The WXYfm model was developed by the Food Standards Agency (FSA) in the UK with an aim of controlling advertising of food to children (Rayner et al., 2005). It is a scoring system where points are assigned based on the nutritional value in 100 g of the food or drink. It uses the following nonbeneficial nutrients (negative nutrients); energy, total sugar, saturated fat and sodium; and counterbalances with beneficial nutrients (positive nutrients), namely fruits, vegetables and nuts (FVN), fiber and protein. The model classifies foods ‘across the board’ (P. Scarborough et al., 2010) as either healthful, intermediate, or less healthful (Quinio et al., 2007) hence making it suitable for use in the current study.

The Ratio of Recommended to Restricted (RRR) model is a tool that provides a summary of the ratio of beneficial food components that should be eagerly consumed, i.e., protein, dietary fiber, calcium, iron, vitamins A and C, to those that should be limited, i.e., energy (calories), sugars, cholesterol, saturated fat, and sodium (Scheidt & Daniel, 2004). The RRR provides a single index that denotes this ratio which consumers can use to compare the nutritional value of food items as opposed to the complexity of interpreting multiple numeric values on food labels, recommendations or standards. The RRR is designed to help consumers make healthful food choices and it can identify nutrient-rich foods within food categories (Scheidt & Daniel, 2004). It was therefore suitable for application in this study.

The GDA Model is a LIM scoring system based on three nutrients to limit: fat, salt, and saturated fatty acids (SFA), with the output being a mean percentage score (Peter Scarborough, Rayner, et al., 2007). The LIM scoring model is a threshold model which categorizes food as ‘healthful’ or ‘less healthful’ based on the amounts of negative nutrients and has been used as the basis for health claims on food labels, in addition to helping consumers reduce the intake of nutrients to limit (Peter Scarborough, Rayner, et al., 2007), and therefore it was selected for use in this study.

Edible insects are a novel food and the paucity of data on their healthfulness may hinder their incorporation into regular diets, or as suitable alternatives to conventional meats. The objective of this study was to evaluate the healthfulness of edible insects and commonly consumed meats in Sub-Saharan Africa using three nutrient profiling models; WXYfm (Ofcom), RRR (Ratio of Recommended to Restricted), and GDA (Guideline Daily Amounts), with a view of identifying the most healthful options for consumers to make informed and better dietary choices.

4.2 Materials and methods

4.2.1 Nutrient composition data for conventional meats and edible insects

Nutrient composition data of conventional meats was obtained from Food Composition Tables (FCTs) available in the FAO INFOODS website (INFOODS, 2021), specifically those written in English;

i. Tanzania Food Composition Tables
ii. West African Food Composition Tables
iii. Kenya Food Composition Tables
iv. Lesotho Food Composition Tables
v. Nigeria Food Composition Tables
vi. Malawian Food Composition Table 2019
vii. Food Composition Tables for Mozambique

Nutrient composition data was included if it was described as ‘raw’ or ‘dried’, under the meat category covering livestock, fish, and wildlife. All data lines with products described as processed, i.e., cooked, salted, braised, smoked, boiled, and broiled were excluded. Blood and fat/oil were also excluded in the nutrient composition data. All organ meats, e.g., heart, brain, etc. (with the exemption of liver) and nonspecific cuts of meat, e.g., chicken heads and legs, were clustered as offal. All missing values and those indicated as ‘trace’ or ‘Tr’ were replaced with 0. Data that was reported as a range was replaced with the median value.

For all the foods that fulfilled the criteria above, data on energy and 11 macro- and micronutrients applicable in WXYfm, RRR, and GDA nutrient profiling models was extracted. The data was tabulated for each of the countries included, in readiness for calculating the final scores for each of the three nutrient profiling models. Nutrient composition data of edible insects was obtained through a systematic review as reported in chapter 2 and by Weru et al., (2021).

4.2.2 Nutrient profiling

4.2.2.1 WXYfm

The modelling started by awarding each of the negative nutrients between a minimum of 0 points or a maximum of 10 points based on the amount of the nutrient in 100 g of food (**Table 4.1**). The total points scored by the negative nutrients were denoted ‘A’ points (Rayner & Scarborough, 2005; Rayner, 2009)

The ‘A’ points are calculated as follows:

$$Total\ 'A' points = (points\ for\ energy) + (points\ for\ saturated\ fat) + (points\ for\ sugar) + (points\ for\ sodium) \ldots \text{Eq 4.1}$$

Table 4. 1: Points scored for negative nutrients per 100 g of food for the WXYfm model

Nutrient	**Points awarded**										
	0	1	2	3	4	5	6	7	8	9	10
Energy (kJ)	≤ 335	>335	>670	>1005	>1340	>1675	>2010	>2345	>2680	>3015	>3350
Saturated fat (g)	≤ 1	>1	>2	>3	>4	>5	>6	>7	>8	>9	>10
Total sugar (g)	≤ 4.5	>4.5	>9	>13.5	>18	>22.5	>27	>31	>36	>40	>45
Sodium (mg)	≤ 90	>90	>180	>270	>360	>450	>540	>630	>720	>810	>900

In a similar manner, the positive nutrients were assigned between 0 and 5 points each, and the total points denoted as 'C' points. **Table 4.2** shows the points scored by each nutrient based on 100 g of food (Rayner & Scarborough, 2005; Rayner, 2009).

The total 'C' points were calculated as follows:

$$Total\ 'C'points = (points\ for\ fruit, veg\ \&\ nut\ content) + (points\ for\ fiber) + (points\ for\ protein) \qquad \text{Eq 4.2}$$

Table 4. 2: Points scored for positive nutrients per 100 g of food for the WXYfm model

Nutrient	**Points awarded**					
	0	1	2	3	4	5
Fruit, Veg & Nuts (%)	≤ 40	>40	>60	-	-	>80
Fiber (g) (AOAC)	≤ 0.9	>0.9	>1.9	>2.8	>3.7	>4.7
Protein (g)	≤ 1.6	>1.6	>3.2	>4.8	>6.4	>8

The overall score was then calculated as follows:

i. If a food scored less than 11 'A' points, OR it scored more than 11 'A' points but with 5 points for fruit, vegetables and nuts then the overall score was calculated as follows:

$$Overall\ score = [total\ 'A'points] - [total\ 'C'points] \qquad \text{Eq 4.3}$$

ii. If a food scored 11 or more 'A' points but having a score of less than 5 points for fruit, vegetables and nuts then the overall score was calculated without regard to the protein value, as shown below:

$$Overall\ score = [total\ 'A' points] - [fiber\ points + fruit, vegetables\ and\ nuts] \ldots\ldots \text{Eq 4.4}$$

Classification of the meats and edible insects was then done based on the final score as follows, (Rayner & Scarborough, 2005; Quinio *et al.*, 2007; Rayner, 2009):

i. If a food scored more than 4 points or more, it was classified as less healthful
ii. If a food scored above 0 points but less than 4 points, then it was classified as intermediate healthful
iii. If a food scored 0 points and below, it was classified as healthful

4.2.2.2 Ratio of Recommended to Restricted (RRR)

Nutrient composition data for edible insects and meat were converted into percent Daily Values (%DVs) based on a 2000 Kcal diet standard amounts, according to FDA and WHO recommendations (Scheidt & Daniel, 2004). The %DVs for the recommended nutrients were capped at 100 in order to protect RRR from extreme values, especially due to fortification (Scheidt & Daniel, 2004). Data for saturated fatty acids was converted into grams before calculating the %DVs. Sugar was absent in the foods evaluated in the study.

The final RRR scores were then calculated using the algorithm shown below:

$$RRR = \Sigma\left(\frac{Nutrient_{recommended}}{6}\right) \div \Sigma\left(\frac{Nutrient_{restricted}}{5}\right) \qquad \text{(Scheidt \& Daniel, 2004)}$$

Where:

$Nutrient_{recommended}$ is the %DVs for protein, dietary fiber, calcium, iron, vitamins A and C (denominator = 6) that should be encouraged in the diet.

$Nutrient_{restricted}$ is the %DVs for nutrients that should be limited in the diet, namely energy (calories), sugars, cholesterol, saturated fat, and sodium (denominator = 5).

All foods that scored 1 or more were classified as healthful while those that scored less than 1 were classified as unhealthful (Scheidt & Daniel, 2004)

4.2.2.3 Guideline Daily Amounts (GDA)

It is based on maximum recommended daily amounts of the three nutrients to limit in diet (fat, saturated fat, and salt) in 100g of food using the following algorithm:

$$\mathrm{LIM} = \frac{\sum_{1}^{3} ratio_j}{3}$$

$$\text{With } ratio_j = \left[\frac{nutrient_j}{MRV_j}\right] \times 100$$

(Masset, 2012)

Where 3 is the three nutrients to limit, nutrient $_j$ is the value, in grams, of the nutrient *j* to limit in 100g of food, and MRV $_j$ is the maximum recommended daily value for nutrient *j* based on GDA, as indicated in **Table 4.3.** GDA score ≥1 is classed as unhealthful while a score <1 imply healthfulness (Masset, 2012).

Table 4. 3: Guideline Daily Amounts used to calculate the LIM Score

Nutrient*	Women (> 19 years)	Men (> 19 years)	Children (5-10 years)
Calories (kcal)	2,000 l	2,500	1,800
Protein (g)	45	55	24
Carbohydrate (g)	230	300	220
Sugars (g)	90	120	85
Fat (g)	70	95	70
Saturated fat (g)	20	30	20
Fiber (g)	24	24	15
Salt (g)	6	6	4

Source: (The Food and Drink Federation, 2020)

*Nutrients in bold are those applicable for the calculation of GDA scores of meats and edible insects

4.2.3: Data analysis

Data analysis was carried out using Kruskal-Wallis Test (Tukey's Studentized Range (HSD) Test

(The SAS System)) on the median values of the scores generated.

4.3: Results and discussion

4.3.1: Nutrient data of edible insects and conventional meats applied in nutrient profiling models

The median values and interquartile range of nutrient data used to calculate the WXYfm model scores are shown in **Table 4.4.** The median values for energy were wide ranging for edible insects (range = 0.00 – 1987.40 KJ per 100 g) compared to the animal source foods (range = 343.00 – 1145.00 KJ per 100 g). The interquartile range for energy was close for most of the products except a few edible insects which had wide ranging values, e.g., *Macrotermes bellicosus* (range = 0.00-1633.07 KJ per 100 g). Energy, saturated fat, and sodium have a negative impact on the WXYfm score (Masset, 2012).

Table 4. 4: Median and interquartile range for nutrients used to calculate WXYfm scores in conventional meats and edible insects

Meat (n)	**Energy (kJ)**	**Protein (g)**	**Fibre (g)**	**Na[1] (mg)**	**SFA[1] (g)**
African carp (2)	394	73.9	0	51.5	0
	(341.5-446.5)	(73.7-74.2)	(0.0-0.0)	(48.8-54.3)	(0.0-0.0)
Barracuda (2)	349.50	89.2	0	89	0
	(349.2-349.7)	(89.2-89.2)	(0.0-0.0)	(89.0-89.0)	(0.0-0.0)
Beef (13)	852	55.98	0	83	0
	(582.0-978.0)	(51.5-73.0)	(0.0-0.0)	(66.0-91.0)	(0.00-5.9)
Beef liver (6)	558.5	68.3	0	69	0
	(549.4-563.5)	(66.9-72.9)	(0.0-0.0)	(69.0-72.0)	(0.0-0.9)
Beef offal (11)	434	77.3	0	126	0
	(415.0-469.4)	(58.5-78.6)	(0.0-0.0)	(90.0-182.0)	(0.0-0.5)
Beef tripe (3)	343	76.6	0	97	0
	(342.5-366.0)	(76.6-77.6)	(0.0-0.0)	(71.5-97.0)	(0.0-1.0)
Cat fish (9)	488	74.7	0	41	0
	(431.0-515.9)	(69.4-79.4)	(0.0-2.0)	(0.0-48.0)	(0.0-0.0)
Chicken (11)	565.1	75.3	0	64	0
	(501.5-831.5)	(57.6-85.0)	(0.0-0.0)	(47.0-72.0)	(0.0-0.8)
Chicken liver (4)	479	71.9	0	71	0.8
	(478.9-482.3)	(68.1-72.5)	(0.0-0.0)	(71.0-71.0)	(0.0-1.6)
Chicken offal (7)	554	61.9	0	69	1.4
	(511.5-588.3)	(50.9-69.2)	(0.0-1.0)	(32.5-75.5)	(0.0-1.9)
Crab (2)	1003.7	55.8	4.6	418.4	0.1
	(927.6-1079.9)	(46.3-65.4)	(2.3-6.9)	(358.1-478.7)	(0.1-0.1)
Duck (3)	1050	47.1	0	74	0
	(798.5-1350.5)	(34.7-58.4)	(0.0-0.0)	(68.5-78.0)	(0.0-6.6)
Fish (17)	638.5	57.34	0	0	0
	(470.0-1277.0)	(49.41-64.69)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)
Goat meat (7)	623	68.7	0	82	0
	(469.5-689.5)	(56.6-80.5)	(0.0-0.0)	(82.0-101.5)	(0.0-0.4)
Guinea fowl (4)	445.1	81.8	0	178.5	0
	(417.2-512.4)	(79.4-84.7)	(0.0-0.0)	(64.8-352.5)	(0.0-0.0)
Lamb liver (2)	613.5	66.8	0	68.5	0
	(582.8-644.3)	(64.9-68.7)	(0.0-0.0)	(67.8-69.3)	(0.0-0.0)

Meat (n)	**Energy (kJ)**	**Protein (g)**	**Fibre (g)**	**Na[1] (mg)**	**SFA[1] (g)**
Lobster (2)	889.7	78.9	0.2	165	0
	(631.4-1147.9)	(77.7-80.1)	(0.1-0.2)	(82.5-247.5)	(0.0-0.0)
Mackerel (4)	527.5	69.5	0	62.5	0
	(519.2-558.8)	(65.1-73.9)	(0.0-0.0)	(59.0-71.0)	(0.0-0.6)
Mutton (4)	1075	42.2	0	68	0
	(1063.8-1093.8)	(41.9-42.6)	(0.0-0.0)	(59.5-76.0)	(0.0-2.4)
Nile Perch (3)	413	83.3	0	97	0
	(384.5-1023.5)	(82.5-83.6)	(0.0-0.0)	(77.5-236.5)	(0.0-0.0)
Pork (7)	1145	42.11	0	58	0
	(1043.8-1568.0)	(25.36-43.13)	(0.0-0.0)	(48.50-64.00)	(0.00-1.32)
Prawn (2)	950.6	75.9	0.3	95.5	0
	(684.8-1216.3)	(74.9-77.0)	(0.2-0.5)	(47.8-143.3)	(0.0-0.0)
Quail (3)	729	64.68	0	53	0
	(618.5-754.3)	(63.86-70.88)	(0.0-0.0)	(51.0-53.0)	(0.0-0.4)
Rabbit (4)	501.1	76.5	0	47	0
	(364.3-568.7)	(73.9-80.7)	(0.0-0.0)	(41.00-54.75)	(0.00-0.17)
Sardine (4)	491.1	77.3	0	77	0
	(436.8-560.0)	(74.9-77.3)	(0.0-0.0)	(67.3-116.5)	(0.0-0.0)
Sheep offal (3)	385	76.1	0	156	0.9
	(381.5-388.5)	(75.8-79.2)	(0.0-0.0)	(138.5-156.5)	(0.9-0.9)
Tilapia (6)	419	82.7	0	52	0
	(403.0-568.4)	(77.3-87.3)	(0.0-0.0)	(13.0-56.5)	(0.0-0.0)
Tuna (3)	568	78.7	0	51	0
	(534.0-576.4)	(78.7-79.6)	(0.0-0.0)	(50.5-51.0)	(0.0-0.0)
Turkey offal (2)	505.10	74.4	0	138	0
	(474.7-535.6)	(69.9-78.9)	(0.0-0.0)	(133.5-142.5)	(0.0-0.0)
Edible insect (n)					
Acheta domesticus (2)	909.6016	69.3	0	0	0
	(454.8-1364.4)	(68.7-69.9)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)
Apis mellifera (5)	1987.4	42.4	0	0	0
	(1987.4-1991.6)	(19.5-49.1)	(0.0-3.9)	(0.0-0.0)	(0.0-0.0)
Blaberus craniifer (2)	1044.50	65.8	0	0	0
	(522.3-1566.8)	(65.4-66.2)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)
Bombyx mori (3)	1853.50	35.9	5.2	0	0
	(1809.6-2004.5)	(29.4-45.9)	(2.6-5.7)	(0.0-0.0)	(0.0-0.0)

Edible insect (n)	**Energy (kJ)**	**Protein (g)**	**Fibre (g)**	**Na[1] (mg)**	**SFA[1] (g)**
Corisella decolor (2)	1414.20 (1395.4-1433.0)	60.6 (59.7-61.5)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Macrotermes bellicosus (4)	815.40 (0.0-1633.1)	30.6 (28.6-38.0)	1.9 (1.3-2.9)	68.5 (60.8-152.3)	0 (0.0-0.0)
Nasutitermes spp (2)	803.30 (401.7-1204.9)	39.39 (29.99-48.80)	17.66 (11.20-24.11)	8.5 (4.25-12.75)	0.02 (0.01-0.03)
Oecophylla smaragdina (4)	0 (0.0-.0.0)	24.1 (8.1-41.5)	4.1 (0.0-10.0)	0 (0.0-17.9)	0.2 (0.0-0.5)
Pachilis gigas (2)	1972.80 (1917.3-2028.2)	64 (63.5-64.5)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Polybia occidentalis (2)	1905.80 (1883.9-1927.8)	61.6 (61.3-61.8)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Polybia parvulina (2)	978.00 (489.0-1467.0)	71.7 (67.0-76.4)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Polyrhachis vicina (3)	0 (0.0-0.0)	0 (0.0-28.3)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Protaetia brevitarsis (2)	874.30 (437.1-1311.4)	50.8 (47.5-54.1)	5.5 (2.8-8.3)	105.8 (52.9-158.7)	0 (0.0-0.0)
Rhynchophorus phoenicis (4)	0 (0.0-624.0)	9.8 (8.9-12.5)	19.5 (12.9-21.9)	16.3 (15.2-49.5)	0 (0.0-0.0)
Tenebrio molitor (5)	0 (0.0-1857.7)	52 (51.0-52.4)	0 (0.0-1.9)	0 (0.0-0.0)	0 (0.0-0.0)
Zophobas morio (3)	0 (0.0-1149.5)	47 (46.5-47.6)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)

[1] Column Abbreviations: SFA: Saturated Fatty Acid
n: sample size; figures in brackets (interquartile ranges)

Reference Nutrient Intakes (RNI): - Energy: 8400 KJ (F), 10500 KJ (M); SFA: 20 g (F), 30 g (M); Na: 2355 mg; Protein: 50 g; Fiber; 30 g (British Nutrition Foundation, 2019; Public Health England, 2016)

The amount of saturated fat was relatively small across the products considering the maximum recommended daily intake of 20 g. Data for saturated fat was scanty as depicted by median values, where 82% of all the products had median values of 0 g per 100 g, while 51% of the total products had 25th and 75th percentile values of 0 g per 100 g. The highest 75th percentile value for saturated fat was 6.6 g per 100 g for duck followed closely by beef at 5.95 g per 100 g, which is far below the recommended daily intake of 20 g, which impacts favorably on their healthfulness. Most of the edible insects had no sodium while crab had the highest median sodium content of 418 mg per 100 g.

Protein and fiber have a positive bearing on the WXYfm score. Only the edible insect *Polyrhachis vicina* had a median value of 0 g per 100 g of protein amongst all the products. The protein values were relatively high as depicted by 40% of 75th percentile of the total food items being above 60 g per 100 g and therefore meeting the daily recommended value of 60 g. However, edible insects had slightly lower median values for protein (0.00 – 71.73 g per 100 g) compared to all the other products (42.00 – 89.20 g per 100 g). The fiber was scanty in that 80% of all the food items had median values of 0 g per 100 g, with 71% of which had values of 0 g per 100 g at both 25th and 75th percentiles. This scenario impacts negatively on the WXYfm score.

Table 4.5 depicts the median values and interquartile range for nutrients applicable to animal source foods used to calculate the RRR scores. Energy, saturated fat, sodium, and cholesterol are the nutrients with an undesirable impact on the RRR score. Cholesterol was virtually absent in all the edible insects and scarcely present in the conventional meats. Sheep offal had the highest median value for cholesterol at 200 mg per 100 g, with a 75th percentile value of 250 mg per 100 g. Of the positive nutrients, it is notable that liver from beef, lamb, and chicken had very high median values for vitamin A (median = 16 566.50, 60 616.06, and 10 986.56 IU per 100 g, respectively), surpassing in multiple times the daily recommended daily value of 5000 IU.

