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The potential contribution and challenges of edible grasshopper (Ruspolia differens) to food and nutrition security in Uganda- a literature review

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Abstract

Insects are being considered a sustainable protein food source for the future to forestall the impending world protein shortage, exacerbated by population growth and climate change. The edible grasshopper *Ruspolia differens*, a high protein insect traditionally consumed in East Africa- particularly in Central Uganda presents an opportunity for local solutions to food and nutritional security. This literature review consolidates research information, mainly derived from peer reviewed articles on online databases, on potential distribution, demand, importance, food safety hazards and, handling and research efforts that support safety of consumption. Key documented findings are that *Ruspolia differens* is highly nutritious and a source of livelihood. Their geographical distribution is expected to widen, increasing availability and access. Food safety hazards from their handling include high counts of bacterial species, yeasts and molds, heavy metals, and a potential for inherent allergens yet the demand and supply chains are expanding. Consequently, a strategy involving all stakeholders is required to support food safety along the value chain. Understanding the contribution of *Ruspolia differens* and minimising obstacles to its exploitation should be a research priority in order to promote the adoption, value addition, and development of insect-derived products aimed at nontraditional insect-eating communities and those who are severely food insecure.

Keywords: *Ruspolia differens, nutritional value, management, food-safety, food security*

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Introduction

Consumption of edible insects, entomophagy, is widespread in many cultures of the world. with one third of the world population identified as insect eaters. The practice has been identified in the diets of 110 countries (Rumpold and Schluter, 2013), with Asia, Africa, and Latin America accounting for the majority of consumption. Over 1900 edible species of insects have been documented; the order Orthoptera-grasshoppers, locusts and crickets contribute about 13% (Ng'ang'a *et al.*,2021) of the documented edible insects in the world (Raheem *et al.*,2019; BfR *et al.*,2019; Van Huis 2013).

The United Nations-Food and Agriculture Organisation (FAO) suggests the use of edible insects as important for food security, livelihood enhancement, and the environment (FAO, 2013). Incorporating insects into regular diets is a nutritious, affordable, and sustainable food strategy that supports the United Nations Development Programme's Sustainable Development Goal 2 of eradicating extreme hunger, reducing poverty, and enhancing health (Garino, 2019). In Africa, insects have largely been promoted for their high nutritional value-depending on species, developmental stage, feeding habits and processing methods (Imathiu, 2020), and livelihood benefits. Their protein composition compares well to traditional beef and are a good source of micronutrients and fat (Kinyuru and Kenji., 2010; Fombong *et al*., 2017). Hence, they can be an important food supplement for undernourished children and are being explored as a food ingredient in food composites (Mmari, 2017).

As a feed source, insects can ably meet the protein requirement for animals even as sources become scarce and less sustainable (Raheem *et al.*,2019). Whereas many animals are natural insect eaters, this is usual for free range methods of husbandry. For farmed animals, insects have been used as feed supplements because of their nutritional and health benefits such as improving health due to the presence of bioactive compounds (Sogari *et al.*,2019).

Insects have long been traded in traditional insect eating communities particularly in Africa, Asia, the Pacific and South America, where they provide income for the resource poor households. They are collected at different life stages and sold in markets as an additional source of income, and the number of households involved are observed to increase overtime (FAO,2013; Odongo *et al*.,2018).

While traditionally harvested from the wild, it is reported that farm-raised insects require less food per kilogramme of body weight than conventional livestock, while emitting less greenhouse gases (Imathiu, 2020) which makes them easier to farm. They are omnivorous in nature, require less space and less water use. However, high labour costs related to insect farming were earlier reported for Europe (Rumpold and Schluter, 2013).

The report on food security and nutrition in Africa (FAO,2020) noted the worsening food insecurity particularly in Sub-Saharan Africa where 20.3% of the population (278 million) remained undernourished (FAO,2019). Food security concerns itself with reliable access to affordable, nutritious and safe food in sufficient amounts (FAO,2013). The most recent regional report on food security (FAO *et al*., 2022) painted a grimmer picture with Africa lagging on these efforts, probably brought on by the COVID-19 pandemic; one fifth of the population faced hunger in 2020, an increase of 46.3 million people than the previous year. In Uganda alone, it was estimated that 23.2% of the population (10.6 million) are severely food insecure and remain undernourished (FAO,2021).

Insects therefore provide an opportunity for developing countries which Imathiu (2020) suggests could be through dietary diversity, food fortification and supplementation. This would be easier starting with where they are already deeply rooted in their cultural food practices not only as food but also as a livelihood option (Odongo *et al*.,2018). Insects would be viewed as an opportunity in the fight against hunger, malnutrition and other nutrient deficiency (Dobermann *et al.*,2017; FAO, 2010) rather than associate it with scarcity which exacerbates phobias towards their consumption (Shockley and Dossey, 2014). While most protein sources are of both plant and animal origin, the latter are considered superior. And with a looming world protein shortage predicted against a growing world population, more diverse quality sources are worth exploiting (Lamsal *et al*.,2019). Efforts have been made by projects such as the INSBIZ project at Makerere University in Uganda, supported by *icipe* by contributing to extensive research on *Ruspolia differens* and its potential applications, standards including extending shelf life of whole insects through improved packaging.

