

REVIEWING ENTOMOPHAGY IN THE DEMOCRATIC REPUBLIC OF CONGO: SPECIES AND HOST PLANT DIVERSITY, SEASONALITY, PATTERNS OF CONSUMPTION AND CHALLENGES OF THE EDIBLE INSECT SECTOR

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ABSTRACT

This paper reviews edible insect species and the host plant diversity associated with them in the Democratic Republic of the Congo (DRC), including their seasonal availability throughout the year. Entomophagy practices are mapped on country scale and nationwide patterns of consumption are explored. Moreover, motives for consumer acceptance (or rejection) of insects as food are reported based on survey data and focus groups. The paper also points out research gaps (concerning notably food-safety risk associated to local species and the effects of processing techniques on nutrient contents or the digestibility of edible insects) and discusses major challenges (as the need for standardisation of local units of sale, the implementation of insects-related regulations and field studies supported by expert taxonomic input) for the sustainable development of the edible insect consumption market in the country. The inventory showed that 148 species of insects are consumed in DRC dominated by the orders of Lepidoptera (60.1%), Orthoptera (10.1%), Coleoptera (8.1%) and Hymenoptera (8.1%). Commonalities were observed throughout the country concerning a minority of the insects consumed (these are notably Rhynchophorus phoenicis, Imbrasia epimethea, Imbrasia oyemensis, Cirina forda), whereas the consumption of several edible species (e.g. Afzeliada afzelii, Hadraphe ethiopica, Rhypopteryx poecilanthes, Acanthacris ruficornis) seems to be restricted to the production areas where they occur, due probably to the absence of a trade system and people's alimentary habits. Furthermore, host plant species for 38 major edible lepidopterans have been inventoried nationwide. Results indicated 122 plant species dominated by 4 families ranked as follows: Fabaceae (34.4%), Phyllanthaceae (10.6%), Meliaceae (4.9%) and Apocynaceae (4.1%). However, given concerns about some host plant species being endangered (Millettia laurentii, Gossweilerodendron balsamiferum) or critically endangered (Autranella congolensis), conservation



strategies and methods of mass-rearing are needed. This article contributes to the growing body of knowledge detailing anthropo- entomophagy in DRC.



1 Introduction

According to FAO *et al.* (2021), hunger and malnutrition have reached critical levels. In 2020, the number of undernourished people in the world (in Africa and in Latin America and the Caribbean notably) continued to rise as the challenges have grown given the COVID-19 pandemic (with its related containment measures) and the global recession it has induced (FAO *et al.*, 2021, Smith and Wesselbaum, 2020). The aforesaid report of the Food and Agriculture Organisation of the United Nations (FAO) also stated that 'several major drivers have put the world off track to ending world hunger and malnutrition in all its forms by 2030'. This is in agreement with FAO *et al.* (2019) reporting that 'with regard to nutrition indicators, we are faring no better. If current trends continue, we will

meet neither the 2030 sustainable development goal (SDG) target to halve the number of stunted children nor the 2025 World Health Assembly target to reduce the prevalence of low birthweight by 30%'.

The situation is likely to be more severe in Africa where many countries already deal with economic downturns, political instability and episodes of internal conflicts which do not build governance for intensive agriculture production and agriculture investments in the medium and longer term (Adenle *et al.*, 2018; Evans, 2018). Given the lack of food and high poverty rates, both rural and unprivileged urban communities increasingly rely on the forest for their livelihoods (Hoare, 2007; Muvatsi *et al.*, 2021). This quest to satisfy household fundamental needs of energy and protein is unsurprisingly a major cause of deforestation and biodiversity erosion (Muafor *et al.*, 2015). To reduce these problems driven by food insecurity, traditional food resources, such as non-timber forest products (NTFP), could assume an important role, in particular those which are cheap, eco-friendly, abundant and easily renewable (Cappelli *et al.*, 2020; Riggi *et al.*, 2016). Among possibilities, edible insects already consumed for decades in many African countries, deserve more attention (Baiano, 2020; Raheem *et al.*, 2019; Van Huis 2020b).

In the Democratic Republic of Congo (DRC), wild insects have been a part in the diets of many ethnic groups for a long time (Bakondongama *et al.*, 2016; Bocquet *et al.*, 2020; Halloran *et al.*, 2018a; Jongema, 2017), but entomophagy (i.e. the practice of eating insects) remains under-documented at national scale. Moreover, though some studies (Bomolo *et al.*, 2017; Latham, 2005; Latham *et al.*, 2021; Lisingo *et al.*, 2010; Looli Boyombe *et al.*, 2021; Malaisse, 1997; Malaisse and Parent, 1980; Mapunzu, 2004; Mbemba, 2013; Mbemba and Remacle, 1992; Nsevolo *et al.*, 2016) have given insights into edible insect biodiversity in DRC, recent reviews (Baiano, 2020; Hlongwane *et al.*, 2020) gave clear results (in terms of research papers) and showed real opportunities for insect consumption development for sub-Saharan African (SSA) countries except for DRC - though it is one of the world's prime biodiversity hotspots (Washington *et al.*, 2013).

To date, the broadest lists of edible insects in DRC have been compiled by Mitsuhashi (2016) and Jongema (2017). In his book dealing with edible insects of the world (about 2,140 species); the first author cited 98 edible insects identified at species level for DRC. However, his list was hampered by



spelling mistakes on some scientific names and redundancy (due to the re-use of synonyms). In his worldwide list of about 1,900 edible insects, the second author mentioned 90 species for DRC (by taking more care about alternative taxonomic names and correcting for many synonyms), but the challenge of redundancy still remains.

Yet, the number of edible insects across the country is likely to be more substantial because numerous species consumed by the different ethnic groups countrywide have in most cases not been systematically identified (Malaisse, 2002). However, to achieve a complete inventory of them would be a herculean task when taking into account at least two compounding challenges.

First, traditional ecological knowledge (TEK) regarding edible species identification, collection or management is empirical and orally shared. Unfortunately, this TEK is being lost because of a backdrop of war and political unrest which leads indigenous people in some regions of the country to make irrevocable changes to their traditional lifestyle (Payne *et al.*, 2016). Secondly, official estimates based on vernacular names (also called ethnospecies) are difficult and unreliable because one vernacular name may cover several scientific names (Djouffa *et al.*, 2021; Nsevolo, 2016). In fact, Congolese' dialects (with more than 210 living languages) (Lloyd, 2010) do not necessary provide descriptions that could be used in scientific knowledge; numerous species being named based on visual features according to the plants they feed on (or the noise they make while feeding) (Bocquet *et al.*, 2020; Lisingo *et al.*, 2010).

Given the aforementioned challenges, special mention should be made about some studies, expressly Bomolo *et al.* (2017), Latham (2005), Latham *et al.* (2021), Malaisse (1997), Malaisse and Parent (1980) and Mapunzu (2004). These authors gave relevant insight about TEK in their study areas in DRC and documented their lists of edible insect species with scientific names, host plants diversity, methods of gathering, with special reference to vernacular names used for most of identified species. The sustainable use of such data could help address food insecurity issues in DRC, given the cultural appropriateness of insect consumption (Malaisse, 1997; Nsevolo *et al.*, 2016; Nsevolo and Theeten, 2015), the nutritional value of local insect species (Kodondi *et al.*, 1987a,b; Malaisse, 2010) and their potential for mass production (Van Huis, 2020b; Varelas, 2019). In this respect, farming insects for human consumption as initiated by the FAO (Halloran *et al.*, 2018a) and formal programs for cataloguing edible insect species countrywide, should be given more attention and support both from the national government and assistance programmes.

This paper aims to contribute to the growing body of knowledge regarding entomophagy (i.e. edible insects and host plants diversity, their seasonal availability, patterns and motives of consumption as well as the challenges of the sector) in DRC. It was hypothesised that on a national scale, the number of edible insect species and host plants - based on Linnaean nomenclature - is broader than compiled to date and that differences exist between provinces in the entomophagy practice. For the main recorded insect species, information about vernacular names, accepted species names, and alternative taxonomic names used in the literature is provided, along with the list of host plant species. This information, mapped on a national scale, would be useful for enhancing edible insect management, their farming and their sustainable contribution to the welfare of populations in this central African country.