Vitamin C was very low whereby 66.7% of the total products had a median value of 0 mg per 100 g, and 57.8% of all the food products had 0 mg per 100 g at the 25th and 75th percentiles. Of the edible insects, 71% had a median value of 0 mg per 100 g for both calcium and iron. Crab and lobster had the highest median values for calcium (median = 1091.38 and 1191.00 mg per 100 g, respectively), while the edible insects *Nasutitermes spp* and *Macrotermes bellicosus* had the highest median content of iron (median = 32.60 and 46.80 mg per 100 g, respectively).

Table 4. 5: Median and interquartile range for nutrients used to calculate RRR scores in 100g of conventional meats and edible insects

Meat (n)	**Energy (kcal)**	**Protein (g)**	**Fiber (g)**	**Ca[1] (mg)**	**Fe[1] (mg)**	**Vit A (IU)**	**Vit C (mg)**	**Na[1] (mg)**	**SFA[1] (g)**	**Chol[1] (mg)**
African carp (2)	93.5 (80.8-106.3)	73.9 (73.7-74.2)	0 (0.0-0.0)	28.5 (20.8-36.3)	0.9 (0.8-1.0)	16.6 (10.0-23.3)	0 (0.0-0.0)	51.5 (48.8-54.3)	0 (0.0-0.0)	0 (0.0-0.0)
Barracuda (2)	82.7 (82.5-82.8)	89.2 (89.2-89.2)	0 (0.0-0.0)	26 (26.0-26.0)	0.9 (0.9-0.9)	23.3 (23.3-23.3)	0 (0.0-0.0)	89 (89.0-89.0)	0 (0.0-0.0)	0 (0.0-0.0)
Beef (13)	204 (139.0-235.0)	55.98 (51.5-73.0)	0 (0.0-0.0)	9 (5.0-13.0)	2.1 (1.4-2.3)	0 (0.0-33.3)	0 (0.0-0.0)	83 (66.0-91.0)	0 (0.00-5.9)	0 (0.0-0.0)
Beef liver (6)	132.5 (130.3-134.5)	68.3 (66.9-72.9)	0 (0.0-0.0)	6 (5.3-6.8)	7.8 (5.4-8.8)	16566.5 (16561.5-30398.9)	1.3 (1.1-10.8)	69 (69.0-72.0)	0 (0.0-0.9)	0 (0.0-206.3)
Beef offal (11)	103.7 (98.8-111.9)	77.3 (58.5-78.6)	0 (0.0-0.0)	10 (7.0-13.0)	4.6 (4.3-6.1)	46.7 (0.0-1396.7)	9 (2.6-10.1)	126 (90.0-182.0)	0 (0.0-0.5)	0 (0.0-50.0)
Beef tripe (3)	82 (81.5-87.5)	76.6 (76.6-77.6)	0 (0.0-0.0)	69 (39.0-69.0)	0.6 (0.6-1.3)	0 (0.0-0.0)	0 (0.0-1.5)	97 (71.5-97.0)	0 (0.0-1.0)	0 (0.0-50.0)
Cat fish (9)	117 (102.0-123.2)	74.7 (69.4-79.4)	0 (0.0-2.0)	38 (14.0-44.0)	0.9 (0.7-9.5)	25 (10.0-50.0)	0 (0.0-6.5)	41 (0.0-48.0)	0 (0.0-0.0)	0 (0.0-0.0)
Chicken (11)	134.7 (119.7-198.5)	75.3 (57.6-85.0)	0 (0.0-0.0)	11 (9.5-12.0)	1.1 (1.0-1.1)	56.7 (23.3-76.7)	0 (0.0-1.0)	64 (47.0-72.0)	0 (0.0-0.8)	0 (0.0-0.0)
Chicken liver (4)	114.3 (114.1-115.1)	71.9 (68.1-72.5)	0 (0.0-0.0)	8 (7.3-8.8)	8.6 (7.3-8.8)	10986.6 (8239.9-14814.9)	17.9 (17.9-19.1)	71 (71.0-71.0)	0.8 (0.0-1.6)	0 (0.0-75.0)
Chicken offal (7)	132 (122.3-140.8)	61.9 (50.9-69.2)	0 (0.0-1.0)	6.5 (2.7-10.0)	3.6 (1.1-6.1)	30 (0.0-1889.9)	3.7 (1.6-13.6)	69 (32.5-75.5)	1.4 (0.0-1.9)	0 (0.0-150.0)
Crab (2)	239.5 (221.2-257.7)	55.8 (46.3-65.4)	4.6 (2.3-6.9)	1091.9 (558.9-1624.9)	15. (8.9-21.6)	70 (35.0-105.0)	3.5 (1.8-5.3)	418.4 (358.1-478.7)	0.1 (0.1-0.1)	0 (0.0-0.0)
Duck (3)	253 (191.7-324.0)	47.1 (34.7-58.4)	0 (0.0-0.0)	11 (8.0-11.0)	2.4 (2.2-2.4)	130 (105.0-148.3)	2.8 (1.4-4.3)	74 (68.5-78.0)	0 (0.0-6.6)	0 (0.0-0.0)
Fish (17)	138 (113.00-238.00)	57.34 (49.41-64.69)	0 (0.0-0.0)	0 (0.00-180.00)	0 (0.00-3.00)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)

Meat (n)	**Energy (kcal)**	**Protein (g)**	**Fiber (g)**	**Ca[1] (mg)**	**Fe[1] (mg)**	**Vit A (IU)**	**Vit C (mg)**	**Na[1] (mg)**	**SFA[1] (g)**	**Chol[1] (mg)**
Goat meat (7)	149 (111.9-165.0)	68.7 (56.6-80.5)	0 (0.0-0.0)	11 (10.0-12.0)	2.4 (2.2-2.8)	0 (0.0-41.7)	0 (0.0-0.2)	82 (82.0-101.5)	0 (0.0-0.4)	0 (000-0.0)
Guinea fowl (4)	105.5 (98.5-121.9)	81.8 (79.4-84.7)	0 (0.0-0.0)	31 (26.0-34.5)	0.4 (0.0-1.2)	3.3 (0.0-28.3)	0.5 (0.0-1.1)	178.5 (64.8-352.5)	0 (0.0-0.0)	0 (0.0-0.0)
Lamb liver (2)	146 (138.5-153.5)	66.8 (64.9-68.7)	0 (0.0-0.0)	9.5 (9.3-9.8)	8.5 (8.4-8.6)	60616.1 (38591.3-82640.8)	12 (8.0-16.0)	68.5 (67.8-69.3)	0 (0.0-0.0)	0 (0.0-0.0)
Lobster (2)	210.4 (149.3-271.4)	78.9 (77.7-80.1)	0.2 (0.1-0.2)	1911 (986.5-2835.5)	14.7 (7.8-21.7)	0 (0.00-0.0)	5 (2.5-7.5)	165 (82.5-247.5)	0 (0.0-0.0)	0 (0.0-0.0)
Mackerel (4)	125.5 (123.6-133.0)	69.5 (65.1-73.9)	0 (0.0-0.0)	24.5 (23.0-26.5)	1.0 (0.9-2.3)	73.3 (47.5-95.0)	0.9 (0.0-1.9)	62.5 (59.0-71.0)	0 (0.0-0.6)	0 (0.0-0.0)
Mutton (4)	258.2 (257.0-261.7)	42.2 (41.9-42.6)	0 (0.0-0.0)	11 (10.0-12.0)	1.9 (1.7-2.1)	16.7 (0.0-33.3)	0 (0.0-0.0)	68 (59.5-76.0)	0 (0.0-2.4)	0 (0.0-25.0)
Nile Perch (3)	98 (91.0-243.0)	83.3 (82.5-83.6)	0 (0.0-0.0)	133 (111.0-324.5)	1 (0.9-2.5)	50 (35.0-335.0)	0 (0.0-0.0)	97 (77.5-236.5)	0 (0.0-0.0)	0 (0.0-0.0)
Pork (7)	286 (265.0-383.5)	42.11 (25.36-43.13)	0 (0.0-0.0)	11 (10.50-19.00)	1.4 (0.98-1.60)	0 (0.00-3.33)	0 (0.0-0.0)	58 (48.50-64.00)	0 (0.00-1.32)	0 (0.0-0.0)
Prawn (2)	224.9 (161.9-287.9)	75.9 (74.9-77.0)	0.3 (0.2-0.5)	55.1 (53.2-57.1)	0.8 (0.4-1.1)	33.3 (16.7-50.0)	0.2 (0.1-0.2)	95.5 (47.8-143.3)	0 (0.0-0.0)	0 (0.0-0.0)
Quail (3)	175 (148.00-180.99)	64.68 (63.86-70.88)	0 (0.0-0.0)	10 (10.00-11.50)	2.6 (2.4-3.3)	156.7 (96.7-200.0)	6 (5.5-6.1)	53 (51.0-53.0)	0 (0.0-0.4)	0 (0.0-28.0)
Rabbit (4)	130.1 (109.0-135.4)	76.5 (73.9-80.7)	0 (0.0-0.0)	13 (12.8-13.8)	1.4 (1.2-1.6)	16.67 (0.00-33.33)	0 (0.0-0.0)	47 (41.00-54.75)	0 (0.00-0.17)	0 (0.0-0.0)
Sardine (4)	124.4 (103.5-199.8)	77.3 (74.9-77.3)	0 (0.0-0.0)	71 (63.8-416.5)	1.8 (1.7-2.9)	63.3 (58.3-102.5)	0 (0.0-0.0)	77 (67.3-116.5)	0 (0.0-0.0)	0 (0.0-0.0)
Sheep offal (3)	93.7 (92.0-101.5)	76.1 (75.8-79.2)	0 (0.0-0.0)	10 (9.5-11.5)	6.4 (6.4-6.6)	316.7 (158.3-5316.6)	20 (15.5-25.5)	156 (138.5-156.5)	0.9 (0.9-0.9)	200 (100.0-250.0)
Tilapia (6)	97.5 (93.0-126.1)	82.7 (77.3-87.3)	0 (0.0-0.0)	13.5 (2.5-86.0)	0.9 (0.1-2.4)	0 (0.0-25.0)	0 (0.0-0.0)	52 (13.0-56.5)	0 (0.0-0.0)	0 (0.0-0.0)

Meat (n)	**Energy (kcal)**	**Protein (g)**	**Fiber (g)**	**Ca^1 (mg)**	**Fe^1 (mg)**	**Vit A (IU)**	**Vit C (mg)**	**Na^1 (mg)**	**SFA^1 (g)**	**Chol^1 (mg)**
Tuna (3)	139 (128.5-139.1)	78.7 (78.7-79.6)	0 (0.0-0.0)	14 (9.5-14.0)	1.1 (0.9-1.1)	86.7 (73.3-86.7)	0 (0.0-0.0)	51 (50.5-51.0)	0 (0.0-0.0)	0 (0.0-0.0)
Turkey offal (2)	120.5 (112.9-127.9)	74.4 (69.9-78.9)	0 (0.0-0.0)	17 (16.5-17.5)	3.2 (3.0-3.5)	213.3 (183.3-243.3)	4.6 (3.8-5.4)	138 (133.5-142.5)	0 (0.0-0.0)	0 (0.0-0.0)
Edible insect (n)										
Acheta domesticus (2)	217.4 (108.7-326.1)	69.3 (68.7-69.9)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Apis mellifera (5)	475 (475.0-476.0)	42.4 (19.5-49.1)	0 (0.0-3.9)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Blaberus craniifer (2)	249.5 (124.8-374.5)	65.8 (65.4-66.2)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Bombyx mori (3)	443 (432.5-479.1)	35.9 (29.4-45.9)	5.2 (2.6-5.7)	0 (0.0-47.9)	0 (0.0-2.5)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Corisella decolor (2)	338 (333.5-342.5)	60.6 (59.7-61.5)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Macrotermes bellicosus (4)	390.9 (292.3-415.1)	30.6 (28.6-38.0)	1.9 (1.3-2.9)	48.9 (37.5-55.6)	46.8 (35.2-56.4)	699.9 (424.9-1208.2)	0.1 (0.0-0.1)	68.5 (60.8-152.3)	0 (0.0-0.0)	0 (0.0-0.0)
Nasutitermes spp (2)	192 (96.0-288.0)	39.39 (29.99-48.80)	17.66 (11.20-24.11)	13 (6.50-19.50)	32.6 (16.30-48.90)	1236.55 (618.27-1854.82)	0 (0.0-0.0)	8.5 (4.25-12.75)	0.02 (0.01-0.03)	0 (0.0-0.0)
Oecophylla smaragdina (4)	0 (0.0-0.0)	24.1 (8.1-41.5)	4.1 (0.0-10.0)	0 (0.0-8.9)	0 (0.0-20.4)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-17.9)	0.2 (0.0-0.5)	0 (0.0-0.0)
Pachilis gigas (2)	471.5 (458.3-484.8)	64 (63.5-64.5)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Polybia occidentalis (2)	455.5 (450.3-460.8)	61.6 (61.3-61.8)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0))	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Polybia parvulina (2)	233.8 (116.9-350.6)	71.7 (67.0-76.4)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)
Polyrhachis vicina (3)	0 (0.0-0.0)	0 (0.0-28.3)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0 (0.0-0.0)	0.0 (0.0-0.0)	0 (0.0-0.0)
Protaetia brevitarsis (2)	208.9 (104.5-313.4)	50.8 (47.5-54.1)	5.5 (2.8-8.3)	243.4 (235.8-250.9)	12.73 (10.9-14.5)	0 (0.0-0.0)	0 (0.0-0.0)	105.8 (52.9-158.7)	0.0 (0.0-0.0)	0 (0.0-0.0)

Edible insect (n)	**Energy (kcal)**	**Protein (g)**	**Fiber (g)**	**Ca[1] (mg)**	**Fe[1] (mg)**	**Vit A (IU)**	**Vit C (mg)**	**Na[1] (mg)**	**SFA[1] (g)**	**Chol[1] (mg)**
Rhynchophorus	602.9	9.8	19.5	1.5	9.2	0	0	16.3	0	0
phoenicis (4)	(589.8-615.0)	(8.9-12.5)	(12.9-21.9)	(0.3-11.0)	(6.4-14.6)	(0.0-0.0)	(0.0-0.0)	(15.2-49.5)	(0.0-0.0)	(0.0-0.0)
Tenebrio molitor	0	52	0	0	0	0	0	0	0	0
(5)	(0.0-444.0)	(51.0-52.4)	(0.0-1.9)	(0.0-39.4)	(0.0-10.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)
Zophobas morio	0	47	0	0	0	0	0	0	0	0
(3)	(0.0-274.7)	(46.5-47.6)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)	(0.0-0.0)
RDV*	**2000**	**60**	**25**	**1000**	**18**	**5000**	**60**	**2400**	**20**	**300**

[1] Column Abbreviations: - Ca: Calcium; Fe: Iron; Na: Sodium; Chol: Cholesterol

n: sample size; figures in brackets (interquartile ranges)

* Reference daily values (RDV) for adults and children 4 or more years of age based on a 2000 calorie intake for nutrients (World Health Organization, 1991; US Food and Drug Administration (FDA), 2007)

Table 4.6 presents the percent Daily Values (%DVs) of the nutrients applied to calculate the RRR scores in this study. Protein had the highest DVs where most of the foods recorded more than 100% DVs and thus truncated at 100. The truncation of DVs helps to shield RRR model from inordinate values especially those arising from food fortification (Scheidt & Daniel, 2004). Only sheep offal had a value for cholesterol (66.7%). Fiber and saturated fatty acid were also scarce across the food items. Considering the food items, most of the edible insects had zero %DVs for most of the nutrients. Examples include *Polyrhachis vicina* Roger, *Tenebrio molitor,* and *Zophobas morio* which had %DVs for only one nutrient each out of the 10 nutrients applied in the model.

Table 4. 6: Percent DVs for recommended and restricted nutrients used in the RRR model

Meat	n	%DVs									
		Energy (kcal)	Protein (g)	Fiber (g)	Ca[1] (mg)	Fe[1] (mg)	Vit A (IU)	Vit C (mg)	Na[1] (mg)	SFA[1] (g)	Chol[1] (mg)
African carp	2	4.68	100*	0.00	2.85	5.00	0.33	0.00	2.15	0.00	0.00
Barracuda	2	4.13	100*	0.00	2.60	5.00	0.47	0.00	3.71	0.00	0.00
Beef	13	10.20	93.29	0.00	0.90	11.67	0.00	0.00	3.46	0.00	0.00
Beef liver	6	6.63	100*	0.00	0.60	43.33	100	2.17	2.88	0.00	0.00
Beef offal	11	5.19	100*	0.00	1.00	25.56	0.93	15.00	5.25	0.00	0.00
Beef tripe	3	4.10	100*	0.00	6.90	3.33	0.00	0.00	4.04	0.00	0.00
Cat fish	9	5.85	100*	0.00	3.80	5.00	0.50	0.00	1.71	0.00	0.00
Chicken	11	6.74	100*	0.00	1.10	6.11	1.13	0.00	2.67	0.00	0.00
Chicken liver	4	5.71	100*	0.00	0.80	47.75	100*	29.92	2.96	3.90	0.00
Chicken offal	7	6.60	100*	0.00	0.65	19.94	0.60	6.17	2.88	6.80	0.00
Crab	2	11.97	93.07	18.38	100*	84.58	1.40	5.83	17.43	0.35	0.00
Duck	3	12.65	78.48	0.00	1.10	13.33	2.60	4.67	3.08	0.00	0.00
Fish	17	6.90	95.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Goat meat	7	7.45	100*	0.00	1.10	13.33	0.00	0.00	3.42	0.00	0.00
Guinea fowl	4	5.27	100*	0.00	3.10	2.33	0.07	0.83	7.44	0.00	0.00
Lamb liver	2	7.30	100*	0.00	0.95	47.22	100*	20.00	2.85	0.00	0.00
Lobster	2	10.52	100*	0.64	100*	81.67	0.00	8.33	6.88	0.00	0.00
Mackerel	4	6.28	100*	0.00	2.45	5.72	1.47	1.50	2.60	0.00	0.00
Mutton	4	12.91	70.32	0.00	1.10	10.56	0.33	0.00	2.83	0.00	0.00

		%DVs									
Meat	**n**	**Energy (kcal)**	**Protein (g)**	**Fiber (g)**	**Ca[1] (mg)**	**Fe[1] (mg)**	**Vit A (IU)**	**Vit C (mg)**	**Na[1] (mg)**	**SFA[1] (g)**	**Chol[1] (mg)**
Nile Perch	3	4.90	100*	0.00	13.30	5.56	1.00	0.00	4.04	0.00	0.00
Pork	7	14.30	70.18	0.00	1.10	7.78	0.00	0.00	2.42	0.00	0.00
Prawn	2	11.25	100*	1.21	5.51	4.17	0.67	0.25	3.98	0.00	0.00
Quail	3	8.75	100*	0.00	1.00	14.44	3.13	10.00	2.21	0.00	0.00
Rabbit	4	6.50	100*	0.00	1.30	7.69	0.33	0.00	1.96	0.00	0.00
Sardine	4	6.22	100*	0.00	7.10	10.00	1.27	0.00	3.21	0.00	0.00
Sheep offal	3	4.68	100*	0.00	1.00	35.56	6.33	33.33	6.50	5.00	66.67
Tilapia	6	4.88	100*	0.00	1.35	5.17	0.00	0.00	2.17	0.00	0.00
Tuna	3	6.95	100*	0.00	1.40	6.11	1.73	0.00	2.13	0.00	0.00
Turkey offal	2	6.02	100*	0.00	1.70	18.00	4.27	7.67	5.75	0.00	0.00
Edible insect											
Acheta domesticus	2	10.87	100*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apis mellifera	5	23.75	70.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blaberus craniifer	2	12.48	100*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bombyx mori	3	22.15	59.92	20.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corisella decolor	2	16.90	100*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macrotermes bellicosus	4	19.54	50.97	7.40	4.89	100*	14.00	0.10	2.85	0.00	0.00
Nasutitermes spp	2	9.60	65.65	70.64	1.30	100*	24.73	0.00	0.35	0.08	0.00
Oecophylla smaragdina	4	0.00	40.22	16.52	0.00	0.00	0.00	0.00	0.00	1.21	0.00
Pachilis gigas	2	23.58	100*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Edible insect	**n**	**%DVs** **Energy (kcal)**	**Protein (g)**	**Fiber (g)**	**Ca[1] (mg)**	**Fe[1] (mg)**	**Vit A (IU)**	**Vit C (mg)**	**Na[1] (mg)**	**SFA[1] (g)**	**Chol[1] (mg)**
Polybia occidentalis bohemani	2	22.78	100*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polybia parvulina	2	11.69	100*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyrhachis vicina Roger	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Protaetia brevitarsis	2	10.45	84.73	22.12	24.34	70.72	0.00	0.00	4.41	0.06	0.00
Rhynchophorus phoenicis	4	30.15	16.35	78.04	0.15	50.83	0.00	0.00	0.68	0.00	0.00
Tenebrio molitor	5	0.00	86.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zophobas morio	3	0.00	78.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

n: sample size
*Values truncated to 100
[1] Column abbreviations - Ca: calcium; Fe: iron; Na: sodium; SFA: saturated fatty acids; Chol: cholesterol

Table 4.7 shows the nutrient data that was applied in calculating the GDA scores for this study. Each data set was used to calculate scores for women, men, and children, respectively. Data for saturated fatty acids and sodium are similar to those used in RRR model (**Table 4.5)**. The fat content was highest in duck (median = 66 g per 100 g) and lowest for *Macrotermes bellicosus* (median = 2.41 g per 100 g). The FDA recommends a total of 65 g of fat in a 2000 Kcal diet (FDA 2007), which indicates that duck would meet the daily value when only 100 g is consumed. But when considering the GDA recommendations for calculating the LIM scores (**Table 4.3**), all the median and 75th percentile values were below the upper limits for women, men, and children, except duck whose 75th percentile value (71.25 g per 100 g) exceeded the upper limit for women and children.