This literature review attempts to consolidate current documented information on potential contribution of grasshoppers particularly *Ruspolia differens* to food security-their distribution, the demand, nutritional importance, handling, consumption and food safety hazards along its value chain in Uganda.

Materials and Methods

A literature search was conducted within electronic databases- Google Scholar (https://scholar.google.com/), and PubMed (https://pubmed.ncbi.nlm.nih.gov) using search phrases such as 'grasshoppers and food security', '*Ruspolia differens* and food safety', 'food security in Uganda, East Africa', '*Ruspolia differens* products', hazards of grasshoppers', 'allergic reactions from grasshoppers'. The bulk of the studies accessed were identified through cross references. The search criteria were confined to articles published in peer reviewed journals, and book chapters in English language from 2008 to date. Accepted papers and only one thesis dissertation was included in the search, while conference proceedings and papers were excluded.

Findings

Present and projected distribution of R. differens

Ruspolia differens Serville 1838 (also called "*nsenene*" in Luganda), belongs to subfamily Copiphorinae (coneheads), family Tettigoniidae and is a native species to sub-Saharan Africa (Matojo, 2017). Other species, as documented by Matojo (2017), are only found in Asia, Europe and North America and not found in sub-Saharan Africa (SSA).

Presently, *R. differens* are documented to be found in several districts of Uganda: Masaka, Hoima, Mbarara, Kabale, Kampala (Leonard *et al*., 2020; Odongo *et al*., 2018; Okia *et al*.,2017; Ssepuya *et al*., 2016; Agea *et al*.,2008) and as far as Lira and Alebtong (Akullo *et al.,*2016;). Local reports have also indicated intense swarms sighted and commercially trapped in Nebbi, Mityana, Mubende, Kyegegwa, Masindi, Zombo and Arua districts (Fig.1). Central Uganda are the key traditional consumers of grasshoppers *R. differens*, where it's considered a delicacy, and Masaka and Kampala districts host the biggest markets for its trade and consumption. Grasshoppers are also reported to be found in other East African countries (Okia *et al.*,2017; Ssepuya *et al.*,2016; Agea *et al*.,2008).

The longhorn grasshopper *R. differens* exhibits different colours -purple, brown, green. The swarms are non-destructive to crops and vegetation (Leonard *et al*.,2021). The swarming season occurs twice a year after the rainy season such as March to May for the first season, and November to December for the second (Ssepuuya *et al*.,2016; Kinyuru *et al*.,2010; Agea *et al*.,2008).

R. differens are still largely harvested from the wild, for both home consumption and trade, and while efforts for industrial mass production are being explored (Tanga *et al*.,2021), no documented successes were found. However, lifecycle trials revealed their optimum growth temperatures to be between 22^0C and 32^0C, ideally in the tropics (Lehtovaara *et al.*,2018). Additionally, Leonard *et al.* (2021) in their insect life cycle modelling predicted that distribution of *R. differens*, growth and development were all temperature dependent. They reported development stages lasting 14-15 days for egg incubation at an ideal temperature of 30-32^0C, and 28^0C to 30^0C from nymphs to adults in 52.5 to 58 days. The models further predicted a potential increase in suitable habitats for *R. differens* development within Central and East Africa raising prospects for its role in food security in the region.

Demand and supply chain of Ruspolia differens in Uganda

The grasshopper is the most consumed and commercialized of the 20 species of edible insects in Uganda (Odongo *et al*.,2018) with a growing number of players in the trade (Sengendo *et al*.,2020; Mugo, 2019; Odongo *et al*.,2018; Agea *et al*.,2008). The supply chain consists of many participants including commercial and subsistence collectors, wholesalers, transporters and retailers. Consumers largely access grasshoppers as raw and unplucked from collectors and wholesalers, and, raw or processed (plucked and fried, or dried) from retailers with minimal value addition in processing and packaging. The intensity of swarms and their availability determine their price (Mugo,2019; Donkor *et al*.,2022). By 2020, minimal technological interventions for value addition (for processing and storage), lack of standardization and inadequate market information plagued the food value chain