2. Study area, search procedure and data analysis

STUDY AREA

The study focuses on DRC, which is by area the largest country in sub-Saharan Africa (Herderschee *et al.*, 2011) and the 4th most populous country in Africa (UNFPA, 2020), with more than 60% of its inhabitants living in rural areas (Muvatsi *et al.*, 2021). Since 2015, a new provincial structure came into effect resulting in 26 provinces subdivided into 145 territories on the political-administrative level (Marivoet *et al.*, 2018). However, before 2015, the country had only 11 provinces (correspondence of provinces before and after 2015 is illustrated in Supplementary Figure S1).

The country, crossed by the Equator and located between the 5° North latitude and 13° South latitude, is divided into four main climatic zones and lines within the inner humid tropical (or equatorial) climatic region. Its key topographic features include diverse reliefs (mountain ranges, high plateaus, a large river basin, a major valley, and a low coastal plain) with an important river network (i.e. the Congo river and its many tributaries and lakes). Most of the country is composed of the central Congo Basin, the centre of which is blanketed by an intricate forest system known as the 'equatorial rainforest' (Malaisse, 1997; Mazamay *et al.*, 2020; Oppong and Woodruff, 2007).

The Congo Basin - whose role in the planetary circulation and the Earth system is undisputed (Washington *et al.*, 2013), is home to numerous species of plants and wildlife (FAO, 2006). Unfortunately, its many endemic species of flora and fauna are being affected (Ciza *et al.*, 2015; Muvatsi *et al.*, 2021) since the country is facing serious development challenges (as the second-largest hunger crisis in the world after Yemen) coupled with environmental problems (e.g. deforestation for mining, wood fuel, overexploitation of natural resources for human food and/or other essential needs) (Voiculet and Panoiu, 2020; Von Grebmer *et al.*, 2019).

SEARCH PROCEDURE

The primary data presented in this study relied on information gathered and recorded by the first author from a combination of 10 years of field work (regarding farming of edible insect species) and focus groups (with key informants who had indigenous knowledge on local edible insects), as well as on two surveys in April 2012. The first was a survey focusing on consumption patterns of edible insects (i.e. the number of edible insects, peak of availability on markets, stages of insects consumed, modes of preparation and motives) and involved 275 interviewees randomly selected in the capital city Kinshasa. The second (which involved 67 edible insect sellers selected among the 15 main markets of Kinshasa) was designed to give an overview of the trade of edible insects locally (e.g. prices, seasonal availability, modes of conservation). A part of these data has been published (and the reader should kindly refer to it for further details on methodology) (Nsevolo *et al.*, 2016). In addition, a database (giving a preliminary insight of edible insect diversity in the country) implemented with the Global Biodiversity Information Facility (GBIF) and the Royal Museum for Central Africa (RMCA) is available online (Nsevolo and Theeten, 2015).



Secondary data (*viz.* nationwide edible insect species, host plants, seasonality, collection and processing techniques) were compiled from literature review about entomophagy practices using bibliographic databases, online public access catalogue (OPAC) and academic search systems (Google scholar, PubMed, Web of Science) (Gusenbauer and Haddaway, 2020). Keywords and *ad hoc* search strings like 'anthropo-entomophagy', 'food insects', 'edible insects', 'insect consumption', 'diversity of edible insects', 'nutrient content of edible insects', 'non-timber forest products', 'NTFP', 'non-conventional food', 'underutilised foods' were used in association with keywords like 'Zaire', 'Congo Kinshasa', 'DR Congo', 'DRC' or one of the 11 former provinces of the country (such as 'Katanga', 'Equateur', 'Bas- Congo', 'Bandundu') (Supplementary Figure S1) given that the majority of available literature refers to the configuration before the year 2015. As a second step, references of selected literature - both in French or in English - were screened for relevant data extraction (i.e. new edible species, unrecorded host plants, patterns of consumption notably) and analysis.

DATA ANALYSIS

Data sources explored for the database generation were highly heterogeneous (*viz.* reports, proceedings, books, journal articles, online databases, monographs) since no restriction regarding the publication types was enforced. Therefore, in order to avoid inaccuracy (in Latin names of edible species) and redundancy during counting, alternative taxonomic names of recorded edible insect species were checked using four authoritative taxonomic databases: Catalogue of Life (CoL), Global Biodiversity Information Facility taxonomic backbone (GBIF), Integrated Taxonomic Information System (ITIS) and Global Lepidoptera Names Index (LepIndex). Similarly, the names (accepted ones and synonyms), the uses and conservational status of host plant species were also checked prior to inventory - using Plant Resources of Tropical Africa (Prota4U), the International

Union for Conservation of Nature's Red List of Threatened Species and CoL.

Finally, patterns of edible insect consumption between provinces were explored by Principal Components Analysis (PCA) using the R statistical software (version 3.6.1) and then mapped using QGIS (version 2.18.15). However, exclusion criteria were defined prior to data compilation (Table 1). Reasons for exclusion included notably edible insects not identified up to the species level (or those only known by their vernacular names) and literature published before the country achieved independence (on June 1960). Indeed, the years from 1960 onwards (till end of 2021 included) have been chosen as a time frame given that achieving an inventory of edible insect species of DRC in its eventful history would be definitively impossible (the country has been chronologically known under different names: Congo Free State, Belgian Congo, Republic of the Congo-Leopoldville, DRC - its current but old name, Zaire and has undergone a multitude of administrative reforms) (Bruneau, 2009).



3. Nationwide inventory of edible insect species

The list of insect species used as food across the country, the stages at which they are consumed in their developmental cycle and the number of recorded host plants are fully given in Supplementary Table S1. Based on their Latin names (and correcting for synonyms), 148 species belonging to 100 genera, 31 families and 9 orders have been recorded on a national scale. This number of edible insects is higher than those reported from other SSA countries - e.g. 9 species for Ghana (Anankware *et al.*, 2016), up to 31 species for Cameroon (Djouffa *et al.*, 2021; Ngute *et al.*, 2020), 22 for Nigeria (Alamu *et al.*, 2013), 75 species for Gabon (Detilleux et al., in press), up to 96 for Central African (CA) Republic (Balinga *et al.*, 2004; Roulon-Doko, 1998), 28 species for the Republic of Congo (Mabossy-Mobouna *et al.*, 2016), 27 for Botswana (Obopile and Seeletso, 2013), 60 for Zambia (DeFoliart, 1999), 38 for Angola (Lautenschlager *et al.*, 2017) and 20, 13, 6 for Uganda, Burundi and Rwanda, respectively (Okia *et al.*, 2017).

Of these 9 orders consumed in DRC, the majorities are Lepidoptera (60.1%), Orthoptera (10.1%), Coleoptera and Hymenoptera (8.1% each). Following these are the Hemiptera (6.1%), Blattodea (4,7%) and Neuroptera (1.6%). Below 1.0% are the Odonata and Mantodea (Supplementary Table S1). The results of the current study concerning the leading position of the top three first orders are consistent with those reported by the International Centre of Insect Physiology and Ecology (ICIPE) (Kelemu *et al.*, 2015) and by Van Huis (2020a) for Africa as a whole. However, additional information is provided for DRC as Hymenoptera should be considered as major as Coleoptera (with regard to the number of edible species reported countrywide).

Table 1. Inclusion/exclusion criteria used for data compilation and database generation.

