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ORIGINAL RESEARCH ARTICLE

"It is edible, so we eat it": Insect supply and consumption in the central highlands of Madagascar

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Abstract

Entomophagy is a common practice in many parts of Madagascar, but the supply of insects for local consumption has hardly been explored. This study analyses insect harvesting, marketing and consumption in the central highlands of Madagascar. Based on focus group discussions, key informant interviews and interviews on markets, research shows that some insects are highly esteemed by consumers. The main species consumed are wild silkworm chrysalis, locusts, and beetles. The seasonal supply of edible insects does not satisfy the demand of the population. Insects are mostly harvested by villagers for own consumption. Only some species are marketed on the local level, and there are few traders involved. However, at least seasonally, insects seem to be an important food and income source for farmers and urban consumers. As wild harvesting is limited, and even decreased in recent years, shifting from wild gathering to rearing could compensate for this falling trend and offer a higher, more continuous supply of insects in a chronic food insecure region.

Keywords Entomophagy · Edible insects · Wild silkworm · Ambositra · Sandrandahy

Introduction

Entomophagy, the consumption of insects, has been described as a possible solution to nutrition and food security, a solution with a low ecological footprint and the potential to improve livelihoods of poor people (FAO 2013; Halloran et al. 2014). Insects are consumed by many ethnic groups in Africa, Asia and Latin America where they form part of the local diets and are an important protein source (Gahukar 2011). There are efforts to rationalize the production of insects for food in the form of rearing. For example, around 20,000 cricket farms are operating in Thailand, representing already an important livestock sector and income source for thousands of farmers in this country (Hanboonsong et al. 2013). Nevertheless, most insects consumed worldwide still come from wild harvesting (FAO 2013). One important exception is the silkworm, which has been used in Asia for centuries for the double purpose of fibre (silk) and food (larvae, pupae) production. As a by-product, silkworms have been considered a delicious food in many Asian and some African countries including Madagascar (DeFoliart 1995).

Wild harvested insects can play an important role for local diets. Collecting of insects is mostly done for home consumption, but some species are also traded in informal, local or regional markets. Consumers eat insects for their taste, but also as an additional protein source in times of food constraints (FAO 2013). Normally, the supply is only seasonal because insects depend on certain plants, and there are no processing or storage facilities in use. Moreover, there are concerns that availability of insects decreases due to overharvesting, leading to lower consumption and trade, but there is rare evidence on this issue (FAO 2013).

Entomophagy has a long tradition and still is a common practice in many parts of Madagascar. Insects are a traditional, nutritious and affordable food for the rural population. Jongema (2015) lists 34 edible species, whereas

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Randrianandrasana and Berenbaum (2015) report 53 edible species. There is no data showing the importance of insect consumption in Madagascar in terms of quantities or nutritional values, even less of the consumption trend in the last decades. However, there are concerns that entomophagy practises as well as the supply of insects for local demand have decreased because of destruction of natural habitats, thereby undermining the potential of insect consumption for nutrition and food security in Madagascar (Randrianandrasana and Berenbaum 2015).

There is a need to promote Research for Development (R4D) activities in Africa to strengthen the sustainable use of edible insects, including marketing studies and the socio-cultural-economic background of communities (Kelemu et al. 2015). The objective of this paper is to use a case study in the central highlands of Madagascar for analysing which insects are preferred and eaten, and why they are consumed. Furthermore, this article examines the availability of insects for local consumption and how consumers are supplied. Moreover, the role of insects as a local food and income source is investigated.

The rest of the article has been organized in the following parts: the first section provides a short description of the study site. Second, we explicate our data collection process. Third, results are presented concerning availability and consumption habits of insects, as well as the local supply system in general, and the wild silkworm supply more specifically. Then, we try to interpret these results in the discussion section. Finally, some conclusions for the promotion of insect consumption for better nutrition are drawn.

Study site description

The study was conducted in three locations in the central highlands of Madagascar: 1) Ambositra, the chief town of Amoron'i Mania region, located 261 km south from Antananarivo, the capital city of Madagascar. It is a small town which has around 42 thousand inhabitants (INSTAT 2019), compared to 32 thousands in 2001 (Cornell University 2001). 2) In five villages of Sandrandahy (20°21′ 00“ South, 47°17'42” East) located in the Fandriana District, 22 km away from Ambositra. Sandrandahy is a rural town, but with 28 thousand inhabitants in 2001 not much smaller than Ambositra (Cornell University 2001; no updated population data available). 3) Moreover, a field visit to Ambohimanjaka, approximately 200 km south of Antananarivo, was done in order to visit a silkworm breeding center. The region around Ambohimanjaka in the so-called Col des Tapia woodlands (*Uapaca bojeri Euphorbiaceae*) is one of the main locations where the wild silkworm species (*Borocera cajani*) can be found (Fig. 1).

The principal reasons to choose this region were on the one hand that the consumption of insects is already integrated in the food habits of the population and that sericulture is developed in the area. On the other hand, the risk of food insecurity in the region is high and there are only limited socio-economic potentials for the local population.

The region Amoron'i Mania is situated on the highlands of Madagascar. The Betsileo are the main ethnic group in this region; they represent more than 90% of the inhabitants. The region is an integral part of the southern zone of the Central Highlands whose altitudes vary between 1,200 to 1,500 m. The climate of the region is a tropical type of altitude with two well marked seasons (ONE 2007):

- Hot and humid season, from October to April: 85–90% of rain; with a peak of rainfall and temperature in December–January (300 mm per month, 18–21 °C);
- Cool, dry season, May to September: less than 40 mm of monthly rainfall; 13–16 °C average temperature.