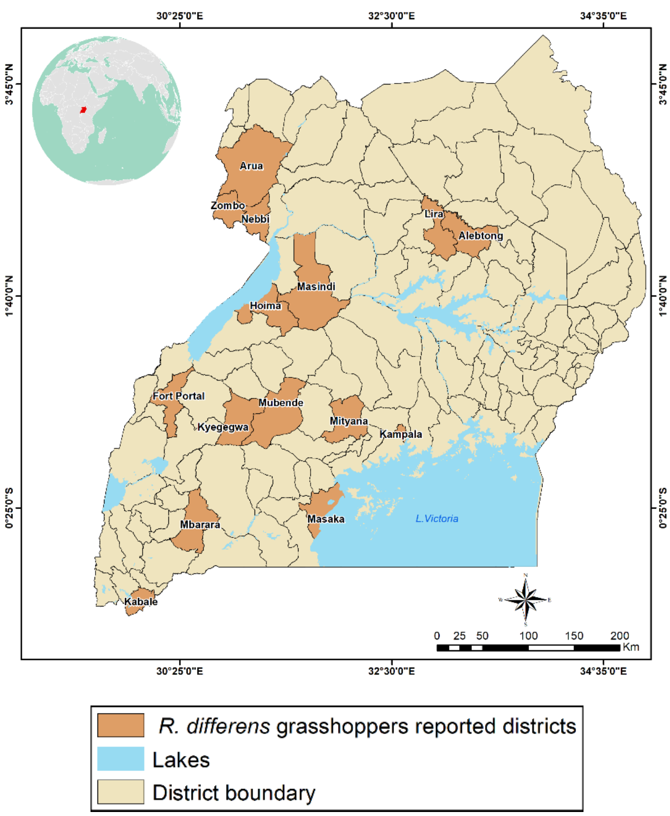

Figure 1: Districts of Uganda where R. differens have been sighted in season

(Odong *et al*.,2017; Okia *et al*.,2017; Nakimbugwe *et al*.,2020). However, a review by Tanga *et al*. (2021) reports standards that have been developed to guide safe handling, processing and consumption of *R. differens* in Uganda. This standard- "US 2146:2020 Edible insect specification" (https://www.unbs.go.ug) targets insects and their products trade on the Ugandan market. Local markets are considered important vehicles for both an inclusive economy and food security.

Therefore, bottlenecks such as the absence of conclusive breakthroughs in on-farm rearing of grasshoppers, could possibly be overcome by processing into various food products for extended shelf life and enforcing regulatory standards (Mwangi *et al*.,2019).

Collection and processing practices

Wild Harvesting: Harvesting of *R. differens* particularly in the Lake Victoria basin have been well documented by several research studies- (Ssepuuya *et al*.,2019; Odongo *et al*.,2018; Okia *et al*.,2017): Grasshoppers were indigenously handpicked from the wild- in plantations, grass fields and cropland bushes in the morning - primarily by women and children for home consumption (Agea *et al*.,2008; Akullo *et al*.,2016; Okia *et al*.,2017). However, with increasing urbanization, swarms are documented to be attracted by streetlights at night (Agea *et al*.,2008).

This practice has further morphed, largely driven by increasing demand (Odong *et al.,*2017), to include locally made light traps for mass collection at makeshift commercial collection sites as observed in Central Uganda. Collection at these establishments usually takes place between 10:00 p.m and 2:00 p.m. Iron sheets reflect light to attract the grasshoppers that slide into metallic drums smeared with used oil and sprinkled with cassava or maize flour- the insects drop and slide down into the drums in droves (Ssengendo *et al*.,2021; Ssepuuya *et al*.,2019; Okia *et al*.,2017). Among some landless, rooftops were also used as harvesting and collection centers in urban areas (Odong *et al*.,2017). Similar traps were documented to be used for commercial harvesting in the wider East African region, particularly Lake Victoria basin (Nganga *et al*.,2018 and Mmari *et al*.,2017).

Processing: New or used sacks are generally used to transport grasshoppers to homesteads for processing or informal markets, where they are sold raw or processed. Prior to washing and cooking, appendages- wings, legs, ovipositor- are removed, a process called plucking. (Ssepuuya *et al*.,2019). Documented traditional methods of processing *R. differens* include toasting (also referred to as dry frying or pan frying), airdrying, boiling, sundrying (Akullo *et al*.,2016; Nyagena *et al*.,2020;), salting followed by boiling and sun-drying for long term storage. Others which include sautéing and deep frying are often preferred by commercial processors commonly observed in outdoor markets. The grasshoppers are mainly consumed as a snack, and stew in rural areas (Ssepuuya *et al*.,2019; Okia *et al*.,2017).

Documented findings reviewed thus far show *Ruspolia differens* to be an affordable food option with low-cost investments, even for the landless poor. And given the predicted increase in favourable ecosystems or habitats for their reproduction and development in East and central Africa, availability is expected to improve- an opportunity for livelihood improvements through trade.