Table 4. 7: Median and interquartile range for nutrients used to calculate GDA scores in 100g of conventional meats and edible insects

Meat (n)	**Fat (g)**	**SFA^1 (g)**	**Na^1 (mg)**
African carp (2)	13.4 (8.1-18.7)	0 (0.0-0.0)	51.5 (48.8-54.3)
Barracuda (2)	0 (0.0-0.0)	0 (0.0-0.0)	89 (89.0-89.0)
Beef (13)	41 (20.8-50.4)	0 (0.00-5.9)	83 (66.0-91.0)
Beef liver (6)	15.2 (13.0-15.2)	0 (0.0-0.9)	69 (69.0-72.0)
Beef offal (11)	14 (14.0-15.6)	0 (0.0-0.5)	126 (90.0-182.0)
Beef tripe (3)	23.4 (22.5-23.4)	0 (0.0-1.0)	97 (71.5-97.0)
Cat fish (9)	24.2 (16.1-24.3)	0 (0.0-0.0)	41 (0.0-48.0)
Chicken (11)	28.7 (12.6-39.7)	0 (0.0-0.8)	64 (47.0-72.0)
Chicken liver (4)	20.4 (18.0-20.4)	0.8 (0.0-1.6)	71 (71.0-71.0)

Meat (n)	**Fat (g)**	**SFA^1 (g)**	**Na^1 (mg)**
Chicken offal (7)	24.1 (17.9-27.5)	1.4 (0.0-1.9)	69 (32.5-75.5)
Crab (2)	0 (0.0-0.0)	0.1 (0.1-0.1)	418.4 (358.1-478.7)
Duck (3)	66.2 (61.1-71.3)	0 (0.0-6.6)	74 (68.5-78.0)
Fish (17)	22.9 (13.9-30.3)	0 (0.0-0.0)	0 (0.0-0.0)
Goat meat (7)	27.4 (19.5-31.8)	0 (0.0-0.4)	82 (82.0-101.5)
Guinea fowl (4)	0 (0.0-0.0)	0 (0.0-0.0)	178.5 (64.8-352.5)
Lamb liver (2)	19.4 (17.6-21.3)	0 (0.0-0.0)	68.5 (67.8-69.3)
Lobster (2)	0 (0.0-0.0)	0 (0.0-0.0)	165 (82.5-247.5)
Mackerel (4)	25.4 (21.8-25.9)	0 (0.0-0.6)	62.5 (59.0-71.0)
Mutton (4)	54.4 (53.8-55.4)	0 (0.0-2.4)	68 (59.5-76.0)
Nile Perch (3)	8.4 (6.2-10.3)	0 (0.0-0.0)	97 (77.5-236.5)
Pork (7)	55.14 (54.96-66.22)	0 (0.00-1.32)	58 (48.50-64.00)
Prawn (2)	0 (0.0-0.0)	0 (0.0-0.0)	95.5 (47.8-143.3)
Quail (3)	26.3 (20.4-32.1)	0 (0.0-0.4)	53 (51.0-53.0)
Rabbit (4)	13.38 (11.42-15.30)	0 (0.00-0.17)	47 (41.00-54.75)

Meat (n)	**Fat (g)**	**SFA[1] (g)**	**Na[1] (mg)**
Sardine (4)	25.7	0	77
	(18.6-40.5)	(0.0-0.0)	(67.3-116.5)
Sheep offal (3)	14.4	0.9	156
	(13.6-14.9)	(0.9-0.9)	(138.5-156.5)
Tilapia (6)	6.7	0	52
	(6.3-11.5)	(0.0-0.0)	(13.0-56.5)
Tuna (3)	11.8	0	51
	(9.1-14.5)	(0.0-0.0)	(50.5-51.0)
Turkey offal (2)	0	0	138
	(0.0-0.0)	(0.0-0.0)	(133.5-142.5)
Edible insect (n)			
Acheta domesticus (2)	17.2	0	0
	(17.0-17.5)	(0.0-0.0)	(0.0-0.0)
Apis mellifera (5)	20.6	0	0
	(19.8-21.5)	(0.0-0.0)	(0.0-0.0)
Blaberus craniifer (2)	23.2	0	0
	(22.6-23.7)	(0.0-0.0)	(0.0-0.0)
Bombyx mori (3)	27.1	0	0
	(27.1-28.9)	(0.0-0.0)	(0.0-0.0)
Corisella decolor (2)	8.4	0	0
	(7.7-9.0)	(0.0-0.0)	(0.0-0.0)
Macrotermes bellicosus (4)	2.4	0	68.5
	(1.6-8.4)	(0.0-0.0)	(60.8-152.3)
Nasutitermes spp (2)	14.16	0.02	8.5
	(13.71-14.60)	(0.01-0.03)	(4.25-12.75)
Oecophylla smaragdina (4)	12.1	0.2	0
	(10.4-19.3)	(0.0-0.5)	(0.0-17.9)
Pachilis gigas (2)	22.7	0	0
	(20.9-24.6)	(0.0-0.0)	(0.0-0.0)
Polybia occidentalis (2)	23.7	0	0
	(21.4-26.0)	(0.0-0.0)	(0.0-0.0)

Edible insect (n)	**Fat (g)**	**SFA[1] (g)**	**Na[1] (mg)**
Polybia parvulina (2)	8.6 (4.3-12.8)	0 (0.0-0.0)	0 (0.0-0.0)
Polyrhachis vicina (3)	9 (7.7-12.1)	0 (0.0-0.0)	0 (0.0-0.0)
Protaetia brevitarsis (2)	12.9 (11.7-14.1)	0 (0.0-0.0)	105.8 (52.9-158.7)
Rhynchophorus phoenicis (4)	56.9 (51.6-61.6)	0 (0.0-0.0)	16.3 (15.2-49.5)
Tenebrio molitor (5)	32 (31.0-32.9)	0 (0.0-0.0)	0 (0.0-0.0)
Zophobas morio (3)	35 (34.5-37.3)	0 (0.0-0.0)	0 (0.0-0.0)

n: sample size
values in brackets (interquartile ranges)
[1]Column abbreviations: SFA: saturated fatty acids; Na: sodium

It is evident that both edible insects and conventional meats have varied nutritional contents. Edible insects had a more profound variation than conventional meats. This is attributable to differences in individual species traits (Nowak et al., 2016). Among the selected insects, sodium was not detected and this is a vital impetus to encourage the adoption of insects in the daily diets since there is need to reduce sodium consumption so as to reduce diet-related diseases (Van Horn et al., 2016). Additionally, all the edible insects reported no cholesterol and this is good news for the promotion of edible insects to be consumed liberally, since dietary cholesterol is associated with cardiovascular events (Carson et al., 2020)

Reduced intake of cholesterol in diet has a beneficial outcome on cardiovascular health (Van Horn et al., 2016). Due to nutrient variability, promotion of edible insects' consumption should be species-specific. Fiber is an important food component having positive effects on human health (Anderson et al., 2009), but it was largely absent in foods under the current study. Though some few edible insects and crab contained some amount of fiber, the lack of fiber in these animal-based foods should be expected since fiber is principally a plant-based nutrient (Anderson et al., 2009).

The presence of fiber in edible insects is mainly due to chitin which is the main component of the insects' exoskeleton (Akhtar & Isman, 2017).

4.3.2: Nutrient profiles of edible insects and conventional meats

4.3.2.1: WXYfm nutrient profile scores

Figure 4.1 represents median values for WXYfm scores of edible insects and conventional meats under study. All the meats and edible insects in this study were classified as healthful by the WXYfm scoring system since they were all below the target of 4. The most frequent median score was -4 with 26.7% followed by -3 with 15.6% of the total foods evaluated. Out of all the food items evaluated, 97.8% had median value scores of 0 and below, and only one food item scored above 0 (*Pachilis gigas:* median = 0.5). Accordingly, the edible insect *Pachilis gigas* would be classified as intermediate healthful since the WXY score is above 0 but less than 4 (Mike Rayner, 2009). *Rhynchophorus phoenicis* was significantly different from *Pachilis gigas* (p = 0.0011). Seven edible insects (*Rhynchophorus phoenicis*, *Nasutitermes spp.*, *Oecophylla smaragdina*, *Acheta domesticus*, *Bombyx mori*, *Terebrio molitor*, and *Zophobas morio*) had more favorable scores than all the conventional meats evaluated. In Kenya, *Acheta domesticus* (house crickets) and *Nasutitermes spp* (termites) are available and are regularly consumed in Siaya county (Pambo et al., 2018)

Overall, all the foods evaluated in this study can be promoted for consumption by everyone. In a different study, beef offal was classified as more healthful than crickets, mealworms, and palm weevil larvae (Payne et al., 2015). In the current study, however, some specific edible insects, i.e *Rhynchophorus phoenicis* (palm weevil), *Nasutitermes spp* (termite)., and *Oecophylla smaragdina* (green tree ant) would be a better choice since they scored better than other conventional meats such as duck, pork, and beef. It would therefore be advisable to consider species-specific edible insects based on the healthfulness scores when promoting alternatives to conventional animal-based foods.

The demand for more affordable and healthful alternatives to animal protein has been growing in Africa with edible insects being the suitable candidates to replace the expensive and scarce meat products (Raheem et al., 2019). This study is therefore timely in providing data on healthfulness of edible insects for consumers to make informed choices to meet this demand. The current data does not place edible insects as superior to conventional meats, but as ‘equals’, based on their comparable healthfulness, hence providing variety of choices. The study therefore does not condemn the consumption of conventional meats in any way. Nonetheless, the choice of edible insects over conventional meats has non-nutritional advantages including faster production, less carbon emissions, less feed and water, less land space, more feed conversion ratio, and a higher percentage of edible body weight (Baiano, 2020). Though insects are consumed as a cultural practice or tradition, non-insect eaters are accepting these unique foods due to promotion of edible insects through insect-based processed products (Pambo et al., 2018).

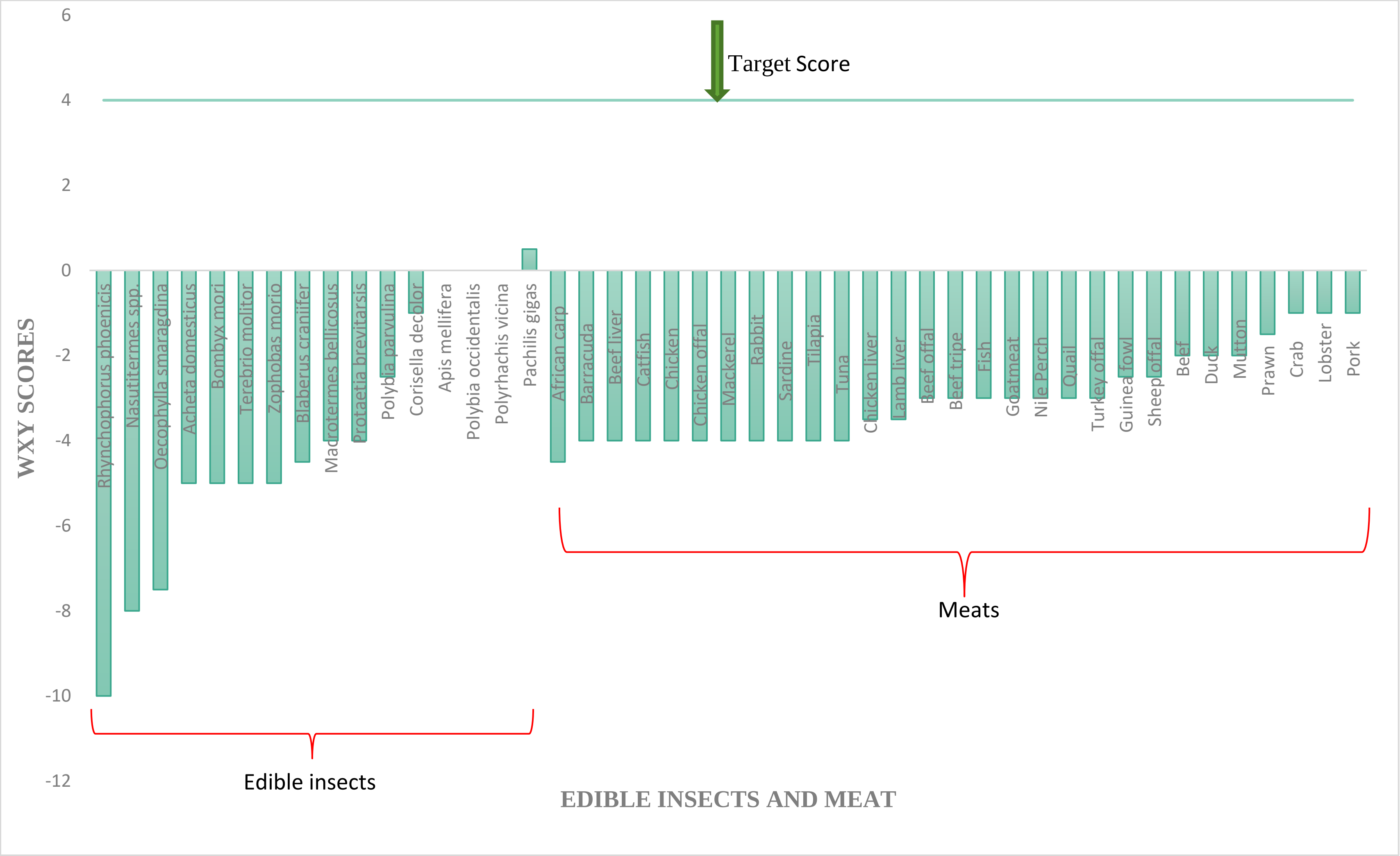

Figure 4. 1: Median WXYfm scores for edible insects and meat

4.3.2.2: RRR nutrient profile scores

The median values for RRR scores of edible insects and conventional meats in the study are presented in **Figure 4.2**. With the exception of *Polyrhachis vicina* (ants) and duck (median = 0 & 0.83, respectively), all the food items evaluated using the RRR model were categorized as healthful since they scored above the target of 1. The edible insect *Nasutitermes spp.* (termites) had the highest score (median = 62.26), followed by chicken liver, beef liver and lamb liver (median = 18.88, 18.63 & 18.32, respectively) while *Polyrhachis vicina* (ants) had the lowest score (median = 0). There were no significant differences in the scores ($\alpha = 0.05$).

In addition, there was no clear classification of edible insects as more healthful than conventional meats by the RRR model, as depicted by different edible insects having similar median scores as the conventional meats, e.g., guinea fowl, *Oecophylla smaragdina* (green tree ant), goat meat, and *Corisella decolor* (water boatman) (median = 4.12, 4.16, 4.21, & 4.89, respectively); Nile perch, mutton, sheep offal, and *Apis mellifera* (honey bee) (median = 2.43, 2.64, 2.7 & 2.87, respectively); mackerel and *Macrotermes bellicosus* (termites) (mean = 7.40 & 7.49, respectively); and *Blaberus carniifer* (cockroaches), tuna, *Polybia parvulina* (wasp), *Acheta domesticus* (house cricket), and lobster (median = 10.01, 10.03, 10.12, 10.25 & 10.51, respectively), among others. But, the specific scores are helpful in guiding the choice of one food item over the other, with a higher score always being a better choice, since RRR is a nutrient density scoring model (Scheidt & Daniel, 2004).

The RRR model classified edible insect *Polyrhachis vicina* (ants) and duck as unhealthful and *Nasutitermes spp* (termites).as the most healthful. The choice of a better alternative food item within a food category can be determined by RRR model as demonstrated in this study. In the edible insects' category, *Nasutitermes spp* (termites) would be a better choice than *Polyrhachis vicina* (ants). Similarly, liver from chicken, beef, and lamb are a better choice than duck and pork, while the African carp is a better healthful choice than the Nile perch. Making dietary choice is very intricate (Sobal & Bisogni, 2009) and it is influenced by multidimensional factors with the most outstanding being healthfulness, sensory appeal, convenience, and price (Neacsu et al., 2017).

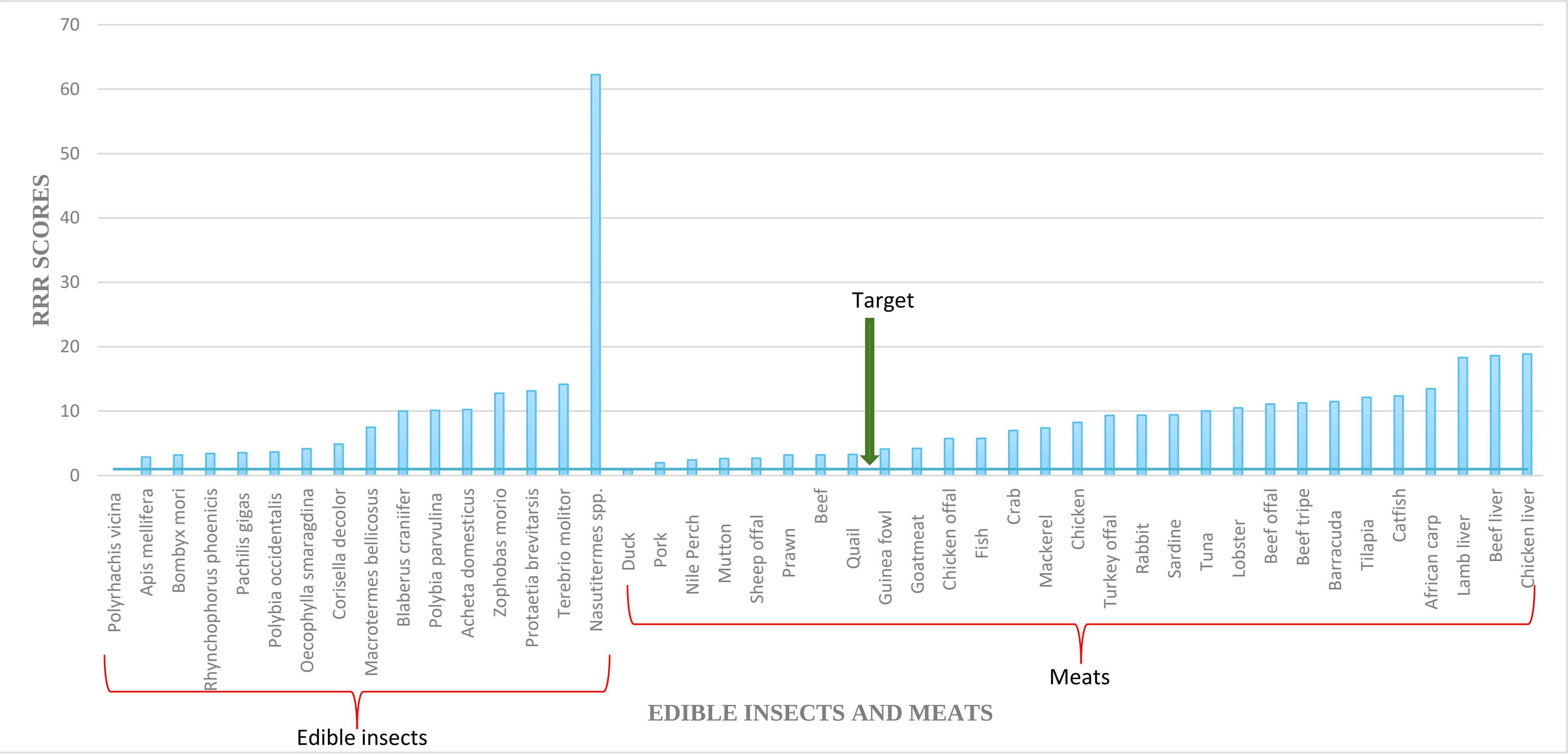

Figure 4. 2: Median RRR scores for edible insects and conventional meats

4.3.2.3: GDA nutrient profiling scores

Figure 4.3 depicts the median values for GDA scores of edible insects and conventional meats included in the study. The target score for the GDA scoring system is 1, in which scores above 1 mean the food is unhealthful and those below the target represent healthfulness. Only duck (median = 1.31 & 1.32 for women and men, respectively) was categorized as unhealthful by the GDA scoring system. Based on nutritional requirements for children aged 5 to 10 years, the duck had a median score of 0.95 which is borderline unhealthful. Two edible insects, *Macrotermes bellicosus* (termites) with a median score of 0.06 (women) and 0.05 (men), and *Polyrhachis vicina* (ants) (median = 0.01, children) were classified as the most healthful food items according to GDA model.