Inclusion criteria

• English (or French) full-text paper published in a peer-reviewed journal or scientific literature with:

Focus on insect consumption practices

- Focus on using edible insects as alternative to meat
- Focus on NTFP, non-conventional or underutilised food from DRC

Exclusion criteria

- Studies older than 1960
- Studies on farming insects for animal feed
- Studies on animal manure as insect feed
- · Insect products produced for animal feed
- Imprecise taxa and ethnospecies unidentified at the species level
- Inconsistent paper with implausible data or misidentification concerns

LEPIDOPTERA (BUTTERFLIES, MOTHS)

Typically eaten at larval stage (i.e. caterpillars), Lepidoptera stands out as the leading group of insects consumed in DRC. Thirteen (13) families were identified and ranked as follows: Saturniidae (22 genera and 53 species: 59.5%), Sphingidae (9 genera and 10 species: 11.2%), Notodontidae (8



genera and 9 species: 10.1%), Hesperidae (3 genera and 3 species: 3.3%), Noctuidae (2 genera and 3 species: 3.3%), Psychidae (1 genus and 3 species: 3.3%) and Nymphalidae (2 genera and 2 species: 2.2%). The representatives of the remaining families (Brahmaeidae, Erebidae, Lasiocampidae, Limacodidae, Lymantriidae and Pieridae) are reported in Supplementary Table S1.

Moreover, *Imbrasia (Nudaurelia*) (Saturniidae), points out as the most represented genus with 16 edible species also reported as an important source of income, proteins and vitamins countrywide (Latham, 2005; Latham *et al.*, 2021; Lisingo *et al.*, 2012; Malaisse and Parent, 1980; Mapunzu, 2004). Furthermore, *Imbrasia ertli*¹ notably; called 'Mwinzu' or 'Misa-Misa' in DRC, gives an example of the existing commonalities between SSA countries in the use of insects as food, since this caterpillar is also widely consumed in Zambia, South Africa, Cameroon, Congo-Brazzaville, CA Republic, Zimbabwe, Botswana and Angola (Kelemu *et al.*, 2015). Similar examples of shared commonalities between DRC and SSA countries are also reported notably concerning *Cirina forda* (DeFoliart, 1999; Kusia *et al.*, 2021), *Imbrasia belina* (Malaisse, 2005), *Imbrasia obscura* (Mabossy-Mobouna *et al.*, 2018), *Imbrasia oyemensis* (Balinga *et al.*, 2004), *Buneae alcinoe* or *Anaphe panda* (Kelemu *et al.*, 2015). This fact is noteworthy as it can serve as a path to the promotion of the trade of specific species with high commercial value, as well as widening their market across SSA countries.

ORTHOPTERA (GRASSHOPPERS, CRICKETS, LOCUSTS)

Edible orthopterans are mainly consumed in DRC at adult stage (Supplementary Table S1). A total of 5 families are concerned and ranked as follows: Acrididae (8 genera and 8 species: 53.3%), Gryllidae (2 genera and 2 species: 13.3%), Pyrgomorphidae (2 genera and 2 species: 13.3%), Tettigoniidae (1 genus and 2 species: 13.3%) and Gryllotalpidae (1 genus, 1 species: 6.6%). Of these 15 orthopterans species reported in DRC (Kekeunou and Tamesse, 2016; Malaisse and Parent, 1980; Ombeni and Munyuli, 2017), some are also widely consumed on the continent as *Brachytrupes membranaceus, Zonocerus variegatus, Locusta migratoria* and *Nomadacris septemfasciata* (Babarinde *et al.*, 2021; Kelemu *et al.*, 2015).

The consumption of such species considered as pests of crops or valuable trees deserves to be pointed out as these insects are difficult to control in DRC. In the literature, edible insect consumption has been claimed as a sustainable way of pest management and food procurement (DeFoliart, 1995; Riggi *et al.*, 2016; Van Huis, 2020a). Such an example is reported for *Z. variegatus* and *Cyrtacanthacris aeruginosa* in Uganda. A reduction of their populations in crops fields resulted from a successful campaign to promote the eating of these grasshoppers (Akullo *et al.*, 2017). The same strategy for insects pest control has also been reported in Thailand concerning *Patanga succincta* (Johannson, 1763). The high demand and price for this edible locust have led some farmers to grow maize to feed this insect, rather than harvesting the crop (Durst *et al.*, 2010).

¹ The full species names of insect taxa cited throughout this document are listed in Supplementary Table S1.



However, attention should be paid as important pests in many areas are likely to be exposed to chemicals during their whole life cycle (Babarinde *et al.*, 2021; Banjo *et al.*, 2006; Van Huis, 2013). Unfortunately, although residual pesticides in edible species raises concern over food safety (Murefu *et al.*, 2019; Saeed *et al.*, 1993), data clearly demonstrating the safety of consumption of insects are lacking in DRC. The scarcity of such valuable data points out research gaps to be filled as safety is a necessary condition for every item (whether insects or not) in order to meet society's approval as food (Belluco *et al.*, 2013, 2018).

COLEOPTERA (WEEVILS, BEETLES, WOOD-BORING LARVAE)

Coleoptera inventoried in the current study are from 5 families ranked as follows: Cerambycidae (6 genera and 6 species: 50.0%), Dynastidae (2 genera and 3 species: 25.0%), Cetoniidae, Dryophthoridae and Dysticidae (1 genus and 1 species: 8.3% each) (Supplementary Table S1). A representative of this order - the palm weevil (*Rhynchophorus phoenicis*), reported to be by far the most consumed insect in many African countries (e.g. Burkina Faso, Cameroon, Ivory Coast) (Kelemu *et al.*, 2015; Sere *et al.*, 2018) is also greatly popular and sought after in DRC for his high economic value (Malaisse, 1997; Mapunzu, 2004; Payne *et al.*, 2016; Takeda, 1990).

The larvae locally called 'Mpose' or 'Nsombi' is considered as a delicacy and can be eaten raw. Globally, coleopterans are mainly consumed at immature stage, even though the uncommon consumption of adults is also reported by informants for some representatives (e.g. *Oryctes boas, Oryctes owariensis, R. phoenicis*). Furthermore, for Coleoptera, it has been reported a consumption of 154 g/person/day for the capital city (Kinshasa) (Nsevolo *et al.,* 2016) but gaps about quantitative data still remain for the edible insect sector on a national scale. Few data are available so far, whether concerning edible insects trade or daily intake at household level making the assessment of their contribution to food security a challenge.

HYMENOPTERA (BEES, WASPS, ANTS)

Edible representatives of Hymenoptera in DRC are from two families: Apidae (7 genera and 10 species) and Formicidae (2 genera and 3 species) (Supplementary Table S1). The honey, eggs and larvae of *Apis mellifera adansoni*, as well as the pupae of *Hypotrigona gribodoi* or winged adults of *Carebara junodi* are reported as being consumed in the country (Malaisse, 2010; Takeda, 1990). Furthermore, the consumption of *Carebara vidua* in DRC deserves to be pointed out as this insect (reported as being sought after for its flavour, nutritional and medicinal values) is considered as an endangered species (Ayieko *et al.,* 2012). Therefore, although this species gives an example of existing similarities across northern, eastern, southern and central Africa (e.g. Sudan, South Sudan, Kenya, Malawi, Zambia, South Africa, Zimbabwe, Botswana, CA Republic) (Kelemu *et al.,* 2015), there is a call for a more sustainable exploitation of *C. vidua* in order to save it from extinction.



HEMIPTERA (CICADAS)

Cicadidae family (with 5 genera and 8 species) remains the most eaten hemipterans in the country (Malaisse, 1997; Malaisse and Parent, 1980). Except Belostomatidae (with *Lethocerus cordofanus* as unique representative), no other family of Hemiptera seems to be consumed in the country (Supplementary Table S1). An additional example of commonalities between DRC and other central or southern African countries in the use of insect as food is given by *Ioba leopardina* (Cicadidae) (Kelemu *et al.*, 2015).

BLATTODEA (TERMITES)

All edible termites reported as food in DRC belong to Termitidae (DeFoliart, 2002; Kelemu *et al.*, 2015; Mitsuhashi, 2016) and this lines with results reported from South Africa (Netshifhefhe *et al.*, 2018). In DRC, 3 genera are reported ranked as follows: Macrotermes (4 species), Pseudocanthotermes (2 species) and Megagnathotermes (1 species) (Supplementary Table S1). Furthermore, based on key informants during focus groups, quite all the castes of these insects (i.e. soldiers, winged adults, workers, queen) are consumed as they are considered as a culinary delicacy in DRC (Supplementary Table S1) (Bomolo *et al.*, 2017; Malaisse, 1997).