Potential role of R.differens in diet diversity, fortification, supplementation and affordability of food

Lokuruka (2020) reports that hunger, undernourishment and micronutrient deficiency are still existent in resource poor communities of Uganda. Their report cites inadequate calorie intake despite presence of food while 30-33% children suffer from chronic malnutrition, 15% underweight and 6% suffer acute malnutrition- a little under 9% estimated for Sub-Saharan Africa (Shockley and Dossey, 2014). An earlier review by Tidermann- Andersen *et al* (2011) examining iron and zinc content of diets of school children (9-15 years) in Kumi district in Eastern Uganda particularly highlighted the low daily zinc intake in their predominantly vegetable based diets.

Reviewing the status of malnutrition in Uganda, Adebissi *et al.* (2019) highlighted prevalence of acute malnutrition and micronutrient deficiency among children (five years and under) in different parts of the country including refugee settlements. Western and Eastern Uganda especially Karamoja experienced high levels of acute malnutrition and underweight respectively. Interestingly, these values were directly correlated with low access to food, low diet diversity and low-income status of the household (Adebissi *et al*., 2019).

In addition, household incomes can be increased during grasshopper season through local trade. According to the FAO report on food security for 2022, the covid-19 pandemic has exacerbated existing disparities in access to food. In 2021, 112 million more people were unable to afford a healthy diet on a global scale. By 2020, 3.0% more people in low-income countries will be unable to afford a healthy diet (FAO *et al.,*2022). Urban slum households in Kampala were found to be food insecure and suffered from low dietary quality resulting in high levels of undernourishment (Wanyama *et al*.,2019) unlike the higher socioeconomic status households whose diets comprised of high calories from consumption of highly processed carbohydrates and sugars, and organ meats (Auma *et al.,*2019). Studies have observed diets in rural communities of Uganda as reliant on staples, associated with stunting and wasting in children five years and under (Amaral *et al.,* 2018), also among the school age children and adolescents in rural areas of Eastern Uganda (Isabirye *et al.,*2020; Ochola and Masibo, 2019). Similar findings were documented for poor farm households in South Central Uganda where minimal consumption of animal protein was observed (Nabuuma *et al*.,2018). Such findings underscore the need to explore the available quality protein sources such as *R. differens* which can be easily accessed by poor households using affordable technology.

Nutritional investigations have found *R. differens* to have a rich nutritional profile;- high protein content (36-44%), fat (41-48%), carbohydrates (2-4.9%), fiber (3.9-11.14%), carotenoids (900-2300µg/100g), and minerals-potassium (259.7-370.6mg/100g), phosphorus (121-140.9mg/100g), calcium (24.5-27.4mg/100g), Iron (13.0-16.6mg/100g), zinc (12.4-17.3mg/100g), manganese (2.5-5.3mg/100g), vitamins- retinol, niacin, folic acid α-tocopherol, riboflavin, and polyunsaturated fatty acids with minor differences in geographical location (Ssepuya *et al.,*2016; Kinyuru *et al*.,2010). Grasshopper oil was also found to have omega-3- fatty acids; α- linolenic acid (ALA)-15µg/mg, eicosapentaenoic acid (EPA)-45µg/mg, and docosapentaenoic acid (DHA)-8.2µg/mg, richer than some plant oils (Cheseto *et al.,*2020). Nutrients that are found most deficient in young children in food insecure areas are documented as protein, calcium, iron, and zinc. Daily recommended intake of these nutrients is difficult to ensure with limited animal food sources in the diet, yet *R. differens* provides comparatively higher amounts than many lean meats (Kinyuru *et al*.,2010). Iron aids proper functioning of immune system, and other body processes especially in adolescent girls and women with a recommended dietary intake of 15-18mg/day. Zinc is a vital micronutrient to support children's growth, and for the immune system, while calcium supports the musculoskeletal and nervous system. (Vaclavik and Christian 2014).

R. differens are a very potent nutrient source to partially substitute staples in fortification of foods. They have been ground into powder or paste after drying and used to enrich foods. In some documented cases, fortification further improved texture and fiber content of flours although off flavours are a limitation that can be improved by defatting and regulating amounts of insect powder (Mwangi *et al*., 2019). In baked products (breads, buns, cakes, cookies) and composite flours, a much higher protein value and improved texture have been reported for different grasshopper species (Cheseto *et al*.,2020; Kinyuru *et al*.,2019; Mwangi *et al*.,2019). Attempts have also been made to use their oil in confectionery products such as cookies (Cheseto *et al*.,2020), where consumer acceptance was higher than cookies baked with olive oil. Given the high protein and fat content (energy), grasshoppers could substitute for soy protein-deemed costlier in low-income areas-to combat protein, micronutrient and calorie deficiency in undernourished populations.

Shockley and Dossey (2014) discussing dietary consumption of insects by humans cited a range of applications which included relevance in industrial food production and use as ingredient in Ready to Use Therapeutic Foods (RUTFs)- for treating malnutrition- which should contain at least 25-33% animal sourced ingredients. Such foods provide high energy while improving growth rate. The study asserts that even small amounts of intervention would lead to great health outcomes.