The economy of the zone is essentially based on agriculture and in particular that of rice, which is the staple food of the population. This rice production is subject to strong constraints, including pressure on land, with plots measuring an average of 0.30 ha per household in 2007 (ONE 2007). According to the Ministry of Economy and Planning (MEP 2015), individual income is estimated at $ 0.54 per day. Poverty is visible at the level of undernourishment, resulting from various factors: small areas of land with low fertility, insufficient livestock, large families, low prices of agricultural and artisanal products, increase in food prices (rice, starchy foods) during the lean season of seven months, according to FAO (2017). The region is one of the most affected in Madagascar concerning stunting and chronic malnutrition, reaching 64% and 68.8%, respectively, of the population (FAO 2017).

Our analysis of livelihoods and farming systems confirmed these data: most people in the five villages of Sandrandahy make their living by farming complemented necessarily by wage labour. Subsistence agriculture on small plots of land is predominant with hardly any selling of surplus of agricultural produce, only some livestock (chicken). Main staple crops are rice, cassava, sweet potato, and maize, combined with livestock (chicken, pork, and zebu). Most people complement their agricultural work by other activities such as daily labour, for example, working on rice fields, petty trading, work in construction, silk clothes production, etc.

Data collection methods

This study was conducted in October 2018 by nine researchers of ProciNut project, which promotes production and

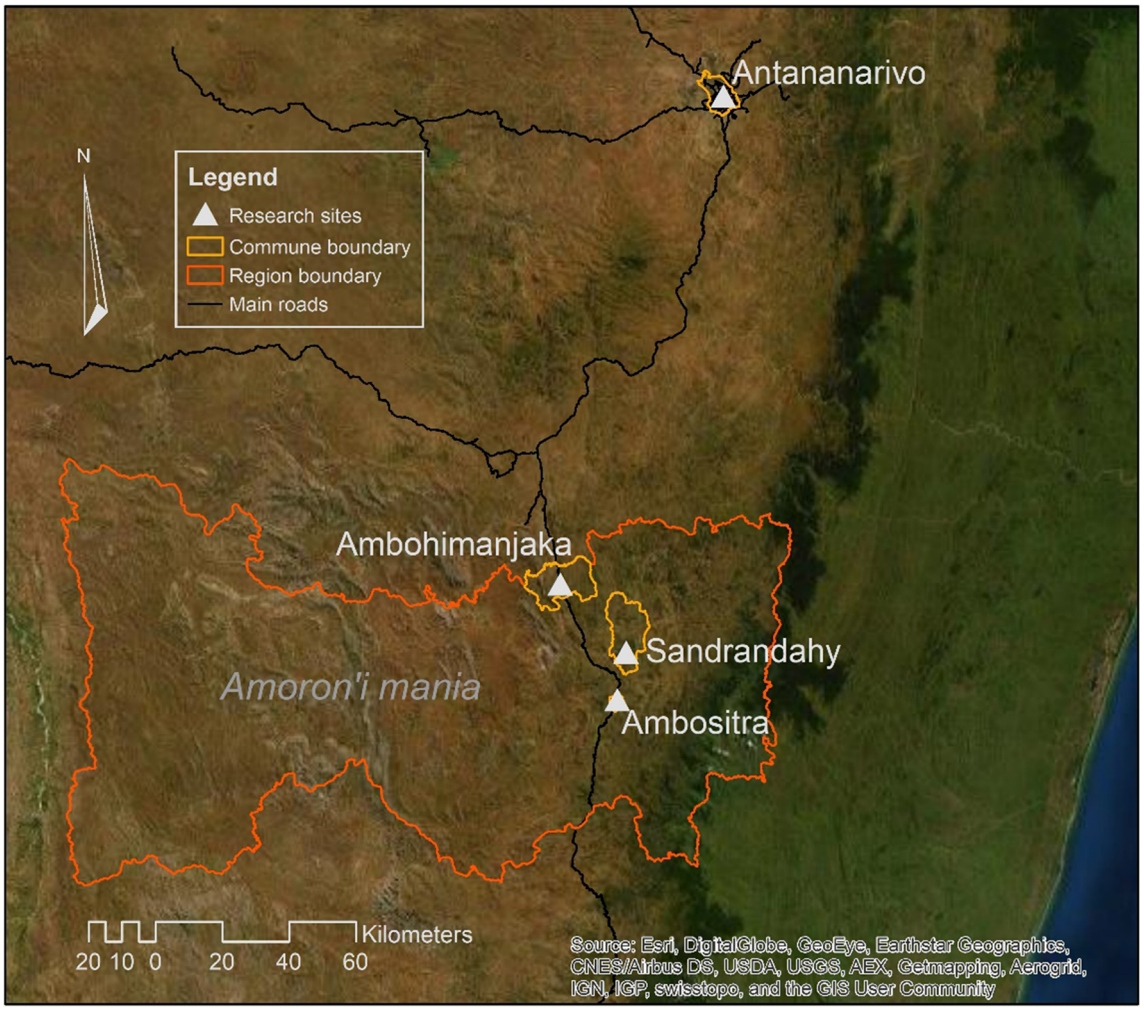

Fig. 1 The study sites

processing of edible insects for improved nutrition in Madagascar. The approach consisted of meetings in the format of Focus Group Discussions (FGD), Key Informant Interviews (KII) and Market Interviews (MI) conducted in the neighbourhood of Sandrandahy (FGD and MI), in Ambositra (KII and MI), in Ambohimanjaka (KII) and in Antananarivo (KII).

FGD were conducted in each of the five communities of Sandrandahy. The community members were assigned to three group types of different compositions regarding age and gender (men, women, youth) with 4–10 participants each. (Differentiation based on other criteria such as education etc. was not applied in order to simplify the process.) Every group dealt with one of three topics, which consisted of 1) economic aspects and institutional networks of the village; 2) farming system and insect collection; and 3) food culture and consumption behaviour (see Questionnaire in the Annex III). The different groups were deliberately assigned to each of the three topic so that all topics could be covered by at least one group type. A semi-structured questionnaire was used to cover these topics. Also, Participatory Rural Appraisal (PRA) tools such as seasonal calendar and insect photo cards were incorporated in the FGD. In total, 12 FGD were conducted (three on topic 1, four on topic 2, and five on topic 3).