However, the number of termites' species used as food is likely to be under-reported so far. In fact, many ethnospecies still remain veiled as accurate identification and reporting remain a challenge (Bocquet *et al.*, 2020). For example, Bakondongama *et al.* (2016) reported 24 species of termites harvested in Kisangani (Province Orientale, Supplementary Figure S1) that might be consumed by local people or used as feed; but in the list, these authors omitted to point out which species are precisely intended for human food; leaving thus an ambiguity. Hence, field studies supported by expert taxonomic input and involving local ethnic groups through citizen science - for unveiling vernacular names (Nsevolo, 2016), should yield higher numbers of edible species in poor-studied provinces.

MINOR GROUPS (DRAGONFLIES, MANTIS, ANTLION)

Apart from the orders mentioned above, three additional taxa of edible insects are also reported in DRC. They belong to Neuroptera (*Hagenomyia tristis* and *Lachlathetes moestus* from Myrmeleontidae), Odonata (*Trithemis arteriosa* from Libelludidae) and Mantodea (*Sphodromantis centralis* from Mantidae) (Malaisse, 2010; Malaisse and Parent, 1980) (Supplementary Table S1).

4. Distribution of insect species and patterns of consumption

The number of edible insect species vary between provinces of DRC, as already reported in other SSA countries such as Burkina Faso (Sere *et al.,* 2018), Botswana (Obopile and Seeletso, 2013) or



Cameroon (Djouffa *et al.*, 2021). From a national standpoint, two provinces emerge with more than 40 edible species inventoried locally (namely Katanga with 50 species then Bas-Congo with 43 species). Such results mostly related to the amount of research done for these two provinces (notably by Malaisse, 1997, 2010; Latham, 2005; Latham *et al.*, 2021) were expected since they corroborate Van Huis (2015). Accordingly, further exploration of edible insect diversity in relatively poor-studied provinces of the country (e.g. Bandundu: 24 species, Equateur: 16, Kinshasa: 14, Province Orientale: 12, Sud-Kivu: 10, Kasaï: 8 species) is advocated.

Moreover, the principal component analysis (PCA) gave an insight into insect consumption patterns on country scale and showed existing differences in entomophagy practices between the provinces of DRC (Figure 1). On one hand, some edible insect species (namely C. forda, I. oyemensis, I. epimethea and R. phoenicis) are consumed countrywide (hence could be considered commonalities), whereas on the other hand, many other species seem to be restricted in their occurrence areas (Figure 2). Examples of these include species in the family Cicadidae (i.e. Afzeliada afzelii, Afzeliada duplex, Munza fulva, Uqada limbalis) and a representative of Limacodidae (namely Hadraphe ethiopica) only consumed in the Katanga province or species in the family Lymantriidae (Rhypopteryx poecilanthes) and Sphingidae (Acherontia atropos, Hippotion eson, Platysphinx stigmatica) only consumed in the Bas-Congo province. Supplementary examples are given by species of Acrididae (i.e. Acanthacris ruficornis, Anacridium burri, Homoxyrrhepes punctipennis, Ornithacris pictula, L. migratoria, N. septemfasciata) as well as a representative of Gryllotalpidae (i.e. *Neocurtilla hexadactyla*) whose consumption is restricted to the Sud-Kivu province (Figure 1). Reasons thereof are undoubtedly numerous and more than probably linked to culture and people's alimentary habits (Mignon, 2002). However, one additional reason could be the absence of a trade system for these species restricted to their occurrence zones as reported for Carbula marginella (Thunberg, 1822) in the northern Sudanian area (Sere *et al.*, 2018).

It is noteworthy that, even though anthropogenic pressure has already been strong enough to lead to a significant decline of some edible insect populations in the country (e.g. in the Bandundu province) (Leleup and Daems, 1969); most edible species are still harvested from the wild (Latham, 2005; Malaisse, 1997) and few mass-production programs have been initiated to meet consumer demand. This situation requires attention about edible species that should be promoted for trade to meet the increasing demand for edible insects and how they could be sustainably farmed (Babarinde *et al.*, 2021) without disturbing the natural balance in their natural habitats in DRC.

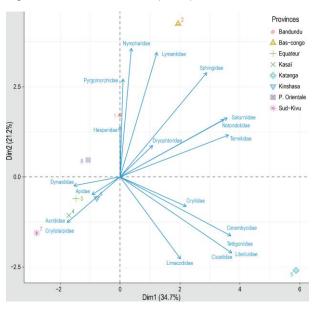
5. Consumer attitudes and motives

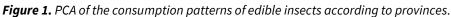
Although it is reported that the consumption of insects in the country seems not to be gender dependent (Nsevolo *et al.*, 2016), few information is available concerning attitudes and opinions of Congolese consumers towards edible insects so far. Field investigation performed in Kinshasa at household level revealed that insect consumption is mainly driven by the levels of proteins and vitamins in edible insects (49.9%) (Figure 3). Additionally, 13.2% of the respondents also considered



entomophagy as a food habit driven by culture or tradition and 11.5% eat insects as they considered them as tasty and delicious.

These results suggesting that edible insects are considered a regular food source in DRC (rather than an emergency food item) are in line with those reported across African countries where insects are included as a normal part of diets throughout the year (Akullo *et al.*, 2017; Kelemu *et al.*, 2015). However, the barriers driving avoidance and/or abhorrence of edible insects (notably disgust, food habits, religious beliefs and fear) (Figure 4) deserve more attention as they should help to overcome the neophobia or to limit abandonment trends of this ancestral and reliable source of proteins for new processed products in urban areas(Malaisse, 2005; Mapunzu, 2004; Nsevolo *et al.*, 2016; Van Huis *et al.*, 2013).





6. Inventory of plant species associated with edible insects

HOSTS FOR SELECTED LEPIDOPTERANS

Supplementary Table S2 summarises the names of 122 plant species (79 genera split in 35 families) recorded nationwide as host plants for 38 edible lepidopterans. These data indicate a variety of host plant species dominated by far by Fabaceae family with 42 representatives belonging to 21 genera (34.4% of the total diversity), followed by the family Phyllanthaceae (10.6%), Meliaceae (4.9%) and Apocynaceae (4.1%) - these 4 families represented together 54.0% of the plant species recorded in the country. Moreover, plants in the Fabaceae indicate 3 outstanding genera (representing together



41.8% of this family): *Brachystegia* with 8 representatives, followed by *Albizia* with 6 representatives and then by *Millettia* with 4 representatives. For Phyllanthaceae, two taxa (*Uapaca spp.* and *Bridelia spp.*) should be mentioned as they constitute 61.5% of the representatives of this plant family.

A global review of Supplementary Table S2 is also really informative as it shows various strategies of feeding behaviour, from monophagous caterpillars (namely *A. atropos, E. carteri*) to polyphagous species (e.g. *I. epimethea, A. insignata*). Moreover, some polyphagous species (e.g. *B. alcinoe, C. forda*) are reported to feed on more than 19 different plant species. The top example of this strategy is given by a representative of the family Notodontidae (namely *E. lactea*) as it feeds on 30 different plant species countrywide. However, overall, current results line with Kusia *et al.* (2021) given that recorded edible saturniid species (in Supplementary Table S1) have been reported from more diverse agroecological zones and have a much more varied diet than the remaining taxa of Lepidoptera reported throughout the country (for instance 67.1% of the plant diversity recorded in Supplementary Table S2 serves as food to family Saturniidae versus 25.7% to Notodontidae notably) (Figure 5).