Given the widespread evidence of status of hunger, undernourishment (Table 1) and low dietary diversity particularly for East African region where dependence on staples is the norm, high quality nutrient foods like grasshopper-though well researched- would be considered underutilized. Potential applications for *R. differens* and its trade are immense if guided by the extensive research. Research efforts into farm reared grasshoppers for year-round production-should be considered urgent and intensified.

Hazards associated with R. differens

Consumption of edible insects has associated hazards, documented in several studies as microbiological, chemical, and biological in nature (Rumpold and Schluter, 2013; Dobermann *et al.,* 2017; van der Fels-Klerx *et al*.,2018). Some hazards are considered inherent while others are introduced during their handling, influenced by habitat, insect species, production stage, feeding habits and processing methods (Mezes, 2018). Wild harvesting in particular raises potential challenges including contamination with microbial organisms and parasites, allergens, antinutrients, pesticide residues, and moulds for many edible insects (Imathiu, 2020).

Table 1: Country level estimates of undernourishment, moderate or severe food insecurity, and malnutrition in East Africa.

Country	Percentage undernourishment in total population (%)		Prevalence of severe food insecurity in the total population (%)		Prevalence of moderate to severe food insecurity in the total population (%)		Prevalence of wasting in children (%).(<5 years)	Prevalence of stunting in children (%) (<5 years)		Prevalence of anaemia in women (15-49 years) (%)	
YEARS (RANGE)	2004–06	2019–21	2014–16	2019–21	2014–16	2019–21	2020	2012-	2020	2012	2019
Uganda	n.a	n.a	19.2	23.2	63.4	72.5	3.5	34.1	27.9	31.3	32.8
Tanzania	28.4	22.6	20.6	25.8	48.8	57.6	3.5	38.3	32.0	40.3	38.9
Kenya	28.5	26.9	15.0	26.1	50.7	69.5	4.2	27.8	19.4	28.4	28.7
Rwanda	35.3	35.8					1.1	40.5	32.6	18.3	17.2
Burundi	n.a	n.a	n.a		n.a		4.8	56.8	57.6	31.1	38.5
South Sudan		n.a	n.a	62.3	n.a	86.4	n.a	32.1	30.6	34.7	35.6

n.a- data not available. *Source*: *The State of Food Security and Nutrition in the World* (SOFI), 2022 edition https://data.unicef.org/resources/sofi-2022/

Potential hazards from wild collection of R.differens

Documented hazards associated with collection or harvesting of *Ruspolia differens* from the wild in Uganda are physical, chemical and microbial in nature. Sengendo *et al.* (2021) documents dangers associated with the light traps used in traditional harvesting: the mercury light bulbs commonly used if improperly disposed, can accumulate mercury in the ground which winds up in the food chain. These traps also capture, together with the grasshoppers, non-target insects such as the Nairobi fly, *Paederus sabaeus* (Fabricius) among others whose secretions are reported to burn the skin and cause temporary blindness on contact with the eyes. The outcome of this study (Sengendo *et al.*,2021) was a modified trap which if rolled out would significantly save electricity with the bulbs, significantly reduce amounts of various non target insects trapped minimizing adverse effects and reduce the need for use of waste cooking oil and cassava flour. Waste cooking oil in general has been associated with formation of carcinogenic compounds (Zahri *et al.*,2021) which can be absorbed into living cells.

Valtonen *et al.*, (2017) demonstrated in their experiment on feeding habits of *R. differens* in Uganda that several grass species and inflorescences were the preferred feed for the grasshoppers. However, through these, grasshoppers have become exposed to pesticide residues and other contaminants. In a study by Kasozi *et al* (2019) atomic absorbance spectrometric (AAS) method revealed high exposure of wild harvested grasshoppers to heavy metals particularly lead, beyond acceptable safe limits. The heads of *R. differens* samples from Central Uganda had heavier concentration, believed to be from vegetation exposed to pesticides. Interestingly, the study observed significant differences in concentrations based on geographical location- higher in Central than western Uganda. A later study by Labu *et al.*, (2022), revealed no evidence of bioaccumulation of agrochemicals in *R. differens* both raw and processed collected from Market centers in Kampala, Uganda. Further investigations are necessary to support these findings, and location-specific studies would be necessary to identify hotspots. Non-essential heavy metals- such as cadmium, lead, mercury etc. are elements reported to be prone to bioaccumulation (van der Fels-Klerx, 2018)., In this regard, sustainable farming of *R. differens* in a controlled environment becomes urgent to improve safety.