The KII included village representatives, experts of national and regional organisations dealing with agriculture and nutrition, research institutions, different regional and national development projects and NGO, as well as local silk associations. In total, we interviewed 20 organisations (see the list in the Annex IV). Discussions were held on the same topics mentioned above, but depending on the organisation or key informant, in each KII, some aspects have been considered more closely than others.

Local markets in Ambositra and Sandrandahy were visited in order to interview vendors trading edible insects and their customers by using a structured interview guide. Questions concerned the type of insects marketed or consumed, preferences and perception of insects as food, as well as the sources, prices, quantities and frequencies of insect marketing and consumption,

amongst others (see Questionnaire in the Annex I and II). As it was not the main season for edible insects, only seven insect vendors on the markets of Ambositra (5) and Sandrandahy (2) could be interviewed. Moreover, 18 consumers were randomly chosen and interviewed at the market of Ambositra (15) and Sandrandahy (3).

Results

Availability of edible insects

People around Sandrandahy identified different insects which are known and eaten in the villages (see Annex 1). However, even by using photo cards, it was sometimes difficult to get to know which exact species were meant by the villagers. One problem was that some terms do not necessarily denominate special species, but a certain stage in the life cycle of a certain insect family. For example, "*Sakivy*" denominates larvae of *Coleoptera* in general. Another problem was that the names can change from place to place. For example, "*Sakiviy*" are sometimes also called "*Abado*".

The main insects consumed in the study region consist of different beetles found in the wild, and which are eaten as larvae ("*Sakivy*") as well as adults ("*Voangory*", "*Voanosy*"). Another important edible insect are silkworm larvae ("*Zana-dandy*") and pupae ("*Soherina*"). In the region, some farms produce the domesticated silkworm (*Bombyx mori*). However, more important are the wild silkworms (*Borocera cajani, Borocera madagascariensis*) which are found in the tapia forests. Locusts ("*Valala*") are also caught in the wild, especially if there is an invasion. There are a number of other insects known, some of them are eaten, but on an irregular basis, such as "*Akitra*" (crickets) and "*Jorery*" (cicadae).

Most insects are only obtainable seasonally, i.e. in the hot, rainy season, from October to March, see Table 1. For example, utmost all beetle larvae can be found in the fields from August to November. The adult beetles are then collected mainly between October and January. Locusts can be found all the year round, but are often caught if there is an infestation in the cultivated fields, which occurs periodically, mainly in the rainy season. Production of the bivoltine *Bombyx mori* is mainly from September to May, when enough mulberry leaves are available. The wild silkworm has two seasons per year, when the cocoons can be collected in the forest, which is being done in May to July and November to December. Cicadae are found mainly from November to February. This means that most edible insects are found in the lean season, which in the region starts in October and extends until March, when food prices are high and availability of rice is low.

Consumption habits and preferences

As mentioned above, the widespread and chronic food and nutritional insecurity affects 69% of the population in the region (FAO 2017). The consumption pattern of people is dominated by rice, and complemented by cassava, maize, legumes and chicken. Food shortages occur when rice reserves run out some time after harvest (April to May). When this occurs, farmers will have to buy rice at the local market, if possible, complemented by meat or dried fish. Nevertheless, incomes are often insufficient to allow for that. If there is no other choice, people eat only manioc leaves together with rice. The shortage of rice mostly starts in November and is especially strong in the months of January and February.

Therefore, for villagers, insects are a welcomed additional food resource they can get "for free" in their fields or in the surroundings of the communities. They like to combine insects with rice as the main dish. As the foremost consumed insects appear between November and December, their harvesting coincides with the lean season. For farming households, insects are a welcomed complement to their limited diet diversity, which was expressed in one FGD in a rather laconic way: "*it is edible, so we eat it*". Insects are a traditional food, consumed when available, and not for specific reasons.

Most urban consumers in Ambositra consider insects as a tasty, appetizing dish. Insects are also viewed as a "special" food because supply is only seasonal, and coincides with Christmas. Some consumers prefer insects to meat, because insects are seen as the relatively cheaper food. Other reasons why people consume insects include health aspects: insects are preferred as a healthy product for their vitamin, calcium and protein content. Most consumers are not aware of nutritional aspects, but eat insects as a traditional food. In general, we could not find differences in preferences between men and women, or between younger and older consumers.

The most preferred insects are silkworm chrysalis (67% of interviewed consumers eat them), adult beetles (67%) and beetle larvae (56%), locusts (28%) and cicadae (17%). Crickets, especially the field crickets (*Gryllus bimaculatus*) are normally not eaten by adults, only by children from two years on, because the consumption is believed to help them learning to speak. Only few consumers (2 out of 18) interviewed at the market in Ambositra do not like and hence do not consume any insects. In these cases, the reason for not consuming was mainly allergy problems. People use to consume insects once to twice a week during the season of the respective insect, if they have to buy it on the