Overall, some edible insects performed significantly ($p < 0.0001$**)** better on healthfulness based on the GDA scoring system compared to conventional meats, namely *Macrotermes bellicosus* (termites) (median = 0.06, 0.05, & 0.01 for women aged above 19 years, men aged 19 years and above, and children, respectively), *Corisella decolor* (water boatman) (median = 0.12 & 0.09 for women and men, respectively), *Polybia parvulina* (wasp) (median = 0.12 & 0.09 for women and men, respectively), and *Polyrhachis vicina* (ants) (median = 0.13, 0.09, & 0.07 for women, men and children, respectively). The Nile perch (median = 0.14 & 0.11 for women and children, respectively), tilapia (median = 0.14, 0.15, & 0.11 for women, men and children, respectively), and tuna (median = 0.19 & 0.15 for women and children, respectively) were categorized more favorably by the GDA model than all the other conventional meats under study. Pork (median = 0.86, 0.87, & 0.72 for women, men and children, respectively), mutton (median = 0.82, 0.835, & 0.72 for women, men and children, respectively), and beef (median = 0.75, 0.75, & 0.56 for women, men and children, respectively) compared closely with *Rhynchophorus phoenicis* (palm weevil) (median = 0.83, 0.615, & 0.85 for women, men and children, respectively) and were classified as the least healthful by the GDA model.

The LIM scoring system, GDA, used in the current study categorizes foods under three subgroups, viz. women, men, and children. Foods under women and men were almost similarly classified, in terms of healthfulness, although the specific scores had differences. The duck was classified as unhealthful for both women and men, and borderline healthful for children. *Macrotermes* *bellicosus* (termites) was the most healthful for both women and men, while *Polyrhachis vicina* (ants) was the most healthful for children based on the LIM scores. Accordingly, duck is an unhealthful food choice and therefore should be consumed sparingly.

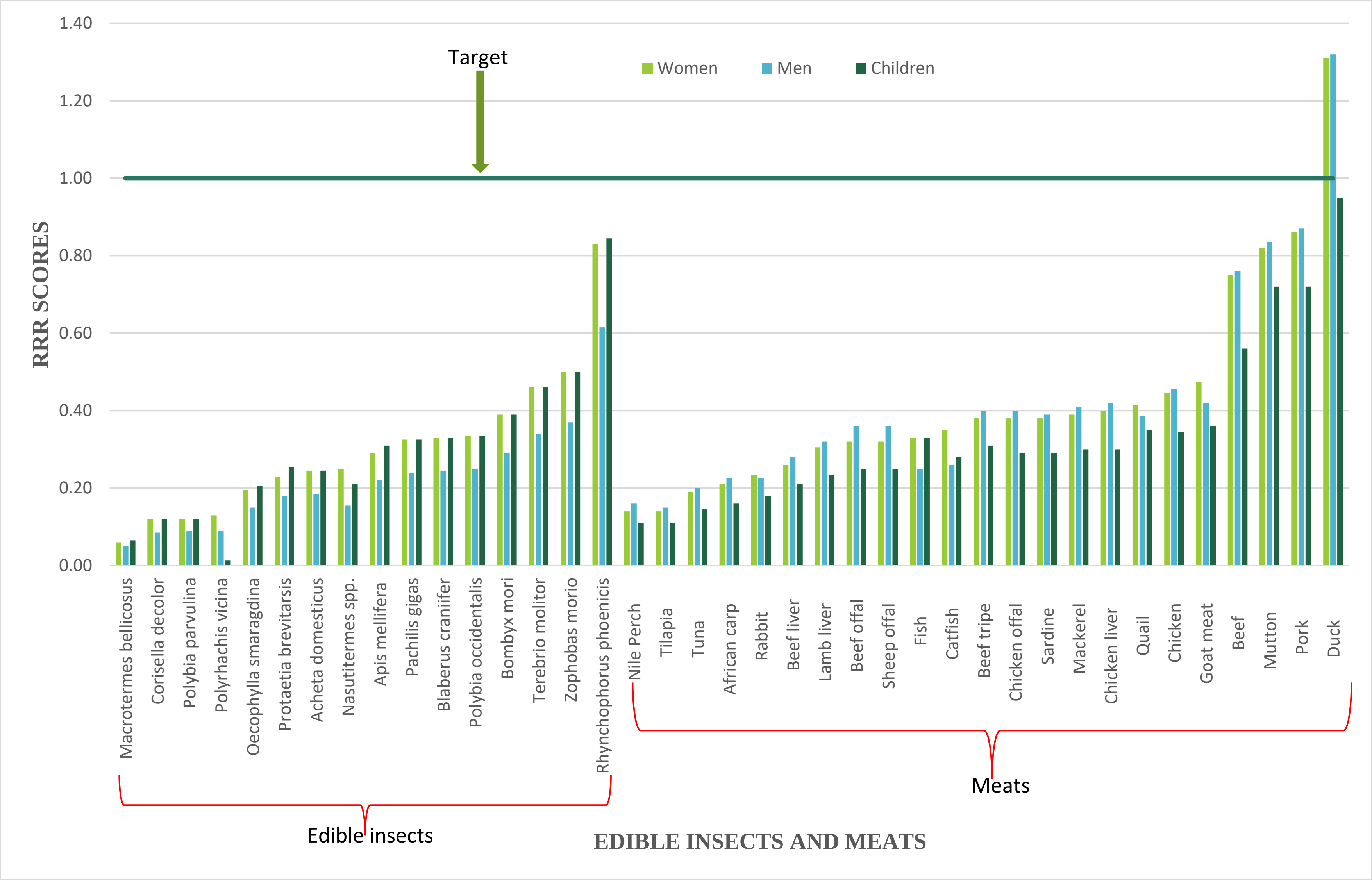

Figure 4. 3: Median GDA scores for edible insects and conventional meats

It is clear that insects would be a better choice in terms of healthfulness. Additional benefits of choosing edible insects include environmental conservation, animal welfare, and affordability (Machovina *et al.*, 2015; Schönfeldt and Hall, 2012). Further, animal-based foods have been associated with lifestyle-related illness like cardiovascular events, cancer, and diabetes (Schönfeldt & Hall, 2012) in addition to environmental degradation with adverse effects on water sources, soil fertility, biodiversity, and climate (Machovina *et al.*, 2015; Revell, 2015).

In order to encourage consumption of foods from edible insects by non-traditional consumers, issues related to availability, acceptability - including palatability, the yuck factor, and regulatory framework need to be addressed (Pambo et al., 2018). A study carried out in Kenya on willingness to pay for termite-based food products, revealed that high nutritional value (healthfulness), food safety assurance, and recommendation by a nutritionist were positively correlated with purchase intentions, notwithstanding the existence of the custom of consuming edible insect (Alemu et al., 2015). It is therefore imperative to have concerted efforts from all the players, and especially producers of edible insects-based foods, nutritionists, and government regulators in augmenting the uptake of these novel foods.

4.3.2.4: Comparison of healthfulness outcomes between WXYfm, RRR, and GDA models

When comparing the healthfulness outcomes from the three models employed, the study found that classification of the same foods was not identical, but near similar. For instance, the WXY model classified *Rhynchophorus phoenicis* (palm weevil) as the most healthful, while RRR model's most healthful was *Nasutitermes spp.* (termites) The GDA model classed *Macrotermes bellicosus* (termites) (women and men) and *Polyrhachis vicina* (ants) (children) as most healthful. It is worth noting that *Polyrhachis vicina* (ants) was classified as unhealthful by RRR model. But this can be explained by *Polyrhachis vicina* (ants) missing values for 10 out of 11 nutrients used to calculate the RRR score. The missing values are attributable to missing data points in the source data (Weru et al., 2021). On the other hand, both RRR and GDA models gave duck the same verdict of being unhealthful. The lack of data points for some of the nutrients, e.g., vitamin C and sodium, used by the nutrient profiling models had an undue influence on the healthfulness outcomes. For instance, if a negative nutrient lacks data, the model would pick that as a zero, which may not have been the case and hence imputing a 'positive' sense to the healthfulness of the food in question. Conversely, if a positive nutrient lacks data, then a ‘negative’ sense is attributed to the healthfulness of that particular food.

As mentioned earlier, WXY model did not classify any food as unhealthful, and so the duck would be acceptable healthful-wise, according to the model. It should however be recognized that these models use different parameters and algorithms hence the varied outcomes are not surprising. The WXY model uses 4 negative and 3 positive nutrients while RRR model uses 6 positive and 5 negative nutrients which would invariably generate differences in healthfulness. The inclusion of fruits, vegetables, and nuts (FVN) in the WXY model also influenced the scores negatively in this study since the food items under consideration were purely of non-plant material.

4.4: Conclusions and recommendations

This study has elevated the need for considering the healthfulness of foods to enhance dietary choice for better nutrition. Foods can look nutritious based on the nutritional content on the food label but could be unhealthful and thereby misleading to consumers. The models used here can be applied to other foods based on need.

The call for replacing conventional meats with edible insects therefore needs to be based on actual healthfulness of the specific foods. In this study, edible insects performed better in general compared to other animal-based foods in regards to relative healthfulness. Except the duck, all other meats were classified as healthful and thus, we cannot conclude that they should be avoided or removed from the diet. But it is important to compare their healthfulness so that one is able to select the better alternatives amongst the food items, thereby getting the full benefits of healthful choices, since healthful diets impart health benefits to the consumer

Due to different parameters applied by various nutrient profiling models, it would be helpful to consider the purpose of each model before applying it to various foods. For instance, GDA is purely a LIM scoring system aimed at reducing the intake of sodium, sugar, fat, and saturated fatty acids in our diets, and for regulating health claims on foods. Therefore, if the aim is to reduce negative nutrients in the diet, or to determine if a food should carry a health claim or not, then the GDA model should be chosen. In this study, and for the evaluation of insect-based foods, RRR model would be the most appropriate to use since it applies both positive and negative nutrients to generate a nutrient-density score.

Edible insects should be evaluated on a species-to-species basis when considering them as suitable alternatives to conventional meats, in view of healthfulness alone. Beyond that, and seeing that only one of them (*Polyrhachis vicina* (ants)) was classed as unhealthful by RRR only, edible insects are a more sustainable food choice compared to conventional meats due to other non-nutritional benefits such as environmental sustainability and may not risk consumers to problems associated with lifestyle diseases.

CHAPTER FIVE

HEALTHFULNESS AND COST-EFFECTIVENESS OF REPLACING CONVENTIONAL MEATS WITH EDIBLE INSECTS IN RECIPES

5.1: Introduction

Different cuisines represent diverse cultures of the world we live in, and recipes derived from specific cuisines can predict the health of the people in that specific culture (Min et al., 2018) since recipes can be used to determine the healthfulness of food (Mejova et al., 2015). Depending on the source, recipes can influence food choice and the ensuing nutritional intake thereby affecting the nutritionally related public health issues of a population (Jones & Freeth, 2013). In East Africa, for instance, 'nyama choma' (roasted meat) is a cuisine associated with affluence and the recipe include beef or goat meat that is roasted and eaten in the company of friends and associates, and plentiful amounts of alcohol are consumed. This has evolved into a 'nyama choma' culture and it could have both positive and negative public health outcomes since on the one hand, meat is nutrient-dense, and on the other, alcohol and red meat overconsumption have been associated with lifestyle illnesses (Gorski et al., 2016).

With the advancement of information technology and the Internet of Things (IOT), recipes can be accessed easily with the click of a button on recipe websites like Allrecipes (https://www.allrecipes.com), giving users diversity of food choices to pick from (Li & McAuley, 2020). In Africa, most of the recipes and cuisines are handed down to children through word of mouth from grandmothers and mothers, while television and radio cookery programs reinforce and/or supplement the cooking techniques taught (Cusack, 2000). As exemplified in Kenya, newspapers, magazines, and internet blogs also feature articles and columns on cuisines and they influence food recipes, what people eat, and how they eat it. More than 500 recipe-based blog posts were identified in Kenya between 2014 to 2020 (O\'Neill, 2020).

A recent study in Nakuru County, Kenya, revealed 33 traditional recipes offered in hotels and restaurants (Zocchi & Fontefrancesco, 2020). Nationally, a recipe book is available in Kenya containing 142 mixed recipes, and includes methods of preparing the food (FAO/GoK, 2018b). In Malawi, the national food composition table contains recipes with nutrient content of the ingredients also provided (Averalda et al., 2019). Apart from Kenya, Malawi is the only other country with a publicly available national recipe book which is part of the food composition tables of the country. This would therefore provide a good basis for comparison of diets with Kenya. In addition, there is a lot of similarities of recipes between the two countries. For example, samosa, beef stew, and *omena* stew are common meat-based cuisines in Kenya and Malawi.

The price of food can affect its purchase, thereby affecting how much and/or how often the food item is consumed, in which case, a change in the price of food will cause a change in consumption of that particular food (Andreyeva et al., 2010). Diet costs and food prices could hinder the shift by consumers from unhealthful diets to healthful ones, especially among the poor, because more healthful foods invariably cost more than less healthful food items (Maillot et al., 2007).

The price of meat from conventional livestock e.g., beef, poultry, pork, and fish continues to increase thereby creating demand for more affordable, but healthful alternatives, and edible insects could present a suitable choice (Raheem et al., 2019). Dietary guidelines should take into account both the healthfulness (nutrient profiles) and the cost of foods (or nutrients) so as to help consumers select the most affordable yet nutritious diets (Maillot et al., 2007).

It is not yet clear if replacing conventional meats with edible insects in diets would have a positive effect on the nutritional profiles of the diets or not, and if such a substitution would be cost-effective. Most studies have focused on the nutritional value of edible insects without delving into their inclusion in recipes to replace conventional meats. Substituting meats with edible insects would be an important step towards realizing universal consumption of these novel foods. If the substitution would improve the healthfulness of diets and be cost-effective, then an impetus would be achieved towards better nutrition.

Some of the common insects consumed in Kenya and Malawi are grasshoppers, crickets and termites (Magara et al., 2021; Raheem et al., 2019; Mikkola, 2012). Replacing meat recipes with these insects may therefore be the most viable option. This study therefore sought to evaluate the healthfulness and cost of recipes whose meat were replaced with the three insects. The results would guide consumers in making food choices that are healthful and affordable at the same time, and choices that are favorable to environmental conservation.

5.2: Materials and methods

5.2.1: Healthfulness of conventional meat recipes

5.2.1.1: Nutritional data of conventional meat recipes

Conventional meat recipes nutrient data were obtained from Kenyan Food Recipes 2018 book (FAO/GoK, 2018b) and Malawi Food Composition Table 2019 (Averalda et al., 2019). The selected data sources are comprehensive, are recent, and contain latest recipe data sets. All meat recipes were carefully identified, extracted and recorded in an excel workbook for further processing. The recipe data extracted included the names of the recipes, the ingredients, the amount of ingredients, the edible conversion factors of each ingredient. The edible amounts of each recipe ingredient were calculated as follows:

$$Edible\ Amount = Ingredient\ quantity\ X\ Conversion\ factor \text{ .... Eq 5.1}$$

The nutritional data of all the recipes was obtained by retrieval from the respective Food Composition Tables of Kenya and Malawi (FAO/GoK, 2018a; Averalda et al., 2019) and the data was recorded for each of the ingredients. The total amount of each nutrient, e.g., protein, was calculated for each meat recipe, e.g., beef stew, by summing up all the nutrient quantities for each of the nutrients in the recipe. To standardize the data, all the recipe nutrient quantities were converted to per 100 g for use in evaluating the healthfulness of the meat recipes. For instance, the total amount of protein in beef stew recipe (Kenya) was 182.74 g from a total recipe amount of 2067 g. Conversion of protein in beef stew to per 100 g was done as follows:

$$Protein\ per\ 100g\ food = \frac{182.74}{2067}\, x\ 100 = 8.84g \text{ .... Eq 5.2}$$

5.2.1.2: Nutrient profile scores of conventional meat recipes

Using the nutritional data obtained in subsection 5.2.1.1, nutrient profile scores were generated to get the healthfulness of the meat recipes using three nutrient profiling models: WXYfm, RRR, and GDA, as described in chapter 4.2.2.

5.2.2: Healthfulness of conventional recipes whose meats are replaced with edible insects

5.2.2.1: Nutritional data of conventional recipes whose meats are replaced with edible insects

Cricket, termite, and grasshopper were selected to replace meats in the conventional meat recipes. These insects are some of the most consumed in Africa (Raheem et al., 2019) and their nutritional data is available in food composition tables. The meat items in the conventional meat recipes were substituted with the selected edible insects to create ‘new’ recipes constituting edible insects as the main ingredients, while all the other recipe ingredients remained the same. These ‘new’ recipes were renamed ‘edible insects-substitute recipes’. Nutritional data of the edible insects were obtained from systematic review data presented in Chapter 3 and published by Weru et al. (2021). The nutritional data of all other ingredients was obtained and processed as described in subsection 5.2.1.1.

5.2.2.2: Healthfulness of edible insects-substitute recipes

The healthfulness of edible insects-substitute recipes was evaluated by applying the data obtained in subsection 5.2.2.1 to the three nutrient profiling models: WXYfm, RRR, and GDA, as described in subsection 4.2.2.

5.2.3: Cost of recipes

5.2.3.1: Cost of conventional meat recipes

The prices of all the ingredients constituting the conventional meat recipes were obtained and recorded for each of the ingredients. The price data was searched out between May and June, 2021 from the following online market places:

1. FarmLink MarketPlace (farmlinkkenya.com) (Farmlinkkenya, 2021)
2. Selina Wamucii | Global Food and Agriculture Marketplace (Selina Wamucii, 2021)
3. M-Farm (https://www.mfarm.co.ke/) (M-Farm, 2021)
4. Melbur FOODS (https://foods.melbur.co.ke/) (Mercy and Muya 2021)

5. https://jiji.co.ke/ (jiji.ke, 2021)
6. Yaoota (https://yaoota.com/en-ke/) (Yaoota, 2021)
7. https://www.jumia.co.ke/ (Jumia Kenya, 2021)

Where the price was indicated in US dollars, the value was converted into Kenya shilling (Ksh) using the prevailing rate by Central Bank of Kenya (CBK). The price data was then computed to obtain the total cost of each of the meat recipes. For standard comparisons, the recipe amounts were converted to 100g.

5.2.3.2: Cost of edible insects-substitute recipes

Price data for cricket, termite, and grasshopper were obtained from published articles (Caparros Megido et al., 2016; J. N. Kinyuru & Ndung'u, 2020; Kisaka et al., 2018; M. W. Mmari et al., 2017; Odongo et al., 2018).. The prices for all the other ingredients in the recipes were maintained as obtained and described in subsection 5.2.3.1.

5.2.4: Data analysis

A two samples T-test (Tukey's Studentized Range (HSD) Test (The SAS System)) was performed to compare the healthfulness scores (WXYfm, RRR, and GDA) and cost of conventional meat recipes and edible insects-substitute recipes between Kenya and Malawi while a paired T-test compared data from within each country.

5.3: Results and discussion

5.3.1: Nutrient content of conventional meat recipes and edible insects-substitute recipes

A total of 21 conventional meat recipes were retrieved from the Kenyan FCT and 13 were obtained from Malawian FCT. Beef stew, fried tilapia, *matoke*, meat samosa, and *omena* stew (silver sardine stew) recipes appeared in both Kenya and Malawi FCTs. However, the nutritional value of the recipes was dissimilar owing to the different ingredients included, and this could be explained by cultural differences in the two countries since the culture of a people greatly influences what specific ingredients or food items are included in their food recipes or cuisines (Gorski et al., 2016). To cite an example, **Table 5.1** shows the ingredients in beef stew as recorded from Kenyan and Malawian FCTs, respectively. It is important to note that the quantities of the ingredients were standardized to per 100g of the recipes for ease of comparisons. Salt and fat (cooking oil) are two important ingredients that should be limited in diet and that are included in the Kenyan beef stew. This would be expected to have an impact on both the nutrient value and healthfulness of the recipes, since ‘negative’ nutrients have a negative influence on the nutrient profile scores. Not surprisingly, the energy value and sodium content are higher in Kenyan beef stew (energy = 80.96 kcal, Na = 112.98mg per 100g) than in Malawian beef stew (energy = 56.59, Na = 16.48mg per 100g) (**Table 5.2**). The absence of salt and cooking oil in the Malawian beef stew recipe can explain the low salt and energy values. It is possible that the Malawians don’t include salt and cooking oil when preparing beef stew based on the recipe provided (**Table 5.1)**.

