REVIEW

Nutritional composition and safety aspects of edible insects

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Insects, a traditional food in many parts of the world, are highly nutritious and especially rich in proteins and thus represent a potential food and protein source. A compilation of 236 nutrient compositions in addition to amino acid spectra and fatty acid compositions as well as mineral and vitamin contents of various edible insects as derived from literature is given and the risks and benefits of entomophagy are discussed. Although the data were subject to a large variation, it could be concluded that many edible insects provide satisfactorily with energy and protein, meet amino acid requirements for humans, are high in MUFA and/or PUFA, and rich in several micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium, and zinc as well as riboflavin, pantothenic acid, biotin, and in some cases folic acid. Liabilities of entomophagy include the possible content of allergenic and toxic substances as well as antinutrients and the presence of pathogens. More data are required for a thorough assessment of the nutritional potential of edible insects and proper processing and decontamination methods have to be developed to ensure food safety.

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1 Introduction

Entomophagy, i.e., the consumption of insects, is traditionally practiced in many parts of the world. Generally, insects were found to be highly nutritious and to represent good sources of proteins, fat, minerals, vitamins, and energy [1]. For example, a 100 g of caterpillars (larvae of moth or butterfly) was found to provide with 76% of the daily required amount of proteins and with nearly 100% of the daily recommended amount of vitamins for humans [2]. The energy content of insects is on average comparable to meat (on a fresh weight basis) except for pork because of its particularly high fat content [3]. Taking into consideration that insects have a high fecundity, can be multivoltine, have a high feed conversion efficiency, low space requirement, and are omnivorous in addition to their nutritive value, edible insects can contribute to world food security and represent an interesting food and feed alternative, especially to meat products and fish meal. However, antinutritive components and harmful ingredients of insects should also be taken into account. It was reported that insects can cause allergic reactions [4] and can contain toxic substances [5]. The majority of the more than 2000 edible insect species (List of edible insects of the world (April 4, 2012), http://www.ent.wur.nl/UK/Edible+insects/Worldwide+species+list/) are collected in the wild up to today [6]. Therefore, little is known about their nutritive value. A compilation of nutrient compositions of edible insects in addition to amino acid spectra and fatty acid compositions as well as mineral and vitamin contents of edible insects derived from literature and an overview of the nutritive value and risks of edible insects are given in this paper.

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Abbreviations: nd, not detected; **NFE**, nitrogen-free extract; **NPU**, net protein utilization; **PER**, protein efficiency ratio; **SFA**, saturated fatty acids; **UFA**, unsaturated fatty acids

2 Nutrient composition

A compilation of 236 nutrient compositions of edible insects as published in literature (based on dry matter) is given in Table 1. Mean values of nutrient contents of all insects belonging to the same insect order are indicated in bold. If necessary, values were based on dry matter and converted

Table 1. Nutritional composition [%] and energy content [kcal/100 g] of edible insects (based on dry matter)

Edible insects (based on dry matter)	Protein [%]	Fat [%]	Fiber [%]	NFE [%]	Ash [%]	Energy content [Kcal/100 g]	Origin
Blattodea (cockroaches)	**57.30**	**29.90**	**5.31**	**4.53**	**2.94**		
Blaberus sp.[1]	43.90	34.20	8.44	10.09	3.33		Mexico; wild
Periplaneta americana L.[1]	65.60	28.20	3.00	0.78	2.48		Mexico; wild
Periplaneta australasiae F.[1]	62.40	27.30	4.50	2.73	3.00		Mexico; wild
Coleoptera (beetles, grubs)	**40.69**	**33.40**	**10.74**	**13.20**	**5.07**	**490.30**	
Analeptes trifasciata[2]	29.62	18.39	1.96	43.60	4.21		Nigeria; wild
Aplagiognathus spinosus[3]	26.00	36.00	15.00	19.00	3.00		Mexico; wild
Aplagiognathus spinosus[4]	25.80	36.38	15.01	19.53	3.28	508.30	Mexico; wild
Arophalus rusticus[4]	20.10	56.06	5.14	17.04	1.66	652.30	Mexico; wild
Callipogon barbatus[3]	41.00	34.00	23.00	1.00	2.00		Mexico; wild
Copris nevinsoni Waterhouse[5]	54.43	13.61	15.15	7.63	9.18		Thailand; wild
Cybister flavocicinctus[4]	69.01	5.64					Mexico; wild
Holotrichia sp.[5]	51.74	5.41	19.31	11.20	12.34		Thailand; wild
Homolepta sp.[3]	54.00	18.00	12.00	10.00	7.00		Mexico; wild
Metamasius spinolae[4]	69.05	17.44	3.65	9.24	0.62		Mexico; wild
Oileus rimator[3]	21.00	47.00	13.00	18.00	2.00		Mexico; wild
Oryctes boas (larvae)[2]	26.00	1.50	3.40	38.50	1.50		Nigeria; wild
Oryctes rhinoceros (larvae)[6]	50.48	0.66		33.25	15.25	342.14	Nigeria; wild
Oryctes rhinoceros (larvae)[7]	30.15	38.12		17.16	14.13		Nigeria; wild
Oryctes rhinocerus Linnaeus (larvae)[8]	57.81	0.73	1.40	24.51	15.56		Nigeria; wild
Passalus af. Punctiger[3]	26.00	44.00	15.00	12.00	3.00		Mexico; wild
Phyllophaga sp.[4]	47.41	18.81	4.17	15.92	13.69	282.74	Mexico; wild
Phyllophaga sp. (larvae)[9]	42.52	5.72	12.30	15.36	24.10	282.32	Mexico; wild
Rhantus atricolor[4]	71.10	6.37	12.26	5.67	4.60		Mexico; wild
Rhynchophorus phoenicis (larvae)[2]	28.42	31.40	2.82	48.60	2.70		Nigeria; wild
Rhynchophorus phoenicis (larvae)[10]	41.69	37.12			3.27	478.60	Nigeria; wild
Rhynchophorus phoenicis (larvae; early stage)[11]	10.33	69.78	25.14	5.60	2.69		Nigeria; wild
Rhynchophorus phoenicis (larvae; late stage)[11]	11.47	67.83	18.80	8.54	2.54		Nigeria; wild
Rhynchophorus phoenicis (larvae)[6]	35.63	19.50		40.14	4.74	479.14	Nigeria; wild
Rhynchophorus phoenicis (larvae)[12]	25.70	59.43	3.67	5.49	5.70		Nigeria; wild
Rhynchophorus phoenicis F (larvae)[7]	22.06	66.61		5.53	5.79		Nigeria; wild
Rhynchophorus phoenicis (pupae)[12]	37.57	50.65	2.58	5.98	3.23		Nigeria; wild
Rhynchophorus phoenicis (adult)[11]	8.85	55.04	22.90	15.97	1.43		Nigeria; wild
Rhynchophorus phoenicis (adult)[12]	35.57	46.69	7.47	4.21	6.06		Nigeria; wild
Scyphophorus acupunctatus[3]	36.00	52.00	6.00	6.00	1.00		Mexico; wild
Scyphophorus acupunctatus[4]	35.49	51.68	5.55	5.86	1.42	555.40	Mexico; wild
Scyphophorus acupunctatus (larvae)[9]	35.49	50.51	5.55	5.84	2.61	618.78	Mexico; wild
Tenebrio molitor (adult)[13]	60.20	20.80	16.30	0.01	2.70	427.90	Mexico; reared
Tenebrio molitor (larvae)[14]	47.18	43.08	7.44	0.26	3.08	577.44	USA; reared
Tenebrio molitor (larvae)[15]	49.43	38.07	6.53		2.84		USA; reared
Tenebrio molitor (adults)[14]	65.29	14.88	20.22	3.86	3.31	379.61	USA; reared
Tenebrio molitor (larvae)[14]	49.08	35.17	14.96	7.09	2.36	539.63	USA; reared
Tenebrio molitor (larvae)[13]	47.70	37.70	5.00	7.10	3.00	554.30	Mexico; reared
Tenebrio molitor (pupae)[13]	53.10	36.70	5.10	1.90	3.20	550.00	Mexico; reared
Tenebrio molitor[16]	51.88	31.10	14.50		4.30		USA; reared
Tenebrio molitor (Mighty Mealys™)[16]	48.13	40.30	11.20		3.20		USA; reared
Tesseratoma papillosa[5]	50.54	23.55	13.85	6.71	5.35		Thailand; wild
Trichoderes pini[4]	41.09	36.72	9.37	9.04	3.78	530.96	Mexico; wild
Zophobas morio[16]	43.13	40.80	13.00		3.50		USA; reared
Zophobas morio[14]	46.79	42.04	9.26	2.61	2.38	575.53	USA; reared
Diptera (flies)	**49.48**	**22.75**	**13.56**	**6.01**	**10.31**	**409.78**	
Copestylum haggi & anna[3]	37.00	31.00	15.00	8.00	8.00	460.00	Mexico; wild
Drosophila melanogaster[16]	56.25	17.90	16.20		5.20		USA; reared
Ephydra hians[4]	35.87	35.87	9.75	6.56	12.25	216.94	Mexico; wild
Eristalis sp.[4]	40.68	11.89	13.27	8.21	25.95		Mexico; wild
Musca domestica (larvae)[17]	63.99	24.31		1.25	5.16	552.40	S. Korea; reared
Musca domestica L. (pupae)[18]	63.10	15.50			5.30		USA; reared

Table 1. Continued

Edible insects (based on dry matter)	Protein [%]	Fat [%]	Fiber [%]	NFE [%]	Ash [%]	Energy content [Kcal/100 g]	Origin
Hemiptera (true bugs)	**48.33**	**30.26**	**12.40**	**6.08**	**5.03**	**478.99**	
Abedus sp.[4]	67.69	6.20	16.41	6.65	3.05	352.56	Mexico; wild
Acantocephala declivis[3]	35.00	45.00	18.00		1.00	547.00	Mexico; wild
Agonoscelis pubescens (Thunberg)[19]	28.20	57.30		4.40	2.50		Sudan, wild
Aspongubus viduatus F.[19]	27.00	54.20		7.00	3.50		Sudan, wild
Axayacatl[4]	62.80	9.67	10.46	2.47	3.30	346.73	Mexico; wild
Belostoma sp.[4]	70.87						Mexico; wild
Edessa conspersa[4]	36.82	45.76	10.00	4.21	3.21		Mexico; wild
Edessa montezumae[4]	37.52	45.87	10.88	2.08	3.65		Mexico; wild
Edessa petersii[3]	37.00	42.00	18.00	1.00	2.00	530.00	Mexico; wild
Edessa sp.[3]	33.00	54.00	11.00		1.00	622.00	Mexico; wild
Edessa sp.[4]	34.24	51.23	9.12	2.01	3.40		Mexico; wild
Edessa cordifera[4]						622.00	Mexico; wild
Euchistus zopilotensis[4]						551.08	Mexico; wild
Euschistus egglestoni[3]	35.00	45.00	19.00		1.00	548.00	Mexico; wild
Euschistus strennus[4]	41.84	41.68	13.41	0.01	3.06		Mexico; wild
Euschistus sp. (nymphs, adults)[9]	37.65	46.72	12.78	3.33	6.83	583.74	Mexico; wild
Hoplophorion monograma[3]	64.00	14.00	18.00	1.00	3.00	394.00	Mexico; wild
Hoplophorion monograma[4]	59.57	14.32	23.00	0.54	2.57	394.14	Mexico; wild
Krizousacorixa azteca J ("ahuahutle" eggs)[20]	53.60	4.33	3.00	18.07	21.00		Mexico; wild
Ahuahutle (mosquito eggs)[4]	56.55	4.43	6.22	11.80	21.00	328.99	Mexico; wild
Meimuna opalifera Walker[5]	47.23	8.53	19.22	15.98	9.04		Thailand; wild
Neortholomus sp.[9]	48.25	34.51	5.10	9.62	2.42	542.08	Mexico; wild
Pachilis gigas (adults)[3]	65.00	19.00	10.00	2.00	3.00	445.00	Mexico; wild
Pachilis gigas (nymphs)[3]	63.00	26.00	5.00	2.00	4.00	498.00	Mexico; wild
Pachilis gigas[4]	65.39	19.43	9.41	2.47	3.30	445.43	Mexico; wild
Proarna sp.[3]	72.00	4.00	2.00	18.00	3.00	401.00	Mexico; wild
Umbonia reclinata[3]	29.00	33.00	13.00	13.00	11.00	470.00	Mexico; wild
Hymenoptera (ants, bees)	**46.47**	**25.09**	**5.71**	**20.25**	**3.51**	**484.45**	
Apis mellifera (honeybee)[2]	21.00	12.30	2.00	73.60	2.20		Nigeria; wild
Apis mellifera (honeybee)[21]	52.00	7.50	11.10				Canada; reared
Apis mellifera (larvae and pupae)[3]	50.00	21.00	3.00	22.00	4.00	475.00	Mexico; wild
Apis mellifera (larvae and pupae)[9]	50.42	20.59	3.33	22.13	3.53	474.65	Mexico; wild
Apis mellifera (larvae)[3]	42.00	19.00	1.00	35.00	3.00	475.00	Mexico; wild
Apis mellifera (larvae)[4]	41.68	18.82	1.33	34.82	3.35		Mexico; wild
Apis mellifera (pupae)[3]	49.00	20.00	3.00	24.00	4.00	476.00	Mexico; wild
Apis mellifera (pupae)[4]	49.30	20.21	2.67	24.26	3.56	476.00	Mexico; wild
bee brood[22]	40.52	20.26	0.86	34.48	3.45	482.33	USA; reared
Atta mexicana B (ants)[20]	66.00	24.02	2.06	4.92	3.00		Mexico; wild
Atta mexicana (ants)[3]	46.00	39.00	11.00	0.00	4.00	555.00	Mexico; wild
Atta cephalotes (reproductors)[3]	43.00	31.00	10.00	14.00	2.00	391.00	Mexico; wild
Brachygastra azteca[3]	63.00	22.00	3.00	9.00	3.00	481.00	Mexico; wild
Brachygastra mellifica[3]	53.00	30.00	3.00	11.00	3.00	522.00	Mexico; wild
Carebara vidua Smith (female)[23]	42.50	49.45	7.19		1.61		Kenya; wild
Liometopum apiculatum H (ant eggs)[20]	40.90	33.96	1.30	15.99	7.85		Mexico; wild
Liometopum apiculatum[4]	37.33	42.13	9.68	7.81	3.05	535.44	Mexico; wild
Liometopum apiculatum (larvae, pupae)[9]	39.67	36.87	2.44	19.22	1.80	566.36	Mexico; wild
Liometopum occidentale var. *Luctuosum*[4]	41.68	36.21	2.10	17.61	2.40		Mexico; wild
Melipona beeckeii[3]	29.00	41.00	6.00	20.00	3.00	469.00	Mexico; wild
Mischocyttarus sp.[4]	57.33	24.26	7.68	6.51	4.22		Mexico; wild
Myrmecosistus melliger[3]	4.90	6.00	3.00	77.00	4.00	401.00	Mexico; wild
Myrmecosistus melliger[3]	9.45	5.80	2.90	77.73	4.12	400.68	Mexico; wild
Myrmecosistus melliger[9]	9.35	5.90	3.12	77.57	4.02	400.05	Mexico; wild
Oecophylla smaragdina Fabricius (weaver ant)[5]	53.46	13.46	15.38	11.15	6.55		Thailand; wild
Oecophylla smaragdina Fabricius (queen caste)[5]	37.46	36.87	8.26	14.43	2.98		Thailand; wild
Pogonomyrmex barbatus[3]	45.79	34.25	2.79	7.86	9.31		Mexico; wild
Pogonomyrmex sp.[4]	46.26					522.77	Mexico; wild