Table 1 Main edible insects in the area of Sandrandahy

Malagasy name	English name	Latin name	Consumption/Season
Landikely	Domesticated silkworm	*Bombyx mori*	Chrysalis eaten, Sept-May
Zana-dandy: larva			
Soherina: pupa			
Landibe	Wild silkworm	*Borocera cajani*	Chrysalis eaten, May–July and Nov-Dec
Zana-dandy: larva		*Borocera madagascariensis*	
Soherina: pupa			
Jorery	Cicadoidea		Eaten Nov-Feb
Valala	Locust	*Locusta migratoria*	Eaten whole year, periodically/unregularly
Sakivy	Larva in general for Coleoptera		Larva eaten, rainy season (Oct-March)
Abado: larva	June bug	*Amphimallon solstitiale*	Larva and adult eaten, rainy season (Oct-March)
Voangory: adult		*Phyllophaga* sp.	
Abado: larva	May beetle	*Serica* sp.	Larva and adult eaten, rainy season (Oct-March)
Voangory: adult			
Voanosy	Beetles	Examples: *Rina nigra*	Larva and adult eaten, rainy season (Oct-March)
Voangory	Scarab beetles and others	Examples: *Hexodon unicolor* *Rhynchophorus* sp. *Bricoptis variolosa* *Tenebrio molitor* *Scarites* sp.	Larva and adult eaten, rainy season (Oct-March)
Akitra or Angeli-kary	Field cricket	*Gryllus bimaculatus*	Eaten by children, periodically/unregularly
Angeli-kary or Zazavery	House cricket	*Acheta domesticus*	Eaten by children, periodically/unregularly

urban market, or even every day, if they or their children can collect them in the fields.

Supply for local consumers

In the five villages visited, insect supply comes mainly from wild harvesting and is principally designated to self-consumption. Insects are sold only if there is a good (surplus) harvest. Sometimes, insects are given also as feed to chicken. In the rainy season, mainly *Coleoptera* larvae and adults are collected by farmers and their children when working in the rice fields. As an example to illustrate this, farm households collect and fill around two bottles of 1.5 l of adult beetles every day in one to two hours during the seasonal high which lasts only about 15 days. In the rest of the season (mainly November and December), quantities are smaller. 4–5 tins (of around 200 g each) of June bugs larvae can be collected daily during their short season in around two hours. Other examples of the quantities different people collect and eat during the season include one to four tins of beetle larvae, four times a week; or one bottle (1.5 l) of cicadae, daily.

It seems that the amount of gathered insects is difficult to increase, because of two reasons: first of all, there are not much more insects easily to be harvested. Second, farm families are also time constrained to go more often collecting insects, especially when the rice planting season starts. Households at this time also sell their labour force working in rice fields of bigger farmers.

Sometimes beetle and silkworm larvae are also bought at town market by the people of the villages, but this is rather unusual, as it implies monetary expenses. Silkworms are considered expensive by the farmers and therefore, are often not available for the villagers even during season.

At Ambositra, where a daily market exists, urban consumers buy insects normally on a weekly basis, between 1 and 6 tins (of around 200 g each) per week in season. Prices are higher for pupae (around 1,500–2,500 Ar/tin or 0.37–0.63 €/tin)[1] than for adult beetles or cicadae (around 500–1,000 Ar/tin). Consumer daily expenditures on food differ significantly (between 2,000 and 20,000 Ar per day), but it seems that consumers with lower general food expenditures do not buy less insects than consumers with higher food expenditures. Accordingly, seasonal expenditures on insects as a proportion of total expenditures vary greatly.

The insect vendors at Ambositra market are provided by insect collectors during season every day. Some retailers sell up to 100 tins (around 20 kg) per day in high season, but quantities vary strongly. There are also collectors who sell their own harvest on the market directly to consumers. At the same time there are collectors who buy from other collectors in the villages and bring the harvest to the market. Larvae and pupae and adult beetles are only accepted alive by the final consumer, and for this reason, the collectors put the insects or in bags filled with water, or in a basket covered by green leafs. They are transported to the town by "country taxis". Retailers in the market of Ambositra take around 200–500 Ar/tin as margin. Depending on the final price, this represents a gross margin of 10–20%. The main cost for the retailers is the produce; for the collectors, the transport which cost around 5,000–8,000 Ar per voyage, besides the basket (2,000 Ar/unit).

Insect prices are determined by the law of demand and supply: when there are a lot of insects at the high of the season, prices are lower, and at the end of the season, when demand is still high but supply is getting scarce, prices rise, for example, from around 1,800–2,000 Ar/tin to 2,500 Ar/tin. The price trend of recent years is increasing in accordance with the price of rice (which people use as indicator of general inflation), in the opinion of the sellers. Besides general inflation, one of the causes for rising prices could also be that the availability of insects has been reduced: in one FGD it was reported that five years ago, double amounts of larvae could be found compared to today. Also, adult beetles have significantly decreased according to villagers.

Silkworm chrysalis as a by-product for local consumption

Silkworms in the region are dominated by the wild silkworm species *Borocera cajani* that grows on tapia trees (*Uapaca bojeri*), where it is harvested. Tapia tree is an endemic Malagasy tree of the central highlands, where it forms forests. The domesticated species is *Bombyx mori* (and also the Eri silkworm, *Philosamia ricini*) which feeds on mulberry tree leaves. Its production cycle is much shorter than for the wild species: from eggs to cocoon, it takes only around 5–6 weeks until silk can be extracted. On the contrary, the reproduction cycle of the wild silkworm is around 145 days. This is why farmers are not interested in domestication of *Borocera cajani.*

Silk and food production are complementary activities for both species: but whereas the domesticated silkworms are not storable, as they are boiled with the chrysalis inside, for the wild silkworm, the farmers remove the chrysalis from the cocoon before further processing. The chrysalis are sold as food and the cocoons are sold separately. Harvesting time for the wild species is only twice a year from November–February and May–July, because of the long reproduction cycle of *B. cajani*. After July, it is not allowed to collect silkworms in the wild until November.

As there are only few tapia trees in the surroundings of Sandrandahy and Ambositra, most of the wild silkworms are harvested in areas up to 50–80 km far away from these towns (mainly in Ambatofinandrahana, Ambohimanjaka, Ambavatapia and Manandriana). Whereas cocoons of domesticated silkworm can be obtained from farms around Ambositra. Nevertheless, the silk association in Sandrandahy uses only 20% of silk from the domesticated but 80% from the wild silkworm. It seems that the supply of wild silkworms is much higher than of the domesticated, the latter having furthermore decreased in recent years because of a disease attacking the larvae.