Table 5. 1: Beef stew recipes from Kenyan and Malawian FCTs

Kenya	Amount	Malawi	Amount
Beef, medium fat without bone, raw	1kg	Beef, raw	80g
Onions - red skinned raw unpeeled	164g	Tomato, ripe, raw	48g
Tomatoes, red ripe	304g	Water	25g
Salt, iodized	3g	Onion, raw	14g
Cooking oil	20g		
Water	682g		

Table 5.2 shows the nutrient data applied in the models to evaluate the healthfulness of the conventional meat recipes. Overall, the highest energy content was in Kenyan fried tilapia (energy = 599.42 kcal/100g) while the lowest was in Malawian fish powder stew (energy = 33.44 kcal/100g). Fat was highest in Kenyan fried tilapia (fat = 63.35g/100g) and lowest in Malawian fish powder stew (fat = 1.3g/100g). The British Nutrition Foundation recommends a daily reference intake (RI) of 70g of fat, based on a 2000kcal diet (British Nutrition Foundation, 2019). Consequently, the Kenyan fried tilapia would meet 90.5% of the recommended daily amount of fat, when only 100g is consumed. Sodium content was highest in Kenyan stewed goat meat (Na = 585.61mg/100g) and the lowest was in Malawian fried tilapia (Na = 0.32mg/100g). Interestingly, all the recipes from Malawi, except lake sardine stew, had lower sodium contents (range = 0.32 – 62.38mg/100g) than all the Kenyan recipes (range = 69.53 – 585.61mg/100g). A 2019 report by UNICEF showed lower household consumption of iodized salt in Malawi compared with Kenya (UNICEF, 2019). Additionally, all Malawian recipes had zero cholesterol. Saturated fat content

was below the RI of 20g per day for all the recipes in this study. The diversity of ingredients in the various recipes would invariably yield differences in nutrient content between Kenyan and Malawian recipes.

The human body requires iron throughout life, but iron requirements are high in infants, adolescents, and menstruating women. These high iron needs can be met through diets having adequate amounts of meat and foods with plenty amounts of ascorbic acid, or through enriching commercial food products with iron and ascorbic acid (FAO & WHO, 1998). The highest iron content was in Malawian beef liver stew (Fe = 6.52mg/100g) which would meet the daily iron requirements for children 4 to 6 years old (6.1 mg/day) (British Nutrition Foundation, 2019), with the lowest being in Kenyan stewed quails (Fe = 0.58mg/100g).

Table 5. 2: Nutrients used to calculate nutrient profile scores in 100g of conventional meat recipes

RECIPES	**Energy (kJ)**	**Energy (kcal)**	**Protein (g)**	**Fat (g)**	**Fibre (g)**	**Ca (mg)**	**Fe (mg)**	**Na (mg)**	**Vit A (IU)**	**Vit C (mg)**	**Chol (mg)**	**SAFA (g)**
Kenya												
Aluru (stewed quails)	1655.68	401.98	4.15	41.67	0.25	38.96	0.58	241.99	94.41	3.99	17.93	6.55
Beef Stew	338.29	80.96	8.84	4.14	0.38	5.99	5.60	112.98	40.71	4.42	27.43	1.69
Biryani Stew	605.65	146.09	4.78	11.43	1.21	19.05	3.08	348.87	106.59	10.74	12.33	2.22
Fried chicken	2053.57	497.71	10.69	49.54	0.00	7.65	1.43	299.36	151.36	0.69	56.60	8.49
Fried *omena*	1544.89	374.11	12.20	35.26	0.68	553.93	1.79	257.88	187.30	11.71	192.20	5.75
Fried Tilapia	2468.94	599.42	7.21	63.35	0.00	40.08	0.99	227.29	24.78	0.00	23.07	9.64
Hydrabadi Biryani	453.80	108.27	3.32	5.13	0.62	21.77	0.72	279.80	98.60	2.25	6.32	0.70
Matoke	269.49	63.99	2.69	1.73	1.19	8.55	1.76	219.80	57.05	7.97	5.66	0.32
Meat samosa	1541.49	371.56	7.56	29.71	1.22	19.53	4.56	69.53	125.05	2.98	15.19	5.07
Minced meat balls	377.16	90.50	6.58	5.46	0.61	10.11	4.21	183.79	62.85	4.89	19.27	1.56
Okra meat dish	357.87	85.72	7.31	4.60	1.26	22.04	4.73	309.48	120.78	10.62	20.75	1.48
Omena (silver sardine stew)	670.34	162.07	5.49	14.10	0.45	237.57	0.76	294.83	143.95	4.92	77.07	2.62
Pilau (spiced rice)	640.93	153.05	3.78	7.73	0.72	11.96	1.95	284.19	32.45	3.42	6.52	1.42
Qanchibelo (Beef, Maize & Wheat Flour mix)	362.17	86.08	6.13	1.99	1.72	38.27	3.62	139.30	122.71	17.19	14.27	0.83
Stewed chicken	513.50	122.97	10.50	7.00	0.79	13.12	1.73	290.81	193.08	13.81	52.72	1.98
Stewed dried fish	653.01	157.33	10.09	12.23	0.88	75.03	1.00	79.35	130.11	7.74	0.00	1.38
Stewed goat meat	691.58	166.16	11.79	11.49	0.52	10.75	1.45	585.61	77.00	6.57	57.15	3.63
Stewed guinea fowl	343.64	82.37	9.13	4.63	0.28	17.04	1.11	382.41	26.08	3.90	37.91	0.48
Stewed Nile perch	547.02	130.46	19.28	5.46	0.24	141.05	1.20	371.62	185.36	3.01	0.00	0.39
Stir fried beef	369.88	88.63	8.90	4.94	0.39	6.16	5.64	188.55	40.38	4.38	27.60	1.82
Stir fried goat meat	389.45	93.26	8.37	5.37	0.41	8.51	1.06	216.07	60.93	5.61	40.41	2.15

RECIPES	Energy	Energy	Protein	Fat	Fibre	Ca	Fe	Na	Vit A	Vit C	Chol	SAFA
Malawi	**(kJ)**	**(kcal)**	**(g)**	**(g)**	**(g)**	**(mg)**	**(mg)**	**(mg)**	**(IU)**	**(mg)**	**(mg)**	**(g)**
Beef mince, fried	573.19	137.31	13.77	8.017	0.378	83.55	6.138	38.1	0.933	1.62	0	0.721
Beef stew	239	56.59	6	1.31	0.273	151.27	6.46	16.48	40.24	4.53	0	0
Beef, liver, stew	353.67	84.79	3.491	5.101	1.24	280.69	6.516	16.54	2154	20.3	0	0.4496
Chicken stew	557.24	133.73	16.62	6.394	0.603	108.14	2.62	36.06	52.07	10.47	0	0.229
Fish powder stew	139.8	33.44	2.156	1.304	0.832	222.68	5.09	3.4	61.599	6.52	0	0
Fish, catfish, fresh, fried	694.68	166.56	14.49	9.463	0.096	35.11	1.386	62.38	109.57	0	0	0.309
Fish, tilapia, fresh, fried	810.82	194.91	10.15	13.09	0.238	91.37	3.669	0.32	1.133	1.14	0	0.8246
Fish, tilapia, fresh, grilled	549.92	132.74	10.06	10.25	0	103.76	3.572	45	170	0	0	2.4726
Lake sardine stew, with groundnut flour	1182.67	282.45	40.63	11.34	2.283	830.53	6.32	130.47	141.53	4.51	0	0.136
Mutton stew	398.68	95.93	4.697	6.607	0.877	100.08	2.365	21.01	786.79	4.6	0	0.1066
Plantain and beef casserole	374.57	88.5	4.884	1.346	0.394	106.43	3.847	13.3	84	8.34	0	0.103
Rabbit stew	516.65	123.54	16.69	5.385	0.082	50.12	1.172	57.47	52.666	0.49	0	0.103
Samoosa, beef filling, fried	845.49	202.32	13.26	11.16	0.467	70.87	5.785	27.99	0.133	0.73	0	1.0187

SAFA: saturated fatty acids

Values are sum totals of recipe ingredients’ nutrient amounts

Source: own compilation

Protein content for Malawian lake sardine stew (with groundnut) was the highest (protein = 40.63g/100g: 81.26% RI) while the lowest protein amount was in Malawian fish powder stew (protein = 2.16g/100g: 4.32% RI). Dietary fiber, which is important in fighting chronic illnesses like hypertension, diabetes, and obesity, was limited in the recipes (range = 0.00 – 2.28g/100g) since fiber is only present in plant based foods like nuts, grains, legumes, fruits, and vegetables (Anderson et al., 2009). Therefore, the little fiber present in the meat recipes resulted from the plant-based ingredients included.

There remains a prevalence of calcium deficiency globally, and animal products are a major source of dietary calcium (Kumssa et al., 2015). In the present study, Malawian lake sardine stew (with groundnut) would be the best source of calcium (ca = 830.53mg/100g) enough to meet the dietary calcium requirements for all age groups, except males 11 to 18 years old (British Nutrition Foundation, 2019). Kenyan beef stew had the lowest calcium amount (ca = 5.99mg/100g) and hence it would be a poor source of dietary calcium. Malawian beef liver stew was the best in terms of vitamin A and C contents (vit A = 2154IU/100g; vit C = 20.3mg/100g) while Malawian samosa was poorest in vitamin A (vit A = 0.133IU/100g). The following recipes had zero amounts of vitamin C: Kenyan fried tilapia, Malawian grilled tilapia, and Malawian fried catfish. Vitamin A is important for embryonic development, visual functions and in the reproductive system, among other physiological roles, while vitamin C is important in enhancing iron absorption, and it has a protective role as an antioxidant (FAO & WHO, 1998).

When the meats in the conventional meat recipes were replaced with edible insects, there were observable changes in the nutritive content of the ‘new’ recipes. For example, **Table 5.3** and **Table 5.4** show nutrient data for protein, fiber, fat, and sodium, to illustrate the change in nutritive value when conventional meats were replaced with edible insects in recipes. As depicted in **Table 5.3**, there was an increase in protein content in most recipes whose meats were replaced with cricket, and termite. In the Kenyan recipes, the increase in protein content was significant for both cricket (P=0.000061) and termite (P=0.038514) substitute recipes, while for Malawi the protein increase was significant in cricket-substitute recipe (P=0.006838). A review of edibles insects as a protein source reported crickets, termites, and grasshoppers as viable sources of dietary protein (T.-K. Kim et al., 2019) and a recent systematic review on the nutritional value of edible insects showed protein as a key nutrient present in these novel foods (Weru et al., 2021).

The amount of protein reduced in the following cricket recipes: Kenyan stewed dried fish and stewed Nile perch, and Malawian fish powder stew and lake sardine stew (with groundnut flour). For the termite recipes, the protein content reduced in Kenyan chicken stew, fried *omena*, *omena* stew, stewed dried fish, and stewed Nile perch, and Malawian fish powder and lake sardine stew~~.~~ In the grasshopper recipes, protein content reduced in all except in Malawian beef stew, beef liver stew, fried tilapia, and grilled tilapia. The protein reduction when grasshopper replaced the meat in Kenyan recipes was significant (P=0.000003) but the change was not significant (P=0.066079) in Malawian recipes. The selection of edible insects as a protein source, or for any other nutritional benefit, should therefore be species-specific in order to take advantage of the diversity is this nutrient-rich food resource (Weru et al., 2021).

The fiber content increased significantly in all the edible insects-substitute recipes. The presence of chitin in insects' exoskeleton contributes to the high amounts of fiber in edible insects (Jantzen da Silva Lucas et al., 2020). The benefits of dietary fiber are enormous including cardiovascular protection, bowel movement, satiety, weight management among others (Anderson et al., 2009). Including edible insects in our diets would therefore be beneficial in enhancing nutritional diets and the health of the population.

Table 5. 3: Protein and fiber content of meat and edible insects-substitute recipes

	Protein content in 100g recipe*				**Fiber content in 100g recipe***			
RECIPES	**Meat (g)**	**Cricket (g)**	**Termite (g)**	**Grasshopper (g)**	**Meat (g)**	**Cricket (g)**	**Termite (g)**	**Grasshopper (g)**
Kenya								
Aluru (stewed quails)	4.15	**29.97**	**6.39**	3.16	0.25	**4.85**	**1.11**	**0.47**
Beef Stew	8.84	**26.22**	**14.83**	5.84	0.38	**4.52**	**2.75**	**1**
Biryani Stew	4.78	**12.24**	**7.35**	3.49	1.21	**2.99**	**2.23**	**1.48**
Fried chicken	10.69	**34.09**	**19.12**	7.32	0	**5.43**	**3.11**	**0.74**
Fried *omena*	12.2	**12.22**	7.07	3.01	0.68	**2.55**	**1.75**	**0.96**
Fried Tilapia	7.21	**21.83**	**12.25**	4.69	0	**3.48**	**1.99**	**0.48**
Hydrabadi Biryani	3.32	**7.5**	**4.83**	2.72	0.62	**1.59**	**1.17**	**0.76**
Matoke	2.69	**6.27**	**3.92**	2.07	1.19	**2.05**	**1.68**	**1.32**
Meat samosa	7.56	**17.18**	**10.87**	5.89	1.22	**3.51**	**2.54**	**1.56**
Minced meat balls	6.58	**18.79**	**10.79**	4.47	0.61	**3.52**	**2.28**	**1.05**
Okra meat dish	7.31	**20.46**	**11.84**	5.04	1.26	**4.38**	**3.05**	**1.72**
Omena (silver sardine stew)	5.49	**5.5**	3.63	2.16	0.45	**1.13**	**0.84**	**0.55**
Pilau (spiced rice)	3.78	**7.91**	**5.21**	3.07	0.72	**1.71**	**1.29**	**0.87**
Qanchibelo (Beef, Maize & Wheat Flour mix)	6.13	**15.18**	**9.25**	4.57	1.72	**3.87**	**2.95**	**2.04**
Stewed chicken	10.5	**32.29**	**18.36**	7.36	0.79	**5.85**	**3.68**	**1.54**
Stewed dried fish	10.09	8.54	5.21	2.58	0.88	**2.09**	**1.57**	**1.06**
Stewed goat meat	11.79	**37**	**20.91**	8.22	0.52	**6.36**	**3.86**	**1.39**
Stewed guinea fowl	9.13	**26.17**	**14.77**	5.77	0.28	**4.42**	**2.65**	**0.89**
Stewed Nile perch	19.28	16.03	9.07	3.57	0.24	**2.76**	**1.68**	**0.61**

RECIPES	**Protein content in 100g recipe***				**Fiber content in 100g recipe***			
	Meat (g)	**Cricket (g)**	**Termite (g)**	**Grasshopper (g)**	**Meat (g)**	**Cricket (g)**	**Termite (g)**	**Grasshopper (g)**
Kenya								
Stir fried beef	8.9	**26.39**	**14.93**	5.88	0.39	**4.56**	**2.78**	**1.01**
Stir fried goat meat	8.37	**26.19**	**14.82**	5.85	0.41	**4.54**	**2.78**	**1.03**
P-value		0.000061	0.038514	0.000003		0.000002	0.000021	0.008933
Malawi								
Beef mince, fried	13.77	**39.59**	**22.32**	8.69	0.38	**6.65**	**3.97**	**1.31**
Beef stew	6	**28.89**	**16.36**	**6.47**	0.27	**5.01**	**3.07**	**1.14**
Beef, liver, stew	3.49	**20.84**	**11.94**	**4.92**	1.24	**4.1**	**2.72**	**1.35**
Chicken stew	16.62	**28.88**	16.32	6.41	0.6	**4.94**	**2.99**	**1.05**
Fish powder stew	2.16	2.15	1.63	1.22	0.83	**0.99**	**0.91**	**0.83**
Fish, catfish, fresh, fried	14.49	**42.21**	**25.46**	12.25	0.1	**6.18**	**3.58**	**1**
Fish, tilapia, fresh, fried	10.15	**49.78**	**28.58**	**11.85**	0.24	**7.93**	**4.64**	**1.38**
Fish, tilapia, fresh, grilled	10.06	**56.04**	**31.44**	**12.03**	0	**89.3**	**51.14**	**13.25**
Lake sardine stew, with groundnut flour	40.63	31.86	19.83	10.34	2.28	**6.35**	**4.49**	**2.63**
Mutton stew	4.7	**14.18**	**8.43**	3.88	0.88	**2.97**	**2.07**	**1.19**
Plantain and beef casserole	4.88	**12.71**	**7.47**	3.34	0.39	**2.29**	**1.48**	**0.68**
Rabbit stew	16.69	**44.83**	**25.46**	10.18	0.08	**7.11**	**4.11**	**1.13**
Samoosa, beef filling, fried	13.26	**45.17**	**26.07**	10.99	0.47	**7.11**	**4.15**	**1.2**
P-value		0.006838	0.069045	0.066079		0.052738	0.053702	0.062829

*Values in bold indicate an increase in nutrient content. Statistical significance is set at $p<0.05$

Table 5.4 presents fat and sodium nutrient data for meat and edible insects-substitute recipes. Cricket recipes recorded the highest number of increases in sodium content, with all except 3 (Kenyan okra meat dish, stewed dried fish, and stewed Nile perch) of the recipes recording an increase in sodium content. The substitution of meats with edible insects had greater impact on sodium increase for most of the Malawian recipes than the Kenyan recipes. Of the Malawian recipes, 100% of all the recipes had at least one recipe increase in sodium, while 69% had an increase in sodium for all the edible insects-substitute recipes. The lake sardine stew (with groundnut) was the least affected among the Malawian recipes with only the cricket recipe having an increase in sodium content. High sodium consumption is associated with increased morbidity and mortality due to obesity, high blood pressure, and incidences of cardiovascular diseases and it should therefore be reduced in the diet (Grillo et al., 2019). Going by the Maximum Recommended Value (MRV) for sodium which is 2300 mg per day (Schneeman, 2001), Kenyan stewed guinea fowl cricket-substitute recipe (Na = 735.99mg) would supply 31.99% of MRV indicating that the substitution with cricket would still be safe. The changes in fat content in all the recipes were not significant in view of RDA and hence would not impact health negatively.

Fat content increased in all the edible insects-substitute recipes except in 3 grasshopper recipes: Kenyan fried chicken and stewed chicken, and Malawian mutton stew. The fat present in edible insects is of superior quality since it contains fewer saturated fatty acids (SFAs) and more polyunsaturated fatty acids (PUFAs) (Sampat Ghosh et al., 2017). Additionally, these fats can be used to meet the increasing demand for animal fat, and have functional application in enhancing flavor and texture of foods (Sampat Ghosh et al., 2017). Conversely, fats from animal-source foods have high amounts of SFAs which have been implicated in negative health outcomes e.g., correlation with increased cardiovascular diseases (Alejandre et al., 2019). There are efforts to replace SFAs in animal products with PUFAs derived from alternative sources so as to reduce the saturation (Alejandre et al., 2019).

The increase in nutrient content implies that the meat that was replaced by the edible insects had less amounts of that nutrient. Or, put differently, the increase in nutrient content implies that the edible insects contained more of that nutrient than the original meat, since it is only the meat ingredient that was substituted in the recipe. Using the example of Kenyan fried tilapia, the fat content increased in all the recipes after tilapia was replaced with edible insects. Therefore, tilapia had less fat than all the edible insects that replaced it in the recipe. A previous study reported that edible insects were way much superior to conventional meat in terms of nutrient content (Siulapwa et al., 2012).

The change in nutrient content indicates that substitution of meats with edible insects can have both positive and negative effect on nutritive value of the diet. For instance, fiber increased in all the edible insects-substitute recipes and this increase is positive since meats are devoid of fiber.