Table 1. Continued

Edible insects (based on dry matter)	Protein [%]	Fat [%]	Fiber [%]	NFE [%]	Ash [%]	Energy content [Kcal/100 g]	Origin
Polistes instabilis[3]	31.00	62.00	3.00	2.00	2.00	655.00	Mexico; wild
Polistes canadensis[4]	61.52	31.07	3.68	1.80	1.93		Mexico; wild
Polistes major[4]	64.45						Mexico; wild
Polybia sp. (adults)[3]	63.00	13.00	15.00	4.00	6.00	473.00	Mexico; wild
Polybia sp.[4]	57.73	19.22	1.78	20.56	0.71	482.93	Mexico; wild
Polybia sp. (larvae, pupae)[9]	58.40	17.15	3.23	17.12	4.10	455.60	Mexico; wild
Polybia occidentalis nigratella[3]	61.00	28.00	2.00	11.00	3.00	445.00	Mexico; wild
Polybia occidentalis nigratella[4]	61.21	27.03	1.97	6.59	3.20	444.80	Mexico; wild
Polybia occidentalis nigratella (larvae, pupae)[9]	61.10	22.94	1.95	11.01	3.00	494.00	Mexico; wild
Polybia occidentalis bohemani[3]	62.00	19.00	4.00	13.00	3.00	466.00	Mexico; wild
Polybia occidentalis bohemani[4]	61.57	18.74	3.53	12.70	3.46		Mexico; wild
Polybia parvulina[3]	61.00	21.00	6.00	8.00	4.00	462.00	Mexico; wild
Polyrhachis vicina Roger (from Zhejiang)[24]	36.12	18.00	29.13	14.22	2.52		China; reared
Polyrhachis vicina Roger (from Guizhou)[24]	45.40	17.40	28.88	4.16	4.16		China; reared
Trigona sp.[3]	28.00	41.00	6.00	21.00	3.00	593.00	Mexico; wild
Vespula squamosa[3]	63.00	22.00	3.00	10.00	3.00	490.00	Mexico; wild
Vespula sp.[4]	52.84	29.66	3.02	11.04	3.44		Mexico; wild
Isoptera (termites)	**35.34**	**32.74**	**5.06**	**22.84**	**5.88**		
Macrotermes bellicosus[25]	34.80	46.10			10.20		Nigeria; wild
Macrotermes bellicosus[2]	20.40	28.20	2.70	43.30	2.90		Nigeria; wild
Macrotermes bellicosus[7]	38.36	36.12		14.25	11.26		Nigeria; wild
Macrotermes natalensis Haviland (alate caste)[26]	65.62	21.35	7.85	1.13	4.05		Nigeria; wild
Macrotermes nigeriensis[27]	23.47	38.37	6.40	23.25	8.52		Nigeria; wild
Macrotermes notalensis[2]	22.10	22.50	2.20	42.80	1.90		Nigeria; wild
Termes sp.[5]	42.63	36.55	6.14	12.34	2.34		Thailand; wild
Lepidoptera (butterflies, moths)	**45.38**	**27.66**	**6.60**	**18.76**	**4.51**	**508.89**	
Aegiale (Acentrocneme) hesperiaris[3]	40.00	30.00	5.00	21.00	3.00	593.00	Mexico; wild
Aegiale (Acentrocneme) hesperiaris[4]	40.34	29.85	4.66	21.29	3.86	592.50	Mexico; wild
Aegiale hesperiaris k (maguey grub)[20]	30.88	58.55	0.12	8.16	2.29		Mexico; wild
Aegiale hesperiaris (larvae)[9]	40.24	29.45	5.27	19.89	5.15	504.63	Mexico; wild
Anaphe infracta (caterpillars)[2]	20.00	15.20	2.40	66.10	1.60		Nigeria; wild
Anaphe panda (caterpillars)[25]	45.60	35.00	6.50		3.70	543.00	Zaire; wild
Anaphe recticulata (caterpillars)[2]	23.00	10.20	3.10	64.60	2.50		Nigeria; wild
Anaphe spp. (caterpillars)[2]	18.90	18.60	1.68	46.80	4.10		Nigeria; wild
Anaphe venata (caterpillars)[2]	25.70	23.21	2.30	55.60	3.20		Nigeria; wild
Anaphe venata (larvae)[28]	60.03	23.22			3.21	610.00	Nigeria; wild
Arsenura armida[3]	52.00	8.00	12.00	20.00	8.00	356.00	Mexico; wild
Ascalapha odorata[3]	56.00	15.00	12.00	4.00	6.00	419.00	Mexico; wild
Bombyx mori[3]	58.00	35.00	2.00	1.00	4.00	555.00	Mexico; wild
Bombyx mori (spent pupae)[29]	48.70	30.10			8.60		India; reared
Bombyx mori (larvae)[14]	53.76	8.09	6.36	25.43	6.36	389.60	USA; reared
Bombyx mori (larvae)[15]	69.84	9.52	5.95		11.11		USA; reared
Brunaea alcinoe (caterpillars)[26]	74.34	14.10	5.55	3.16	2.85		Nigeria; wild
Catasticta teutila[3]	60.00	19.00	7.00	7.00	7.00	438.00	Mexico; wild
Catasticta teutila[4]	59.76	19.16	7.28	6.71	7.09	438.20	Mexico; wild
Cirina forda Westwood (larvae)[30]	33.12	12.24	9.40	38.12	7.12	359.00	Nigeria; wild
Cirina forda Westwood (caterpillars)[26]	74.35	14.30	6.01	2.36	3.10		Nigeria; wild
Cirina forda (caterpillar)[2]	20.20	14.20	1.80	66.60	1.50		Nigeria; wild
Cirina forda (Westwood) (larvae flour)[31]	20.94	13.09		56.86	9.11		Nigeria; wild
Cirina forda (Westwood) (larvae)[32]	62.25	5.25		20.98	11.51		Nigeria; wild
Comadia redtembacheri[4]	29.04	43.29	6.44	20.60	0.63	614.39	Mexico; wild
Comadia redtembacheri (larvae)[9]	42.07	47.98	6.24	1.58	2.13	607.83	Mexico; wild
Eucheira socialis[4]	48.78	22.71	9.98	15.19	3.34	438.80	Mexico; wild
Eucheria socialis[3]	47.00	16.00	9.00	22.00	7.00	439.00	Mexico; wild
Galleria mellonella (larvae)[15]	38.80	58.55	8.92		2.17		USA; reared
Galleria mellonella[16]	41.25	51.40	12.10		3.30		USA; reared
Galleria mellonella[14]	33.98	60.00	19.52	3.37	1.45	650.13	USA; reared

Table 1. Continued

Edible insects (based on dry matter)	Protein [%]	Fat [%]	Fiber [%]	NFE [%]	Ash [%]	Energy content [Kcal/100 g]	Origin
Heliothis zea[3]	42.00	29.00	4.00	21.00	4.00	513.00	Mexico; wild
Heliothis zea[4]	41.98	29.00	4.14	21.02	3.86	512.82	Mexico; wild
Hylesia frigida[3]	42.00	10.00	12.00	29.00	7.00	372.00	Mexico; wild
Imbrasia belina (larvae)[7]	54.26	23.38		10.98	11.38		Nigeria; wild
Imbrasia oyemensis (caterpillars)[33]	61.59	25.36			2.78		Ivory Coast; wild
Imbrasia opimethea (caterpillars)[34]	62.47	13.33			3.98		Zaire; wild
Imbrasia truncata (caterpillars)[34]	64.72	16.40			3.99		Zaire; wild
Laniifera cyclades[4]	45.85	30.34	4.97	14.22	4.62	513.34	Mexico; wild
Laniifera cyclades (larvae)[9]	45.50	30.49	4.87	14.34	4.77	512.83	Mexico; wild
Latebraria amphipyrioides[3]	57.00	7.00	29.00	1.00	6.00	293.00	Mexico; wild
Nudaurelia oyemensis (caterpillars)[34]	61.08	12.15			3.76		Zaire; wild
Phasus sp.[4]	32.73	60.35	4.10	1.13	1.69		Mexico; wild
Phasus triangularis[3]	15.00	77.00	4.00	2.00	2.00	762.00	Mexico; wild
Phasus triangularis[4]	13.17	77.17	5.31	3.00	1.35	776.85	Mexico; wild
Samia ricinii (prepupae grown on castor leaves)[35]	54.20	26.20	3.26	3.26	4.00	459.69	India; reared
Samia ricinii (prepupae grown on tapioca leaves)[35]	54.00	26.20	3.14	3.14	4.10	461.84	India; reared
Samia ricinii (pupae grown on castor leaves)[35]	54.60	26.20	3.45	3.45	3.80	468.05	India; reared
Samia ricinii (pupae grown on tapioca leaves)[35]	54.80	25.00	3.62	3.58	4.20	459.21	India; reared
Xyleutes redtembacheri[3]	43.00	48.00	6.00	1.00	2.00	614.00	Mexico; wild
Odonata (dragonflies, damselflies)	**55.23**	**19.83**	**11.79**	**4.63**	**8.53**	**431.33**	
Aeschna multicolor[4]	54.24	16.72	9.96	6.23	12.85		Mexico; wild
Anax sp.[4]	56.22	22.93	13.62	3.02	4.21	431.33	Mexico; wild
Orthoptera (crickets, grasshoppers, locusts)	**61.32**	**13.41**	**9.55**	**12.98**	**3.85**	**426.25**	
Acheta domesticus (adults)[16]	64.38	22.80	19.10		5.10		USA; reared
Acheta domesticus (adults)[14]	66.56	22.08	22.08	2.60	3.57	455.19	USA; reared
Acheta domesticus (adults)[15]	70.75	18.55	16.35		5.03		USA; reared
Acheta domesticus (juvenile crickets)[16]	55.00	9.80	16.40		9.10		USA; reared
Acheta domesticus (nymphs)[14]	67.25	14.41	15.72	3.93	4.80	414.41	USA; reared
Acheta domesticus (nymphs)[15]	70.56	17.74	14.92		4.84		USA; reared
Acheta domestica L.[1]	64.10	24.00	6.20	2.12	3.55		Mexico; wild
Acrida exaltata[36]	64.46	7.07	7.73	3.64	4.98	495.00	India; wild
Arphia fallax S.[1]	71.30	6.52	11.58	8.11	2.41		Mexico; wild
Brachytrupes membranaceus Drury (adults)[26]	35.06	53.05	6.30	2.33	3.25		Nigeria; wild
Brachytrupes portentosus Lichtenstein[5]	48.69	20.60	11.61	9.74	9.36		Thailand; wild
Brachytrupes spp.[2]	6.25	3.24	1.01	85.30	1.82		Nigeria; wild
Brachytrupes sp.[1]	61.20	18.70	7.42	7.60	5.05		Mexico; wild
Boopedon af. *Flaviventris*[4]	75.95	8.43	10.35	2.32	2.95		Mexico; wild
Boopedon flaviventris B.[1]	59.30	11.00	10.10	16.59	2.98		Mexico; wild
Conocepalus triops L.[1]	71.00						Mexico; wild
Cytacanthacris aeruginosus unicolor[2]	12.10	3.50	1.50	60.50	2.10		Nigeria; wild
Encoptolophus herbaceus[1]	57.60	11.80	11.02	17.22	2.87		Mexico; wild
Hieroglyphus banian[36]	63.61	7.15	7.16	4.81	4.86	566.00	India; wild
Idiarthron subquadratum S. & P.[1]	65.20	8.17	11.10	4.42	3.79		Mexico; wild
Melanoplus mexicanus[4]	77.13	4.22	12.17	4.04	2.44		Mexico; wild
Melanoplus mexicanus[1]	58.90	11.00	10.01	16.50	3.94		Mexico; wild
Melanoplus sp.[4]	62.93					376.00	Mexico; wild
Melanoplus femurrubrum (nymphs, adults)[9]	77.00	4.20	12.10	4.08	2.59	361.46	Mexico; wild
Oxya fuscovittata[36]	63.96	6.49	7.51	7.51	5.01	465.00	India; wild
Romalea sp.[1]	75.30	12.30	9.73	0.19	4.25		Mexico; wild
Romalea colorata S.[1]	72.70	16.30	6.33	0.00	4.64		Mexico; wild
Ruspolia differens (brown)[37]	44.30	46.20	4.90		2.60		Kenya; wild
Ruspolia differens (green)[37]	43.10	48.20	3.90		2.80		Kenya; wild
Schistocerca sp.[3]	61.00	17.00	10.00	7.00	4.60	427.00	Mexico; wild
Schistocerca sp.[4]	61.10	17.00	10.00	7.00	4.60		Mexico; wild
Spathosternum prasiniferum prasiniferum[36]	65.88	8.11	6.96	6.36	5.11	550.00	India; wild
Sphenarium borrei B.[1]	63.70	10.40	9.81	12.40	3.96		Mexico; wild
Sphenarium histrio[3]	77.00	4.00	12.00	4.00	2.00	363.00	Mexico; wild

Table 1. Continued

Edible insects (based on dry matter)	Protein [%]	Fat [%]	Fiber [%]	NFE [%]	Ash [%]	Energy content [Kcal/100 g]	Origin
Sphenarium histrio[4]	74.78	8.63	10.53	2.59	3.47		Mexico; wild
Sphenarium histrio (nymphs, adults)[9]	71.15	6.72	11.79	8.01	2.30	376.43	Mexico; wild
Sphenarium mexicanum S.[1]	62.10	10.80	4.06	22.64	0.34		Mexico; wild
Sphenarium purpuracens[20]	71.50	5.75	3.89	16.36	2.50		Mexico; wild
Sphenarium purpurascens[3]	56.00	11.00	9.00	21.00	3.00	404.00	Mexico; wild
Sphenarium purpurascens[4]	52.60	19.56	11.04	14.49	2.31	404.44	Mexico; wild
Sphenarium purpurascens Ch.[1]	65.20	10.80	9.41	11.63	2.95		Mexico; wild
Sphenarium sp.[4]	67.02	7.91	10.67	8.12	6.28	393.04	Mexico; wild
Sphenarium spp.[3]	68.00	12.00	11.00	5.00	5.00	390.00	Mexico; wild
Sphenarium spp.[1]	67.80	11.50	10.51	4.65	4.87		Mexico; wild
Taeniopoda auricornis W.[1]	63.00	10.20	8.34	14.52	3.97		Mexico; wild
Taeniopoda sp.[1]	71.00	5.85	10.56	9.59	2.95		Mexico; wild
Trimerotropis pallidipennis[4]	62.93	22.20	7.63	2.63	4.79		Mexico; wild
Trimerotropis sp.[4]	65.13	7.02	10.20	13.87	3.78	379.06	Mexico; wild
Trimerotropis sp.[1]	65.10	7.02	10.20	10.20	3.78		Mexico; wild
Zonocerus variegatus (adult)[1]	62.73	2.49	3.61	29.40	4.11		Nigeria; wild
Zonocerus variegatus[2]	26.80	3.80	2.40	63.20	1.20		Nigeria; wild

NFE, nitrogen-free extract, i.e., carbohydrates (NFE = 100% – (protein + crude fat + ash + crude fiber + moisture).
1 [14], 2 [12]; 3 [1]; 4 [11]; 5 [13]; 6 [19]; 7 [17]; 8 [18], 9 [15], 10 [28]; 11 [26]; 12 [29]; 13 [8]; 14 [16]; 15 [47]; 16 [40]; 17 [23]; 18 [53]; 19 [54]; 20 [10]; 21 [22]; 22 [55]; 23 [56], 24 [9]; 25 [30]; 26 [2]; 27 [57]; 28 [58]; 29 [21]; 30 [59]; 31 [60]; 32 [46]; 33 [61]; 34 [62]; 35 [63]; 36 [64]; 37 [65].

to the same units (e.g., nitrogen content was converted into protein content by the factor 6.25). In addition, the country of the insects' origin and its upbringing (collected in the "wild" or "reared") is included in the table. For further visualization of the tremendous data amount, the average values of the insect orders including their SDs are illustrated in a vertical-bar chart in Fig. 1.