The production of wild silkworm pupae is approximately 10 kg per hectare of forest. Farmers get around 15–25,000 Ar/kg of cocoon (chrysalis already taken out). The chrysalis, if not eaten in the family, is marketed or directly in the villages[2] or in Ambositra, for 500 Ar/tin in the village and 700–1,000 Ar/tin in town. Whereas the cocoons are sold to buyers who take them to Ambositra or to Antananarivo, for the pupae there are no middlemen present. Farmers will take them to the market by themselves, or some collectors will buy the chrysalis from other collectors and then sell it on the market. It seems that all chrysalis extracted from cocoon (except dead chrysalis which are not accepted by consumers) are marketed and consumed or in the villages or in town.

Table 2 presents a rough calculation of gross income farmers around Ambohimanjaka can get by selling the cocoon and the chrysalis. No costs (labour, transportation, etc.) are included. First of all, Table 2 illustrates the importance of silkworm production for the villages. An estimated 500 ha of Tapia forest exist in the area. With an average production of 10 kg cocoon/ha, around 5 tons of cocoon can be attained per season. Even more interesting is that 45 t of chrysalis can be obtained seasonally, i.e. in one to two months. This means

[1] 4000 Ar equaled 1 € at the time of the study.

[2] Here we refer to the villages where the wild silkworms are collected on a larger scale; not to the five villages visited around Sandrandahy.

Table 2 Estimated production and gross income of wild silkworm in the area of Ambohimanjaka

	ha	kg/ha	Production in kg	Price/kg (Ar)	Gross income (1000 Ar)	Gross income (Euro)
Cocoon	500	10	5,000	20,000	100,000	25,000
Chrysalis	500	90	45,000	3,750	168,750	42,188
Total					268,750	67,188

Source: own calculations based on interview data (it was assumed that wild silkworm cocoon is 10% of total weight; average price of 1 tin (=200 g) of chrysalis: 750 Ar)

that more than one ton of chrysalis per day can be consumed or sold by the villagers (of approximately 10,000 people) in the area. Second, it is interesting to see that the selling of the chrysalis of *B. cajani* for food consumption makes up 169 million Ar (63% of total income), whereas income from cocoon for silk production is only 100 million Ar (37%).

Discussion

In the region around Sandrandahy, consumption of insects is a common and traditional practice, as in other parts of Madagascar. The main species consumed are wild silkworm chrysalis (*Borocera madagascariensis, Borocera cajani*), locusts (*Locusta migratoria*) and different beetles' larvae and adults. This is a similar result to the one presented by Randrianandrasana and Berenbaum (2015) in a study carried out in Ambatofinandrahana, a town 70 km south of Ambositra, also located in the central highlands and habited by the Betsileo ethnic group. They found that silkworm pupae (92%), locusts (86%), a saturniid larvae called "Kijaja" (55%), and dragonfly nymphs (53%) were the most consumed insects in this area.

There are other insects known and eaten, but not so frequently and by fewer people. This is also the case in the study carried out in Ambatofinandrahana, where around 15 different edible species were found, but only four species were consumed by more than half of interviewees (Randrianandrasana and Berenbaum 2015). It is not known what exactly the causes of this limited consumption pattern are. One explanation could be that only some insects are highly esteemed by consumers, and not all edible insects are equally valued. It could also be a question of availability, and easiness to collect certain species. Also, it seems that collection is very traditional as people mainly collect what their ancestors did (Randrianandrasana and Berenbaum 2015).

The supply of most insects is temporarily restricted and occurs mainly during the rainy season. This seems to be a characteristic of entomophagy also in other African regions such as south-eastern Nigeria (Ebenebe et al. 2017). Locusts are gathered periodically during infestations, and they seem to be the only species which are dried and stored for up to one year. Adult and larvae of terrestrial beetles occur during rainy season. As this coincides with the first half of the lean season, these insects are a welcomed complement to the daily diet. Reared silkworm of *Bombix mori* is available during eight to nine months of the year, but the pupae production is limited. The wild silkworm (*Borocera cajani*) only has two seasons of around two months each. The seasonality and limited availability means that the existing supply of edible insects does not satisfy the demand of the population. A fact that seems not to be restricted to this location, but occurs in other regions of Africa as well. For example, Odongo et al. (2018) showed that local demand of grasshoppers (*Ruspolia differens*) and other species is higher than supply in the Lake Victoria Basin of Uganda and Burundi.

One may ask what are the reasons behind this mismatch between supply and demand? Besides the life cycle of certain species which limits occurrence during the year, increasing wild harvesting during high season also seems to be difficult. Insect gathering is done in a rather opportunistic way, meaning that edible insects are collected while working on the rice fields, often by children or youths. Adults are time constrained for collecting more insects, especially at the rice planting season. Also, there are no processing and storing facilities (such as freezers) used to prolong supply to the off-season. This may be due to the fact that people prefer to buy pupae alive, that all insects are easily sold during season, and that storing would not be economical. Moreover, increasing the production of domesticated silkworms (*Bombix mori*) has limiting factors such as the large quantities of mulberry leaves required, investment costs of tools and equipment needed, and the labour intensity of silkworm production, besides other problems related to silk production and marketing.

Another explanation could be the decreasing trend of insect availability, reflected by rising prices, even if it is not totally clear if this trend really exists, to which degree and for which species. Also, its possible causes are not well researched. One explanation found in other places is deforestation and bushfires. For example, Vantomme et al. (2004) described that in the Congo basin region, logging of forests, pesticides and bushfires are threatening caterpillar populations which are used for human consumption, putting in danger the nutritional and socio-economic benefits of wild insect harvesting. Intentionally set fires at the end of the dry season are a common practice in the study region of Sandrandahy.