It is noteworthy that some plant species play a vital role as food for many caterpillar species at once. The prime example is *Julbernardia paniculata*² reported as food for 17 insect species (*A. insignata*, *A. gigas*, *A. semialba*, *B. alcinoe*, *C. hyperbius*, *D. uniformis*, *E. lactea*, *G. richelmanni*, *G. zambesina*, *G. hecate*, *G. ata*, *H. ethiopica*, *I. epimethea*, *I. ertli*, *I. macrothyris*, *L. saturnus* and *M. parva*). Similar examples are given by some others representatives of Fabaceae (*B. taxifolia*, *B. boehmii*), albeit to a lesser extent. Such ecological associations should be highlighted as this information could be used to promote agroforestry or reforestation programs, as well as opening new opportunities to rural communities that live around woodlands for cultivation of specific edible insect species.

Moreover, these plant species and many others species of diverse families reported in this study (e.g. *Mangifera indica* from Anacardiaceae, *Persea americana* from Lauraceae, *Uapaca guineensis* from Phyllanthaceae, *Petersianthus macrocarpus* from Lecythidaceae or *Ricinodendron heudelotii* from Euphorbiaceae) not only serve as host plants for edible insects but they are also vital to local people who depend on natural resources for diverse reasons (fruits, forage, coal, carbohydrates, timber, tannins, fibre or medicinal uses) (Supplementary Table S2) (Muvatsi *et al.*, 2021). Undoubtedly, this situation could represents a conflict of use that requires more attention. Therefore, as forests and savannas provide shelter and perfect milieu for numerous edible insect and food plant species (Latham, 2005; Lisingo *et al.*, 2010; Malaisse, 1997) and, taking into account the conservational status of some host plants (Supplementary Table S2), the development of conservation strategies that preserve traditional resources in DRC could be enhanced by acting on the desire of local populations for protection of edible insect species and their host plants. Such an approach has been successfully implemented in Zambia (DeFoliart, 1997).

² The full species names of plant taxa cited throughout this document are given in Supplementary Table S2.



HOSTS FOR MAJOR COLEOPTERANS

Supplementary Table S1 reported some edible coleopterans considered as pests of valuable trees of the family Arecaceae such as *R. phoenicis*, reported to be a major pest of Raphia or Palm trees notably (Muafor *et al.*, 2015). During focus groups, informants reported that the ecological association of this insect species with these representatives of Arecaceae is well-known, as grubs of *R. phoenicis* are typically sold fresh living along main roadsides and kept in containers mixed with substrate from its food plants. These reports are consistent with findings from other sub-Saharan countries since *R. phoenicis* is reported to be highly appreciated and requested (DeFoliart, 1995; Kelemu *et al.*, 2015).

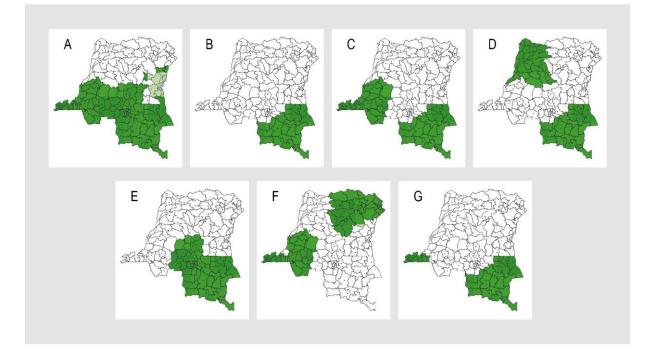
Furthermore, *R. phoenicis* also gives an excellent example of how unregulated harvest of edible insects from the wild could threat natural plantations of valuable trees in the country. Informants reported that anthropogenic pressure has led to significant regression of natural populations of palms in some production areas - as *R. phoenicis* has long been traditionally 'semi-farmed' and harvested on palms (i.e. basically palms are to be cut down). Therefore, they are favourable to alternative production system on sugarcane (*Saccharum officinarum* L.) as proposed by the Agro-Veterinary Center in Kinshasa (Centre Agro-Veterinaire Tropical de Kinshasa in French; CAVTK) (R.M. Lundanda, personal communication, May 17, 2021).

FOOD FOR ORTHOPTERANS

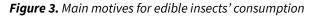
Edible orthopterans reported in Supplementary Table S1 are known to be polyphagous insects and globally considered as pests collected in field crops and fallows (Kekeunou and Tamesse, 2016). This is also in line with Bakondongama *et al.* (2017) who reported *Z. variegatus* (Pyrgomorphidae) for instance, as a fearsome devastator on food cultivation in the northeast part of the country. Similar example is given with *B. membranaceus*, reported in DRC to cause damage to vegetables (Walangululu and Mushagalusa, 2000). These reports are consistent with those from informants who additionally acknowledged that collection of *B. membranaceus* for human consumption rely on TEK passed down from a generation to another. As a significant part of traditional diets and one of the major edible orthopterans reported so far (Mapunzu, 2004; Nsevolo *et al.*, 2016), the rearing of *B. membranaceus* is linked to potential economic, social and ecological proceeds. Therefore, the development of rearing facilities - in addition to pre-tests done by the CAVTK (Halloran *et al.*, 2018a), should receive more attention, as it could impact positively on rural development and economy.

Figure 2. Maps of Entomophagy in DRC.





Edible insect species belong to: (A) Orthoptera (Acrididae, Catantopidae, Gryllidae, Gryllotalpidae, Pyrgomorphidae and Tettigoniidae); (B) Hemiptera (Cicadidae), Neuroptera (Myrmeleontidae), Mantodea (Mantidae) and Odonata (Libellulidae); (C) Blattodea (Termitidae); (D) Hymenoptera (Apidae and Formicidae); (E) Lepidoptera (Limacodidae); (F) Lepidoptera (Nymphalidae); (G) Lepidoptera (Noctuidae, Sphingidae and Lymantriidae). According to data compiled in the present study, the consumption of Dryophthoridae and Dynastidae (Coleoptera) or Saturniidae and Notodontidae (Lepidoptera) is a nationwide practice (not illustrated here).



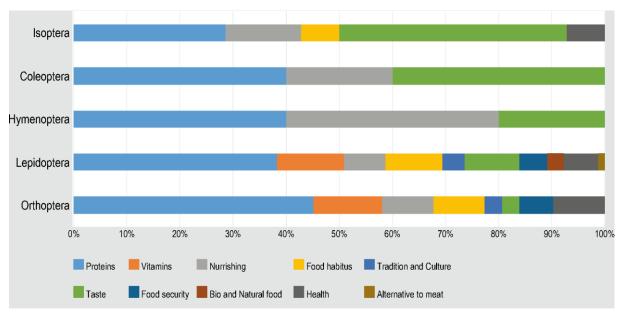




Figure 4. Main reasons for refusal of edible insects as food

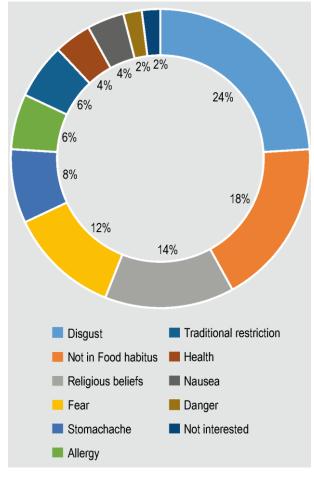
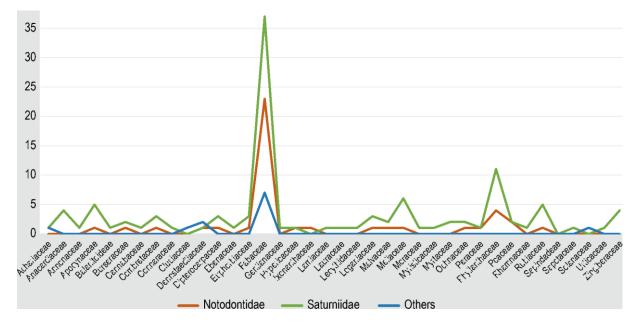


Figure 5. Host plants' diversity associated to edible lepidopterans





7. Seasonality, harvesting and processing methods

SEASONAL AVAILABILITY

Edible insects' seasonal availability on local markets varies according to species, seasonal conditions and phytogeographical zones (Latham, 2008; Mapunzu, 2004) - although some species (like *R. phoenicis* and *A. centaurus*) might be available all year-round (Malaisse, 1997; Nsevolo *et al.,* 2016) (Table 2). Unfortunately, as TEK regarding edible insect seasonality and their host plants availability is orally transmitted, few data are available in literature and gaps still remain for many edible species. However, the peak of abundance of several species in their respective ecological zones is globally reported to be linked with the rainy season (Malaisse, 1997; Latham, 2005; Latham *et al.,* 2021) - likely as it corresponds to abundance of their food plants. This is consistent with the study of Bomolo *et al.* (2017) who additionally mentioned that this seasonal availability is correlated to relatively high level of consumption.