It can basically be observed that the composition of edible insects is generally subject to a large variation. For example, the species of the order Coleoptera (beetles, grubs) have an average protein content of 40.69% with protein contents of the species within this order ranging from 8.85 to 71.10%. It is assumed that this variation not only originates from differences between species and developmental stages [7] but also from different feed [8] and origins as well as differences in measuring methods.

Considering the average contents of the different orders of insecta, the main components of insects are protein and fat, followed by fiber, nitrogen-free extract (NFE), and ash in no particular order (see also Fig. 1).

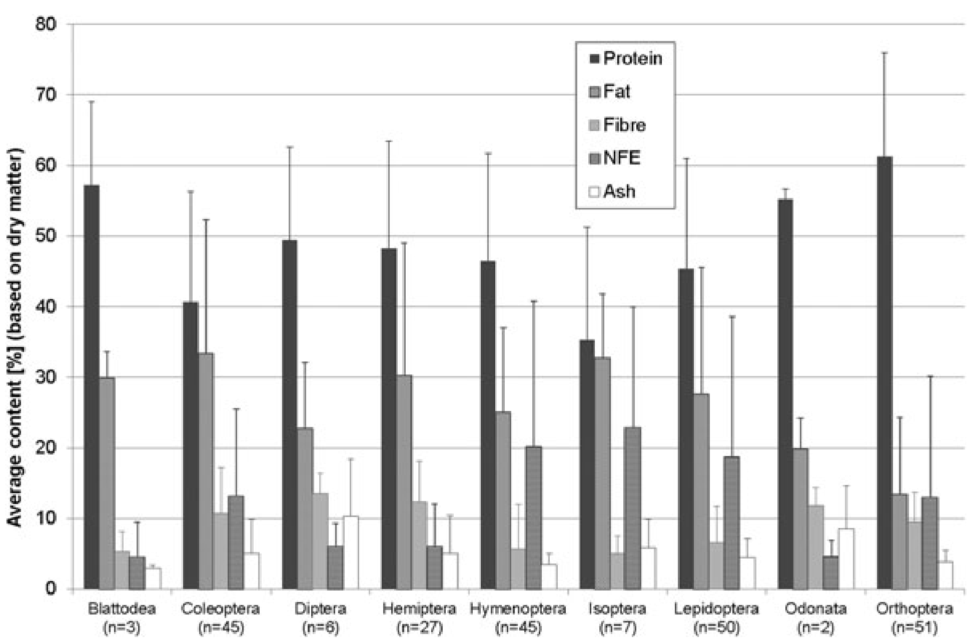

Figure 1. Average nutrient contents [%] (based on dry matter) of edible insects belonging to the same order. n, number of insect samples obtained from literature; NFE, nitrogen-free extract. Insect orders: Blattodea (cockroaches), Coleoptera (beetles, grubs), Diptera (flies), Hemiptera (true bugs), Hymenoptera (ants, bees, wasps), Isoptera (termites), Lepidoptera (butterflies, moths), Odonata (dragonflies, damselflies), Orthoptera (grasshoppers, crickets, locusts).

Average fiber contents range from 5.06% for Isoptera (termites) to 13.56% for Hemiptera (true bugs) with maximum yields for the black ants *Polyrhachis vicina* Roger from the Chinese provinces Guizhou and Zhejiang (Hymenoptera) and the larvae of the moth *Latebraria amphipyrioides* (Lepidoptera) with 28.88, 29.13, and 29.00%, respectively [1, 9]. Species with the lowest fiber contents include larvae of *Aegiale hesperiaris* k (maguey worm; Lepidoptera) with 0.12% [10], larvae of the honeybee *Apis mellifera* (Hymenoptera) with 1.00–1.33% [1, 11], and the cricket *Brachytrupes* spp. (Orthoptera) with 1.01–11.61% [2, 12–14].

The content of NFE, a commonly calculated value representing carbohydrates other than fiber, varies between 4.63% for Odonata (dragonflies, damselflies) and 22.84% for Isoptera (termites, ants). The insects richest in carbohydrates are the cricket *Brachytrupes* ssp. (Orthoptera) with 2.33–85.30% [2, 12–14], the ant *Myrmecosistus melliger* with 77.00–77.73% [1, 11, 15], and the honeybee *A. mellifera* with 22.00–73.60% [1, 11, 12, 15] (both of the order Hymenoptera). Insects with the lowest carbohydrate contents include the ant *Atta mexicana* (Hymenoptera) with 0.00–4.92 [1, 10], the beetle *Tenebrio molitor* (Coleoptera) with 0.01–3.86% [8, 16], and the bug *Euschistus strennus* (Hemiptera) with 0.01% [11]. It is noteworthy that the authors Banjo et al. [12] resulted in outstandingly high NFE contents in comparison to other authors and consequently measured low fat, fiber but also protein contents.

The average ash contents of edible insects vary between 2.94% for Blattodea (cockroaches) and 10.31% for Diptera (flies) with maximum yields of 25.95% for *Eristalis* sp. (Diptera) [11], 21.00% for mosquito eggs of *Krizousacorixa azteca J* (common name "ahuahutle"; of the order Homoptera) [10, 11], and 14.13–15.56% for larvae of *Oryctes rhinoceros* (Coleoptera) [17–19]. The lowest ash contents were found for *Sphenarium mexicanum* S. (Orthoptera) with 0.34% [14], *Metamasius spinolae* (Coleoptera) with 0.62% [11], and *Comadia redtembacheri* (Lepidoptera) with 0.63–2.13% [11, 15].

The mean energy contents of edible insects range from 409.78 to 508.89 kcal/100 g (based on dry matter) with maximum energy contents as high as 762.00 to 776.85 kcal/100 g for *Phasus triangularis* (Lepidoptera) [1, 11], 655.00 kcal/100 g for *Polistes instabilis* (Hymenoptera) [1], and 652.30 kcal/100 g for *Arophalus rusticus* (Coleoptera) [11]. Minimum energy contents obtained include 216.94 kcal/100 g for *Ephydra hians* (Diptera) [11], 282.32–282.74 kcal/100 g for *Phyllophaga* sp. (Coleoptera) [11, 15], and 293.00 kcal/100 g for *L. amphipyrioides* (Lepidoptera) [1]. Again the margin of deviation becomes clearly visible, even within the same order as in this case Lepidoptera (butterflies and moths) the energy content fluctuates considerably. However, the maximum and minimum energy contents found are overall outliers, 79.65% of all 113 energy contents of edible insects obtained from literature range above 400 kcal/100 g, 40.94% above 500 kcal/100 g. Consequently, the energy contents of most edible insects are substantial even in comparison to meat which is due to the two major components of insects: protein and fat.

2.1 Protein contents and amino acid spectra

Proteins represent the main component of the nutrient composition of insects (see Fig. 1). Considering the average contents of the insect orders in Table 1, the protein contents of edible insects amount to between 35.34% for Isoptera (termites) and 61.32% for Orthoptera (crickets, grasshoppers, locusts). The species *Melanoplus femurrubrum*, *Sphenarium histrio*, and *Melanoplus mexicanus* (all from the order Orthoptera) yielded the highest protein contents with 77.00, 71.15–77.00, and 58.90–77.13%, respectively [1, 11, 14, 15]. It is noteworthy that within all nine insects orders included in Table 1, maximum proteins contents between 56.22% (Odonata) and 77.13% (Orthoptera) have been obtained with maximum protein contents of above 70% for four of the nine orders (based on dry matter). Comparing the maximum protein yields of species of the order Orthoptera with up to 77.13% with maximum protein contents of plants (35.8% for dry soy beans (Danish Food Composition Databank ed. 7.01 (11.09.2012), http://www.foodcomp.dk/v7/fcdb_default.asp) insects but especially grasshoppers potentially represent an excellent alternative protein source. Furthermore, the use of pesticides for the preservation of plants in favor of grasshoppers becomes debatable.

However, the quality of the insect proteins in comparison to other animal and plant proteins has to be assessed in feeding trials. Evaluating the protein quality of different insect meals fed to weanling rats it was observed that proteins from both cricket meals tested (*Acheta domesticus* and *Anabrus simplex*) were equal or superior to soy protein as an amino acid source [20]. By contrast, in feeding trials with rats the protein quality of spent silk worm pupae, a by-product of the silk industry, showed a significant lower protein quality than casein despite a higher chemical score regarding food intake, weight gain, protein digestibility, protein efficiency ratio (PER), and net protein utilization (NPU). This was attributed to a bad odor of the silkworm pupae meal and the growth depressing pupal hormone ecdysone. The chemical score of the spent silk worm pupae protein was 60 in comparison to 100 for whole egg protein [21] and 55.3 for casein [22]. In feeding trials with chicks, an improved growing performance and carcass quality of broiler chicks was yielded supplementing chick feed with 10–15% of housefly larvae. In the breast muscle of the chicks, the protein content remained constant whereas its lysine and tryptophan content increased. This had been attributed to the optimal amino acid profile, high protein content of 63.99% dry weight, or high protein digestibility of 98.5% of the larvae [23]. A comparison of whole dried honey bees and honey bee protein isolate from the same source revealed that the removal of chitin via an alkaline treatment improved the nutritional quality of the insect protein as measured by increased protein digestibility, amino acid availability, NPU, and PER when fed to rats. The honey bee protein isolate had a protein digestibility, NPU, and PER comparable to casein [22].

Table 2. Amino acid content of edible insects [mg/g protein]