Interestingly, burning is not a problem for the pyrophitic tapia trees. On the contrary, fires promote and help to preserve the tapia woodlands (Kull 2002). The declining trend in wild silkworm moths has different causes, summarized by Razafimanantsoa et al. (2012), which include gathering of cocoons in a destructive way, introduction of new plant species competing with tapia trees, and overharvesting of the pupae. The authors also mention bush fires destroying silkworms, young tapia trees and their seedlings and sprouts. Nevertheless, Razafimanantsoa et al. (2012) report that pressures on wild silkworm population have decreased by introducing community management practices of tapia forests and better harvesting practices of wild silkworm (*Borocera cajani)*. This could be confirmed by our study. In the region around Ambohimanjaka, it seems that deforestation rates nowadays are much lower than a decade ago. One of the main reasons mentioned is that forest management has been handed over from central government to local communities in 1996. This decentralization in resource management seems to have helped conserve the forests. Furthermore, a NGO in the region is working with communities to prevent deforestation and protect the forests by applying management methods to reduce human pressures on *B. cajani* and its habitat. The NGO also operates a breeding center to produce silkworm eggs which are released in the tapia forests. The rationale is to maintain high silkworm populations which allow high harvesting rates which in turn is an incentive for forest conservation. However, there are also concerns that a too high density of silkworm population can become a threat to the forest as too much leaves of tapia will be eaten by the larvae.

Already in 1985, Gade reported that collection and consumption of insects from tapia woodland, such as wild silkworm and caterpillars, have a long tradition, providing different tastes to the daily diets and also being an important protein source for the local population, especially in the lean season (Gade 1985). The main dish in Madagascar is rice, which has a relatively poor nutritional quality. The shortage of animal proteins is one of the main nutritional problems in the region (Badjeck et al. 2013). Moreover, meat prices are increasing and many people cannot afford buying meat. Thus, insects are, besides beans, an alternative, more affordable protein source. Nevertheless, as discussed above, insect prices are also rising so that higher supplies would be necessary to cheapen the produce on the market.

But still, consumers prefer insects to meat, not only for the taste, but also because of the more affordable prices. For example, beef costs around 9,000 Ar/kg and chicken 13,000 Ar/kg in Ambositra, which is more expensive than adult beetles or cicadae (between 2,500 and 5,000 Ar/kg). However, pupae cost around 10,000 Ar/kg, meaning that their price is comparable to that of meat. This is in line with the findings of Odongo et al. (2018) who report insect prices nearly as high as beef prices in town markets of Uganda and Burundi. Agea et al. (2008) document prices for grasshoppers (*Ruspolia nitidula*) of US $2.80 per kilogram, even higher than those of beef with a retail price of US $2 per kg in Kampala. It seems that insects sold in town markets as a delicacy can achieve prices that are no longer affordable for the poorer strata of the urban population. Nevertheless, consumers in Ambositra still see insects as a less expensive alternative to meat. The perception of consumers that insects are cheaper may also be influenced by the lower quantities of insects needed for one dish.

In general, one can differentiate two types of consumers: on the one hand, urban consumers which have to buy the insects on the market, and for whom insects are a tasty, highly valued delicacy. On the other hand, rural households which do not have the money to buy the relatively expensive insects, but harvest them in their fields, and consume them as a complement to their poor diet. For these farming households, insects are (almost) such a thing as "free lunch". Odongo et al. (2018) also observed that consumers of urban areas consider insects a delicacy, and are willing to pay high prices, whereas rural households collect insects mainly for own consumption at home. This is not to say that poorer urban consumers do not buy insects. At least in Ambositra market, it seems that consumer with lower general food expenditures (probably poorer persons) do not necessarily spend less on insects. Nevertheless, villagers would rather not buy insects on the market because of high prices.

In contrast to some Asian countries such as Thailand (see Hanboonsong et al. 2013), insect value chains are not well developed, or, as one key expert put it: "*there are no insect value chains in Madagascar*". Insects are mainly harvested for own consumption by the rural population. Only some species are marketed on the local level, and there are few traders involved. Collectors sell the insects or directly on the market, or to local retailers. This supports the findings of Odongo et al. (2018) that in district markets in Burundi and Uganda, most edible insects originated from own collection of traders, and only in urban markets, traders bought insects from other traders or collectors. Marketing margins of retailers in Ambositra are relatively modest (10%–20%), the same margin range reported by Agea et al. (2008) for grasshoppers in Kampala. These margins, as the authors explain, can be kept at modest levels -even if high demand exists- when enough retailers enter the business.

Apart from transport, there is no value addition made in the insect trade in the region. At the moment, no methods are used for processing insects, except cooking to consume them immediately after having harvested or bought them. One exception are locusts, which are sometimes dried and conserved up to one year. Yet, the idea of milling locusts to powder is not widespread. As edible insects are highly perishable products, appropriate methods to preserve and store them are necessary to avoid spoilage and post-harvest losses (Kinyuru et al. 2018). However, conservation and storing techniques which

could allow insect consumption outside the season are not yet applied. As explained, this could be due to high demand so that all insects are consumed easily during season. Contrary to the situation in Sandrandahy, in Uganda, 60% of traders execute different processing activities such as drying, roasting, salting and refrigeration (Odongo et al. 2018). This difference might be attributed to the special species marketed (in this case, grasshoppers), and/or to consumer preferences, and/or to different storing strategies of traders who find it lucrative to sell insects off-season. Nevertheless, as post-harvest handling influences nutritional values and biological hazards (Manutungi et al. 2017), it would be necessary to evaluate the different methods used for processing (such as boiling, frying, and drying) as well as for handling, storage and retailing to maximize beneficial outcomes and minimize dangers for consumers.