Furthermore, it is noteworthy that the seasonal availability for some species is relatively shorter than for others (e.g. 2-4 months for *A. insignata, E. lactea* or *G. hecate* as compared to 4-6 months for *A. panda* or *B. alcinoe*) and that the number of availability seasons differs according to biogeographic zones (e.g. *B. alcinoe, C. caenis* or *I. epimethea* occur twice a year in northern provinces versus once a year in southern provinces) (Table 2). These findings not only due to insect voltinism, are probably linked in part to the prevalence of food plants and specific conditions within the ecological zones of occurrence, as reported by Malaisse (1997).

The turnover (and the temporal distribution) of edible insect species in-between production areas guarantees steady supply of certain species in local markets of main cities, as reported notably for Kinshasa (Nsevolo *et al.,* 2016). The prime example is given by *C. forda* considered as a nationwide commonality and reported to be available between September to January in the western parts of the country (as Bas-Congo or Bandundu provinces), from March to May in the southern provinces (i.e. Katanga) and from August to September in the northern province (i.e. Province orientale) (Table 2). Thereby, Kinshasa as the country's official administrative, economic and cultural centre is provided quite all year-round with this edible species collected from the other provinces of the country (Latham, 2005; Malaisse, 1997; Mapunzu, 2004; Nsevolo *et al.,* 2016).

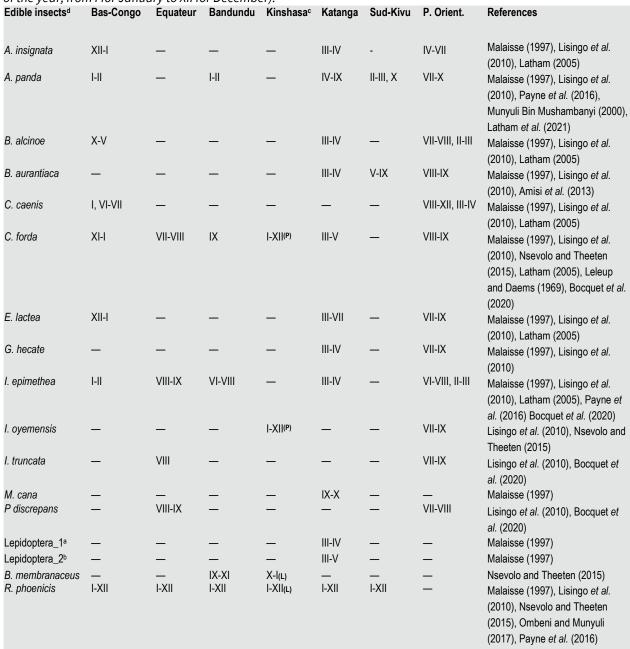


Table 2. Seasonal availability of selected edible insect species by provinces (roman numerals stand for months of the year, from I for January to XII for December).

^a Lepidoptera_1 group: C. hyperbius, G. richelmanni, G. zambesina, G. kuntzei, I. dione, I. macrothyris, A. insignata, D. uniformis.

^b Lepidoptera_2 group: G. ata, I. rubra, L. saturnus, M. parva, T flavinata, U. terpsichore, R. mediata.

^c In local markets of Kinshasa, some species are available all year-round whether living/fresh (L) or processed (P).

^d The full species names of insect taxa cited in this table are listed in Supplementary Table S1.

Harvesting techniques

Most insect species consumed in DRC are not farmed but mainly collected from different natural habitats (forests, savannas or farmlands) in their respective ecological zones (Latham, 2005;



Malaisse, 1997). Daily yields vary significantly according to years, seasons, insect species and host trees. It has been reported for example, an average of 9.1 kg/year/tree of *C. forda* harvested on 'Tali' (*Erythrophleum suaveolens* (Guill. & Perr.) Brenan), or up to 11.3 kg/tree/year of *I. oyemensis* harvested on 'Sapelli' (*Entandrophragma cylindricum* (Sprague) Sprague) (Muvatsi *et al.*, 2021).

Collection techniques mainly vary according to insect species and their behaviour (lonely, clumped species, scrolling or flying), as well as their host plant (tree, shrub or grass) or substrate types. They remain mostly traditional; children and women being the key actors (Latham, 2005; Malaisse, 1997). These findings are consistent with reports from others African countries as Nigeria (Alamu *et al.*, 2013), Botswana (Moreki, 2014) or Uganda (Akullo *et al.*, 2017). Harvesting activity of some edible insects may involve skilful young children for climbing on trees (e.g. *Bunaeopsis licharbas, Coeliades libeon, Hippotion osiris* - Lepidoptera) or women for collecting edible species clumped on grass by hand picking (e.g. *A. atropos, A. panda, I. epimethea* - Lepidoptera) (Latham *et al.*, 2021; Malaisse, 2010; Tango, 1981). Some other species are traditionally dug out of their holes using the hoe (e.g. *B. membranaceus* - Orthoptera) or attracted by light in baskets (e.g. *Macrotermes sp.* - Blattodea). If trees are to be cut down (e.g. for *R. phoenicis* - Coleoptera), or when physical effort is needed, men are the key actors (Malaisse, 1997).

As some edible insect species (e.g. *Anaphe venata, Micragone cana* - Lepidoptera) can cause unpleasant reactions or allergy to certain individuals, key informants during focus groups reported that collection techniques rely on TEK passed down from a generation to another. This is in agreement notably with reports from Malaisse (1997), Malaisse (2010), Latham (2005) and Latham *et al.* (2021) who additionally gave detailed description concerning harvesting techniques of several edible insects. For instance, when collecting caterpillars of *Achaea catocaloides*, special sounds and calls (*viz. 'Heh, heh'*) are made that cause the insect to jerk from side to side, making them easy to see and spot by children who collect them (Latham *et al.*, 2021). Characteristic droppings found on the ground below trees are also indicative of certain species of Lepidoptera (e.g. *Aurivillius triramis, Athletes gigas, B. alcinoe*) feeding on it (Tango, 1981). As many others edible species are harvested haphazardly while collectors search for edible insects, the host trees can be marked (with a cross for instance) or objects can be fastened on those trees to show that colonies found on them are claimed and must not be taken (Latham *et al.*, 2021).

Thanks to a certain number of local initiatives and implemented programmes (by the Salvation Army or by Non-Governmental Organisations for Development) - particularly in the western provinces of the country (namely Bas-Congo and Bandundu), local comunities are encouraged to planting host trees of edible caterpillars (e.g. *Funtumia africana, Ricinodendron heudelotii, Pentaclethra spp.*) in order to reintroduce edible insect species (declining or not) in targeted areas (A. Konda, personal communication, December 1, 2019). Local residents are also sensitised to observing customary laws and traditional harvesting periods (enforced by local chiefs to protect species from overexploitation), to limit unsustainable harvesting of insects (as the collection of immatures larvae or chrysalides under the ground for instance) and to avoid intrusive techniques of collection (notably trees felling and bushfires) (Latham *et al.*, 2021) as well as the use of host plants for combustion (coal



or wood fuel) given its significant impact on the disappearance of some edible insect species in their usual production areas (Bomolo *et al.,* 2017; Looli Boyombe *et al.,* 2021).

