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The mineral composition of five insects as sold for human consumption in Southern Africa

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Edible insects have been proposed as an alternative protein source that is economically and environmentally preferable to livestock, and certain species may be high in nutrients that benefit human health. We present data describing the mineral content of five edible insects as sold in South Africa and Zimbabwe. We report high variation between and within species, and note that these insects contain significant quantities of potentially beneficial, and potentially harmful, micronutrients. Two caterpillars were notably high in Fe and Zn, which are important nutrients for combating iron deficiency anemia. Na content varied both between and within species, suggesting that some sellers add quantities of salt that could be harmful to health. Mn levels were high in edible termites. We concluded that caterpillars can be promoted as nutrient rich foods in southern Africa; that added salt should be limited in commercial products; and that further research is required to determine whether common serving sizes of termites may put consumers in danger of manganese poisoning.

Key words: Edible insects, nutrition, mineral composition, micronutrients, Lepidoptera.

INTRODUCTION

The global food system is approaching crisis. Land clearance for agriculture is causing accelerated environmental degradation (Green et al., 2005), yet demand for food continues to increase as the world population continues to rise (Godfray et al., 2010). The intensive production and promotion of insects as human food and animal feed has been suggested as one strategy to combat this situation, most notably in two landmark reports published in 2010 and 2013 by the Food and Agriculture Organisation of the United Nations (FAO) (Durst et al., 2013). When farmed, insects have a significantly lower environmental impact compared with traditional livestock, as they use less land and energy (Oonincx and De Boer, 2012), have a higher feed

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Abbreviations: DALYs, Disability-adjusted life years; **Na,** sodium; **K,** potassium; **Ca,** calcium; **Mg,** magnesium; **Al,** aluminium; **P,** phosphorus; **S,** sulphur; **Cu,** copper; **Fe,** iron; **Mn,** manganese; **Zn,** zinc; **DRI,** daily recommended intake.

conversion ratio (DeFoliart, 1995), and produce fewer carbon emissions (Oonincx et al., 2010; Vantomme et al., 2014). Based on this evidence, edible insects are one potential ‘panacea’ to the crisis facing the world food system. Currently, malnutrition is the most important risk factor for illness and death on a global scale, and women are disproportionately affected (Müller and Krawinkel, 2005). Malnutrition comprises not only protein-energy malnutrition but also micronutrient deficiencies, which can lead to death and disease as well as impairment in mental and physical development (Olness, 2003; Rivera et al., 2003). Recently, insects have been advocated as nutritionally preferable to other protein sources (Van Huis et al., 2013). Previous studies have shown that several edible insects are high in certain micronutrients (Bukkens, 1997; Belluco et al., 2013), and therefore they may have potential as an important food in combating problems of under-nutrition and micronutrient deficiency. Specifically, many edible insects are high in iron and zinc (Kinyuru et al., 2012). Both of these nutrients are crucial in combating iron deficiency anemia, which is the most prevalent nutritional disorder worldwide and impairs both physical and cognitive ability, thus reducing the work productivity of adults and the learning capacity of children (Armstrong and Summerlee, 2014). Iron and zinc deficiencies combined are responsible for 2.4 and 1.9% of disability-adjusted life years (DALYs) respectively (Black, 2003). Of the insects sold in southern Africa the mopane caterpillar (*Imbrasia belina*) in particular has been highlighted as containing high quantities of these nutrients (Van Huis et al., 2013).

One common way of addressing dietary deficiencies in essential minerals is through supplementation programmes, but compliance is often low, reducing the efficacy of such schemes (Schultink, 1996). If commercially available edible insects are indeed high in key micronutrients it may be preferable to redirect investment to promoting increased consumption of these traditional foods, which are culturally acceptable foods that are already part of the diet. This would have the added advantage of reducing dependency on food supplementation programmes and imported products.

In order to contribute to the evidence regarding the potential of edible insects to address the public health challenge of micronutrient deficiency in this region, we present data on the mineral content of commercially available insects as sold in multiple locations in Zimbabwe and one from South Africa. The insect species analysed in our study are nutritionally and economically significant across Zimbabwe and South Africa: approximately 318 and 133 tonnes, respectively, of Lepidopteran and Isopteran species are harvested and sold as food in Zimbabwe annually (Dube et al., 2013), and the trade in *I. belina* in South Africa alone is estimated to be worth US$30-50 million per annum (Makhado et al., 2014). *I. belina* and Macrotermes spp are consumed by over 50% of the population of Zimbabwe, including approximately 60% of 16 to 25 year olds and up to 95% of people aged over 55 (Dube et al., 2013).