Table 5. 4: Fat and sodium content of meat and edible insects-substitute recipes

RECIPES	**Fat content in 100g recipe***				**Sodium content in 100g recipe***			
	Meat	**Cricket**	**Termite**	**Grasshopper**	**Meat**	**Cricket**	**Termite**	**Grasshopper**
Kenya	**(g)**	**(g)**	**(g)**	**(g)**	**(mg)**	**(mg)**	**(mg)**	**(mg)**
Aluru (stewed quails)	41.67	**49.31**	**43.94**	**41.87**	241.99	**411.05**	**243.1**	**244.66**
Beef Stew	4.14	**9.51**	**12.32**	**6.58**	112.98	**219.48**	84.72	89.03
Biryani Stew	11.43	**13.74**	**14.95**	**12.48**	348.87	**394.58**	336.74	338.59
Fried chicken	49.54	**53.28**	**56.97**	49.43	299.36	**469.51**	292.56	298.22
Fried *omena*	35.26	**37.02**	**38.29**	**35.7**	257.88	**270.78**	209.9	211.84
Fried Tilapia	63.35	**69.95**	**72.32**	**67.48**	227.29	**337.71**	224.39	**228.02**
Hydrabadi Biryani	5.13	**6.52**	**7.18**	**5.83**	279.8	**310.35**	278.79	279.8
Matoke	1.73	**2.84**	**3.42**	**2.23**	219.8	**241.76**	213.97	214.86
Meat samosa	29.71	**32.69**	**34.25**	**31.06**	69.53	**128.5**	53.88	56.27
Minced meat balls	5.46	**9.23**	**11.21**	**7.17**	183.79	**258.59**	163.94	166.97
Okra meat dish	4.6	**8.66**	**10.79**	**6.44**	309.48	390.04	288.1	291.37
Omena (silver sardine stew)	14.1	**14.74**	**15.2**	**14.26**	294.83	**299.51**	277.42	278.13
Pilau (spiced rice)	7.73	**9.01**	**9.68**	**8.31**	284.19	**309.5**	277.48	278.5
Qanchibelo (Beef, Maize & Wheat Flour mix)	1.99	**4.79**	**6.25**	**3.26**	139.3	**194.72**	124.59	126.83
Stewed chicken	7	**10.48**	**13.92**	6.89	290.81	**449.28**	284.47	289.75
Stewed dried fish	12.23	**13.35**	**14.17**	**12.49**	79.35	78.02	38.66	39.92
Stewed goat meat	11.49	**18.21**	**22.18**	**14.07**	585.61	**735.93**	545.72	551.81
Stewed guinea fowl	4.63	**11.75**	**14.57**	**8.82**	382.41	**516.46**	381.58	**385.9**

RECIPES	**Fat content in 100g recipe***				**Sodium content in 100g recipe***			
	Meat	**Cricket**	**Termite**	**Grasshopper**	**Meat**	**Cricket**	**Termite**	**Grasshopper**
Kenya	**(g)**	**(g)**	**(g)**	**(g)**	**(mg)**	**(mg)**	**(mg)**	**(mg)**
Stewed Nile perch	5.46	**7.81**	**9.53**	**6.02**	371.62	368.85	286.46	289.1
Stir fried beef	4.94	**10.35**	**13.18**	**7.4**	188.55	**295.73**	160.11	164.45
Stir fried goat meat	5.37	**10.12**	**12.93**	**7.19**	216.07	**322.36**	187.86	192.17
P-value		0.244351	0.170598	0.389404		0.038114	0.290641	0.319663
Malawi								
Beef mince, fried	8.02	**19.92**	**24.19**	**15.48**	38.1	**245.08**	**40.8**	**47.34**
Beef stew	1.31	**9.43**	**12.52**	**6.2**	16.48	**177.75**	**29.48**	**34.23**
Beef, liver, stew	5.1	**9.74**	**11.94**	**7.45**	16.54	**129.29**	**24.05**	**27.42**
Chicken stew	6.39	**13.42**	**16.52**	**10.19**	36.06	**177.36**	28.8	33.55
Fish powder stew	1.3	**1.38**	**1.51**	**1.24**	3.4	**10.71**	**4.52**	**4.72**
Fish, catfish, fresh, fried	9.46	**18.32**	**22.46**	**14.01**	62.38	**265.65**	**67.56**	**73.9**
Fish, tilapia, fresh, fried	13.09	**24.22**	**29.45**	**18.76**	0.32	**296.46**	**45.76**	**53.78**
Fish, tilapia, fresh, grilled	10.25	**23.17**	**29.24**	**16.83**	45	**388.67**	**97.73**	**107.04**
Lake sardine stew, with groundnut flour	11.34	**17.38**	**20.35**	**14.28**	130.47	**173.56**	31.25	35.8
Mutton stew	6.61	**6.24**	**7.66**	4.76	21.01	**84.72**	16.63	18.81
Plantain and beef casserole	1.35	**4.95**	**6.25**	**3.61**	13.3	**76.02**	**14.12**	**16.1**
Rabbit stew	5.39	**16.29**	**21.07**	**11.31**	57.47	**283.62**	54.58	**61.91**
Samoosa, beef filling, fried	11.16	**18.64**	**23.36**	**13.72**	27.99	**267.15**	**41.2**	**48.43**
P-value		0.007522	0.002214	0.04605		0.000011	0.41293	0.259369

*Values in bold indicate an increase in nutrient content. Statistical significance is set at $p<0.05$

Consumption of high amounts of fiber has benefits in protecting the body's health and reversing diseases (Anderson et al., 2009), and edible insects would play a pivotal role in improving heath. Conversely, the increase in sodium has a negative effect on the nutritive value of the diet since sodium is a nutrient to limit. Foods with high amounts of sodium would be excluded from health and nutrient-density claims (Drewnowski & Fulgoni, 2008). But by using nutrient profiling models, especially those that consider a balance of positive and negative nutrients, or a combination of different models, the classification of foods based on healthfulness can be achieved to avoid condemnation of foods based on a single 'negative' nutrient (Iberoamerican Nutrition Foundation (FINUT) 2017).

5.3.2: Nutrient profile scores of conventional meat recipes and edible insects-substitute recipes

5.3.2.1: WXYfm scores of conventional meat recipes and edible insects-substitute recipes

The results of healthfulness of conventional meat recipes and edible insects-substitute recipes as represented by their WXYfm nutrient profile scores are shown in **Table 5.5.** The WXYfm model cut-off point for healthfulness is 4, meaning that if a food scores 4 points or more, it is classified as less healthful (Mike Rayner, 2009). Accordingly, 35% of the conventional meat recipes from Kenya would be classified as less healthful compared to 0% of the Malawian recipes. After substituting the meats in the recipes with edible insects, there was no adverse change in healthfulness among the Malawian recipes and all the edible insects-substitute recipes remained in the healthful category. Most of the scores actually improved, for instance, mutton stew's score was more favorable upon substitution with any of the edible insects.

For the Kenyan recipes, pilau (spiced rice), stewed Nile perch, and stir-fried goat meat recipes changed from a healthful status to a less healthful one upon substitution with cricket. A similar case occurred with pilau when the meat was substituted with brown grasshopper. All the other Kenyan recipes improved on healthfulness or remained the same when edible insects replaced the conventional meats. It is therefore clear from this study that edible insects can improve the healthfulness of diets without necessarily modifying the recipes in any other way. More healthful diets are associated with better health outcomes in the population (Masset, 2012).

Table 5. 5: WXYfm scores of conventional meat recipes and edible insects-substitute recipes

	Conventional meat recipe	Edible insects-substitute recipes		
COUNTRY		**Cricket**	**Termite**	**Grasshopper**
Kenya				
Aluru (stewed quails)	12	-4	12	11
Beef Stew	-2	20	-5	-3
Biryani Stew	2	-1	0	2
Fried chicken	17	-5	16	14
Fried *omena*	11	-3	10	10
Fried Tilapia	18	10	19	18
Hydrabadi Biryani	2	-2	0	3
Matoke	0	-4	0	0
Meat samosa	4	12	2	4
Minced meat balls	0	1	-6	-1
Okra meat dish	0	-4	-4	0
Omena stew	4	-5	5	5
Pilau (spiced rice)	3	6	2	4
Qanchibelo *(Beef, Maize & Wheat Flour mix)*	-2	2	-6	-2
Stewed chicken	0	-2	-3	-1
Stewed dried fish	-3	-4	-2	0
Stewed goat meat	11	-1	0	2
Stewed guinea fowl	0	-4	-1	2
Stewed Nile perch	0	10	-2	3

	Conventional meat recipe	**Edible insects-substitute recipes**		
Kenya		**Cricket**	**Termite**	**Grasshopper**
Stir fried beef	-1	3	-4	-2
Stir fried goat meat	0	18	-3	-1
P-values	-	0.5064	0.0014	0.4824
Malawi				
Beef mince, fried	-4	-4	-5	-4
Beef stew	-5	-7	-6	-4
Beef, liver, stew	-2	-6	-5	-3
Chicken stew	-4	-6	-6	-4
Fish powder stew	-1	-2	0	0
Fish, catfish, fresh, fried	-3	-4	-4	-4
Fish, tilapia, fresh, fried	-3	-2	-4	-3
Fish, tilapia, fresh, grilled	-2	1	-3	-5
Lake sardine stew, with groundnut flour	-3	-6	-6	-5
Mutton stew	-1	-7	-6	-3
Rabbit stew	-2	-6	-4	-5
Samoosa, beef filling, fried	-4	-3	-6	-4
Plantain and beef casserole	-3	-4	-5	-1
P-values	-	0.0514	0.0007	0.1795

Statistical significance is set at $p<0.05$

To compare the differences in WXYfm scores between the conventional meat recipes and edible insects-substitute recipes, a paired samples T-test was conducted. Among the Kenyan recipes, termite (t-value = 3.70) edible insects-substitute recipe scores were significantly different (p=0.0014) from the conventional meat recipes. Thus, termite would be the preferred substitute for meat in Kenyan recipes. For the Malawian recipes, the termite (t-value = 4.48, p=0.0007) recipes had significantly different scores when compared with the conventional meat recipes. Therefore, termite would still be chosen to substitute meat in Malawian recipes for improved healthfulness.

A two samples T-test results in **Table 5.6** show means and standard errors of WXYfm scores of conventional meat recipes and edible insects-substitute recipes from Kenya and Malawi. All the Malawian recipes were significantly more healthful than the recipes from Kenya. The recipes from Malawi were derived from traditional cuisine, whose culinary culture can influence healthfulness (Averalda van Graan et al. 2019). Culture is a great influencer of food choice, including how to acquire, prepare and consume food, and it invariably affects healthfulness (Monterrosa et al., 2020). On average, Malawian termite recipes (mean = -4.61 ± 0.47) would be the best choice amongst all the recipes in the study. It is therefore clear that the choice of edible insect for improving the healthfulness of diets should be insect-specific, as opposed to generalizing the impact of substituting meat items with edible insects. Additionally, some food items (ingredients) included in recipes impact negatively on healthfulness, e.g., cooking oil, suggesting that reformulation of recipes to remove or modify some of these unfavorable ingredients would yield positive healthful results.

Table 5. 6: Means and standard errors of WXYfm scores of conventional meat and edible insects-substitute recipes in Kenya and Malawi

COUNTRY	n	Conventional meat recipes	Edible insects-substitute recipes		
			Cricket	Termite	Grasshopper
Kenya	21	3.62 ± 1.37 ^{a}	2.05 ± 1.68 ^{a}	1.43 ± 1.55 ^{a}	3.24 ± 1.22 ^{a}
Malawi	13	-2.85 ± 0.34 ^{b}	-4.31 ± 0.65 ^{b}	-4.61 ± 0.47 ^{b}	-3.46 ± 0.42 ^{b}
P-value		0.0009	0.0069	0.0052	0.0002

Means with the same superscript in the same column are not significantly different at $p<0.05$

5.3.2.2: RRR scores of conventional meat recipes and edible insects-substitute recipes

Table 5.7 shows the RRR scores of conventional meat recipes and edible insects-substitute recipes. Recipes with scores of ≥1 are considered healthful (Scheidt & Daniel, 2004) and therefore would be a better choice. Overall, 52.4% of the Kenyan conventional meat recipes would be classified as unhealthful according to RRR model.

Table 5. 7: RRR score of conventional meat recipes and edible insects-substitute recipes

COUNTRY	Conventional	Edible insects-substitute recipes		
Kenya	**meat recipe**	**Cricket**	**Termite**	**Grasshopper**
Aluru (stewed quails)	0.28	1.19	0.89	0.31
Beef Stew	1.78	4.26	22.98	3.68
Biryani Stew	1.17	1.73	2.85	1.26
Fried chicken	0.26	0.98	2.40	0.42
Fried *omena*	0.76	1.02	1.61	0.67
Fried Tilapia	0.19	0.53	1.14	0.19
Hydrabadi Biryani	0.73	1.90	2.09	0.88
Matoke	1.80	2.51	4.01	2.10
Meat samosa	0.84	1.33	2.26	0.85
Minced meat balls	1.49	3.01	8.38	2.09
Okra meat dish	1.74	3.13	7.54	2.42
Omena stew	0.70	0.82	1.12	0.61
Pilau (spiced rice)	0.80	1.17	1.83	0.80
Qanchibelo *(Beef, Maize & Wheat Flour mix)*	3.16	5.11	12.66	5.32
Stewed chicken	1.07	3.83	13.17	3.13
Stewed dried fish	2.26	2.24	3.92	1.72
Stewed goat meat	0.52	2.31	5.96	1.29
Stewed guinea fowl	0.74	2.37	6.35	1.30
Stewed Nile perch	2.18	2.16	5.25	0.47
Stir fried beef	1.54	3.54	13.56	2.53
Stir fried goat meat	0.72	3.47	12.45	2.49
P-values	-	<.0001	0.0003	0.0318
Malawi				
Beef mince, fried	4.81	4.14	20.02	4.46

Malawi	**Conventional meat recipe**	**Edible insects-substitute recipes**		
		Cricket	**Termite**	**Grasshopper**
Beef stew	16.70	6.49	64.29	16.24
Beef, liver, stew	17.65	7.18	28.45	12.43
Chicken stew	6.60	5.06	25.97	7.21
Fish powder stew	31.96	25.38	37.65	33.61
Fish, catfish, fresh, fried	2.53	3.98	19.24	4.02
Fish, tilapia, fresh, fried	2.96	3.74	17.83	3.39
Fish, tilapia, fresh, grilled	2.01	8.59	20.92	4.19
Lake sardine stew, with groundnut flour	4.64	5.54	21.30	7.83
Mutton stew	8.46	7.77	33.62	14.79
Rabbit stew	7.77	4.60	39.64	6.61
Samoosa, beef filling, fried	3.81	4.03	22.89	4.17
Plantain and beef casserole	3.28	6.11	18.63	8.50
P-values	-	0.2706	<.0001	0.1978

Statistical significance is set at $p<0.05$

The impact of substituting meats with edible insects in Kenyan recipes was evident since the scores improved upon substitution, thus reducing the percentage of unhealthful recipes, as follows: 14.3% of cricket recipes, 4.8% of termite recipes, and 42.9% of grasshopper recipes would be classified as unhealthful. All the Malawian recipes scored above the RRR threshold for healthfulness and would therefore be classified as healthful. The impact of substitution on Malawian conventional meat recipes did not change the classification status of the recipes.

All the edible insects-substitute recipe scores were significantly different ($p<0.05$) from the scores of conventional meat recipes from Kenya. Thus, substitution of conventional meats with edible insects in recipes had a significant positive impact on the healthfulness of the recipes. This suggests that inclusion of edible insects in diets can significantly improve the healthfulness of foods. For the recipes from Malawi, only the termite recipes were significantly different (t-value = -6.82, $p<.0001$) from the conventional meat recipes. Termite would thus be the best choice for substituting conventional meats in recipes in Malawi. Therefore, based on the RRR scores, consumers can select termite recipes over the other recipes for better health. These results on healthfulness can also be used by food processors as a guide on the best choice of edible insects to incorporate in new product formulations. Manufactured food products that incorporate cricket flour as an ingredient, e.g., cricket protein bars, cinnamon cricket muffins, and cricket cookies, are already available in the market in the USA (Jasinski et al., 2019).

Table 5.8 indicates results of a two samples T-test that was conducted to compare the RRR scores of recipes from Kenya and Malawi. Overall, conventional meat recipes from Kenya had the lowest mean score (1.18 ± 0.17) while termite recipes from Malawi had the highest mean score (28.50 ± 3.61). All the recipes from Malawi were significantly ($p<0.05$) more healthful than the Kenyan recipes. Although all the recipes from Malawi were classified as healthful by the RRR model, the termite recipes had the highest mean score (28.50 ± 3.61) and therefore the best in terms of healthfulness.

Table 5. 8: Means and standard errors of RRR scores of conventional meats and edible insects-substitute recipes in Kenya and Malawi

SOURCE	n	Conventional meat recipes	Edible insects-substitute recipes		
			Cricket	Termite	Grasshopper
Kenya	**21**	1.18 ± 0.17^{a}	2.31 ± 0.27^{a}	6.31 ± 1.25^{a}	1.64 ± 0.28^{a}
Malawi	**13**	8.7 ± 2.40^{b}	7.12 ± 1.58^{b}	28.50 ± 3.61^{b}	9.80 ± 2.31^{b}
P-value		0.0003	0.0007	<.0001	<.0001

Means with the same superscript in the same column are not significantly different at $p<0.05$
n: sample size

5.3.2.3: GDA scores of conventional meat recipes and edible insects-substitute recipes

The GDA scores of conventional meat recipes and edible insects-substitute recipes are depicted in **Tables 5.9** and **5.10.** The scores that are ≥1 indicate unhealthfulness and those below 1 are considered healthful (Scarborough et al. 2007). Most of the recipes were classified as healthful by the GDA scoring system with only three Kenyan recipes (aluru, fried chicken, and fried tilapia) recoding scores of ≥1 for women and children while only fried tilapia recorded unhealthful scores for men. This means that all the conventional meat and edible insects-substitute recipes were healthful for men except Kenyan fried tilapia. Since GDA is a LIM scoring system, one can be confident that the recipes in this study would not oversupply the nutrients to limit in diet.

Table 5. 9: GDA scores of conventional meat recipes and cricket edible insects-substitute recipes

	Conventional meat recipe			Edible insects-substitute recipes		
				Cricket		
COUNTRY	**WOMEN**	**MEN**	**CHILDREN**	**WOMEN**	**MEN**	**CHILDREN**
Kenya						
Aluru (stewed quails)	1.03	0.76	1.08	1.21	0.91	1.29
Beef Stew	0.19	0.15	0.22	0.24	0.20	0.28
Biryani Stew	0.42	0.34	0.50	0.44	0.36	0.53
Fried chicken	1.26	0.93	1.32	1.28	0.97	1.38
Fried *omena*	0.90	0.67	0.96	0.89	0.67	0.95
Fried Tilapia	1.48	1.08	1.53	1.62	1.20	1.69
Hydrabadi Biryani	0.23	0.20	0.29	0.26	0.22	0.33
Matoke	0.13	0.12	0.18	0.14	0.13	0.19
Meat samosa	0.71	0.51	0.72	0.73	0.54	0.76
Minced meat balls	0.23	0.19	0.27	0.27	0.22	0.32
Okra meat dish	0.27	0.23	0.34	0.31	0.27	0.39
Omena stew	0.46	0.36	0.52	0.45	0.36	0.52
Pilau (spiced rice)	0.30	0.25	0.36	0.31	0.26	0.38
Qanchibelo *(Beef, Maize & Wheat Flour mix)*	0.13	0.11	0.16	0.15	0.13	0.19
Stewed chicken	0.32	0.26	0.38	0.34	0.30	0.44
Stewed dried fish	0.28	0.21	0.29	0.29	0.22	0.31
Stewed goat meat	0.59	0.49	0.72	0.62	0.54	0.78
Stewed guinea fowl	0.25	0.23	0.33	0.41	0.36	0.52
Stewed Nile perch	0.26	0.23	0.33	0.29	0.25	0.37
Stir fried beef	0.24	0.19	0.28	0.29	0.24	0.35
Stir fried goat meat	0.28	0.22	0.32	0.29	0.25	0.36
P-values	-	-	-	0.0017	0.0002	0.0002
Malawi						
Beef mince, fried	0.17	0.12	0.17	0.42	0.34	0.48
Beef stew	0.03	0.02	0.03	0.21	0.17	0.25
Beef, liver, stew	0.10	0.08	0.11	0.21	0.17	0.24

COUNTRY	Conventional meat recipe			Edible insects-substitute recipes		
				Cricket		
Malawi	**WOMEN**	**MEN**	**CHILDREN**	**WOMEN**	**MEN**	**CHILDREN**
Chicken stew	0.12	0.09	0.13	0.29	0.23	0.33
Fish powder stew	0.02	0.02	0.02	0.02	0.02	0.03
Fish, catfish, fresh, fried	0.18	0.14	0.19	0.39	0.32	0.45
Fish, tilapia, fresh, fried	0.23	0.17	0.23	0.51	0.41	0.58
Fish, tilapia, fresh, grilled	0.29	0.21	0.30	0.62	0.49	0.70
Lake sardine stew, with groundnut flour	0.22	0.18	0.25	0.33	0.26	0.36
Mutton stew	0.11	0.08	0.11	0.13	0.10	0.14
Rabbit stew	0.11	0.08	0.12	0.36	0.30	0.42
Samoosa, beef filling, fried	0.22	0.16	0.23	0.40	0.32	0.46
Plantain and beef casserole	0.03	0.02	0.03	0.11	0.09	0.12
P-values	-	-	-	<.0001	<.0001	<.0001

Statistical significance is set at $p<0.05$

Table 5. 10: GDA scores of termite and grasshopper edible insects-substitute recipes