Hazards from processing activities

In general, studies have emphasized pathogenic risk arising from handling practices of *R. differens*. Ng'ang'a *et al* (2021) in their review assessing food safety risks of *R. differens* cites microbial risks as high total viable counts, high counts of *Enterobacteriaceae*, and lactic acid bacteria, yeasts and molds. Harvesting, transportation, and removal of appendages have been associated with microbial contamination- increased bacterial endospores, yeasts and molds. Spreading fresh harvest directly on the ground and reusing old produce bags are likely sources of contamination (Ng'anga *et al.,*2018). Ssepuuya *et al.* (2019) concluded that nutritional profile and handling practices were responsible for faster spoilage of raw and processed grasshopper samples. The rich nutritional profile supports growth of several microorganisms including *Clostridium* and *Campylobacter*, which are responsible for spoilage and several foodborne illnesses. Other organisms identified were *Enterobacteriaceae*, aerobic spores, yeasts and moulds. These, coupled with the high temperatures in the tropics promote faster spoilage of *R. differens*. The market centers and trapping sites in that order were identified as the high-risk points of contamination (Labu *et al.,*2021). The samples from the markets had the highest load of pathogenic bacteria- *Staphylococcus sciuri, Acinetobacter baumannii* and *Serratia marcescens*- than the other points (Labu *et al*.,2021). Another study revealed contamination of raw forms of grasshoppers *R. differens* with faecal coliforms pointing to trapping sites points or practices (Nyagena *et al*.,2020).

However, common processing methods- boiling, drying, roasting smoking, deep frying- were shown to sufficiently eliminate common food borne pathogens- except bacterial endospores- raising confidence in traditional processing methods (Labu *et al*.,2021); Ssepuuya *et al*.,2019). Nyagena *et al.* (2020) found that boiling and toasting *R. differens* considerably reduced the total viable counts, eliminating *E.coli* and enteric bacteria, *Salmonella spp*,, while toasting completely removed yeasts and molds. Oven drying had minimal effect in lowering counts while solar drying only had significant effect when combined with boiling. Refrigeration temperature of 5^0-7^0C has been generally recommended for storage of edible insects to prevent spore growth (van der Fels-Klerx, 2018). *Ruspolia differens* are highly prone to quick spoilage even after processing. An earlier study established vacuum packaging and freeze drying as able to maintain sensory attributes and prolong shelf life to up to 12 weeks (Ssepuya *et al.*,2016). Whereas they do not reflect the real-life situation prevalent in the communities, they would be useful when packaging for far flung areas, and those where grasshoppers are not available.

Evidence from research also highlights a potential for microbiological contamination in products derived from insect powders. Mwangi *et al.* (2019) found total variable counts, yeast and mold levels much higher than recommended limits for products such as minced meat in a flour composite of grasshopper powder and wheat used to make bread. This contamination of product was in part attributed to release of microorganisms from the insect gut during milling.

Potential allergenicity in R. differens products

Generally, research has indicated the ability of insects to trigger allergic reaction when consumed by sensitive individuals (van Huis 2013; Pener,2014; Barre *et al*.,2019; BfR *et al*., 2019; Garino *et al*.,2020). And globally, the prevalence of insect allergies is estimated at 1-7% inhaled or ingested combined (Mohd, 2018). A food allergy is described as an adverse immune response reaction from consumption of food, caused by a type of antigen (allergen) found in the food. This response could cause result into serious illness or fatality (Imathiu, 2020; Pener, 2016). Insect allergy has been documented to elicit reactions such as skin rashes, itching, swelling, reddening; gastrointestinal reactions such as diarrhoea, abdominal pain, nausea and vomiting; and respiratory asthma (de Gier and Verhoeckx, 2018) with fatalities (anaphylaxis) in severe cases. No documented studies regarding allergenicity of *R. differens* were found in the search -whether in Uganda or elsewhere.

Figure 2: Display of processed R.differens sold out of season at Nakasero market (left) and at Masaka food market (right) in Uganda

Table 2: Relevant literature reviewed on food security situation in Uganda, and research contributions related to R.differens.

Research Article	**Relevant topic/subject**	**Relevant conclusions**
Mottaleb *et al*.,2021	Food security Uganda	Demand for food in Uganda projected to increase. Demand for protein- fish and meat projected to grow by 37-46% by 2030
Shockley and Dossey (2014)	Nutritional security	Insects can be an ingredient in industrial food production for Ready to Use Therapeutic Foods (RUTFs)- for treating malnutrition
FAO *et al*., 2022	Food security and nutrition report	Uganda has not met the targets for SDG 2, exacerbated by impacts of Covid-19. By 2020 moderate to severe food insecurity had risen to over 70%.
Tidermann- Andersen *et al*.,(2011); Nabuuma *et al*.,2018; Ochola and Masibo 2019; Amaral *et al*.,2019; Isabirye *et al*.,2020	Diet diversity and quality	School children in rural Uganda ate a predominantly vegetable based diet, low animal protein intake. Diet inadequate to meet daily zinc requirement. Heavy reliance on staples especially in rural areas of Uganda, minimal consumption of animal protein
Adebissi *et al*.,2018	Food security	Undernourishment directly related to low access to food, affordability and diet diversity
Lokuruka 2020; Wanyama *et al*.,2019	Food security	Hunger, undernourishment, and micronutrient deficiency rampant in poor communities in Uganda. Low diet diversity and quality in urban slums in Uganda
Leonard *et al*.,2021	Entomology	Presently there are 2 swarming seasons for *R. differens* per year, projected by climate modeling to increase to increase to 3 or 4 by 2050. Future distribution of *R. differens* expected to be more widespread in East and Central Africa, with more suitable habitats