Insects can form an important income source for collectors and traders (see Agea et al. 2008; Odongo et al. 2018), but in our study region, this is restricted to short periods. Indeed, all merchants interviewed also trade with other products such as fish and only engage in the insect business during season. For villagers in Sandrandahy, cash income from insect selling is rather rare, as home consumption is predominant. This is in line with Tamesse et al. (2018) which found that only 4% of village households in southern Cameroon sold insects on the local market. In Ambohimanjaka, wild silkworm harvesting does provide both, a significant source of income[3] (from cocoon and chrysalis selling) and a major, nutritious food source to the local communities. Even if the focus is on silk, and food is considered a by-product, silkworm chrysalis' monetary value can be even higher than cash income from cocoons. Other studies have shown that in Ambohimanjaka, 6.5% of household cash income comes from tapia woodlands (not only from wild silkworm, but also from fruits, firewood, medicinal plants, and mushrooms). Poorer, more numerous families often get over 25% of their income from the woodlands (Randriamboavonjy, 2000, cited in Kull 2002).

Conclusions

Before concluding, we have to admit that the results of our study are based mainly on qualitative data received through FGD and KII and still have to be completed by quantitative research. Also, market research is built on a limited number of rather opportunistic interviews with traders and consumers. More quantitative and statistically significant data still has to be gathered by ProciNut project through surveys and systematic value chain research to confirm results and deepen the understanding of entomophagy in Malagasy highlands.

Having that said, this study suggests that insect consumption can contribute to alleviate the widespread and chronic food and nutrition insecurity in the region and improve livelihoods of the poor. Insects already provide a protein and micronutrient source in the lean season and urban consumers like insects as a delicious diet. Insects can be considered a 'poor men's food' as well as an urban speciality food. Nevertheless, insect supply is seasonal and limited and does not match demand. It seems that wild harvesting is coming to its limits. Moreover, the pupae of the silkworm are already fully used as food.

Complementing gathering by rearing could compensate the decreasing trend of wild harvesting and offer a higher, more continuous supply of insects. Delivering insects to the market in the off-season would offer an additional income for farmers and would also provide a nutritious food for rural and urban households. However, species for which rearing is feasible and for which demand is present would have to be identified. For example, rearing of the wild silkworm (*Borocera cajani*) seems not an interesting option because of its long life cycle. The altitude of the highlands might also be an obstacle for rearing insects such as crickets. Nonetheless, Kinyuru and Kipkoech (2018) have shown that in cooler regions of Kenia, cricket production is feasible in terms of hatching rates, weight gain, and nutrient content. Yet, as crickets are not so well esteemed by the consumers of Ambositra, it remains to be seen if market demand for reared crickets would be sufficient. In the case of locusts, people are very sceptical towards rearing, because they consider locusts also as a pest and would fear outbreaks.

Despite the traditional consumption habits and the high demand of edible insects, value chains have not well developed yet. Besides transportation, there is nearly no value added in the insect trade. This may be due to consumers' preferences to buy fresh, alive insects. However, experiences in other countries have shown that there is also demand of dried, roasted, or frozen insects. Moreover, a potential demand for new products made out of insect powder, for example snacks such as "*cacapigeon*" (a crispy fried snack consumed throughout Madagascar) may exist and might be an option to increase protein consumption by the local population.

Development activities on edible insects as a potential food security tool are gathering momentum in Madagascar, highlighted by currently running projects and by the inclusion of entomophagy in the most recent national nutrition action plan. Nonetheless, the potential role of government programmes and policies in different sectors require further investigations. Generally, to

[3] Compared to the average income of around 0,50 € per day, the estimated income in Ambohimanjaka would be approx. 67 €/person in one to two months.

ensure the sustainability of edible insects as an important food source, more support is needed from governmental bodies such as the National Office for Nutrition or the Agricultural Ministry.

Research in Madagascar also continues with many open questions, for example on the contribution of insects to household nutrition, on environmental impacts on insect populations, on the socio-economic benefits of insect harvesting and rearing, on gender and intra-household aspects of insect harvesting and consumption, on the feasibility of insect farming of different species, on the adoption of rearing as a livelihood alternative to poor people, on the development of value chains, to mention just a few. A combined effort of local populations, national policy makers and academia is necessary to enhance R&D of edible insects in Madagascar.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Annexes

Annex I: Questionnaire for Consumers

1. What are your 3 first staple foods? Which one do you prefer?
2. Where do you get your food from?
3. How much of your income you spend on food?
4. Do you eat insects? Which? How often?
5. How much each time (more/less/equal than plate)?
6. Do you consume insects during the whole year?
7. Which insect do you prefer?
8. Why do you eat insects?
9. Where do you get insects from?
10. Do you know where these insects come from?
11. What are your first 3 words to describe insects?
12. How much insects do you buy? (precise quantity)
13. Did you hear of any health problem related to insect consumption?

Annex II: Questionnaire for Traders

1. Which insects do you buy/sell?
2. Where do you get the insects from?
3. How do you get the insects?
4. How much do you pay per insect?
5. How much do you sell? What frequency?
6. Where do you sell insects?
7. Who are your customers?
8. How do you handle the insects?
9. How do you transport insects?
10. Prices of the insects sold?
11. Are there variations in the price you sell? Why?
12. How do you access information about prices?
13. What is the price trend over last years?
14. What are the quality criteria (variety, color, cleanness, wild harvesting/rearing, others)?
15. What are your main costs?
16. How many people are involved in your business?
17. Who are your competitors? How many are there?
18. Is there market demand for more insects?
19. Do you see a potential for new insect species on the market?
20. Do you think rearing insects is a feasible activity in the region? What is needed to start?
21. What are your major problems related to insect marketing?
22. Which solutions can you imagine?