	Edible insects-substitute recipes					
	Termite			Grasshopper		
COUNTRY	**WOMEN**	**MEN**	**CHILDREN**	**WOMEN**	**MEN**	**CHILDREN**
Kenya						
Aluru (stewed quails)	1.06	0.78	1.11	1.03	0.76	1.08
Beef Stew	0.22	0.17	0.24	0.14	0.11	0.16
Biryani Stew	0.43	0.35	0.51	0.40	0.33	0.47
Fried chicken	1.26	0.94	1.32	1.15	0.86	1.21
Fried *omena*	0.89	0.66	0.93	0.85	0.63	0.89
Fried Tilapia	1.60	1.17	1.65	1.54	1.12	1.58
Hydrabadi Biryani	0.26	0.22	0.32	0.24	0.20	0.30
Matoke	0.14	0.13	0.19	0.12	0.11	0.17
Meat samosa	0.72	0.52	0.73	0.68	0.49	0.69
Minced meat balls	0.25	0.20	0.29	0.20	0.16	0.23
Okra meat dish	0.29	0.25	0.35	0.23	0.20	0.29

	Edible insects-substitute recipes					
COUNTRY	**Termite**			**Grasshopper**		
Kenya	**WOMEN**	**MEN**	**CHILDREN**	**WOMEN**	**MEN**	**CHILDREN**
Omena stew	0.45	0.36	0.51	0.44	0.35	0.50
Pilau (spiced rice)	0.31	0.25	0.37	0.29	0.24	0.35
Qanchibelo *(Beef, Maize & Wheat Flour mix)*	0.14	0.12	0.17	0.10	0.09	0.13
Stewed chicken	0.32	0.27	0.38	0.22	0.20	0.28
Stewed dried fish	0.29	0.21	0.30	0.26	0.19	0.27
Stewed goat meat	0.60	0.50	0.71	0.48	0.41	0.60
Stewed guinea fowl	0.39	0.33	0.48	0.31	0.27	0.40
Stewed Nile perch	0.28	0.23	0.34	0.17	0.16	0.23
Stir fried beef	0.27	0.22	0.30	0.19	0.16	0.22
Stir fried goat meat	0.28	0.22	0.32	0.20	0.17	0.24
P-values	0.0100	0.0079	0.0364	0.0033	0.0019	0.0019
Malawi						
Beef mince, fried	0.40	0.30	0.41	0.28	0.21	0.29
Beef stew	0.19	0.14	0.20	0.10	0.08	0.11
Beef, liver, stew	0.20	0.15	0.20	0.13	0.10	0.14
Chicken stew	0.27	0.20	0.28	0.18	0.14	0.19
Fish powder stew	0.02	0.02	0.02	0.02	0.02	0.02
Fish, catfish, fresh, fried	0.36	0.28	0.38	0.25	0.19	0.26
Fish, tilapia, fresh, fried	0.48	0.36	0.49	0.33	0.25	0.34
Fish, tilapia, fresh, grilled	0.58	0.43	0.60	0.41	0.31	0.43
Lake sardine stew, with groundnut flour	0.31	0.23	0.32	0.23	0.17	0.23
Mutton stew	0.12	0.09	0.12	0.08	0.06	0.08
Rabbit stew	0.33	0.25	0.34	0.19	0.15	0.21
Samoosa, beef filling, fried	0.37	0.28	0.38	0.24	0.18	0.25
Plantain and beef casserole	0.10	0.08	0.10	0.06	0.05	0.07
P-values	<.0001	0.0001	0.0001	0.0015	0.0021	0.0030

Statistical significance is set at $p<0.05$

5.3.2.3: Use of traffic lights to classify GDA Scores

The traffic-light labelling method uses traffic lights colors to rate the amounts of nutrients to limit on a front-of-package (FOP) labels: green (low), amber (medium), and red (high) (**Fig 5.1**). For instance, if a food contains a high amount of sodium based on recommended daily intake/value, then the FOP would have a red color code against sodium. The other nutrients to limit (sugar, fat, saturated fat, cholesterol, and energy) would each carry a color code respectively based on the amounts of each in the food, making it easier for consumers to make quick purchase decisions (Emrich et al., 2017).

The scores obtained by the GDA model provide a summary of the nutrients to limit, which gives an overall rating based on all the 'negative' nutrients in the diet. So, if the traffic lights would be used to display the GDA scores, those foods with ≥1 would carry a red color code and those with scores below 1 would have a green color code. This would provide a single color on the FOP label, as opposed to different colors for each nutrient (**Figure 5.1**), hence facilitating food selection and/or purchase decision making.

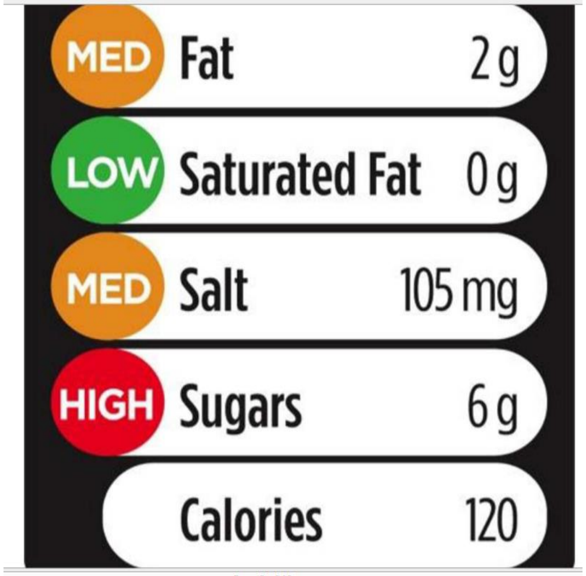

Figure 5. 1: An example of front-of-package traffic-light color coding

Source: (Emrich et al., 2017)

All the edible insects-substitute recipes were significantly ($p<0.05$) different from the conventional meat recipes. Thus, substitution of meats with edible insects had a positive outcome on the healthfulness of the recipes under study.

A two samples T-test to compare the GDA scores of recipes from Kenya and Malawi yielded the results shown in **Table 5.11.** The meat and grasshopper recipes from Kenya were significantly different ($p<0.05$) from the Malawian recipes. Termite recipe scores (children and men) were also significantly different ($p=0.0488$) between Kenyan and Malawian recipes. As earlier mentioned, the presence of unique ingredients in the different countries impacts the healthfulness outcomes, since cuisines and culinary practices are influenced, to a large extent, by national cultures (Cusack, 2000).

Table 5. 11: Means and standard errors of GDA scores of conventional meat and edible insects-substitute recipes in Kenya and Malawi

RECIPES	Group	RECIPE SOURCE		p-value
		Kenya (n = 21)	Malawi (n = 13)	
Conventional meat	**Children**	0.53 ± 0.08 ^{a}	0.15 ± 0.02 ^{b}	0.0015
	Men	0.36 ± 0.06 ^{a}	0.11 ± 0.02 ^{b}	0.0019
	Women	0.47 ± 0.08 ^{a}	0.14 ± 0.02 ^{b}	0.0044
Cricket	**Children**	0.59 ± 0.09 ^{a}	0.35 ± 0.05 ^{a}	0.0631
	Men	0.41 ± 0.06 ^{a}	0.25 ± 0.04 ^{a}	0.0730
	Women	0.52 ± 0.09 ^{a}	0.31 ± 0.05 ^{a}	0.0902
Termite	**Children**	0.39 ± 0.06 ^{a}	0.22 ± 0.03 ^{b}	0.0488
	Men	0.39 ± 0.06 ^{a}	0.22 ± 0.03 ^{b}	0.0488
	Women	0.50 ± 0.09 ^{a}	0.29 ± 0.04 ^{a}	0.0762
Grasshopper	**Children**	0.49 ± 0.09 ^{a}	0.20 ± 0.03 ^{b}	0.0150
	Men	0.34 ± 0.06 ^{a}	0.15 ± 0.02 ^{b}	0.0196
	Women	0.44 ± 0.09 ^{a}	0.19 ± 0.03 ^{b}	0.0339

Means with the same superscript in the same row are not significantly different at $p<0.05$

The nutritional and healthfulness benefits associated with edible insects, as shown in this study, should motivate the adoption of these unique food items in daily diets. In order to encourage consumption of edible insects by the general population, the players in the food value chain, including food processors and caterers, can adopt these healthful edible insects as novel food ingredients in recipes (Jasinski et al., 2019). Some communities in Nigeria already include edible insects as part of ingredients in their cuisine (Ebenebe et al., 2017). In tropical regions, where diets lack animal-source proteins and fats, edible insects have bridged the gap by providing an affordable source of these essential nutrients, in addition to fighting hunger (Illgner et al., 2016).

5.3.3: Cost of conventional meat recipes and edible insects-substitute recipes

The market prices of meat ingredients and edible insects are presented in **Table 5.12.** Among the conventional meats, mackerel was the most expensive at Ksh 1990/= per kg while the cheapest were quail (Ksh 300/= per whole) and catfish at Ksh 300/= per kg. The edible insects' prices were 750/=, 186/=, and 50/= per kg for crickets, grasshoppers, and termites, respectively. The average price for meats was Ksh 590.58 per kg while edible insects averaged Ksh 328.67 per kg. Edible insects were therefore cheaper, on average, than the conventional meats. This finding agrees with a study carried out in Zambia which reported that edible insects were, on average, cheaper than conventional meats (Siulapwa et al., 2012).

Table 5. 12: Market prices of meat ingredients in recipes and edible insects

RECIPES	Meat Ingredient	Quantity	PRICES (Ksh)
Kenya			
Beef Stew	Beef, medium fat without bone, raw	kg	600
Stir fried goat meat	Goat meat, medium fat, raw	kg	600
Stir fried beef	Beef, medium fat, raw	kg	600
Biryani Stew	Beef, raw, medium fat	kg	600
Minced meat balls	Minced raw beef, medium fat	kg	400
Stewed dried fish	Dry fish	kg	420
Omena	Dried *omena* fish	kg	650
Fried Tilapia	Fresh tllapia	whole	400
Hydrabadi Biryani	Mackerel, raw	kg	1990
Stewed Nile perch	Nile Perch	kg	420
Stewed goat meat	Goat meat, medium fat	kg	600
Qanchibelo *(Beef, Maize & Wheat Flour mix)*	Beef, raw medium fat	kg	600

Kenya	**Meat Ingredient**	**Quantity**	**PRICES (Ksh)**
Okra meat dish	Beef, meat	kg	600
Fried *omena*	*Omena*, dried raw	kg	650
Stewed chicken	Chicken, whole	1 - 1.49kg	400
Fried chicken	Chicken, whole	1 - 1.49kg	400
Aluru (stewed quails)	Quails, whole	whole	300
Stewed guinea fowl	Guinea fowl, whole	whole	1500
Meat samosa	Beef, minced	kg	400
Pilau (spiced rice)	Beef	kg	600
Matoke	Beef, medium fat	kg	600
Malawi			
Beef mince, fried	Beef, raw	kg	600
Beef stew	Beef, raw	kg	600
Beef, liver, stew	Beef, liver, raw	kg	700
Chicken stew	Chicken, meat with skin, free range, local, raw	1 - 1.49kg	400
Fish powder stew	Fish powder	kg	350
Fish, catfish, fresh, fried	Fish, catfish, raw	kg	300
Fish, tilapia, fresh, fried	Fish, whole, fresh	whole	400
Fish, tilapia, fresh, grilled	Fish, whole, fresh	whole	400
Lake sardine stew, with groundnut flour	Fish, lake sardine, whole, dried	kg	650
Mutton stew	Mutton, meat, ~20% fat, raw	kg	550
Rabbit stew	Rabbit, meat, raw	kg	800
Samoosa, beef filling, fried	Beef mince, fried	kg	400
Plantain and beef casserole	Beef, raw	kg	600
Edible insects	Crickets	Kg	750
	Termites	Kg	50
	Grasshoppers	kg	186

Source: own compilation

The cost in Ksh/100g of conventional meat recipes and edible insects-substitute recipes are presented in **Table 5.13.** There were changes in cost of recipes after substitution with edible insects. When cricket was used as a substitute for conventional meats in recipes, the price changed upwards in 81% of the Kenyan recipes and in 92% of the recipes from Malawi. Large-scale rearing of crickets has not been achieved and since demand is increasing, crickets remain expensive due to the low supply (J. N. Kinyuru & Ndung'u, 2020). All the other edible insects-substitute recipes were lower in cost than the conventional meat recipes. The price of food items influences choice in addition to other factors such as healthfulness, taste, nutrition knowledge, and food preferences (Emrich et al., 2017), and the cost of food can affect healthful eating (Cade et al., 1999) because foods that are energy-dense (with very few nutrients) tend to be more expensive than nutrient-rich foods (Drewnowski & Fulgoni, 2008).

Table 5. 13: The cost of conventional meat and edible insects-substitute recipes

COUNTRY	**Conventional meat recipe**	**Recipe cost (Ksh/100 g) ***		
		Cricket	**Termite**	**Grasshopper**
Kenya				
Aluru (stewed quails)	21.27	**24.32**	13.35	15.48
Beef Stew	31	**34.63**	4.15	10.07
Biryani Stew	25.85	**27.4**	14.32	16.86
Fried chicken	43.64	**51.34**	11.32	19.09
Fried *omena*	23.01	**24.98**	11.21	13.88
Fried Tilapia	37.83	**40.05**	14.42	19.4
Hydrabadi Biryani	38.59	13.5	6.36	7.75
Matoke	13.8	**14.54**	8.26	9.48
Meat samosa	18.46	**26.9**	10.02	13.3
Minced meat balls	16.13	**26.83**	5.42	9.58
Okra meat dish	29.5	**32.24**	9.19	13.67
Omena	14.01	**14.73**	9.74	10.71
Pilau (spiced rice)	13.66	**14.53**	7.28	8.69
Qanchibelo (Beef, Maize & Wheat Flour mix)	18.96	**20.85**	4.99	8.07
Stewed chicken	37.97	**45.14**	7.87	15.11
Stewed dried fish	13.85	**15.65**	6.75	8.48
Stewed goat meat	53.58	49.85	6.83	15.19
Stewed guinea fowl	67.41	34.73	4.22	10.15
Stewed Nile perch	17.92	**21.68**	3.04	6.66
Stir fried beef	31.37	**35.02**	4.35	10.31
Stir fried goat meat	37.61	34.97	4.55	10.46
P-values	-	0.9741	<.0001	<.0001
Malawi				
Beef mince, fried	43.03	**52.93**	6.73	15.7
Beef stew	31.67	**38.86**	5.32	11.84
Beef, liver, stew	30.43	**32.13**	8.33	12.95
Chicken stew	22.99	**39.96**	6.03	12.62
Fish powder stew	5.77	**6.57**	5.17	5.44
Fish, catfish, fresh, fried	20.7	**49.5**	4.7	13.4
Fish, tilapia, fresh, fried	33.7	**60.96**	6.44	17.03
Fish, tilapia, fresh, grilled	39.49	**72.39**	6.59	19.37
Lake sardine stew, with groundnut flour	41.87	**46.47**	14.28	20.53
Mutton stew	16.06	**20.51**	4.9	7.97
Rabbit stew	62.12	58.42	6.62	16.68
Samoosa, beef filling, fried	29.7	**55.51**	3.89	13.92
Plantain and beef casserole	24.93	**27.93**	13.93	16.65
P-values	-	0.004	<.0001	0.0002

*Values in bold indicate an increase in recipe cost after substitution with edible insects
Statistical significance is set at $p<0.05$

The cost of termite, and grasshopper recipes was significantly different from the cost of conventional meat recipes in Kenya. Accordingly, cricket recipes were similar in cost as the conventional meat recipes, while it would be cheaper to purchase termite and grasshopper recipes than meat recipes in Kenya. For the Malawian recipes, cricket, termite, and grasshopper recipes were significantly different in cost from the conventional meat recipes. And 92% of the cricket-substitute recipes' prices were higher than that of conventional meat recipes. The cricket recipes would therefore cost more than the conventional meat recipes, while it would be cheaper to buy the termite and grasshopper recipes than meat recipes in Malawi.

A two samples T-test to compare the cost of recipes between Kenya and Malawi gave out the results in **Table 5.14.** There were significant differences in the cost of cricket recipes in Kenya and Malawi. It would therefore be cheaper to pay for cricket recipes in Kenya than in Malawi. The mean prices of termite recipes (mean price = 7.98 ± 0.76 & 7.15 ± 0.91, Kenya and Malawi, respectively) were the lowest among all the recipes in the study. This observation can be attributed to the fact that termites, though seasonal, are collected 'free-of-charge' from the wild hence the cost of rearing the insects is not incurred (Kisaka et al., 2018). Even when reared, edible insects are more cost-effective than traditional livestock (Caparros Megido et al., 2016) due to lower feed conversion ratios, less production and processing space, and lower labor costs among other benefits (Flachowsky, 2002; Smil, 2002b; Arnold Van Huis, 2011). When commercial production of crickets is realized, their cost would invariably be cheaper than the current offering.

But crickets seemed a bit pricy compared to other edible insects in this study, to the extent that cricket recipe prices were similar to conventional meat recipes in Kenya and higher than the meat recipes in Malawi. A study in Thailand reported that crickets sold in the local markets were 4 to 5 times more expensive than chicken, based on weight (A. Halloran et al., 2016). The reason why crickets are this expensive can be explained using factors related to the cost of production and demand versus availability. The estimated cost of production for 1kg fresh crickets is between KSh 48 to KSh 132. But once dried, the price escalates to between KSh 500 to KSh 3000 per kilogram (J. N. Kinyuru & Ndung'u, 2020). The live weight of a kilogram of beef ranges between KSh 130 to KSh 180, on average (Ndiritu, 2020). Since crickets are sold when dried, they therefore can't compete favorably price-wise with beef which is sold when it is fresh.

Table 5. 14: Means and standard errors of conventional meat and edible insects-substitute recipes' cost in Kenya and Malawi

SOURCE	n	Conventional Meat	Edible insects-substitute recipes		
			Cricket	Termite	Grasshopper
Kenya	21	28.83 ± 3.15 ^{a}	28.76 ± 2.52 ^{a}	7.98 ± 0.76 ^{a}	12.02 ± 0.82 ^{a}
Malawi	13	30.96 ± 3.91 ^{a}	43.24 ± 5.02 ^{b}	7.15 ± 0.91 ^{a}	14.16 ± 1.17 ^{a}
P-value		0.6757	0.0075	0.4920	0.1326

Means with the same superscript in the same column are not significantly different at $p<0.05$

5.3.4: Comparison of cost and healthfulness of healthful recipes

Figure 5.2 shows charts of the cost of recipes versus their WXYfm scores. Except for cricket-substitute recipes, the overall trends indicated that healthful recipes were less expensive than the less healthful recipes. The scatter plots indicate weak to moderately linear relationships between WXYfm scores (healthfulness) and cost of recipes. The weakest relationship was for cricket-substitute recipe (r = - 0.09) and the strongest was for termite-substitute recipe (r = 0.56). Accordingly, termite would be the best choice to replace meat in conventional meat recipes since it offered a dual benefit of improving healthfulness and imputing cost-effectiveness. The grasshopper would also be a suitable choice (r = 0.16) in replacing conventional meats in recipes. This correlation is quite encouraging in that it illustrates that the consumers can actually pay less for more healthful food choices.

The lowest cost for conventional meat recipes was for Malawian fish powder stew at Ksh 5.77 with a WXYfm score of -1, while the most expensive recipe under conventional meats was Kenyan stewed guinea fowl at Ksh 67.41 with a score of 0. Similarly, the edible insects-substitute recipes had the following lowest and highest prices with their respective WXYfm scores: - cricket: Malawian fish powder stew (Ksh 6.57, -2), Malawian grilled tilapia (Ksh 72.39, 1); termite: Kenyan stewed Nile perch (Ksh 3.04, -2), Kenyan fried tilapia (Ksh 14.42, 19); and grasshopper: Malawian fish powder stew (Ksh 5.44, 0) Malawian lake sardine stew (with groundnut) (Ksh 20.53, -5). Thus, the cheapest recipe (Kenyan stewed Nile perch – termite) at Ksh 3.04 was as healthful (WXYfm score = -2) as the most expensive recipe (Malawian grilled tilapia – cricket) at

Ksh 72.39 with a WXY score of 1. The most unhealthful recipe was Kenyan edible insects-substitute recipe beef stew (cricket) with a WXYfm score of 20 and a cost of Ksh 34.63.

Consequently, healthfulness of recipes did not seem to determine the price of recipes and vice versa, when viewing each of the recipes independently. However, it would still be possible to identify the most affordable yet healthful recipes. For instance, all Malawian fish powder stew recipes had favorable prices and healthful scores at the same time. Consumers can therefore choose the most affordable and healthful recipes for optimum health outcomes. Atwater, (1894) gave some definitions of food in relation to nutritive value and cost, and is quoted thus: “the cheapest food is that which furnishes the largest amount of nutriment at the least cost” and “the best food is that which is both most healthful and cheapest”. Hence, food must be both healthful and affordable.