Lehtovaara *et al*.,2018	Entomology	Tropics are ideal for development of *R. differens*. Optimum growth temperatures are between 22^0C and 32^0C.
Ssepuuya *et al*.,2016; Kinyurru *et al*.,2010	Nutrition	Nutritional composition of *R. differens* comparable to beef. High in protein and fat, polyunsaturated fatty acids and micronutrients.
Donkor *et al*.,2022; Odongo *et al*.,2018; Okia *et al*.,2017	*R. differens* value chain in Uganda	*R. differens* most traded edible insect; the value chains are well developed including subsistence and commercial collectors, wholesalers, processors, transporters and retailers. Demand has risen over the years, a source of income for the poor
Nyagena *et al*.,2020; Ssepuuya *et al*.,2019; Okia *et al*.,2017; Akullo *et al* 2016; Agea *et al*.,2008	*R. differens* value chain in Uganda	Documented traditional and innovative methods of harvesting- hand picking and light traps, and processing- dry frying (toasting), airdying, boiling, sundrying, salting. Sauteing and deep frying preferred by commercial processors.
Sengendo *et al*.,2021	Food safety	A cost effective, modified light trap developed to improve safety of commercial harvesting of *R. differens*
Kasozi *et al*.,2019	Food safety	High exposure of wild harvested *R. differens* to heavy metals- lead, cadmium, related to pesticide use
Labu *et al*.,2022	Food safety	Raw and processed *R. differens* from market centers in Uganda tested free of agrochemicals
Nganga *et al*.,2021;Labu *et al*.,2021; Ssepuuya *et al*.,2019;	Food safety	Market centers high risk points for contamination of *R. differens* with pathogenic bacteria. Microbial risk- total viable counts, *Enterobacterioceae,* lactic acid bacteria, yeasts and molds, bacterial endospores. Common processing methods able to eliminate the pathogens
Imathiu 2020; Ribeiro *et al*.,2019; de Gier and Verhoeckx 2018;	Food safety	Arthropods including grasshoppers are potential allergy triggers and should be investigated. Grasshopper species and crickets found to cause allergic reactions after consumption in Asia
Mwangi *et al*.,2019	Product development	Powdered or pasted *R. differens* can be an ingredient for fortification of foods. Oil can be extracted
Ssepuuya *et al*.,2016	Food safety	Vacuum packing and freeze drying able to prolong shelf life up to 12 weeks
Nakimbugwe *et al*.,2020; Tanga *et al*.,2021	Standards and policy	Standardization a limitation to value addition in edible insect consumption Standards to guide handling and processing of *R. differens* have been developed in Uganda, a collaborative effort of Makerere University and Uganda National Bureau of Standards, with support from Bio-innovate Africa and *icipe.*

However, other grasshopper and locust species were reported to trigger allergic reactions in other parts of the world.

Piromrat *et al.* (2008) reports eight severe cases of anaphylaxis caused by eating fried grasshoppers and crickets observed at a hospital in Thailand. The reactions are not limited to ingestion, but also included inhalation and contact. Later, de Gier and Verhoeckx (2018) also reported food allergies caused by consumption of locusts and the American grasshopper among other insects.

Onset of symptoms of allergies to several insects were noted to range from few minutes to 6h after ingestion but not necessarily on first time of ingestion. This suggests that onset of allergy can occur at any time even for traditional consumers. Ribeiro *et al.* (2019) emphasized the important role played by tropomyosin and Arginine kinase as arthropod pan allergen proteins that are cross reactive in crustacea, the largest allergen trigger in the western world. Hence taxonomic relationships should also be considered in allergen studies.

A review by Pener (2016) indicates cross allergy with different hypersensitivities among different species of insects within the same taxa. This review specifically notes cross reactivity between grasshopper and the cricket, emphasizing the importance of phylogenetic relationship in cross reactivity which should be of interest as regards allergy potential at species level (Garino *et al.,*2019*).* For example, three allergens, arginine kinase (AK), hemocyanin (HC), and glyceraldehyde 3-phosphate dehydrogenase (GAPDH), that have been identified in *Macrobrachium rosenbergii* (shrimp), have equally been identified in the *Gryllus bimaculatus* (cricket) respectively.