Edible insects [mg/g protein]	His	Ile	Leu	Lys	Met	Cys	Met + Cys	Phe	Tyr	Phe + Tyr	Thr	Trp	Val	Arg	Ser	Pro	Ala	Gly	Glu A	origin
Blattodea (cockroaches)	**19.4**	**29.9**	**56.4**	**48.0**	**29.8**	**11.6**	**41.4**	**30.6**	**62.3**	**92.9**	**34.6**	**6.0**	**53.8**	**41.5**	**41.9**	**65.0**	**56.6**	**58.7**	**99.7**	
Periplaneta americana L.[a)]	20.0	31.0	56.0	40.0	36.0	20.0	56.0	31.0	69.0	100.0	36.0	6.0	65.0	51.0	45.0	65.0	61.0	71.0	130.0	Mexico; wild
Periplaneta australasiae F.F.[a)]	18.7	28.7	56.8	56.0	23.6	3.2	26.8	30.2	55.5	85.7	33.2	6.0	42.6	32.0	38.8		52.2	46.3	69.3	Mexico; wild
Coleoptera (beetles, grubs)	**26.3**	**45.6**	**74.2**	**50.6**	**16.2**	**14.6**	**31.9**	**47.1**	**55.7**	**98.6**	**35.2**	**10.1**	**51.9**	**53.9**	**42.6**	**64.1**	**69.5**	**55.2**	**123.7**	
Holotrichia sp.[b)]	16.1	32.1	51.8	18.8			44.6			49.3	26.9	27.1	29.3	32.3	31.3	47.0	58.3	52.8	97.6	Thailand; wild
Oryctes rhinoceros (larvae)[c)]	38.2	39.8	53.0	44.2	19.4	20.2	39.6	46.1	30.9	77.0	33.4		35.0	81.6	37.0	50.1	52.5	47.2	154.6	Nigeria; wild
Rhynchophoris phoenicis (larvae)[c)]	38.9	39.0	54.2	45.0	19.7	20.2	39.9	47.5	29.0	76.5	30.6		35.0	79.2	39.0	50.1	52.5	47.2	156.0	Nigeria; wild
Rhynchophoris phoenicis (larvae)[d)]		77.5	58.9	63.9	12.0	10.6	22.6	32.8	13.6	46.4	28.6	5.1	54.9							Angola; wild
Rhynchophoris phoenicis (larvae)[e)]	11.0	24.0	47.0	42.0	21.0	25.0	46.0	65.0	60.0	125.0	29.0		41.0	24.0	33.0	102.0	76.0	48.0		Nigeria; wild
Sciphophorus acupunctatus (larvae)[d)]	14.7	48.2	78.2	53.5	20.2	26.7	46.9	46.1	63.5	109.6	40.4	8.1	62.0	44.0						Mexico; wild
Sphenarium histrio[d)]	11.0	53.0	87.0	57.0	7.0	13.0	20.0	44.0	73.0	117.0	40.0	6.0	51.0	66.0						Mexico; wild
Sphenarium purpurascens[d)]	22.0	42.0	89.0	57.0	25.0	18.0	43.0	103.0	63.0	166.0	38.0	6.5	57.0	60.0						Mexico; wild
Tenebrio molitor (larvae)[f)]	37.9	49.4	82.2	64.9	19.5	10.9	30.5	43.7	79.9	123.6	40.8	10.3	69.0	60.3	54.6	74.1	80.5	59.8	132.8	USA; reared
Tenebrio molitor (larvae)[g)]	35.3	46.7	77.7	60.9	14.1	8.2	22.3	40.8	77.7	118.5	34.8	9.2	66.3	56.0	49.5	65.8	74.5	53.8	123.9	USA; reared
Tenebrio molitor (adults)[g)]	28.7	43.5	82.7	44.3	12.7	6.8	19.4	26.2	33.3	59.5	34.2	11.0	63.3	43.0	41.4	63.3	76.4	84.4	89.0	USA; reared
Tenebrio molitor (larvae)[g)]	31.6	50.3	106.4	54.5	12.8	8.6	21.4	35.3	74.5	109.8	41.8	8.0	58.8	51.9	51.3	69.5	82.4	55.6	112.8	USA; reared
Zophobas morio[g)]	30.5	47.2	97.0	52.3	10.7	7.6	18.3	34.5	69.5	104.1	39.6	9.1	52.3	48.7	46.7	54.8	72.6	48.2	122.8	USA; reared
Diptera	**22.3**	**32.6**	**57.4**	**62.9**	**27.2**	**5.3**	**36.6**	**50.6**	**56.7**	**107.3**	**38.8**	**28.3**	**46.9**	**49.4**	**60.0**	**27.8**	**58.9**	**45.1**	**98.6**	
Ephydra hians (larvae)[h)]	10.0	40.0	74.0	55.0	19.0			54.0	51.0	105.0	49.0	7.1	61.0							Mexico; wild
Musca domesticus (larvae)[i)]	30.9	22.8	45.3	81.6	36.6	6.6	43.1	55.8	71.1	126.9	35.5	49.5	45.6	56.7	88.0	24.7	75.8	51.1	89.2	S. Korea; rear.
Musca domesticus (pupae)[j)]	26.0	35.0	53.0	52.0	26.0	4.0	30.0	42.0	48.0	90.0	32.0		34.0	42.0	32.0	31.0	42.0	39.0	108.0	USA; reared
Hemiptera (true bugs)	**15.7**	**31.5**	**49.8**	**28.0**	**21.7**	**12.9**	**32.2**	**34.4**	**38.7**	**63.8**	**29.9**	**10.3**	**44.3**	**24.9**	**10.3**		**26.4**	**16.4**	**23.7**	
Agonoscelis pubescens (Thunberg)[k)]	11.4	14.2	19.5	6.4	2.7	4.5	7.2	18.0	8.6	26.6	16.6		17.4	36.9	7.7		13.9	12.8	30.8	Sudan; wild
Aspongubus viduatus F.[k)]	20.6	20.8	22.6	15.5	35.9	21.2	57.1	10.5	17.4	27.9	18.1		25.9	12.8	12.9		38.9	20.0	16.6	Sudan; wild
Hoplophorion monograma[h)]	15.0	41.0	77.0	55.0	19.0			47.0	90.0	137.0	45.0	9.6	74.0							Mexico; wild
Krizousacorixa azteca J (eggs)[l)]		50.0	80.0	35.0	29.0			62.0			40.0	11.0	60.0							Mexico; wild
Hymenoptera (bees, wasps, ants)	**27.0**	**47.8**	**78.4**	**53.8**	**23.8**	**12.9**	**30.5**	**47.5**	**55.3**	**104.3**	**41.7**	**10.3**	**60.5**	**43.5**	**38.2**	**66.7**	**72.3**	**81.3**	**134.3**	
Apis mellifera (honeybee)[m)]	24.0	53.0	93.0	56.0	17.0			39.0	37.0	76.0	43.0		52.0	51.0	53.0	75.0	87.0	70.0	126.0	Canada; rear.
Atta mexicana[d)]	25.0	53.0	80.0	49.0	19.0	15.0	34.0	41.0	47.0	88.0	43.0	6.0	64.0	47.0						Mexico; wild
Atta mexicana[h)]	25.0	53.0	80.0	49.0	34.0			88.0	47.0	135.0	43.0	6.0	64.0							Mexico; wild
Atta mexicana B[l)]		51.0	75.0	51.0	40.0			75.0			41.0	6.0	60.0							Mexico; wild
Bee brood[n)]	23.4	45.7	70.2	61.7	21.3	21.3	42.6	35.1	43.6	78.7	33.0	9.6	52.1	42.6	35.1	60.6	47.9	43.6	137.2	USA; reared
Brachygastra azteca[h)]	28.0	51.0	85.0	61.0	14.0			41.0	65.0	106.0	44.0	7.0	64.0							Mexico; wild
Liometopum apiculatum[d)]	29.0	49.0	76.0	58.0	18.0	14.0	32.0	39.0	68.0	107.0	42.0	8.0	60.0	50.0						Mexico; wild
Liometopum apiculatum[h)]	29.0	44.0	89.0	60.0	18.0			35.0	68.0	103.0	35.0	6.2	48.0							Mexico; wild
Liometopum apiculatum H (eggs)[l)]		45.0	76.0	55.0	45.0			66.0			43.0	7.0	60.0							Mexico; wild
Parachartegus apicalis[h)]	29.0	42.0	77.0	58.0	20.0			43.0	71.0	114.0	47.0	6.2	57.0							Mexico; wild
Polyrhachis vicina Roger (Zhejiang)[o)]	25.8	46.5	69.7	43.7	16.3	7.0	23.2	33.4	53.4	86.8	40.2	27.4	68.8	35.2	48.2	73.7	94.8	128.6	112.1	China; reared
Polyrhachis vicina Roger (Guizhou)[o)]	24.0	45.7	69.8	37.4	23.3	7.3	30.6	35.0	53.3	88.3	42.6	24.6	82.7	37.9	51.1	67.7	88.4	116.0	115.7	China; reared
Vespa sp. (hornet grub)[b)]	35.3	42.6	78.5	59.0			20.8			165.0	45.3	10.1	53.7	41.0	3.8	56.8	43.5	48.2	180.6	Thailand; wild

Table 2. Continued

Edible insects [mg/g protein]	His	Ile	Leu	Lys	Met	Cys	Met + Cys	Phe	Tyr	Phe + Tyr	Thr	Trp	Val	Arg	Ser	Pro	Ala	Gly	Glu A	origin
Isoptera (termites)																				
Macrotermes bellicosus[d)]	51.4	51.1	78.3	54.2	7.5	18.7	26.2	43.8	30.2	74.0	27.5	14.3	73.3	69.4						Nigeria; wild
Lepidoptera (butterflies, moths)	**23.7**	**40.4**	**62.7**	**57.7**	**22.1**	**12.2**	**34.7**	**46.3**	**49.1**	**95.8**	**40.0**	**11.2**	**54.1**	**46.9**	**48.4**	**44.9**	**48.9**	**43.8**	**103.4**	
Aegiale Acentrocneme hesperiaris[h)]	31.0	46.0	72.0	66.0	47.0			51.0	63.0	114.0	76.0	3.0	58.0	57.0	83.0		66.0	59.0	123.0	Mexico; wild
Aegiale hesperiarisd	16.0	49.0	52.0	36.0	10.0			37.0	42.0	79.0	33.0	9.0	47.0	30.0						Mexico; wild
Aegiale hesperiaris k (maguey grub)[l)]		45.0	61.0	50.0	31.0			70.0			41.0	8.0	51.0							Mexico; wild
Anaphe venata (larvae, without hair)[p)]	7.8	21.4	13.1	8.8	0.0			21.4	25.0	46.4	3.8	0.0	17.6	3.2		18.7	18.2	14.1	6.1	Nigeria; wild
Ascalapha odorata (larvae)[h)]	28.0	41.0	69.0	63.0	23.0			95.0	44.0	139.0	40.0	4.4	48.0							Mexico; wild
Bombyx mori (larvae)[f)]	29.5	33.0	48.9	50.0	12.5	9.1	21.6	28.4	34.1	62.5	28.4	6.8	39.8	43.2	38.6	35.2	40.9	58.0	102.3	USA; reared
Bombyx mori (larvae)[g)]	25.8	32.3	52.7	47.3	14.0	8.6	22.6	29.0	31.2	60.2	31.2	7.5	40.9	41.9	36.6	34.4	45.2	60.2	100.0	USA; reared
Bombyx mori (pupae)[q)]	27.0	34.0	62.0	61.0	34.0	14.0	48.0	46.0	56.0	102.0	39.0	15.0	47.0	47.0	37.0	70.0	39.0	36.0	95.0	Japan; reared
Bombyx mori (pupae)[b)]	35.4	46.1	70.6	77.2			36.3			122.0	45.3	19.0	52.2	58.8	37.9	44.4	39.4	29.7	107.3	Thailand; wild
Bombyx mori (pupae)[r)]	22.5	37.7	60.2	53.1	17.5	3.5	21.0	42.5	48.0	90.5	38.3		45.9	46.2	36.8	16.0	38.9	34.6	86.5	Sri Lanka; rear.
Bombyx mori (spent pupae)[s)]	25.0	57.0	83.0	75.0	46.0	14.0	60.0	51.0	54.0	105.0	54.0	9.0	56.0	68.0	47.0	40.0	55.0	46.0	149.0	India; reared
Clanis bilineata (larvae)[t)]	28.5	28.0	35.6	33.6	34.9	26.1	60.1	34.7	34.3	69.0	22.5	9.6	40.1	30.5	30.9	31.2	39.8	30.8	82.3	China, reared
Galleria mellonella (larvae)[g)]	23.4	44.7	87.9	56.0	15.6	7.8	23.4	37.6	62.4	100.0	41.8	8.5	48.2	50.4	74.5	67.4	66.7	52.5	138.3	USA; reared
Galleria mellonella (larvae)[f)]	22.4	41.6	70.8	57.1	27.3	13.0	40.4	37.3	54.0	91.3	36.0	8.7	54.0	50.9	77.0	77.0	71.4	57.8	121.1	USA; reared
Imbrasia epimethea (caterpillars)[u)]	19.7	28.6	81.0	74.2	22.4	18.7	41.1	65.0	75.0	140.0	48.0	16.0	102.0	66.2						Zaire; wild
Imbrasia ertli (caterpillars)[d)]		36.0	36.7	39.3	15.8	13.4	29.2	17.4	13.2	30.6	40.5	8.1	41.9							Angola; wild
Imbrasia truncata (caterpillars)[u)]	17.4	24.2	73.1	78.9	22.2	16.5	38.7	62.2	76.5	139.0	46.9	16.5	102.0	55.5						Zaire; wild
Mellacosoma americanum Fab. meal[v)]	18.0	28.0	48.0	44.0	12.0	7.0	19.0	29.0	34.0	63.0	32.0		36.0	40.0	37.0	28.0	53.0	40.0	89.0	USA; wild
Nudaurelia oyemensis (caterpillars)[u)]	18.1	25.6	82.7	79.8	23.5	19.7	43.2	58.6	75.7	134.0	44.5	16.0	96.0	63.5						Zaire; wild
Omphisa fuscidentalis (caterpillars)[b)]	23.3	33.9	60.0	56.0			41.7			100.7	34.9	41.1	38.8	47.9	41.3	40.7	37.7	32.7	93.2	Thailand; wild
Samia ricinii (prepupae)[w)]	27.9	43.3	65.2	65.4	21.2	5.2	26.4	51.7	63.2	114.9	44.8		52.9	46.9	47.6	60.3	60.5	56.4	129.0	India; reared
Samia ricinii (pupae)[w)]	26.7	44.2	66.3	65.4	23.1	5.3	28.4	52.4	64.0	116.4	47.5		53.6	44.1	52.5	64.6	61.4	49.4	129.0	India; reared
Usta terpsichore (caterpillars)[d)]		108.7	91.3	91.0	11.3	12.9	24.2	55.9	33.0	88.9	50.8	6.6	75.8							Angola; wild
Orthoptera	**21.2**	**39.6**	**74.8**	**53.9**	**19.3**	**12.8**	**29.8**	**46.6**	**61.5**	**100.3**	**35.8**	**8.1**	**50.3**	**53.6**	**41.9**	**53.9**	**77.4**	**54.0**	**94.5**	
Acheta domesticus meal[v)]	25.0	40.0	76.0	59.0	17.0	9.0	26.0	34.0	53.0	87.0	43.0		57.0	78.0	43.0	46.0	86.0	59.0	112.0	USA; reared
Acheta domesticus (nymphs)[g)]	22.1	42.9	95.5	53.9	13.0	8.4	21.4	27.9	55.2	83.1	35.7	5.2	49.4	61.0	41.6	55.2	89.0	52.6	103.9	USA; reared
Acheta domesticus (nymphs)[f)]	25.7	40.6	72.6	62.3	15.4	9.1	24.6	32.0	62.9	94.9	38.9	6.3	60.0	70.9	42.9	61.1	101.1	60.6	117.1	USA; reared
Acheta domesticus (adults)[g)]	23.4	45.9	100.0	53.7	14.6	8.3	22.9	31.7	48.8	80.5	36.1	6.3	52.2	61.0	49.8	56.1	87.8	50.7	104.9	USA; reared
Acheta domesticus (adults)[f)]	22.7	36.4	66.7	51.1	19.6	9.8	29.3	30.2	44.0	74.2	31.1	7.6	48.4	57.3	52.0	54.2	76.9	45.3	104.4	USA; reared
Acheta domestica L. (larvae)[a)]	21.0	42.0	73.0	56.0	15.0	21.0	36.0	33.0	41.0	74.0	35.0	6.0	60.0	63.0	49.0	67.0	70.0	60.0	80.0	Mexico; wild
Acheta testacea Walker[b)]	15.4	29.8	60.9	46.1			30.9			62.4	29.0	24.4	34.4	45.1	35.9	45.2	78.0	47.2	96.8	Thailand; wild
Anabrus simplex meal[v)]	22.0	37.0	68.0	54.0	15.0	13.0	28.0	33.0	47.0	80.0	43.0		49.0	63.0	48.0	39.0	81.0	54.0	104.0	USA, wild
Boopedon flaviventris[h)]	24.0	47.0	88.0	55.0	18.0			41.0	74.0	115.0	44.0	6.0	57.0							Mexico; wild
Boopedon flaviventris[a)]	24.0	47.0	88.0	55.0	18.0	20.0	38.0	41.0	74.0	115.0	44.0	6.0	57.0	43.0	43.0	68.0	59.0	75.0	154.0	Mexico; wild
Brachytrupes sp. (adults)[a)]	20.8	27.1	61.4	59.8	7.9	14.0	21.9	24.1	92.8	116.9	38.6	5.5	40.4	31.1	38.5		62.0	50.9	73.1	Mexico; wild
Melanoplus femurrubrum[a)]	23.1	26.4	58.2	61.7	29.8	11.6	41.4	22.5	56.4	78.9	37.0	6.4	40.9	32.1	29.4	26.6			62.6	Mexico; wild
Patanga succinata L.[b)]	13.5	32.7	59.5	35.7			20.9			60.0	22.3	17.3	35.6	36.0	23.9	48.7	92.7	48.8	76.4	Thailand; wild
Sphenarium histrio G.[a)]	19.0	53.0	87.0	57.0	20.0	13.0	33.0	117.0	73.0	190.0	40.0	6.0	51.0	66.0	51.0	72.0	76.0	53.0	53.0	Mexico; wild
Sphenarium purpurascens Ch.[a)]	22.0	42.0	89.0	57.0	25.0	18.0	43.0	103.0	63.0	166.0	31.0	7.0	57.0	60.0	48.0	62.0	64.0	68.0	107.0	Mexico; wild
Sphenarium purpuracens[l)]		42.0	85.0	57.0	42.0			77.0			39.0	6.0	56.0							Mexico; wild
Taeniopoda auricornis W.[a)]	14.8	41.2	42.5	41.5	18.9	10.7	29.6	51.2	76.4	127.6	20.6	5.8	49.0	35.9	32.9		59.5	30.6	68.3	Mexico; wild
Amino acid requirement in human nutrition[x)]	**15.0**	**30.0**	**59.0**	**45.0**	**16.0**	**6.0**	**22.0**			**30.0**	**23.0**	**6.0**	**39.0**							

Ile, Isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Cys, cysteine; Phe, phenylalanine; Tyr, tyrosine; Thr, threonine; Trp, tryptophan; Val, valine; Arg, arginine; His, histidine; Ser, serine; Pro, proline; Ala, alanine; Gly, glycine; Glu A, glutamic acid; rear., reared.

a) [14], b) [33], c) [19], d) [30], e) [28], f) [47], g) [16], h) [66], i) [23], j) [53], k) [54], l) [10], m) [22], n) [55], o) [9], p) [58], q) [67], r) [68], s) [21], t) [69], u) [62], v) [20], w) [63], x) [25].