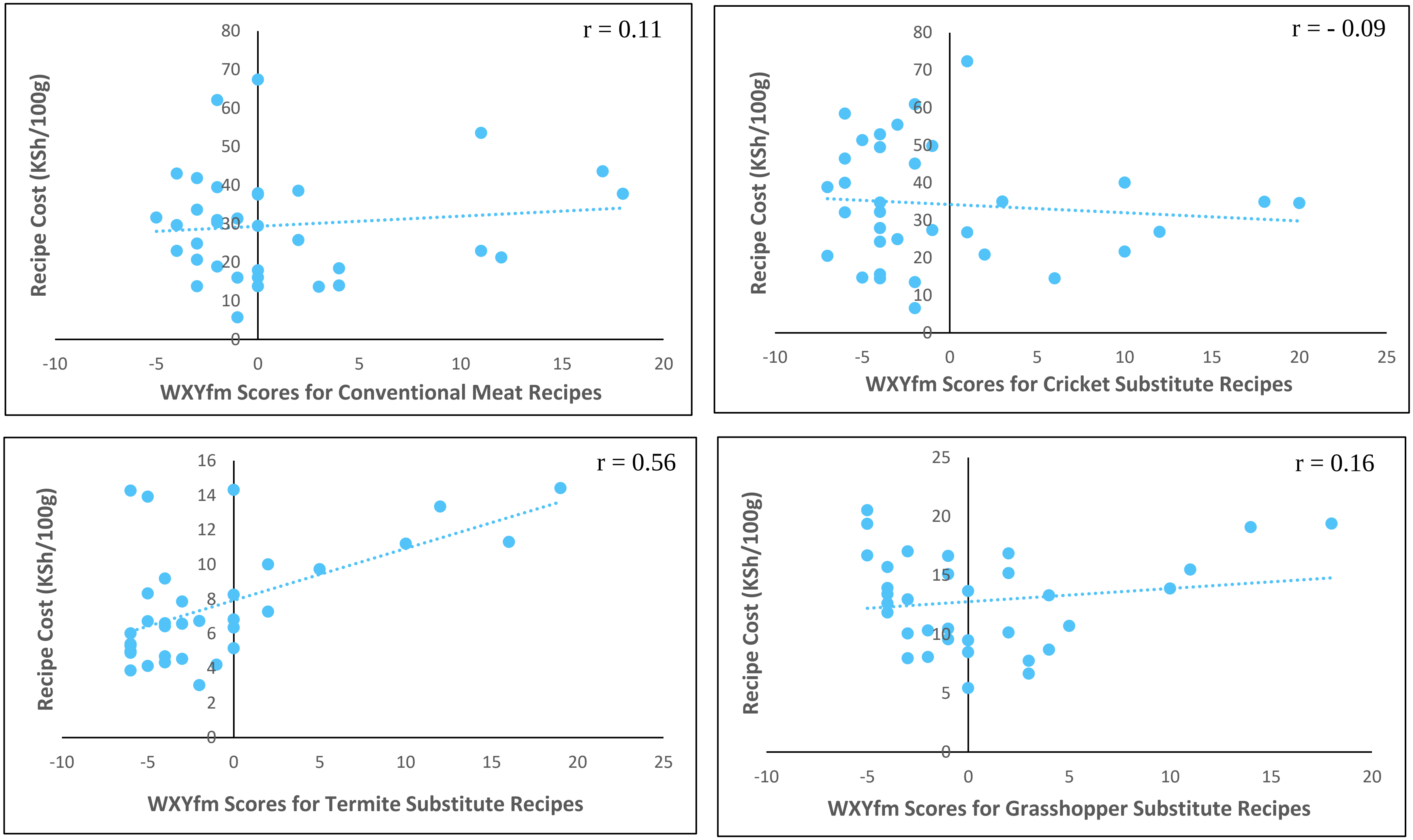

Figure 5. 2: Scatter plots of recipes cost (Ksh/100g) vs the WXYfm scores

Figure 5.3 depicts recipe costs plotted against the RRR scores. The trends in the scatter plots indicate weak negative relation between cost and RRR scores (healthfulness) which is indicative of healthfulness being associated with cost-effectiveness. Since the higher the RRR score the more healthful a food is (Scheidt & Daniel, 2004), then the negative relationship indicated by the correlation coefficients shows that healthful recipes tended to be less expensive. Overall, replacing conventional meats with edible insects had a positive influence on both the healthfulness and cost-effectiveness of the recipes.

The Malawian fish powder stew had the lowest cost (Ksh 5.77) among the conventional meat recipes and it had the highest RRR score of 31.96 while the most expensive (Ksh 67.41) meat recipe (Kenyan stewed guinea fowl) had a score of 0.74. The three most unhealthful meat recipes, i.e., Kenyan fried tilapia (RRR = 0.19, cost = Ksh 37.83), fried chicken (RRR = 0.26, cost = Ksh 43.64), and stewed quails (RRR = 0.28, Ksh 21.27) were not the most or least expensive.

As of the edible cricket recipes, the most healthful recipe (Malawian fish powder stew, RRR = 25.38) was also the most affordable (cost = Ksh 6.57) with the most unhealthful recipe (Kenyan fried tilapia, RRR = 0.53) costing Ksh 40.05. In a similar manner, termite most unhealthful recipe was Kenyan stewed quails (RRR = 0.89, cost = Ksh 13.35) while the most healthful was Malawian beef stew (RRR = 64.29, cost = Ksh 5.32); and grasshopper most unhealthful was Kenyan fried tilapia (RRR = 0.19, cost = Ksh 18.40) with the most healthful being Malawian fish powder stew (RRR = 33.61, cost = Ksh 5.44). But in general, the trends showed that the cost of recipes reduced with increased healthfulness, suggesting that choosing a more healthful recipe would add the benefit of affordability.

It is therefore possible to have unhealthful recipes that are cheap and others being expensive. Conversely, healthful recipes can be both affordable and others expensive. A different study observed that foods with high nutritional quality were not always the most expensive (Maillot et al., 2007). When it comes to food choice, taste, food nutritional value, and the cost play great roles (Drewnowski & Fulgoni, 2008) and nutritionists and dietitians should therefore develop diets, recipes and menus that are tasteful, healthful and affordable (Glanz et al., 1998; Mobley et al., 2009).

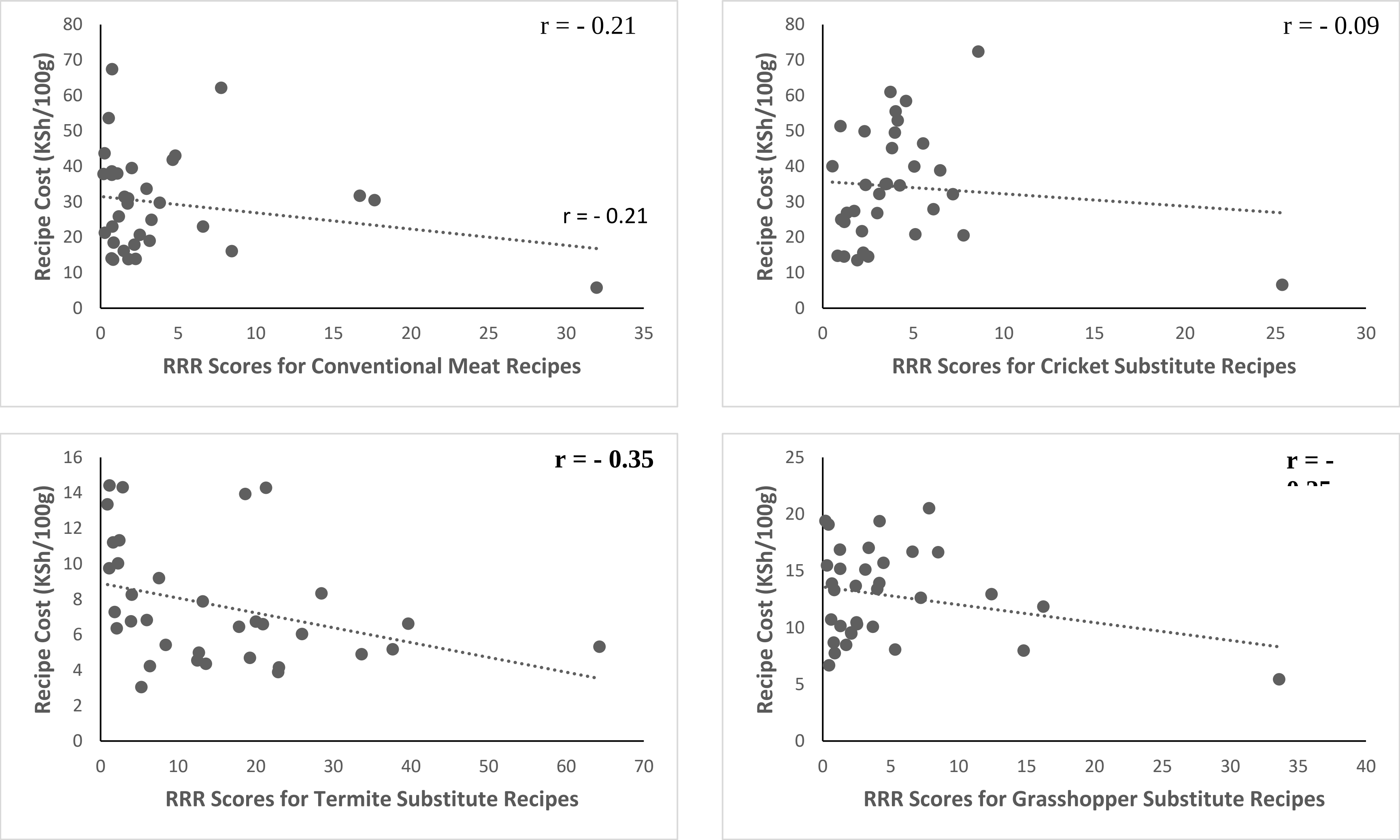

Figure 5. 3: Scatter plots of recipe cost (Ksh/100g) vs the RRR scores

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1: Conclusions

This study sought to evaluate the suitability of edible insects as substitutes for conventional meats in human diet. This was undertaken through collating nutrient data from edible insects, then using nutritional profiling models to compare the healthfulness of conventional meat with that of edible insects, and finally evaluated the healthfulness and cost-effectiveness of replacing meats in conventional meat recipes with edible insects. Classifying foods using healthfulness is an important topic in the field of nutrition since it impacts positively on health outcomes of the population.

Published data showed that edible insects are filled with nutrients that are essential for human nutrition and therefore are nutrient-dense. The data was however wide ranging due to differences in species and other factors related to origin, feed, stage of consumption, sex, and seasonality. Edible insects are protein-rich and hence they are suitable sources of dietary protein and can aptly be used to fight protein energy malnutrition. Based on their balance of nutrients, edible insects are potential novel foods for combating world hunger and enhancing food security.

Most of the edible insects studied performed better than conventional meats on healthfulness indicating their suitability in replacing meats in the diet. This outcome reinforced the nutritional profile strength of edible insects. The three nutrient profiling models applied in the study were robust and they gave similar results in terms of healthfulness of edible insects and conventional meats, hence, they are satisfactory in classifying foods based on nutrient content.

The study further explored the use of edible insects as substitutes in meat recipes to improve the healthfulness of diets. Edible insects have been found to be suitable substitutes for meats in recipes to improve the healthfulness and hence enhance the health outcomes of consumers. But the choice of insects should be based on individual species. All the edible insects used in the study had a positive influence on the healthfulness of the recipes used, but termite stood out as the preferred insect of choice both in Kenya and Malawi. In terms of cost, termite was the most affordable followed by grasshopper both in Kenya and Malawi. Termite gave the dual benefit of healthfulness and cost-effectiveness of recipes thus becoming the edible insect of choice for replacing conventional meats in this study.

The cost of a healthful recipe is dependent upon the cost and healthfulness of the respective ingredients. Hence, the cost-effectiveness and the healthfulness of diets should be considered when making food choices to avoid paying for unhealthful diets. But reformulation of individual recipes can improve both the healthfulness and cost-effectiveness.

6.2: Recommendations

Further studies are needed to evaluate effect of partial substitution of recipes with insects on healthfulness of diets. Studies on the acceptability of edible insects as human food need to be carried out to improve on the available data. The effect of culture and acceptability of edible insects need to be applied in healthfulness studies using nutrient profiling models.

The rearing of edible insects needs to be upscaled to increase their availability in the food industry and hence reduce the cost of these novel foods. Farmers need to be educated on the commercial benefits of edible insects.

Much work is needed to promote consumption of insects by the general population through deliberate efforts by players in the food value chain. Food manufacturers, caterers, nutritionists, and dietitians should adopt edible insects as novel ingredients in product and recipe formulations in a concerted effort to increase the uptake of the edible insects. Edible insects should be included in food baskets used in food and nutrition intervention programmes by government, non-governmental bodies and well-wishers.

Nutrient profiling should be adopted by the government through the Kenya Bureau of Standards as a standard method in evaluating food products to ensure healthful foods, coupled with consumer education, to give consumers an easier way to choose nutrient-dense foods and to encourage the food industry to offer healthful products in order to realize a healthy population.

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APPENDICES

Publications

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ORIGINAL RESEARCH ARTICLE

Nutritional potential of edible insects: a systematic review of published data

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Abstract
Edible insects are a suitable source of valuable nutrients that can meet the nutritional requirements for humans. Published scientific data on their nutritional value has been on the rise in the last decade. There are, however, huge disparities in the nutrient values found in the publications hence the need to appraise the data for quality, collate the results, and give an opinion on the nutrient potential of the insects. Nutritional data were searched systematically from published research articles using Google Scholar, PubMed, Scopus, and Web of Science. A total of 483 published scientific journal articles were obtained and screened for quality based on European Food Information Resource (EuroFIR) guidelines with data from 26 articles meeting the criteria by scoring above 17.5 out of 35 points. A total of 91 insect species in 135 data lines were identified in the search. The results showed a wide variety of nutrient content among different species. The highest and the lowest recorded values for macronutrients were; Carbohydrates: 94.01g/100g, 0.1g/100g; Protein: 81.11g/100g, 1.11g/100g; and Fat: 77.01g/100g, 2.11g/100g. The highest energy value was 762 Kcal/100g and the lowest was 268.3 Kcal/100g. The highest and lowest values for fatty acids were; SFA: 733.46mg/100g, 17.50mg/100g; MUFA: 165.80mg/100g, 5.67mg/100g; and PUFA: 1514.32mg/100g, 3.70mg/100g. For minerals, potassium had the highest reported value of 2515mg/100g while copper had the lowest reported value of 0.0073mg/100g. Among the vitamins, vitamin E had the highest recorded value of 0.925mg/100g while vitamin C had the lowest recorded value of 0.0046mg/100g. The highest recorded value for amino acids was 96.02mg/g of protein for leucine and the lowest reported value was 1.19mg/g of protein for methionine+cysteine. The data shows a great variation even within species and regions, attributable to diet (feeding regime), sex, geographical source, and growth stage. The quality of published data was deficient leading to a high number of papers not meeting the EuroFIR criteria, majorly attributed to the number of analytical samples used during analysis However, the data indicate that edible insects are a good source of nutrients and can be used to fight undernutrition with some insect species providing a significant contribution to the Recommended Daily Allowance. Researchers need to address themselves to data quality when conducting nutritional analysis.

Keywords Edible insects · Recommended daily allowance · Nutrient composition · Nutrients

Introduction

The world population has increased tremendously in the recent past with undernutrition being on the rise (Barennes et al. 2015), and edible insects have been suggested as alternative sources of high-value nutrients (Van Huis 2020; Rumpold and Schlüter 2013; Shadung and Given 2012). As a result, the use of edible insects as human food and livestock feed has increased in the recent past worldwide (Ssepuuya et al. 2017). Insects have been consumed traditionally by more than 2 billion people in over 113 countries in the world; but in most cases, the consumption of insects is purely a cultural practice and by choice based on the palatability

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RESEARCH **Open Access**

Comparison of healthfulness of conventional meats and edible insects in Sub-Saharan Africa using three nutrient profiling models

Johnson Weru[1,2*], Peter Chege[3], Anthony Wanjoya[4] and John Kinyuru[2]

Abstract

Background: Meat and meat products have been blamed for a myriad of problems facing human kind like lifestyle illnesses, environmental degradation, and climate change. Edible insects have been suggested as the suitable alternatives to conventional meats in order to ameliorate these drawbacks. Healthfulness is the ability for a given food to impart health benefits to the consumer. Evidence is however scanty on the healthfulness of both the meats and edible insects in order to have grounds for replacing meats with insects in the diet. This study aimed to comparatively evaluate the healthfulness of meats and edible insects in Sub-Saharan Africa using modern nutrient profiling models.

Materials and methods: Nutritional data for meats and edible insects were obtained from Food Composition Tables (FCTs) and a systematic review, respectively. The data was applied to three nutrient profiling models: the WXYfm (Ofcom) model that was designed to regulate advertising of foods to children, the RRR (Ratio of Recommended to Restricted) model that assesses the ratio of positive to negative nutrients in foods, and the GDA (Guideline Daily Amounts) model which has been used to regulate health claims on foods. Tukey's Studentized Range (HSD) Test (The SAS System) was used to check for significance in differences of healthfulness using mean scores.

Results: The WXYfm model classified all foods as healthful, and *Nasutitermes spp.* was significantly more healthful than duck ($P = 0.05$). The RRR classified all foods as healthful, and *Nasutitermes spp.* was significantly more healthful than all other foods except *Macrotermes bellicosus* and tilapia ($P = 0.05$). Duck (for women and men) and pork (for women), were classified as unhealthful by the GDA scoring system, and duck was significantly less healthful than all other foods ($P < 0.0001$), except for pork and mutton.

Conclusion: Edible insects are promising alternatives to conventional meats, but the choice should be on a species-to-species basis. This would be significant in broadening the choice of protein sources to cater for an ever-increasing world population.

Keywords: Meat, Edible insects, Healthfulness, Nutrient profiling, Scores

Background

The term 'healthful' means promoting good health, e.g., food, while the term 'healthy' means in good health e.g., a healthy person. But the term 'healthy' has been used for both the person and the good food (Drewnowski 2005). Healthfulness therefore implies the ability of a food to impart health benefits to the consumer. Meat is defined as the flesh (skeletal muscle) of animals that is eaten as food. This definition may include connective tissue and the fat attached to the muscle (Williams 2007). In culinary terms, meat is divided majorly into two categories; red meat and white meat. Red meat refers to meat from cattle, sheep, and goat (Williams 2007) while white meat is mainly from poultry (Cosgrove et al. 2005). Meat

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The Role of Edible Insects in Diets and Nutrition in East Africa

Authors
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Abstract

Insects have been used as food, medicine and in rituals by a number of communities in the East African region comprising of Kenya, Uganda and Tanzania over centuries. Progressively, farmed edible insects mainly crickets and grasshoppers are gaining popularity within the region. However, the utilization of the edible insects is hampered by lack of storage and preservation facilities in the rural areas leading to high postharvest losses. Sun drying and roasting have been the main processing methods applied for decades by communities consuming edible insects such as the Luo from Kenya. Recently there has been incorporation of insects as an ingredient in processing of baked products and complementary foods. Culture, taboos, customs and ethnic preferences have highly influenced the consumption of edible insects in East Africa. Edible insects such as grasshoppers, mayfly and termites that are consumed in this region have been shown to be source of both macro and micro nutrients and other components such as chitin which has been linked to improved health and better management of chronic diseases. Therefore, edible insects promise to be a part of the solution to food and nutrition security within the East African region.

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List of conferences and symposia

1. **1st Ruspolia International Symposium December 11, 2019 in JKUAT/Kenya**

   Johnson Weru, John Kinyuru, Peter Chege

   NUTRITIONAL POTENTIAL OF EDIBLE INSECTS: A SYSTEMATIC REVIEW
2. **VIZAFRICA Symposium August 20 – 21, 2018 in JKUAT/Kenya**

   Ndung'u J. W., Kinyuru J. N, and Chege P. M

   NUTRITIONAL POTENTIAL OF EDIBLE INSECTS: A SYSTEMATIC REVIEW OF PUBLISHED DATA FROM ONLINE DATABASES
3. **AFRICA-ai- JAPAN Project: African Union - African innovation - JKUAT AND PAUSTI Network Project March 22 – 23, 2018 in JKUAT/Kenya**

   Johnson Weru, John Kinyuru, Peter Chege

   EDIBLE INSECTS AS A SUBSTITUTE FOR CONVENTIONAL MEAT IN HUMAN DIET. USE OF OPEN DATA IN NUTRITIONAL PROFILING MODELS