Annex III: Questionnaire for FGD

Economic aspects and institutional networks of the village

1. How do people make a living in the community?
2. Are there different income sources for different groups?
3. Which crops and animals do you produce for household consumption and for the market?
4. Where and to whom do you sell?
5. How is the price of your products determined?
6. How is the market access for the village?
7. What role do insects play in the community?
8. Do women work outside the house for income?
9. How do you acquire items you need?
10. If you have no money, where can you get money from?
11. Are you in any contractual agreements with land owners or purchasers (i.e., share cropping / contract farming)?
12. What do you do if your harvest fails?
13. What is your vision for your children? Do the children want to take over the farm, why not?
14. Do you have products in common? (tools, lands, reserves?)
15. What are your main sources of diseases?
16. Do you have a phone? (if not, why?)
17. Do you have network? (just for calls or also Internet?)
18. Do you have a mobile money account?

Farming systems and insect collection

1. What are the main crops you plant / livestock you own?
2. What are the main agricultural problems that you face in this community?
3. How could these problems be solved? What hinders you currently to overcome problems?
4. Do you get support from governmental organizations / extension services / NGOs?
5. Have you introduced new agricultural tools, ideas or have you changed the way you do things in the last 10 years?
6. Have you started/stopped planting some crops in the last 10 years?
7. What inputs do you use (fertilizer organic, chemical, pesticides?) For what and how often?
8. What is needed in order to produce more crops on the land you cultivate?
9. What kind of seeds do you use?
10. Where do you get the seeds from?
11. Are there seeds for legumes available? (are they profitable, affordable?)
12. Is wild harvesting of insects a common practice in your community / family?
13. Which are the major insect species you collect?
14. Which insects do you like best? And why?
15. Since when? Why did you start harvesting them?
16. Have you started/stopped harvesting some insects in the last years? Why?
17. Who is harvesting them (men, women, youth)?
18. Where do you harvest these insects?
19. When do you harvest these insects?
20. Why do you harvest insects?
21. Has the harvest of insects increased/decreased in recent years? Why?
22. What are the knowledge and skills needed to harvest/produce insects and how did you get these skills?
23. How much insects do you harvest/produce per season/year (quantities)?
24. Which is the major use of insects (feed/food, consumption/marketing)?
25. How do you process insects?
26. Is there any preservation of insects? For how long can you store insects?
27. Do you know the prices insects are sold on the market? Are they stable?
28. To whom do you sell insects? Where, when, how often, how much?
29. Are there certain qualities of insects preferred by traders/consumers (variety, color, size, etc.)?
30. How are insects transported to market?
31. How much do you earn by selling insects?
32. What are the major constraints related to insect harvesting/production?
33. Would you like to harvest more insects? What hinders you?
34. Would you like to start rearing insects? Which ones? Why?
35. What do you think are the problems and potentials to start rearing insects?
36. Which support would you need from whom to start rearing insects?

Food culture and consumption behavior

1. Have you experienced food shortages? Did you have reserves to address it? How did you manage?
2. What is your preferred ingredient/dish?
3. What food would you like to eat more?
4. What do you think is the best food for your health and why?
5. How do you transform/process/cook food?
6. What are your main consumption practices?
7. What is your food choice criteria?
8. What do you do with food waste?
9. Do you know what the animal diet requirements are?
10. What are the main benefits of edible insects for you?
11. How often do you eat them? In what quantity? What prevents you to eat more?
12. Since how long do you eat insects? What made you start?
13. In what situation do you eat insects? With whom? Where and when (day and year)?
14. What insects do you eat? Why? What is your favorite?
15. With multiple choices of insects available, what is your factor of choice?
16. Do you know where are these insects from, if they are farmed, what stage they are (larvae, chrysalis, adult), how they are killed? If yes precise.
17. Do you store insects at home before and/or after cooking? How?
18. Do you clean insect before cooking? How?
19. How do you cook insects? With what ingredients? Why?
20. Did you ever face any health problem following insect consumption? Have you heard of some? What are the symptoms? Do you have a name for it?
21. What do you think of your need to eat edible insects? Could you do without them?
22. Where, from whom and for how much do you get insects?
23. How much do you buy? How often?
24. How much budget do insects represent for you?

25. Did the price vary much in the last years (of insects)? What are your first factor of choice when buying insects? Quality Criteria?
26. Do you consider insects largely accepted by everyone around you? How do you see it compared to meat?
27. If not, how to convince people to eat more insects?
28. What do you think of the new products which include processed edible insects? (cake, pasta, etc.)

Annex IV: List of KII (in chronological order)

1. Madagascar Biodiversity Center, Antananarivo
2. Regional Direction of Agriculture and Livestock (DRAE), Ambositra
3. Direction de l'Administration Générale du Territoire (DGAT), Ambositra
4. Circonscription de l'Elevage (CIR), Ambositra
5. District bureau of Office National de Nutrition (ONN), Sandrandahy
6. Centre de Service Agricole (CSA), Sandrandahy
7. District bureau of Office National de Nutrition (ONN), Sandrandahy
8. District bureau of Ministère de l'Agriculture et de l'Elevage (MINAE), Sandrandahy
9. Federasiona ny Vehivavy Tantsaha eto Madagasikara (Federation of Women Farmers - FVTM), Sandrandahy
10. Fampandrosoana sy fampivoaran'ny Fiainam-pianakaviana Iarahana Amin-dry Masera (Work of development and the evolution of the family - FAFIAM, Sandrandahy
11. Conseil Agricole de Proximité (CAP Malagasy), Sandrandahy
12. NGO Vovonana Santatra, Sandrandahy
13. Chiefs of villages (Fokontany), Sandrandahy
14. Sahalandy silk association, Sandrandahy
15. Regional bureau of Office National de Nutrition (ONN), Ambositra
16. Centre Séricicole Soalandy (silk worm breeding association), Ambositra
17. NGO Tanintsika (wild silk worm conservation), Ambositra
18. Projet Appui au Renforcement des Organisations Professionnelles et aux Services Agricoles (AROPA), Ambositra
19. NGO Tanintsika (breeding centre), Ambohimanjaka
20. Insect start-up "Concept Mihary", Antananarivo

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