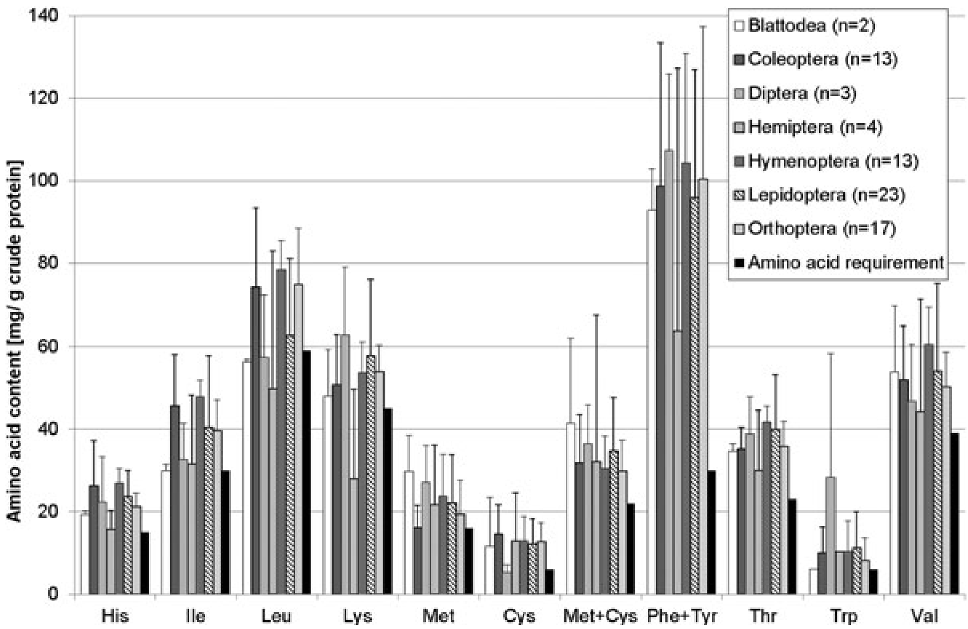

Figure 2. Mean amino acid contents [mg/g crude protein] of edible insects belonging to the same order in relation to amino acid requirements for adults [mg/g protein] published by the WHO [25]. n, number of insect samples per order obtained from literature, Insect orders: Blattodea (cockroaches), Coleoptera (beetles, grubs), Diptera (flies), Hemiptera (true bugs), Hymenoptera (ants, bees, wasps), Lepidoptera (butterflies, moths), Orthoptera (grasshoppers, crickets, locusts). Amino acids: His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Cys, Cysteine; Phe, phenylalanine; Tyr, tyrosine; Thr, threonine; Trp, tryptophan; Val, valine.

The amino acid spectra of edible insects are shown in Table 2 and the average amino acid contents of insects belonging to the same insect order are given in bold values and further illustrated in Fig. 2. Again large variation can be observed, SDs as high as 31.3 were obtained for Lepidoptera for phenylalanine and tyrosine (phe + tyr). Additionally to the aforementioned influence factors, this distribution can be attributed to the partly low data volume ranging from $n = 23$ for Lepidoptera to only $n = 3$ for Diptera. It was stated in literature that insect proteins were shown to be low in the amino acids methionine and cysteine and high in lysine and threonine [24]. This could not be entirely confirmed. Comparing the amino acid requirements for adults published by the WHO [25] in mg/g protein with average amino acid contents of insects belonging to the same order, it can generally be observed that all edible insects meet the amino acid requirements of adults for methionine and methionine + cysteine, and with one exception (Diptera) for cysteine. Aside from the order Hemiptera being low in isoleucine, lysine, phenylalanine + tyrosine, and valine and the order Diptera being short of leucine and cysteine, all insect orders generally meet the requirements of the WHO for amino acids. High values have been obtained for phenylalanine + tyrosine and some insects are rich in tryptophane, lysine, and threonine.

It can be concluded that edible insects in general and species from the order Orthoptera (grasshoppers, crickets, locusts) in particular are rich in proteins and represent a valuable alternative protein source. The nutrient quality of the insect protein is promising in comparison to casein and soy but varies and can be improved by the removal of the chitin. Furthermore, most edible insects provide satisfactorily with the required essential amino acids.

2.2 Lipid contents and fatty acid spectra

Fat represents the second largest portion of the nutrient composition of edible insects (see Fig. 1). The average fat contents per order range from 13.41% for Orthoptera (grasshoppers, crickets, locusts) being rich in protein to 33.40% for Coleoptera (beetles, grubs). In addition, bugs (Hemiptera), termites (Isoptera), Blattodea (cockroaches) and in some cases caterpillars (Lepidoptera) are also rich in fat with average amounts of 30.26, 32.74, 29.90, and 27.66%, respectively. The insect species with the highest amounts of fat include the caterpillars (i.e., larvae) of *P. triangularis* (Lepidoptera) with 77.00–77.13% [1, 11], the palm weevil larvae *Rhynchophorus phoenicis* with up to 69.78% (Coleoptera) [26] and wasps *P. instabilis* (Hymenoptera) with 62.00% fat [1]. The lowest fat contents have been obtained for larvae of *O. rhinoceros* with 0.66–38.12% [17–19], larvae of *Oryctes boas* with 1.50% (both Coleoptera) [12], and *Brachytrupers* ssp. (Orthoptera) with 3.24–53.05% fat [2, 13, 14, 27]. Particularly the fat contents of the palm weevil larvae ($n = 7$), where fat contents as low as 19.50% with carbohydrate contents of up to 48.60% have been reported [17, 19, 26–29], the fat contents of the cricket *Brachytrupes* ssp. ($n = 4$), and larvae of the Asiatic rhinoceros beetle *O. rhinoceros* ($n = 2$) give a general idea of the margin of deviation of the nutrient components of the same species as derived from literature. Since all beetle samples had been collected in Nigeria in the wild, the deviation cannot be attributed to their origin. The fat content also varies between developmental stages and is in general higher in larval and pupal stages than at the adult stage [7].

The fatty acid composition of edible insects as published in literature is summarized in Table 3. In addition to the fatty

Table 3. Fatty acid composition [% fatty acids] of edible insects

Fatty acid composition [% fatty acids]	C14:0	C16:0	C18:0	Other SFA	SFA	C16:1 n7	C18:1 n9	Other MUFA	MUFA	C18:2 n6	C18:3 n3	C18:3 n6	C20:3 n6	C20:4 n6	C20:5 n3	Other PUFA	PUFA	SFA/ UFA	Origin
Aquatic edible insects[a)]					33.40				33.80	14.60	4.50	0.60	0.20	3.70	12.30	0.60	27.90	0.54	Review
Terrestrial edible insects[a)]					32.90				22.50	25.80	17.50	6.70	7.40	35.70	4.60	6.70	44.20	0.49	Review
Coleoptera (beetles, grubs)					**38.49**				**35.72**								**27.14**	**0.61**	
Copris nevinsoni[b)]	1.76	28.97	13.29	nd	44.02	2.75	47.66		50.41	3.92	0.84			0.81			5.57	0.83	Thailand; w
Copris nevinsoni Waterhouse[c)]	0.29	1.31	28.26	1.85	31.71	nd	3.68		3.68		1.75		10.36	40.24	12.94		65.29	0.46	Thailand; w
Cybister limbatus Fabricius[d)]		29.20	4.50	3.60	37.30	7.50	28.50		36.00	13.30	6.30	1.50		4.00	1.60		26.70	0.59	Thailand; w
Helicopris bucephalus[b)]	0.91	40.34	13.25	0.49	54.98	1.61	40.63		42.24	2.13	0.65			nd			2.78	1.22	Thailand; w
Holotrichia sp.[c)]	nd	0.77	27.92	0.73	29.42	0.51	5.59		6.10		nd		13.86	47.26	nd	3.39	64.51	0.42	Thailand; w
Holotrichia sp.[e)]					33.30				30.00								32.40	0.53	Thailand; w
Hydrous cavistanum Bedel[d)]		22.00	5.80	3.40	31.20	3.20	31.10		34.30	21.50	3.10	nd		7.10	2.80		34.50	0.45	Thailand; w
Liatongus rhadamitus[b)]	2.04	28.74	10.70	0.49	41.96	4.84	47.92	0.40	53.16	3.87	0.67			0.50			5.04	0.72	Thailand; w
Onitis spp.[b)]	1.07	18.67	12.98	3.91	36.63	2.32	50.59	0.71	53.62	8.85	0.52			0.39			9.75	0.58	Thailand; w
Onthophagus mouhoti[b)]	1.25	21.65	17.21	3.08	43.18	1.73	45.09	0.60	47.42	8.56	0.43			0.40			9.39	0.76	Thailand; w
Onthophagus seniculus[b)]	1.66	23.86	17.82	1.20	44.55	2.95	43.00		45.96	7.54	1.38			0.60			9.51	0.80	Thailand; w
Oryctes owariensis[f)]	2.50	0.20	0.23	0.12	3.05	37.60	5.24	0.79	43.63	45.46	4.19	1.22					50.87	0.03	Camer; w
Oryctes rhinoceros (larvae)[g)]	3.50	28.70	2.10	0.09	34.39	4.41	41.50		45.91	14.10	1.50			4.10			19.70	0.52	Nigeria; w
Rhynchophorus phoenicis F (larvae)[g)]	3.20	32.40	3.10	0.20	38.90	3.30	40.10		43.40	13.00	3.50			1.20			17.70	0.64	Nigeria; w
Rhynchophorus phoenicis (larvae)[h)]	2.50	36.00	0.30	2.10	40.90	36.00	30.00	0.60	66.60	26.00	2.00						28.00	0.43	Angola; w
Rhynchophorus phoenicis (larvae) oil[i)]		35.30	60.47		95.77		0.72		0.72	3.51							3.51	22.64	Nigeria; w
Tesseratoma papillosa[c)]	nd	0.46	41.00		41.46	nd	7.27		7.27		nd		4.67	46.68	nd		51.35	0.71	Thailand; w
Coleoptera[j)]	1.11	19.66	4.84	1.11	25.61	5.31	37.87	0.03	43.21	19.19	9.70						28.89	0.36	Review
Aquatic Coleoptera[a)]					34.30				35.20		4.70			5.60			30.60	0.52	Review
Terrestric Coleoptera[a)]					27.10				25.50		2.50			43.80			46.80	0.37	Review
Diptera					**33.02**				**47.23**								**15.95**	**0.52**	
Musca domestica (larvae)[k)]	6.83	26.74	2.32		35.89	25.92	21.75		47.67	16.44							16.44	0.56	S. Korea; r
Musca domestica L. (pupae)[l)]	3.20	27.60	2.20	0.40	33.40	20.60	18.30		38.90	14.90	2.10						17.00	0.60	USA; r
Diptera[j)]	2.81	22.55	4.41	2.81	29.77	25.89	28.24	0.99	55.12	12.18	2.23						14.41	0.43	Review
Hemiptera (true bugs)					**43.89**				**32.39**								**22.89**	**0.79**	
Agonoscelis pubescens (Thunberg)[m)]	0.21	11.41	7.77	1.08	20.47	1.04	41.15	0.85	43.04	35.21	1.28						36.49	0.26	Sudan; w
Aspongubus viduatus F.[m)]	0.34	31.33	3.47	2.73	37.87	10.62	45.53	0.62	56.77	4.90	0.45						5.35	0.61	Sudan; w
Lethocerus indicus[d)]		31.80	5.50	2.00	39.30	8.00	34.50		42.50	9.00	3.40	nd		4.10	1.96		18.46	0.64	Thailand; w
Meimuna opalifera Walker[c)]	1.99	2.47	52.53	nd	56.99	0.28	0.92		1.20		nd		10.77	33.03	nd		43.80	1.27	Thailand; w
Hemiptera[j)]	41.63	19.90	3.28	41.63	64.81	2.06	15.51	0.85	18.42	8.90	1.43						10.33	2.25	Review
Hymenoptera (bees, ants)					**29.88**				**48.76**								**21.18**	**0.43**	
Carebara vidua S. (female thorax)[n)]	1.06	27.06	4.82	1.59	34.53	1.86	51.44		53.30	12.19							12.19	0.53	Kenya; w
Carebara vidua S. (female abdomen)[n)]	1.83	28.75	5.94	3.56	40.08	2.93	46.78		49.71	10.20							10.20	0.67	Kenya; w