Hence investigations in the likely allergenic potential of *R. differens* and products where it is used as an ingredient for foods are necessary to warn first time consumers and protect sensitized individuals through proper labelling of these foods.

Research gaps: Overcoming bottlenecks in utilization of R.differens as a food source

Use of Indigenous knowledge:For the insect value chains, a lot of attention has been focused on food safety practices of insect farming processes, and for *R. differens* in Uganda, on activities of commercial harvesters and processors (Ssepuuya *et al*.,2019; Mugo, 2020;Labu *et al*.,2021;), while indigenous knowledge presumed to influence household level practices have to a large extent been neglected. Oniango *et al.* (2006) earlier argued that communities should be valued as partners in providing sustainable solutions to local problems especially for foods adapted to local conditions. Ideas that households use in day-to-day life for food processing and other management practices through trial and error are more important for modelling community resilience that supports technology adoption in nutritional interventions (Hlongwane *et al*.,2021; Oniango *et al*.,2006).

This knowledge plays a critical role in ensuring food access, quality, and safety as inclusion of accumulated knowledge, skills and technologies approved, adapted and handed down over time from direct interaction with the local environment. Melgar-Lalanne *et al.* (2019) also notes in reference to insect consumption the contribution of traditional indigenous knowledge as complimentary to the scientific knowledge used in mass production of insects including harvest periods and conditions and the right host plant sources. However, this information is largely missing and needs to be documented to guide development of other low-cost technologies particularly in preservation and storage.

Improving safety of consumption

The short shelf life of processed grasshoppers remains a challenge to food security, worsened by their seasonal availability. Studies reviewed show that in addition to preservation techniques, value addition through processing into ready to eat familiar foods would likely address this challenge (Melga-Lalanne *et al*.,2019; Lombardi *et al*.,2019). Modern technologies fronted to produce insect powders such as freeze drying, oven drying, fluidized bed drying and microwave (Ruzengwe *et al*., 2022; Melga-Lalanne *et al*.,2019) are likely impractical for regular use by low-income households. Further research into efficient and low-cost technologies for preservation and a range of grasshopper-based products are necessary.

Different forms of packaging, and food products with *R. differens* should be explored to complement efforts in improving shelf life. According to Garlic *et al*., (2009), use of appropriate packaging also minimizes or delays loss of flavour and texture of baked food products although the extent is product specific. Knowledge of shelf life is important in the development of any new food products. In addition, information on potential consumer demand for these products is an important determinant of successful product development that is preferences, attitudes, and demand share of the different market segments (Clarkson *et al.*,2019; Alemu *et al.*, 2017).

Hazards have been identified to exist at the different stages of the food value chain. Research efforts reviewed have so far show efforts in development of adaptive technologies- such as modified traps- for traditional practices of harvesting reported in several grasshopper eating communities. These if rolled out to the public would go a long way in evading physical hazards at harvesting stage and would support regulatory standards that have been established in Uganda on the use of insects for human food. However, documented successful stories on technology adoption and other public directed interventions have taken the path of public private partnerships which if explored could reinforce any government efforts in ensuring safe food.

Contamination and accumulation of heavy metals and pesticides in grasshoppers requires further investigation. In the few studies reviewed conclusions are mixed, and one appears localized to certain a geographical location and does not give indication of how widespread the hazards is.

Adequate evidence on microbial contamination at various stages has also revealed that if not well managed, food borne illnesses arising from poor management could cancel gains made in livelihood improvement in the communities. However, all indications show positive contribution of traditional processing methods including innovations such as deep frying to safe products.

There's an obvious need to enforce regulation of management processes put in place in order to safeguard consumer safety, preserve their trust (Nakimbugwe *et al.,* 2020) and avert a likely public health crisis from unsafe food. World over, supply chains of agricultural products have gained prominence because of their role in public health and safety. Products meant for human consumption have required more stringent monitoring including ensuring traceability as a way of gaining public trust in their food sources (Ahumada and Villalobos, 2009).

Hazards from allergens are not supported with adequate research studies despite the documented contribution of arthropod allergy, and in this case, allergy reported from consumption of other grasshopper species. This implies that possibility of allergy reaction from consumption of *Ruspolia differens* should be considered and prevalence investigated before use as an ingredient to caution new consumers through proper labelling.

Conclusion

Prospects for the use of *Ruspolia differens* to combat food and nutritional security in Uganda are very promising. The abundant research information regarding nutritional importance, distribution, handling and value chains of *Ruspolia differens* provide a platform for broadening its wider application for food security. However, challenges related to proper handling, food safety aspects, value addition stand in the way of its optimum exploitation for a range of food applications. All value chain players are critical in the development of local solutions to a sustainable food safety management system: but limited data is available on household level practices and safety of consumption.

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