MATERIALS AND METHODS

We collected samples of commercially available insects in Zimbabwe and in the Limpopo province of South Africa by purchasing insects from markets during 2013 and 2014. Details of specific locations are shown in Table 1. Two samples were received directly during village (Majuru; soldier caste *Macrotermes* spp) and farm (Madora; *I. belina*) visits during the same period. Insects sold at urban markets have undergone treatment to ensure that they are stable at room temperature, using one or a combination of drying, salting and roasting methods. Sellers did not give consistent or detailed descriptions of these processing steps, because no sellers had collected or processed the insects themselves. Therefore, samples were placed ‘as sold’ in plastic containers to avoid contamination, stored at room temperature and transported to Japan. Mineral content analyses were conducted in the Laboratory of Forest Environment and Resources, Nagoya University, Japan. Three (3) individual caterpillars were homogenized for each caterpillar sample, two *Encosternum delorgugei* were homogenised for each *Encosternum* sample, approx. 4 g of alates were homogenised for each termite alate sample, and 2.5 g of termite soldiers were homogenized for the termite soldier (Majuru) sample. Two replicate analyses were performed for each sample, and the results presented here represent the average of the two replications. Since dried caterpillars are usually washed prior to cooking in Zimbabwe, samples of purchased caterpillars were also washed, using ultrapure water. *Macrotermes* and *Encosternum* are sold in a ready-to-eat state, and therefore these samples were not subject to this treatment.

All samples were freeze dried (FDU-1200 EYELA, TOKYO RIKAKIKAI Co., Ltd., Tokyo, Japan). Before and after drying, we weighed the samples to determine the water content. Samples were then homogenized using a mill mixer with titanium-coated stainless blades (BL-229, SUN Co., Ltd., Osaka, Japan), and subject to wet digestion under reflux with nitric acid and hydrogen peroxide (Matusiewicz, 2003) using a high purity PFA Teflon vessel. After filtering the solutions with a 0.45 μm mixed cellulose ester membrane filter (A045A025A, ADVANTEC, Tokyo, Japan), we determined sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), aluminium (Al), phosphorus (P), sulphur (S), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) concentrations by inductively coupled plasma atomic emission spectrometry (ICP-AES; IRIS ICARP, Jarrell Ash Nippon Corp., Japan). This is an accepted analytical method for determining mineral composition of food samples, and is the preferred method for Zn, Fe and Cu (Greenfield and Southgate, 2003). For the analysis process, we used ICP standard solutions (Standard A (Al, Bi, Ni, Pb each 100 mg/L in 1 mol/L HNO_3), Standard B (B, Cd, Cr, Zn each 100 mg/L in 0.1 mol/L HNO_3), Standard C (Co, Cu, Fe, Mn each 100 mg/L in 0.1 mol/L HNO_3), and Standard D (Ba, Ca, K, Mg, Na, Sr each 100 mg/L in 0.1 mol/L HNO_3)) purchased from Kanto Chemical Co., Inc., Japan. Standard solutions were diluted to a desired concentration with 0.1 mol/L HNO_3 and ultra-pure water. To evaluate this analysis method, we checked the precision of ICP-AES by analyzing reference sample (NIES CRM No.1 Pepperbush; NIES CRM No. 7 Tea Leaves; NIES CRM No.9 Sargasso, Environment Agency National Institute for Environmental Studies Tsukuba, Ibaraki, Japan). The certified values or reference values of those materials is determined for elements including Na, K, Ca, Mg, Al, P, S, Cu, Fe, Mn, Zn. Detection limit value (ppb) of each elements were Na (3), K (24.3), Ca (627), Mg (5.7), Al (80.7), P (7.2), S (51.6), Cu (27) Fe (5.1), Mn (0.6), Zn (0.3).

Table 1. Details of samples used for mineral composition analysis.

Sample ID	Local name	Species	Preparation[1]	Source	Country	City/Town/Village
1	Madora	*Imbrasia belina*	Washed	Supermarket	Zimbabwe	Rusape
2		*Imbrasia belina*	Washed	Farm	Zimbabwe	Gwanda
3		*Imbrasia belina*	Washed	Market	Zimbabwe	Bulawayo
4	Gandari	*Imbrasia belina*	Washed	Market	Zimbabwe	Bulawayo
5		*Gynanisa maia*	Washed	Market	Zimbabwe	Bulawayo
6		*Gynanisa maia*	Washed	Market	South Africa	Tzaneen
7		*Gynanisa maia*	Washed	Market	Zimbabwe	Mutare
8	Ishwa	*Macrotermes spp (alate)*	As sold	Market	Zimbabwe	Mutare
9		*Macrotermes spp (alate)*	As sold	Market	Zimbabwe	Mutare
10		*Macrotermes spp (alate)*	As sold	Market	Zimbabwe	Nyika
11	Majuru	*Macrotermes spp (soldier)*	Washed	Village	Zimbabwe	Djairo
12	Amanondu	*Cirina forda*	Washed	Market	Zimbabwe	Bulawayo
13		*Cirina forda*	Washed	Market	Zimbabwe	Bulawayo
14		*Cirina forda*	Washed	Market	Zimbabwe	Bulawayo
15	Haruwa	*Encosternum delegorguei*	As sold	Market	Zimbabwe	Masvingo province
16		*Encosternum delegorguei*	As sold	Market	Zimbabwe	Masvingo province
17		*Encosternum delegorguei*	As sold	Market	Zimbabwe	Masvingo province

Caterpillars were washed before analysis, as this is the common practice in Zimbabwean households. *Macrotermes* and *Encosternum,* however, are not usually washed after purchase, as they are sold in a ready-prepared (boiled/fried and salted) state. These insects, therefore, were not washed before analysis.