Table 3. Continued

Fatty acid composition [% fatty acids]	C14:0	C16:0	C18:0	Other SFA	SFA	C16:1 n7	C18:1 n9	Other MUFA	MUFA	C18:2 n6	C18:3 n3	C18:3 n6	C20:3 n6	C20:4 n6	C20:5 n3	Other PUFA	PUFA	SFA/ UFA	Origin
Carebara vidua S. (male abdomen)[n)]	1.38	25.94	5.78	1.72	34.82	3.31	51.26		54.57	10.61							10.61	0.53	Kenya; w
Polyrhachis vicina Roger (Wenzhou)[o)]	0.60	16.50	4.40	1.4	22.90	9.20	60.80	3.10	73.10	2.40	0.80			0.10	0.40	0.20	4.00	0.30	China; w
Polyrhachis vicina Roger (Guizhou)[o)]	0.60	17.50	4.30	1.5	23.90	8.20	63.00	1.20	72.40	2.10	1.00			0.20	0.10	0.10	3.70	0.31	China; w
Polyrhachis vicina Roger (Zhejiang)[p)]	0.60	19.00	4.30	1.6	25.50	8.90	60.50	1.90	71.30	1.70	0.60			0.10	0.20	0.20	3.10	0.34	China; r
Oecophylla smaragdina[o)]	2.10	20.80	5.80	3.2	31.90	4.30	52.10	2.30	58.70	7.00	0.70			1.00	0.30		9.40	0.47	Thailand; w
Oecophylla smaragdina F. (weaver ant)[c]	0.27	1.19	27.67	0.09	29.22	0.55	1.80		2.35		0.36		9.88	57.82	nd	0.74	68.80	0.41	Thailand; w
Oecophylla smaragdina F. (queen caste)[c)]	0.44	1.68	32.41	0.06	34.59	0.00	1.96		1.96		nd		5.82	57.73	nd		63.55	0.53	Thailand; w
Hymenoptera[j)]	1.55	15.49	4.30	1.55	21.34	4.46	45.77		50.23	10.69	15.54						26.23	0.28	Review
Isoptera (termites)					**41.97**				**22.00**								**36.04**	**0.72**	
Macrotermes bellicosus[h)]	0.18	46.54			46.72	2.09	12.84		14.93	34.42	3.85						38.27	0.88	Nigeria; w
Macrotermes bellicosus oil[q)]	2.17	42.45	2.86	1.50	48.98	2.10	15.84		17.94	24.24	3.90			4.94			33.08	0.96	Nigeria, w
Macrotermes nigeriensis[r)]	0.62	31.39	7.14	0.20	39.35	0.62	52.45		53.07	7.57							7.57	0.65	Nigeria; w
Termes sp.[c)]	0.13	0.78	31.90	0.02	32.83	0.19	1.86		2.05		0.34		8.90	56.01	0.00		65.25	0.49	Thailand; w
Lepidoptera (butterflies, moths)					**37.04**				**23.36**								**39.76**	**0.59**	
Antheraea pernyi (pupae)[s)]		19.92	1.99	0.60	22.51	4.77	30.97		35.74	6.89	34.27					0.39	41.55	0.29	China; r
Bombyx mori (pupae)[s)]		22.77	6.69	nd	29.46	0.60	26.01		26.61	5.90	38.02						43.92	0.42	China; r
Bombyx mori (pupae)[t)]	0.10	24.20	4.50		28.80	1.70	26.00		27.70	7.30	36.30						43.60	0.40	Japan; r
Bombyx mori (spent pupae)[u)]		26.20	7.00		33.20		36.90		36.90	4.20	25.70						29.90	0.50	India; r
Cirina forda Westwood (larvae)[v)]	0.70	13.00	16.00	>1.10	31.60	0.20	13.90	0.50	14.60	8.10	45.30	0.20	<0.10	<0.10	<0.10	0.20	53.80	0.46	Nigeria; w
Imbrasia belina (larvae)[g)]	1.15	31.90	4.71	0.12	37.88	1.80	34.20		36.00	6.02	19.60			0.50			26.12	0.61	Nigeria; w
Imbrasia epimethea (caterpillars)[w)]	0.60	23.20	22.10	0.20	46.10	0.60	8.40		9.00	7.00	35.10					0.40	42.50	0.90	Congo; w
Imbrasia ertli (caterpillars)[h)]	1.00	22.00	0.40	39.50	61.40	22.00	2.00		24.00	20.00	11.00						31.00	1.12	Angola; w
Imbrasia oyemensis[x)]	0.48	45.97	7.21	0.50	54.16		34.62		34.62	11.22							11.22	1.18	Ivory c.; w
Imbrasia truncata (caterpillars)[w)]	0.20	24.60	21.70		46.50	0.20	7.40		7.60	7.60	36.80						44.40	0.89	Congo; w
Nudaurelia oyemensis[w)]	0.20	21.80	23.10	0.20	45.30	0.60	5.60		6.20	5.70	35.60			0.30	1.40	0.40	43.40	0.91	Congo; w
Samia ricinii (prepupae on castor leaves)[y)]		26.45	3.91		30.36	1.90	16.57		18.47	5.62	45.26						50.88	0.44	India; r
Samia ricinii (prepupae on tapioca leaves)[y)]		27.52	3.94		31.46	1.83	18.32		20.15	6.10	41.52						47.62	0.46	India; r
Samia ricinii (pupae on castor leaves)[y)]		26.75	5.61		32.36	1.76	16.19		17.95	4.93	44.74						49.67	0.48	India; r
Samia ricinii (pupae on tapioca leaves)[y)]		27.18	5.45		32.63	1.79	18.46		20.25	5.29	41.38						46.67	0.49	India; r
Lepidoptera[j)]	0.74	25.89	2.27	0.74	28.90	6.36	31.63		37.99	7.67	22.18						29.85	0.43	Review
Orthoptera (crickets, grasshoppers)					**32.05**				**29.37**								**37.08**	**0.48**	
Acheta testacea[e)]					36.50				30.10								31.10	0.60	Thailand; w
Acheta confirmata Walker[d)]		26.10	5.50	1.20	32.80	2.40	31.10		33.50	32.20	1.70	nd		nd	nd		33.90	0.49	Thailand; w
Brachytrupes portentosus Lichtenstein[c)]	nd	1.61	35.79	0.13	37.53	0.71	3.40		4.11		nd		7.94	50.43	nd		58.37	0.60	Thailand; w
Brachytrupes portentosus[e)]					35.00				32.30								29.60	0.57	Thailand; w
Chondracis roseapbrunner Uvarov[d)]		18.20	6.40	1.90	26.50	1.00	20.20		21.20	12.30	40.10	nd		nd	nd		52.40	0.36	Thailand; w
Gryllotalpa africana Beauvois[d)]		28.60	5.60	1.20	35.40	4.80	45.60		50.40	13.80	0.50	nd		nd	nd		14.30	0.55	Thailand; w
Homorocoryphus nitidulus[f)]	0.59				0.59	27.59	6.89	0.28	34.76	45.63	16.19	0.58					62.40	0.01	Camer.; w
Ruspolia differens (green)[z)]	0.90	31.50	5.50	0.40	38.30	1.90	24.60		26.50	31.20	3.20						34.40	0.63	Kenya; w
Ruspolia differens (brown)[z)]	0.70	32.10	5.90	0.20	38.90	1.40	24.90		26.30	29.50	4.20						33.70	0.65	Kenya; w
Orthoptera[j)]	2.04	28.54	8.38	2.04	38.96	2.99	31.52		34.51	11.69	8.97						20.66	0.71	Review
Dictyoptera (cockroaches and termites)																			
Dictyoptera[j)]	3.33	33.56	4.33	3.33	41.22	7.28	42.30		49.58	1.06	nd						1.06	0.81	Review

SFA (saturated fatty acids): C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid. MUFA: C16:1n7 – palmitoleic acid; C18:1n9 – oleic acid. PUFA: C18:2n6 – linoleic acid; C18:3n3 – α-linolenic acid; C18:3n6 – γ-linolenic acid; C20:3n6 – dihomo-γ-linolenic acid; C20:4n6 – arachidonic acid; C20:5n3 – eicosapentaenoic acid (EPA). UFA (unsaturated fatty acids) = MUFA + PUFA. nd, not detected; w, collected in the wild; r, reared; Camer., Cameroon; Ivory c., Ivory coast.

a) [70], b) [71], c) [13], d) [72], e) [33], f) [73], g) [17], h) [30], i) [28], j) [74], k) [23], l) [53], m) [54], n) [56], o) [32], p) [9], q) [17], r) [57], s) [75], t) [67], u) [21], v) [59], w) [62], x) [61], y) [76], z) [65].

acids listed in the table, traces of the odd-numbered fatty acids pentadecanoic (C15:0), heptadecanoic (C17:0), pentadecenoic (C15:1), heptadecenoic (C17:1), and nonadecatrienoic (19:3) acids have been found for some insects. Researchers also found small amounts of the even-numbered saturated fatty acids (SFA) capric acid (C10:0), lauric acid, (C12:0), arachidic acid (C20:0), and behenic acid (C22:0), of the MUFA vaccenic acid (C18:1n11), eicosenoic acid (C20:1n9), and erucic acid (C22:1n9), as well as of the PUFA hexadecadienoic acid (C16:2n6), eicosadienoic acid (C20:2 n6), docosapentaenoic acid (C22:5n3), and docosahexaenoic (C22:6n3; DHA). These fatty acids in edible insects were considered negligible and are summarized under "Other SFA," "Other MUFA," and "Other PUFA" in Table 3. The mean values for SFA, MUFA, PUFA, and the ratio of SFA to unsaturated fatty acids (UFA = MUFA + PUFA) for each insect order are indicated in bold.

The average amount of SFA of edible insect orders ranges from 30.83% for Hymenoptera (ants, bees, and wasps) to 41.97% for Isoptera (termites). The two main components of the SFA are palmitic acid (C16:0) and stearic acid (C18:0). As an exception, for caterpillars (larvae) of *Imbrasia ertli*, the SFA arachidic acid (C20:0) predominated with 38% [30]. The mean fraction of MUFA amounts to between 22.00% for Isoptera and 48.60% for Hymenoptera and the mean fraction of polyunsaturated acids amounts to between 15.95% for Diptera (flies) and 39.76% for Lepidoptera (butterflies and moths). Especially members of the orders Orthoptera and Lepidoptera were found to be comparably high in PUFA. Major MUFA of edible insects include palmitoleic acid (C16:1n7) and oleic acid (C18:1n9). Furthermore, the PUFA linoleic acid (C18:2n6), α-linolenic acid (C18:3n3), γ-linolenic acid (C18:3n6), Dihomo-γ-Linolenic acid (C20:3n6), arachidonic acid (C20:4n6), and eicosapentaenoic acid (C20:5n3; EPA) can be found in the fatty acid spectra of edible insects. In the cases where it had not been distinguished between α- and γ-linolenic acid (C18:3), the data were entered midway of both table columns.

It is conspicuous that in all fatty acid spectra of Raksakantong et al. [13], the MUFA contents are uncharacteristically low in elaidic acid (C18:1n9) and the PUFA contents uncharacteristically high in arachidonic acid (C20:4n6) but devoid of linoleic acid (C18:2n6) in comparison to data published by other authors. In addition, it is mentionable that two fatty acid spectra derived from a review by Bukkens [30] and originating from Angola yield more than 100% which indicates discrepancies.

The fatty acids of insects are generally comparable to those of poultry and fish in their degree of unsaturation, but contain more PUFA [31]. In contrast, beef and pork contain very little PUFA, MUFA make up the greatest portion of the fatty acids present in beef and pork. Similar fatty acid spectra were obtained for some ants (Hymenoptera) with MUFA contents of up to 73.10% [32] and PUFA contents as low as 3.10% [9]. Yhoung-aree [33] observed that house crickets, short-tailed crickets, and scarab beetles have a fatty acid ratio of 1:1:1 (PUFA:MUFA:SFA) being optimal for an adequate fat uptake. This could not be confirmed, but it could be observed that the average ratio of SFA to UFA on ranges between 0.43 and 0.79 which is basically in agreement with Yhoung-aree [33] and clearly shows that unsaturated acids predominate in the fatty acid spectra of edible insects.

For the prevention of coronary heart diseases, a daily uptake of 500 mg EPA (C20:5) + DHA (C22:6) is recommended which can be met by the consumption of 180 g of oily fish per week [34]. Insects for the most part contain only traces of these two PUFA or they have not been detected in insects at all (see Table 3). However, a replacement of SFA with PUFA in general leads to a decrease in the risk of coronary heart diseases and the PUFA α-linolenic acid (18:3 n3) and linoleic acid (18:2 n6) are essential, i.e., they cannot be synthesized by humans [34]. Rather high amounts of linoleic and/or linolenic acids have been reported for the fatty acid profiles of insects in some cases [24]. This corresponds with the data from literature as shown in Table 3 where insect fat is in general especially rich in these two fatty acids. It has to be noted that, analogue to livestock [34, 35], the fatty acid composition of insects is dependent on the feed composition [8, 36]. For example, a significant enrichment in lipids as well as in the omega-3 fatty acids EPA and DHA of black soldier fly prepupae has been accomplished by feeding them fish offal as fatty acid recycling [37].

Just like the fatty acid composition, the cholesterol content in insects varies with their diet [36]. Yhoung-aree [33] studied the cholesterol content per 100 g sample (fresh weight) of insects collected in Thailand and stated that the cholesterol content was high in house crickets (105 mg/100 g), Bombay locusts (66 mg/100 g), scarab beetles (56 mg/100 g), and bamboo caterpillars. In contrast, large fresh, raw eggs contain in comparison with 372 mg cholesterol per 100 g [38] more than three times as much cholesterol. Ekpo et al. [17] determined the total cholesterol content of four insects consumed in Southern Nigeria and resulted in much lower cholesterol contents of between 7.31 mg/100 g dry sample for *Imbrasis belina* and 22.91 mg/100 g dry sample for *R. phoenicis*, total cholesterol contents per 100 g fresh sample were accordingly lower. Ritter [36] stated that insects cannot synthesize cholesterol de novo and contain approximately 0.1% sterols obtained from their diet. Some insect species like, e.g., the honey bee *A. mellifera* are not able to convert the plant sterols to cholesterol. Furthermore, insects naturally feeding on diets containing other sterols than Δ5-sterols lack cholesterol. In addition, it was discovered that it is possible to circumvent the production of cholesterol in insects by replacing Δ5-sterols with, e.g., Δ7-sterols in their diet. This has been accomplished successfully for the Lepidopteran *Heliothis zea*. It is therefore possible to utilize insects as food constituents being nutritionally valuable but low in cholesterol in human diets. The presence and contents of micronutrients has also to be considered, however.