Moreover, based on the conservational status of some host plant species as *Milicia excelsa* [syn. *Chlorophora excelsa*], *Entandrophragma utile*, *Prioria balsamifera* [syn. *Gossweilerodendron balsamiferum*], *Autranella congolensis* (respectively reported in Supplementary Table S2) and taking into account increasing reports of edible insect populations' scarcity in their usual occurrence areas, alternative solutions (such as mass-rearing on diets, semicultivation on alternative food plants) are well-timed and should be promoted countrywide - as they are currently being promoted by the FAO (or the CAVTK) in the capital city and the Bas-Congo province (Halloran *et al.*, 2018a; Mapunzu, 2004).

Processing and preparation techniques

Most of the edible insect species (of Supplementary Table S1) are processed prior to selling, although some of them (e.g. *R. phoenicis* and *B. membranaceus*), are mainly sold alive. The techniques of processing are mostly traditional and might involve boiling, smoking, roasting, frying or simply sun-drying (Table 3) (Latham *et al.*, 2021; Malaisse, 1997; Nsevolo *et al.*, 2016; Tango, 1981). According to key informants during focus groups, processing allows to make edible insects available over longer periods without the use of a refrigerator. Due to unreliable means of transport, the shelf life of most processed insects can be increased enough to brought them to local markets without deterioration.

Furthermore, although edible insects preparation methods vary according to edible insect species, to culture and people's alimentary habits (Latham *et al.*, 2021; Mignon, 2002), similar patterns could be noticed for species of the same genus (e.g. *Athletes spp., Lobobunaea spp.*) (Table 3). However, on a national scale, data concerning the effects of traditional processing techniques (as well as those of preparation methods) on nutrient contents and the digestibility of local insect species are scarce. Based on reports from some African countries, it is likely that the nutritional value of processed (smoked or sun-dried) species is lesser than that of fresh ones (Rumpold and Schluter, 2013).

Moreover, although smoking insects is a common processing technique for lepidopterans notably, little is known about the increasing risk of developing cancer by eating smoked insects (Balinga *et al.,* 2004; Mapunzu 2004). The scarcity of such valuable data points out research gaps to be filled.

Notwithstanding, traditional processing techniques are often used in combination (Table 2) and must be better investigated as they help to reduce the microbial load and the chemical hazards in edible insects (Murefu *et al.*, 2019). This is consistent with results reported for some edible species from DRC - namely *Macrotermes sp.* (Tertmitidae, Blattodea) and two lepidopterans (*Bingubala*, probably *Imbrasia spp.* based on vernacular names and *C. forda*) - found on Belgium markets, as processing methods investigated helped to reduce microorganism counts compared to unprocessed samples (Caparros *et al.*, 2017).

Owing to this concern, more effort should be put into ensuring safer products intended to consumers (Babarinde *et al.*, 2021). For instance, aflatoxins (B1) have already been reported in edible sting bugs stored in used grain containers, as growth and development of the undesirable microorganisms producing these toxins (*Aspergillus flavus* and *Aspergillus parasiticus*) is favoured by



warm temperatures and high humidity (Musundire *et al.*, 2016). Therefore, attention should be paid during all the steps 'from farm to fork' (Bessa *et al.*, 2020), in order to avoid microorganism growth (e.g. moulds) along the value chain of insect species harvested countrywide, possibly resulting in food-safety risk (Mezes and Erdelyi, 2020).

8. National trade and related challenges

On a national scale, quantitative data on foodstuffs production in DRC are scarce (Tollens, 2008) and existing reports about edible insects' sales - e.g. an annual trade of 8 tons of *Imbrasia sp.* with Belgium and France by Tabuna (2000) or those reported by Ramos-Elorduy (2009), are out of date and should be updated. Nonetheless, it is acknowledged that the trade of edible insects in the country is an income-generating activity that involves many people nationwide (collectors, wholesalers, resellers) with women as key actors (Mapunzu, 2004). For Kinshasa, it is reported that 80.0% of its inhabitants consume at least one edible insect species 5 days per month, with an estimated 9,600 tonnes of caterpillars sold each year (N'Gasse, 2003). Thereby, the incomes generated by this activity contribute to women empowerment and to the well-being of households (Nsevolo *et al.*, 2016).

Even though entomophagy is a long-lived tradition, it should be mentioned that the edible insect sector in DRC is still in its infancy (i.e. insect trade remains mainly informal and traditional, markets lacking specific regulation or appropriate management strategies from the State). As a reminder, few data are available about the edible insect trade so far - but this gap is rather the same for meat (or fish) for instance (Marivoet *et al.*, 2018; Tollens, 2008). However, a fairly specific challenge to the edible insect sector (in comparison to the two others) is related to sale units throughout local markets. The results of sellers' survey showed that edible insects are not sold based on standardised international units (*viz.* kg, g) used for meat (or fish), but rather on the basis of unstandardised local units or measures (like 'Ebundeli', 'Verre', 'Ekolo', 'Kopo', 'Lutu', 'Sakombi', 'Linzanza tomate') (Supplementary Figure S2) which might vary from a location to another, depending mostly on the edible insect species. This nationwide situation contributes to making official estimates of insects' trade tricky and unreliable. It should be addressed properly if edible insects are to be sustainably managed to grapple with food insecurity in the country.

9. Ways forward

The realisation of the full potential of edible insects as food in DRC will be associated with several challenges, in addition to those already mentioned in this study (*viz.* the loss of TEK related to edible species, conflicts to be managed between local communities in the use of multipurpose host trees, a better knowledge of the motives and determinants of insect consumption in order to overcome neophobia or to limit abandonment trend, gaps to be filled about the effects of traditional processing and preparation techniques on the nutrient contents or the digestibility of edible insects



and human health, the scarcity of quantitative data on foodstuffs production as well as unstandardised units of sale making estimates of insects' trade tricky and unreliable).

Table 3. Processing and preparation techniques of selected lepidopteran species

Edible insect species	Caterpillars' processing and preparation techniques	References
Achaea catocaloides Aegocera rectilinea	Boiled in water with salt and allowed to dry in the sun Gut contents removed, larvae are then washed and boiled with a little salt and water unt almost dry	Latham <i>et al.</i> (2021) _{II} Latham <i>et al.</i> (2021)
Anaphe panda	Gut not removed. The hairs are removed by singeing them off in a pan over the fire. Larva may also be lightly cooked, dried and powdered for later use	_e Latham <i>et al.</i> (2021)
Athletes gigas	Gut contents removed before boiling larvae with salt and hot peppers	Latham et al. (2021)
Athletes semialbus	Cut open and gut contents squeezed out before being washed	Latham et al. (2021)
Aurivillius triramis Bunaea alcinoe	Gut contents removed before cooking. Prepared by being skewered and roasted, fried or boiled in salt. Also dried, powdered an added to a sauce	Latham <i>et al.</i> (2021) d Tango (1981)
Bunaeopsis aurantiaca	Boiled or roasted	Latham et al. (2021)
Cirina forda	Gut contents must be squeezed out before cooking. The caterpillars are then boiled, dried an cooked in a peanut butter sauce	d Latham <i>et al.</i> (2021)
Coeliades libeon	Boiled or fried and eaten immediately, though more commonly the caterpillars are smoked an stored	d Latham <i>et al.</i> (2021)
Cymothoe caenis	Gut content removed before cooking with salt	Latham (2015)
Elaphrodes lactea	May be cooked in water with salt, cooked without salt and fried with oil and vegetables or fried Latham <i>et al.</i> (2021) in palm oil or peanut oil and eaten	
Epanaphe carteri	Remaining hairs are lost during preparation	Latham et al. (2021)
Gonimbrasia alopia Gonimbrasia belina	Gut contents is removed if larvae have not dropped to the ground to pupate	Latham et al. (2021)
	The gut contents are squeezed out and the caterpillars are boiled, salt is added and then Latham <i>et al.</i> (2021) caterpillars are fried. They are also boiled and dried before storage	
Gonimbrasia jamesoni	Spines are singed off on a metal plate over the fire	Latham et al. (2021)
Hadraphe ethiopica	Gut contents squeezed out before roasting in hot ashes to remove spines	Latham et al. (2021)
Imbrasia epimethea	The remaining hairs may be singed off on a metal plate over a fire before being broken open Latham <i>et al.</i> (2021) and gut contents squeezed out	
Imbrasia obscura	Spines are singed off and the caterpillars are washed, cut open but gut contents are not Payne <i>et al.</i> (2016) removed. They are then wrapped in leaves and roasted	
Lobobunaeoides acetes	Broken open and gut contents are squeezed out. They are then washed, salt and hot peppers Latham et al. (2021) are added, before being boiled in water	
Lobobunaea angasana	Broken open and gut contents are squeezed out. They are then washed, salt and hot peppers Latham et al. (2021) are added, before being boiled in water	
Lobobunaea phaedusa	Washed and salt and hot peppers are added, before being boiled in water	Latham et al. (2021)
, Micragone cana	Stinging hairs are singed off before cooking	Latham et al. (2021)
Nudaurelia rectilineata	Gut contents are removed. Larvae are then boiled in water with salt until the water has dried Tango (1981)	
Platysphinx stigmatica	Broken open and their gut contents squeezed out, then boiled in water with salt and hot Latham et al. (2021) peppers	
Pseudantheraea discrepans	May be boiled with salt until dry and then eaten with hot peppers	Takeda (1990)