RESULTS AND DISCUSSION

Table 1 shows details of the samples used for mineral composition analysis. We analysed a total of 17 samples, representing five species of edible insects. All samples were purchased from markets with the exception of two *I. belina* samples, which were purchased at a farm and a supermarket, respectively, and one sample of *Macrotermes* soldiers. The *Macrotermes* soldiers were obtained at a village in Northeastern Zimbabwe, and were freshly collected for use as food. Table 2 shows the mineral content of each insect sample per 100 gas sold, and the Daily Recommended Intake (DRI) value for each mineral where available. Mineral content varies both between and within species. When compared with DRI values, Fe and Zn content are notably high in all samples, with 100 g providing over and above the DRI of Fe in 11 of 17 samples, and of Zn in only 1 sample (*E. delegorguei*). However, the quantity of these and other minerals that are essential for human health are not consistent within species. For example, Ca ranges from 203 to 810 mg in *I. belina*, and 112 to 564 mg in *Gynanisa maia.* Similarly, Zn ranges from 12 to 36 mg in *I. belina*, and Fe ranges from 9 to 57 mg in *G. maia*. These inconsistencies indicate that the mineral content of wild-harvested insects is likely to be influenced by the soil composition and/or diet at their original location, although the nature of this relationship clearly requires further research.

Na content also varies greatly within species, ranging from 13 to 1501 mg in *I. belina* samples, and from 12 to 2674 mg in *G. maia* samples. This variation is likely to be due to salt that is added to insects during processing by some vendors. As a result, the amount of Na in commercially available insects ranges from negligible to amounts that exceed DRI values. This is supported by comparing results from previous studies; for example reported of Na content per 100 g in *Cirina forda* varies from 44.4 mg (Osasona and Olaofe, 2010) to 210 mg (Akinnawo and Ketiku, 2000), and in *I. belina* from 33.3 mg (Kwiri et al., 2015) to 1032 mg (Rumpold and Schluter, 2013). The variation within species, particularly for key micronutrients, is also evident when our values are compared with previously published data. *I. belina* has been reported to have an average Fe content of 12.7 mg (Rumpold and Schluter, 2013) and 31 mg (Kwiri et al., 2015) per 100 g of dry weight in previous studies. These are already disparate values, and far lower than our range of 63 to 130 mg for fresh weight as sold. In the same species, Zn content is similarly varied according to prior estimates, at 14 mg (Rumpold and Schluter, 2013) and 1.9 mg (Kwiri et al., 2015), but the former is within the range of the quantities presented here.

Similarly, within *Macrotermes* spp., our results are not entirely dissimilar from previously published values in some cases; yet do fall far outside the known range for some minerals. For example, Banjo et al. (2006) report 27 to 29 mg Fe content for *Macrotermes* alates, which is within the range of 12 to 40 mg detected in our three alate samples; similarly our value of 24 mg Fe for

Table 2. Mineral content (mean and range) of five edible insect species, shown alongside nutrient reference values for comparison. All data represents the mean of two replicates.

mg/100 gfw	ID	% water	Na	K	Ca	Mg	Al	P	S	Cu	Fe	Mn	Zn
RDA/AI*			1500*		1000	310		700		900	18	2*	8
Imbrasia belina	1	72	13	1436	203	151	72	565	527	3	63	5	12
	2	62	18	1864	810	312	83	780	636	4	106	7	36
	3	70	1501	1763	746	226	123	777	687	3	109	6	29
	4	93	120	940	310	110	76	410	430	1	130	5	10
Gynanisa maia	5	77	2674	1467	112	167	35	563	384	3	9	1	23
	6	74	12	1942	564	272	50	742	508	3	14	2	21
	7	93	44	1300	410	160	65	500	350	1	57	3	14
Macrotermes spp.	8	88	2086	827	136	81	54	481	237	5	19	714	15
	9	97	324	527	200	63	31	406	189	5	12	554	38
	10	91	2100	710	100	60	42	720	160	5	40	430	9
	11	74	2931	810	189	70	71	292	258	6	24	48	15
Cirina forda	12	90	970	1070	65	162	31	364	411	2	4	6	9
	13	88	481	996	113	171	34	398	459	3	6	6	29
	14	86	407	1210	91	193	35	394	422	3	6	8	12
Encosternum delegorguei	15	82	2967	440	138	101	41	372	456	5	26	1	22
	16	86	1405	227	243	95	331	348	489	28	24	2	59
	17	96	3700	280	68	83	5	340	360	3	35	2	3