Table 4. Mineral composition [mg/100 g] of edible insects (based on dry matter) and recommended daily intakes [mg/day] for adults

Mineral compostion [mg/100 g] based on dry matter	Ca	K	Mg	P	Na	Fe	Zn	Mn	Cu	Se	Origin
Coleoptera (beetles, grubs)											
Analeptes trifasciata[a)]	61.28		6.14	136.40		18.20					Nigeria; wild
Oryctes boas[a)]	45.68		6.62	130.20		2.31					Nigeria; wild
Oryctes rhinoceros L. (larvae)[b)]	0.04	0.20			26.28	4.94					Nigeria; wild
Rhyncophorus phoenicis (larvae)[c)]	208.00	2209.00	33.60	352.00	44.80	14.70	26.50	0.80	1.60		Angola; wild
Rhyncophorus phoenicis (larvae)[d)]	54.10	1025.00	131.80	685.00	52.00	30.80	15.80	3.50			Nigeria; wild
Rhyncophorus phoenicis[a)]	39.58		7.54	126.40		12.24					Nigeria; wild
Tenebrio molitor (larvae)[e)]	47.18	761.54	221.54	697.44	125.38	5.51	11.41	0.92	1.64	0.03	USA; reared
Tenebrio molitor (adults)[e)]	63.64	936.64	166.94	763.09	174.10	6.01	12.73	1.10	2.07	0.04	USA; reared
Tenebrio molitor (larvae)[e)]	44.36	895.01	210.24	748.03	140.94	5.41	13.65	1.36	1.60	0.07	USA; reared
Tenebrio molitor[f)]	120.00		280.00	1420.00		3.97	13.10	0.68	1.78		USA; reared
Tenebrio molitor (Mighty Mealys™)[f)]	30.00		220.00	1270.00		2.59	8.28	0.56	1.49		USA; reared
Zophobas morio[f)]	120.00		180.00	830.00		5.03	8.75	0.15	1.39		USA; reared
Zophobas morio[e)]	42.04	750.59	118.29	562.95	112.83	3.92	7.29	1.02	0.86	0.03	USA; reared
Diptera (flies)											
Drosophila melanogaster[f)]	140.00		130.00	1100.00		45.42	14.70	1.61	0.87		USA; reared
Musca domestica (larvae)[g)]	2010.00			1320.00	660.00	60.40	23.70	5.60	3.40		S. Korea; reared
Hemiptera (true bugs)											
Agonoscelis pubescens (Thunberg)[h)]	759.51	412.52	309.22	923.11	340.41						Sudan; wild
Aspongubus viduatus F.[h)]	1021.21	200.08	301.10	1234.33	401.10						Sudan; wild
Euschistus sp.[i)]	204.00	108.00	1910.00		397.00	57.00	59.00				Mexico; wild
Hymenoptera (ants, bees)											
Apis mellifera (honeybee)[a)]	15.40		5.23	125.50		25.20					Nigeria; wild
Bee brood[j)]	59.48	1159.48	90.95	771.55	55.17	5.56	6.90	0.26	1.72		USA; reared
Carebara vidua Smith (female)[k)]	22.23	51.73	10.41	106.04	26.23	10.69	5.69				Kenya; wild
Liometopum apiculatum[i)]	26.00	24.00	317.00		20.00	5.00	10.00				Mexico; wild
Oecophylla sp.[c)]	48.00	541.00	70.00	517.00	180.00	21.80	10.10	9.06	0.87		Papua; wild
Oecophylla virescens[c)]	79.70	957.00	122.10	936.00	270.00	109.00	16.90	6.30	2.17		Papua; wild
Onyoso mammon (ant)[l)]	32.60					17.70	11.10				Kenya; wild
Polybia occidentalis nigratella[i)]	93.00	54.00	982.00		59.00	35.00	28.00				Mexico; wild
Polybia sp.[i)]	101.00	1080.00	530.00		194.00	50.00	32.00				Mexico; wild
Polyrhachis vicina Roger (from Zhejiang)[m)]	49.10		65.30	387.70		118.00	17.60	25.90	2.40		China; reared
Polyrhachis vicina Roger (from Guizhou)[m)]	108.00		67.60	417.00		53.70	11.90	32.30	1.90		China; reared
Isoptera (termites)											
Agoro (termites)[l)]	132.00					161.00	14.30				Kenya; wild
Macrotermes bellicosus[a)]	21.00		0.15	136.00		27.00					Nigeria; wild
Macrotemres nigeriensis[n)]	0.10	336.00	6.10	1.49	112.00	0.96	0.10	0.08	0.07	0.00	Nigeria; wild
Macrotermis notalensis[a)]	18.00		0.26	114.00		29.00					Nigeria; wild
Ogawo (termites)[l)]	83.00					93.90	8.10				Kenya; wild
Oyala (termites)[l)]	84.70					332.00	11.90				Kenya; wild
Lepidoptera (butterflies and moths)											
Anaphe infracta (caterpillars)[a)]	8.56		1.01	111.30		1.78					Nigeria; wild
Anaphe recticulata (caterpillars)[a)]	10.52		2.56	102.40		2.24					Nigeria; wild
Anaphe spp. (caterpillars)[a)]	7.58		0.96	122.20		1.56					Nigeria; wild
Anaphe venata (caterpillars)[a)]	8.57		1.56	100.50		2.01					Nigeria; wild
Anaphe venata (larvae)[o)]	40.00	1150.00	50.00	730.00	30.00	10.00	10.00	40.00	1.00		Nigeria; wild

Table 4. Continued

Mineral compostion [mg/100 g] based on dry matter	Ca	K	Mg	P	Na	Fe	Zn	Mn	Cu	Se	Origin
Bombyx mori (larvae)[e]	102.31	1826.59	287.86	1369.94	274.57	9.54	17.75	2.49	2.08	0.08	USA; reared
Bombyx mori (spent pupae)[p]	158.00		207.00	474.00		26.00	23.00	0.71	0.15		India; reared
Cirina forda (caterpillars)[a]	8.24		1.87	111.00		1.79					Nigeria; wild
Cirina forda (Westwood) (larvae flour)[q]	12.90	47.60	43.80	45.90	44.40	1.30	24.20	nd	nd		Nigeria; wild
Cirina forda (Westwood) (larvae)[r]	37.20	71.81	69.89	241.77	50.77	5.99	4.27	10 163.10			Nigeria; wild
Cirina forda Westwood (larvae)[s]	7.00	2130.00	32.40	1090.00	210.00	64.00	8.60	7.00			Nigeria; wild
Comadia redtembacheri[i]	68.00	515.00	296.00		283.00	24.00	24.00				Mexico; wild
Conimbrasia belina[c]	174.00	1024.00	160.00	543.00	1032.00	31.00	14.00	3.95	0.91		
Galleria mellonella[f]	60.00		90.00	1200.00		7.73	7.88	0.33	0.31		USA; reared
Galleria mellonella[e]	58.55	532.53	76.14	469.88	39.76	5.04	6.12	0.31	0.92	0.03	USA; reared
Imbrasia epimethea (caterpillars)[t]	224.73	1258.06	402.15	666.67	75.27	13.01	11.08	5.81	1.18		Zaire; wild
Imbrasia ertli (caterpillars)[c]	55.00	1204.00	254.00	600.00	2418.00	2.10		3.40	1.50		Angola; wild
Imbrasia oyemensis (caterpillar)[u]	73.00	680.00			730.00						Ivory coast; wild
Imbrasia truncata (caterpillars)[t]	131.61	1348.44	192.02	841.42	183.39	8.74	11.11	3.24	1.40		Zaire; wild
Nudaurelia oyemensis (caterpillars)[t]	149.46	1107.53	265.59	870.97	139.78	10.22	5.48	5.48	1.18		Zaire; wild
Samia ricinii (prepupae on castor leaves)[v]	75.40		180.00	585.00		25.40	7.10	2.63	1.69		India; reared
Samia ricinii (prepupae on tapioca leaves)[v]	76.80		196.00	572.00		25.20	7.10	2.69	1.78		India; reared
Samia ricinii (pupae on castor leaves)[v]	74.20		178.00	584.00		24.00	7.24	2.54	1.75		India; reared
Samia ricinii (pupae on tapioca leaves)[v]	71.20		187.00	570.00		23.40	7.02	2.61	1.80		India; reared
Usta terpsichore (caterpillar)[c]	391.00	3259.00	59.00	766.00	3340.00	39.10	25.30	6.70	2.60		Angola; wild
Orthoptera											
Acheta domesticus (adults)[f]	210.00		80.00	780.00		11.23	18.64	2.97	0.85		USA; reared
Acheta domesticus (adults)[e]	132.14	1126.62	109.42	957.79	435.06	6.27	21.79	3.73	2.01	0.06	USA; reared
Acheta domesticus (juvenile crickets)[f]	1290.00		160.00	790.00		19.68	15.91	5.28	0.96		USA; reared
Acheta domesticus (nymphs)[e]	120.09	1537.12	98.69	1100.44	589.52	9.26	29.69	3.89	2.23	0.04	USA; reared
Arphia fallax S.[w]	75.00	62.00	657.00		92.00	22.00	16.00				Mexico; wild
Boopedon sp. af. *flaviventris* S.	88.00	66.00	521.00		173.00	24.00	32.00				Mexico; wild
Brachytypes spp.[a]	9.21		0.13	126.90		0.68					Nigeria; wild
Cytacanthacris aeruginosus unicolor[a]	4.40		0.09	100.20		0.35					Nigeria; wild
Encoptolophus herbaceus B.[w]	64.00	65.00	498.00		150.00	17.00	16.00				Mexico; wild
Melanoplus femurrubrum[i]	144.00	76.00	902.00		134.00	37.00	21.00				Mexico; wild
Melanoplus mexicanus S.[w]	120.00	62.00	740.00		110.00	32.00	17.00				Mexico; wild
Ochrottetix cer. Salinus B.[w]	64.00	62.00	532.00		66.00	27.00	26.00				Mexico; wild
Onjiri mammon[l]	341.00					1562.00	25.10				Kenya; wild
Osmilia flavolineata D.G.[w]	80.00	65.00	672.00		173.00	19.00	24.00				Mexico; wild
Ruspolia differens (brown)[x]	24.50	259.70	33.10	121.00	229.70	13.00	12.40	2.50	0.50		Kenya; wild
Ruspolia differens (green)[x]	27.40	370.60	33.90	140.90	358.70	16.60	17.30	5.30	0.60		Kenya; wild
Sphenarium histrio[i]	48.00	41.00	700.00		103.00	26.00	58.00				Mexico; wild
Sphenarium histrio G.[w]	96.00	422.00	744.00		426.00	23.00	21.00				Mexico; wild
Sphenarium histrio G. (adults)[w]	82.00	177.00	420.00		1142.00	16.00	78.00				Mexico; wild
Sphenarium magnum M. (adults)[w]	88.00	574.00	352.00		102.00	20.00	32.00				Mexico; wild
Sphenarium purpurascens Ch. (adults)[w]	112.00	377.00	424.00		609.00	18.00	42.00				Mexico; wild
Sphenarium spp.[w]	120.00	68.00	824.00		915.00	44.00	32.00				Mexico; wild
Zonocerus variegatus (1st instar larvae)[y]	552.00	2030.00	96.00	4500.00	1350.00	910.00	29.00				Nigeria; wild
Zonocerus variegatus (adult)[y]	182.00	761.00	39.00	21 800.00	306.00	184.00	17.00				Nigeria; wild
Zonocerus variegatus[a]	42.16		8.21	131.20		1.96					Nigeria; wild
Recommended daily intakes [mg/day] for adults	**1300**[z]	**4700***	**220–260**[z]	**700***	**≤1500***	**7.5–58.8**[z]	**3.0–14.0**[z]	**1.8–2.6***	**0.9–1.3***	**0.026–0.036**[z]	

nd, not detected.
a) [12], b) [18], c) [30], d) [28], e) [16], f) [40], g) [23], h) [54], i) [15], j) [55], k) [56], l) [39], m) [9], n) [57], o) [58], p) [21], q) [60], r) [46], s) [59], t) [62], u) [61], v) [63], w) [14], x) [65], y) [77], z) [41].
*Linus Pauling Institute's Micronutrient Center (http://lpi.oregonstate.edu/infocenter/ (as seen on September 18, 2012)).

2.3 Vitamin and mineral content of insects

Eighty-five mineral compositions of edible insects as derived from literature and the recommended daily intakes for adults (values in bold) are depicted in Table 4 in mg/100 g based on dry matter. Again a large variation can be observed and it was so enormous that it was abstained from the formation of mean values. It is furthermore striking that most mineral contents of insects collected in Nigeria are comparably low which might be due to their feed composition.

It can be observed that except for larvae of the housefly (*Musca domestica*) [23], all insects analyzed are low in calcium and do not meet the required amount for adults. A 100 g of dried insects also does not fulfill the requirements for the daily uptake of 4700 mg/day for potassium. On the other hand, most insects show very high amounts of phosphorous, and 24 of 60 insects meet the recommended dietary allowance for adults. Of the 77 insects analyzed for their magnesium content, only 23 insects sufficiently supply with magnesium. It is noteworthy that true bugs (Hemiptera) and some species of the order Orthoptera (grasshoppers, crickets, locusts) are especially rich in magnesium. Generally insects are low in sodium. Only some caterpillars (larvae of the order Lepidoptera) have high-sodium contents per 100 g and in two cases even exceed the maximum daily uptake of 1500 mg sodium [30]. The required amount of iron is highly dependent on its bioavailabilty, and the consumer's age and sex—premenopausal women require more than twice as much iron as men and postmenopausal women—and thus varies from 7.5 to 58.5 mg/day. Since no statement can be made about the iron's bioavailability in insects, a required amount of 58.5 mg/day is assumed. Consequently, only ten of 82 insects contain the required amount of irons for adults and especially the cricket *Onjiri mammon* and several termites from Kenya are high in iron [39]. However, insects partially contain much more iron and calcium than beef, pork, and chicken [3]. It was also suggested that the consumption of insects could decrease iron and zinc deficiency in developing countries [39]. Although this could not be confirmed regarding iron supply, most edible insects show high zinc contents. Especially species of the order Orthoptera (grasshoppers, crickets, locusts) could function as zinc supplementing food (ingredients). Furthermore, edible insects contain in most cases sufficient amounts of manganese and copper. Only beetles and termites are generally low in manganese. In the nine cases where it has been determined, the amount of selenium in mg/100 g dry matter is sufficient in all cases but for the termite *Macrotermes nigeriensis*. It can be concluded that, although a 100 g of edible insects generally lack sufficient amounts of calcium and potassium, edible insects have the potential to provide with specific micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium, and zinc. It is furthermore assumed that the content of micronutrients in edible insects can be controlled via feed. In addition, edible insects can be utilized in low-sodium diets.

In addition to minerals, insects provide with several vitamins, and the vitamin contents of edible insects derived from literature and the recommended daily intakes for adults are shown in Table 5. Vitamin A values were calculated as 1U = 0.3 μg retinol according to Barker et al. [40]. It can generally be observed that little data on the vitamin content of edible insects have been published to date and that the available data are subject to deviation.

Referring to vitamin requirements in human nutrition of adults (bold values in Table 5) [41], a 100 g of insects based on dry matter is generally rich in riboflavin, pantothenic acid, and biotin. Insects of the order Orthoptera (grasshoppers, crickets, locusts) and Coleoptera (beetles) are also rich in folic acid. On the other hand, 100 g of insects are not an efficient source of vitamin A, vitamin C, niacin, and in most cases thiamin. By contrast, it was determined that an insect tea made from the excrements of insects contained up to 15.04 mg vitamin C per 100 g [7]. Since the FAO recommends a daily uptake of 45 mg vitamin C for adults [41], a daily consumption of 300 mL of this insect tea covers the recommended daily amount of vitamin C in the nutrition of adults.