Since it is requested to all the members of the Common Market for Eastern and Southern Africa (COMESA) to harmonise regulations and standards in order to ease trade and cooperation within COMESA borders (Grabowski *et al.*, 2020), the absence of insects-related regulations and guidelines should be really addressed in DRC, as it hampers an effective development of the transboundary commerce of edible insect species. Furthermore, as entomophagy mainly lays on ancient tradition



lingering on up-to-now; current national environmental concerns (e.g. overexploitation of timber trees for logging or for wood fuel) (Ciza *et al.*, 2015; Muvatsi *et al.*, 2021) or those associated to globalisation (e.g. environmental pollution or climate change) (Halloran *et al.*, 2018b) made it essential to fill the gap about the legal framework and regulatory environment specifically addressing edible insects and insect-based products. This could help in boosting innovations and facilitating certification of entrepreneurs willing to start insect-related business. The implementation of such a legislation is also expected to foster good practices (e.g. efficient packaging, operative labelling), to lower food-related consumer risks (Grabowski *et al.*, 2020) and to constrain unsustainable husbandry of edible insect species or unfitting management of insects (or insect-based products) along the food chain.

Further gaps to be addressed are related to TEK. As a reminder, the list of edible insects drawn here for DRC is unquestionably incomplete, due notably to numerous ethnospecies or taxa unidentified up to the species level (e.g. *Platysphinx sp., Synagris sp., Anaphe sp., Antheua sp., Cubitermes spp., Goliathus sp., Argemia sp.*) (Supplementary Table S3). This situation that may be due in part to technical limitations of traditional methods based on morphological features or to the lack of experts locally, calls for considering molecular identification (DNA barcoding). Molecular typing should also be of great use to unravel species polymorphism of some edible insects (e.g. *Rhynchophorus spp.*) with massrearing potential in DRC (Monzenga, 2015).

It is noteworthy that actions and programs currently implemented for promoting entomophagy and zootechny development in the DRC are likely to enlarge the list of species consumed so far. This is the case for the species *Samia ricini* (Saturniidae) reported in this study. Its consumption and breeding are being popularised by the Salvation Army in the Kongo-Central (formerly Bas-Congo) province (A. Konda, personal communication, December 1, 2019), but was under-documented to date. This is also the case of *Acheta domesticus* (Gryllidae) in Kinshasa whose consumption is regarded with some revulsion. According to key informants, the species is known locally and called 'Kinzenze ngoma', but it is likely to be restricted to entomotherapeutic uses. The promotion of its consumption, the determinants of acceptance (or abhorrence) and smallscale farming conditions are under investigation by the CAVTK (R.M. Lundanda, personal communication, May 17, 2021).

Additionally, as edible insects have to follow the same health and sanitation regulations as for commonly eaten animal products, challenges regarding food safety - under the *Codex Alimentarius* principles of food hygiene (Fraqueza and Patarata 2017), should also be mentioned. Based on the review from Murefu *et al.* (2019), it is likely that safety concerns related to local edible species have not raised great interest in DRC so far, while this an issue in most African countries (e.g. Zimbabwe, Nigeria, Uganda). Anyway, as edible insects are mostly harvested from the wild, research about potential hazards and safety issues related to local species (i.e. the toxin levels emanating from their feeding plants, microbiological contamination from soil, mycotoxins, antinutrient and inorganic compounds or heavy metals) should gain momentum in DRC, as well as research focusing on allergy concerns due to edible insects' ingestion (Mezes and Erdelyi, 2020).

Given several reports in literature highlighting the chemical composition and the nutritional value of local species (Kodondi *et al.,* 1987a,b; Malaisse, 2010; Malaisse and Parent, 1997; Malaisse *et al.,*



2003; Mbemba and Remacle, 1992), the development of the edible insect sector is advocated as a promising route towards alleviating food insecurity and malnutrition in DRC. For this to happen, cooperation between all the stakeholders is paramount (Van Huis, 2017). They all (i.e. the public sector, the academia and private enterprise, as well as rural communities among others) should be involved to implement regulatory frameworks and operative guidelines on insects and insectbased products, as well as to set up good practices and species-specific safety standards, in order to guide action and research on local edible insects' farming systems, processing, labelling, storage, transport, trade and use.

10. Conclusions

Entomophagy is remarkably ingrained in food habits in DRC, seeing that edible insects are considered as a valuable traditional food since long and a sustainable source of proteins and vitamins, based on survey data from consumers. This study listed 148 edible insects identified at species (100 genera, 31 families and 9 orders dominated by the orders Lepidoptera, Orthoptera, Coleoptera and Hymenoptera). The analysis of consumption patterns (mapped on country scale) indicated species to be considered commonalities and those restricted within their occurrence areas.

The wide biodiversity of edible insects reported here (broader than compiled to date for the country) and host plants diversity (122 plant species belonging to 79 genera split in 35 families dominated by Fabaceae, Phyllanthaceae, Meliaceae and Apocynaceae) call for targeted actions for sustainable management of these flora and fauna resources. These includes methods of mass-rearing *ex situ* or semi-cultivation on alternative diets, the implementation of conservation strategies and the development of regulatory frameworks. Moreover, taking into account the reported conservation status of host plants (as some are endangered or critically endangered species) and potential conflicts of use (as many of them are multipurpose trees), rural communities involved in insect collection in the wild should be sensitised to good practices to be defined thanks to close cooperation between all the stakeholders involved in the edible insect sector.

Additionally, in order to boost consumer demand, to overcame neophobia or to limit abandonment trends in urban areas, new opportunities for edible insects and insects-based products should be envisaged, based on a better understanding of the motives of consumers, as well as the expectations of the market for cheap, tasty and safer products notably. This could be achieved by enhancing research on production and processing methods that guarantee notably the highest nutritional value, the lowest microbial load and chemical hazards, as well as the longest shelf life of processed insects (given issues related to the cold chain, as the country is still facing development challenges).

Assuredly, the necessary steps towards mitigating food insecurity in DRC through edible insects requires, among others, the implementation of constraints on local markets for standardised units of sale (as it is impossible to perform a proper analysis of the edible insects sector without a modicum of reliable statistics); to support cooperation between local ethnic groups, scholars and



experts taxonomists (for unravelling unidentified ethnospecies and unveiling TEK as well); to develop efficient rearing facilities for species contributing to food security and income of rural communities; and to provide financial support for further research intended to fill the gaps.

SUPPLEMENTARY MATERIAL

Supplementary material can be found online at https://doi.org/10.3920/JIFF2022.0024

Table S1. Inventory of edible insect species reported for DRC.

Table S2. Recorded host plants for main edible Lepidopteran species.

Table S3. List of unidentified edible insect species in DRC.

Figure S1. Map of the current configuration of DRC.

Figure S2. The main local units of edible insects could be grouped in two: truncated cones (E,F) and cylinders (A,B,C,D,G).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.



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