N.D. indicates that the presence of this mineral was not detected in the current study. DRIs (Dietary Reference Intake) - RDA (Recommended Daily Allowance) and AI (Adequate Intake, denoted by an asterisk) - values are nutrient reference values developed by the Institute of Medicine of The National Academies and available online at:http://iom.nationalacademies.org/Activities/Nutrition/SummaryDRIs/~/media/Files/Activity%20Files/Nutrition/DRIs/5_Summary%20Table%20Tables%201-4.pdf (published online 2010; accessed 7th July 2015). Values are those recommended for women aged 19-30.

Macrotermes soldiers falls within the 10 to 55 mg range reported by Lesnik (2014). However, the Zn content in the Macrotermes soldier sample is, at 15 mg, below the 24 to 173 mg range reported by Lesnik (2014), and our three (430, 554, 714 mg) values for Mn content of alates far exceed Lesnik's (2014) range of 5 to 131 mg for mixed samples. The nutrient content of *C. forda* has also been reported on a number of occasions, and again it is clear that mineral content varies greatly between samples. Fe content, for example, ranges from 1.3 mg (Osasona and Olaofe, 2010) to 5.34 mg (Omotoso, 2006) to 64 mg (Akinnawo and Ketiku, 2000) in previously published studies, and therefore the values (4 to 6 mg) fall within this range. Similarly, the range of values for Zn content of *C forda* (9 to 27 mg) is similar to the reported values of 24.2 mg (Osasona and Olaofe, 2010), 3.81 mg (Omotoso, 2006) and 8.6 mg (Akinnawo and Ketiku, 2000), and again shows the variation in content of these micronutrients that are essential to human health. This is to our knowledge the first report of the mineral content of *G. maia,* and only the second report for *E. delegorguei.* The values for the Zn (3, 22, 59 mg) and Fe (24, 26, 35 mg) content of *E. delegorguei* are not dissimilar from the previous figures of 46 and 20.2 mg, respectively (Teffo et al., 2007), with the exception of one sample with a very low (3 mg) Zn content. Given the variation reported in other insect species, further research is required to judge whether or not this is a true outlier.

The overall results show that some edible insects contain high amounts of nutrients that are considered to be beneficial to human health, particularly Fe and Zn, when considered in relation to DRI values. *I. belina* samples, for example, contained 350 to 722% and 125 to 450% of the DRIs for Fe and Zn, respectively. If we can better understand the factors that cause variation in mineral content within species, certain edible insects may be useful candidate species for combating iron deficiency anemia. Iron deficiency anemia is a key public health problem in southern Africa, with a severe Fe deficiency of prevalence of 24.1% in one Zimbabwean study, which used blood samples from 3151 people (Sikosana et al., 1998). In South Africa a study of an unquoted number of subjects found a 5.15 and 9 to 12% prevalence of severe Fe deficiency anemia (Nojilana et al., 2007) among children and pregnant women, respectively. Therefore, promotion of insects rich in Fe could help to combat these problems.

However, not all edible insects are alike, and some commercially available insects may contain harmful quantities of nutrients for which there is an established upper limit. This is the case for Na and Mn. High Na values are likely to be due to salt added by vendors. Our results show that the quantity of salt varies greatly between vendors and in many cases 100 g of edible insects as sold has a Na content that exceeds the DRI value of 1500 mg, and excessive consumption could therefore have negative health consequences (Appel et al., 2011). High Mn values are likely to be due to factors specific to the point of origin of the insects, such as soil and water composition. Excess manganese, when inhaled, can cause neurotoxic Parkinson-like symptoms, known as manganism (Dobson et al., 2004). Our results show that termite alates contain up to 13500% of the DRI for Mn and could therefore potentially be harmful to health if consumed in excess; however, the effect of excess dietary manganese is not clear. Overall, our results suggest that while certain commercially available indigenous edible insect foods could be beneficial in combating prevalence of iron deficiency anemia in southern Africa, others require further investigation due to potentially harmful quantities of micronutrients. Further research is required to understand the reasons for variation in mineral content within species. The unregulated and unstandardised addition of salt to edible insects sold at markets may greatly alter their nutritional profile. A final barrier to understanding the health implications of insect foods sold at markets in southern Africa is the lack of data regarding serving size: Data on average serving size for each commonly consumed insect species will be necessary in order to provide informed nutritional recommendations regarding edible insects.

Conflict of interests

The authors did not declare any conflict of interest.

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