Vitamin E activity had been specified in international units (IU) per kilogram, whereas the recommended amount is given in milligram α-TE (α-tocopherol equivalent) per day. Since vitamin E does not only consist of α-tocopherol (1 IU = 1 mg) but of a mixture of antioxidant substances including tocopherols and tocotrienols with partly much lower activities, it is difficult to convert the data to uniform units. However, even assuming the determined vitamin E activities of edible insects are due to pure α-tocopherol, most edible insects but the larvae of the waxworm *Galleria melonella* and the house cricket *A. domesticus* [16, 40] would be poor sources of vitamin E.

In summary, edible insects can be rich in vitamins but species have to be specifically selected for the provision of desired vitamins. Furthermore, it was suggested that the content of vitamins in edible insects can be controlled via feed [42].

3 Liabilities of entomophagy

Besides all the nutritionally beneficial ingredients edible insects supply, caution needs to be exercised regarding endogenous and exogenous risk factors of (edible) insects. Just as it applies for plant and animal food products, some insects are not edible or not safe to eat [43].

Endogenous risk factors comprise for, e.g., antinutrient substances and allergens. For example, it was determined that the pupae of the African silkworm *Anaphe* spp. contain a heat-resistant thiaminase that has been responsible for seasonal ataxic syndrome cases due to thiamin deficiency in Nigeria for the last 40 years [44]. Furthermore, it has been discovered that insects just like other arthropods (e.g., shellfish) can cause allergic reactions. These are caused by injectant allergens (bees, wasps, and ants), contactant allergens, inhalant allergens (e.g., cast skins, excreta), and/or ingestant

Table 5. Vitamin composition of edible insects (based on dry matter)

	Vit A [µg/100 g]	Vit E [IU/kg]	Vit C [mg/100 g]	Vit B1 [mg/100 g]	Vit B2 [mg/100 g]	Vit B3 [mg/100 g]	Vit B5 [mg/100 g]	Vit B7 [µg/100 g]	Vit B9 [mg/100 g]	Origin
Blattodea (cockroaches)										
Periplaneta americana (nymphs)[a)]	8.72		23.84							Mexico; reared
Periplaneta americana (adults)[a)]	48.16		23.84							Mexico; reared
Periplaneta americana L (larvae)[b)]	4.80		23.80							Mexico; reared
Periplaneta americana L (adults)[b)]	0.87		23.80							Mexico; reared
Coleoptera (beetles, grubs)										
Analeptes trifasciata[c)]	12.54		5.41		2.62					Nigeria; wild
Asplagiognathus spinosus (larvae)[a)]			23.43	0.08	0.18	0.42				Mexico; wild
Oryctes boas[c)]	8.58		7.59		0.08					Nigeria; wild
Rhyncophorus phoenicis (larvae)[d)]				3.38	2.51	3.36				Angola; wild
Rhyncophorus phoenicis[c)]	11.25		4.25		2.21					Nigeria; wild
Scyphophorus acupunctatus (larvae)[a)]				0.20	0.25	1.38				Mexico; wild
Tenebrio molitor (larvae)[e)]			6.15	0.31	0.41	10.59	3.72	94.87	0.30	USA; reared
Tenebrio molitor (adults)[e)]			14.88	0.28	2.34	14.80	6.61	77.13	0.38	USA; reared
Tenebrio molitor (larvae)[e)]			3.15	0.63	2.13	10.68	6.88	78.74	0.41	USA; reared
Tenebrio molitor (larvae)[a)]			36.10							Mexico; reared
Tenebrio molitor (pupae)[a)]			15.44							Mexico; reared
Tenebrio molitor (adults)[a)]	22.61		45.73							Mexico; reared
Tenebrio molitor[f)]	24.33	30.00								USA; reared
Tenebrio molitor (Mighty Mealys™)[f)]	4.83	15.00								USA; reared
Zophobas morio[f)]	29.16	32.00								USA; reared
Zophobas morio[e)]		18.29	2.85	0.14	1.78	7.67	4.61	83.14	0.16	USA; reared
Diptera (flies)										
Copestylum anna/ haggi (larvae)[a)]				1.47	2.56	11.07				Mexico; wild
Drosophila melanogaster[f)]	0.00	23.00								USA; reared
Hemiptera										
"Ahuahutle" (eggs)[a)]				0.41	0.81	2.64				Mexico; wild
"Axayacatl" (adults)[a)]				1.01	0.76	4.14				Mexico; wild
Euschistus egglestoni (adults)[a)]				0.15	0.28	0.71				Mexico; wild
Euschistus strennus (adults)[a)]				0.18	0.42	0.75				Mexico; wild
Euschistus taxcoensis (adults)[a)]				0.41	0.18	2.64				Mexico; wild
Thasus gigas (nymphs)[a)]				0.31	0.50	2.26				Mexico; wild
Hymenoptera (ants, bees)										
Apis mellifera (honeybee)[c)]	12.44		10.25		3.24					Nigeria; wild
bee brood[g)]		<2.16	16.38					0.10		USA; reared
Atta cephalotes[a)]				0.61	1.01	1.26				Mexico; wild
Atta mexicana[a)]				0.19	0.53	3.09				Mexico; wild
Brachygastra mellifica (larvae, pupae)[a)]				0.11	0.17	0.25				Mexico; wild
Carebara vidua Smith (female)[h)]	767.00	5.93	0.03	0.46	20.26	0.28			0.45	Kenya; wild
Liometopum apiculatum[a)]	0.88		36.14	0.15	0.34	0.67				Mexico; wild
Liometopum occidentale var. Luctuosum[a)]				0.14	0.29	2.06				Mexico; wild
Oecophylla sp.[d)]				0.44	0.98					Papua; wild
Polybia occidentalis bohemani[a)]				0.45	0.38	1.08				Mexico; wild
Polybia parvulina (larvae, pupae)[a)]				0.44	0.39	2.47				Mexico; wild
Vespula squamosa (larvae, pupae)[a)]				0.18	0.34	6.25				Mexico; wild

Table 5. Continued

	Vit A [μg/100 g]	Vit E [IU/kg]	Vit C [mg/100 g]	Vit B1 [mg/100 g]	Vit B2 [mg/100 g]	Vit B3 [mg/100 g]	Vit B5 [mg/100 g]	Vit B7 [μg/100 g]	Vit B9 [mg/100 g]	Origin
Isoptera (termites)										
Macrotermes bellicosus[c)]	2.89		3.41		1.98					Nigeria; wild
Macrotemres nigeriensis[i)]	350.00		17.76	0.67	1.56	2.74				Nigeria; wild
Macrotermis notalensis[c)]	2.56		3.01		1.54					Nigeria; wild
Lepidoptera (butterflies and moths)										
Anaphe infracta (caterpillars)[c)]	2.95		4.52		2.00					Nigeria; wild
Anaphe recticulata (caterpillars)[c)]	3.40		2.24		1.95					Nigeria; wild
Anaphe spp. (caterpillars)[c)]	2.78		3.20		0.09					Nigeria; wild
Anaphe venata (caterpillars)[c)]	3.12		2.22		1.25					Nigeria; wild
Bombyx mori (larvae)[e)]	273.99	51.45	<5.78	1.91	5.43	15.20	12.49	144.51	0.41	USA; reared
Bombyx mori (spent pupae)[j)]						0.95				India; reared
Cirina forda (caterpillars)[c)]	2.99		1.95		2.21					Nigeria; wild
Conimbrasia belina[d)]				0.58	4.98	11.90				
Galleria mellonella[f)]	4.50	509.00								USA; reared
Galleria mellonella[e)]		32.05		0.55	1.76	9.04	4.87	69.88	0.11	USA; reared
Imbrasia epimethea (caterpillars)[k)]	47.31			0.22	4.30	11.83	7.85	24.73	0.01	Zaire; wild
Imbrasia truncata (caterpillars)[k)]	33.44			0.32	5.50	11.76	11.00	48.54	0.04	Zaire; wild
Latebraria amphypirioides (larvae)[a)]	0.96		46.33							Mexico; wild
Nudaurelia oyemensis (caterpillars)[k)]	32.26			0.22	3.44	10.11	9.46	32.26	0.02	Zaire; wild
Phasus triangularis (larvae)[a)]				0.24	0.47	2.92				Mexico; wild
Spodoptera exigua (larvae)[a)]				0.09	0.17	0.65				Mexico; wild
Usta terpsichore (caterpillar)[d)]				4.04	2.09	0.33				Angola; wild
Xyleutes redtembacheri (larvae)[a)]			17.58	0.31	0.46	1.83				Mexico; wild
Odonata										
Anax sp. (nymphs)[a)]				0.05	0.09	1.29				Mexico; wild
Orthoptera										
Acheta domesticus (adults)[f)]	24.33	81.00								USA; reared
Acheta domesticus (adults)[e)]		63.96	9.74	0.13	11.07	12.59	7.47	55.19	0.49	USA; reared
Acheta domesticus (juvenile crickets)[f)]	14.13	71.00								USA; reared
Acheta domesticus (nymphs)[e)]		41.92	7.86	0.09	4.15	1.43	11.48	21.83	0.63	USA; reared
Acheta domesticus (nymphs)[a)]	0.23		25.47							Mexico; reared
Acheta domesticus (adults)[a)]	0.10		23.92							Mexico; reared
Acheta domesticus (adults)[b)]	0.01		23.90							Mexico; reared
Acheta domesticus (nymphs)[b)]	0.02		25.50							Mexico; reared
Brachytypes spp.[c)]	0.00		0.00		0.03					Nigeria; wild
Cytacanthacris aeruginosus unicolor[c)]	1.00		1.00		0.08					Nigeria; wild
Ruspolia differens (brown)[l)]	280.00	22.64	0.10	n.d.	1.40	2.40			0.90	Kenya; wild
Ruspolia differens (green)[l)]	210.00	29.95	0.10	n.d.	1.20	2.10			0.90	Kenya; wild
Sphenarium magnum (adults)[a)]				0.83	1.28	3.97				Mexico; wild
Sphenarium purpurascens (adults)[a)]				0.27	0.59	1.56				Mexico; wild
Sphenarium sp. (adults)[a)]				0.50	0.66	5.04				Mexico; wild
Zonocerus variegatus (1st instar larvae)[m)]	111.79		0.00							Nigeria; wild
Zonocerus variegatus (adult)[m)]	814.49		0.01							Nigeria; wild
Zonocerus variegatus[c)]	6.82		8.64		0.07					Nigeria; wild
Recommended daily intakes for adults[n)]	**500–600 μg/day**	**7.5–10 mg α-TE/day**	**45 mg/day**	**1.2–1.3 mg/day**	**1.1–1.3 mg/day**	**14–16 mg/day**	**5 mg/day**	**30 μg/day**	**0.4 mg/day**	

Vit, vitamin.
a) [78], b) [14], c) [12], d) [30], e) [16], f) [40], g) [55], h) [56], i) [57], j) [21], k) [62], l) [65], m) [77], n) [41].

allergens. Since contactant and inhalant allergens predominate in insects, the health hazards from insect allergens prevail for personnel of the insect rearing industry [4], but caution is nevertheless advised regarding allergic reactions at the first consumption of edible insects.

Ekop et al. [45] investigated the content of the antinutrients hydrocyanide, oxalate, phytate, and tannin in four insects species but found generally low levels of those four antinutrients that were far below the toxic levels for human consumption. This was in agreement with an antinutritional analysis of larvae of *Cirina forda* (Westwood) yielding in levels of oxalate and phytic acid within nutritionally accepted values and in no tannin [46].

Finke [47] estimated the chitin content in seven commercially reared edible insects and came to the conclusion that the chitin content of these insects amounted to 2.7–49.8 mg/kg based on fresh weight or 11.6–137.2 mg/ kg based on dry matter. Since chitinolytic enzymes produced by bacteria isolated from the gastrointestinal tract of healthy humans have been found [48], it has been acknowledged that chitosan/chitin can be digested by humans.

In addition to toxic, allergenic or antinutrient substances incorporated in insects, extrinsic factors have to be considered as well. Reports of cases of botulism, parasitoses, and food poisoning, e.g., due to aflatoxins caused by entomophagy [49] illustrate the importance of food safety and decontamination regarding edible insects. In addition, some insects sequester toxins via feed and/or synthesize toxins, e.g., cyanogenic or cardiac glucosides, steroids or pederin, as a chemical defense mechanism against insectivores. Consumption of these insects can lead to nausea, vomiting, visual disturbance, or worse [5, 50, 51]. It was also reported that insects harvested in the wild that are usually safe to eat contain pesticides when they have fed in pesticide-treated areas [49]. However, controlled feeding of edible insects with nontoxic plants eliminates the risk of sequestering and pesticide uptake.

An investigation of the microbial fauna on the body surface as well as the gut of the beetle *Oryctes monocerus* revealed the presence of the pathogens *Bacillus cereus*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* as well as nonpathogenic *Bacillus* species [27]. Klunder et al. [52] investigated the microbiological aspects of three fresh, processed, and stored whole edible insects and observed that sporeforming bacteria enduring a boiling step could represent a safety problem in entomophagy. Moreover, storage in a refrigerator subsequent to the thermal treatment is advised to delay microbial spoilage during storage.

It can be concluded that investigations of the microbial contamination of edible insects as well as of the native intestinal microbiota illustrate the potential microbial threat of entomophagy and urge that the decontamination methods and shelf life stability of each edible insect product need to be ensured in order to obtain marketability and food safety. Although antinutrient substance do not appear to be of consequence, more data are required on this subject. In addition, thorough knowledge of the toxic and allergenic potential of edible insects is mandatory before their application in food.

4 Conclusion and future research

It can generally be concluded that edible insects are a potential food and protein source since they have high energy and protein contents, meet amino acid requirements for humans, are high in MUFA and/or PUFA, and rich in several micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium, and zinc as well as riboflavin, pantothenic acid, biotin, and in some cases folic acid. However, it has to be kept in mind that the nutrient composition of insects is highly dependent on the feed. This possibly also opens up opportunities for regulation, enrichment, and addition of certain food ingredients such as the ω-3-fatty acids DHA and EPA via feed.

More research is required on the quality of insect proteins in order to be able to fully assess its value in comparison to plant proteins as well as other animal proteins and more data, especially on the fatty acid composition, mineral and vitamin content of edible insects are necessary for a more profound statement on their nutritional value. In addition to the nutrient profile, the presence of potentially harmful ingredients such as toxins, allergens, and antinutrients should be investigated further. Because of the potential microbial threat as well as the rapid spoilage of raw edible insects, decontamination methods and storage conditions have to be evaluated and developed.

The authors have declared no conflict of interest.

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