The role of edible insects in healthy human diets

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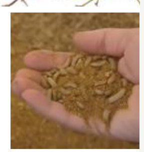
Beebrood-pea soup by Roberto Flores. Photo: Afton Halloran

We eat diverse diets – where do insects belong?



?

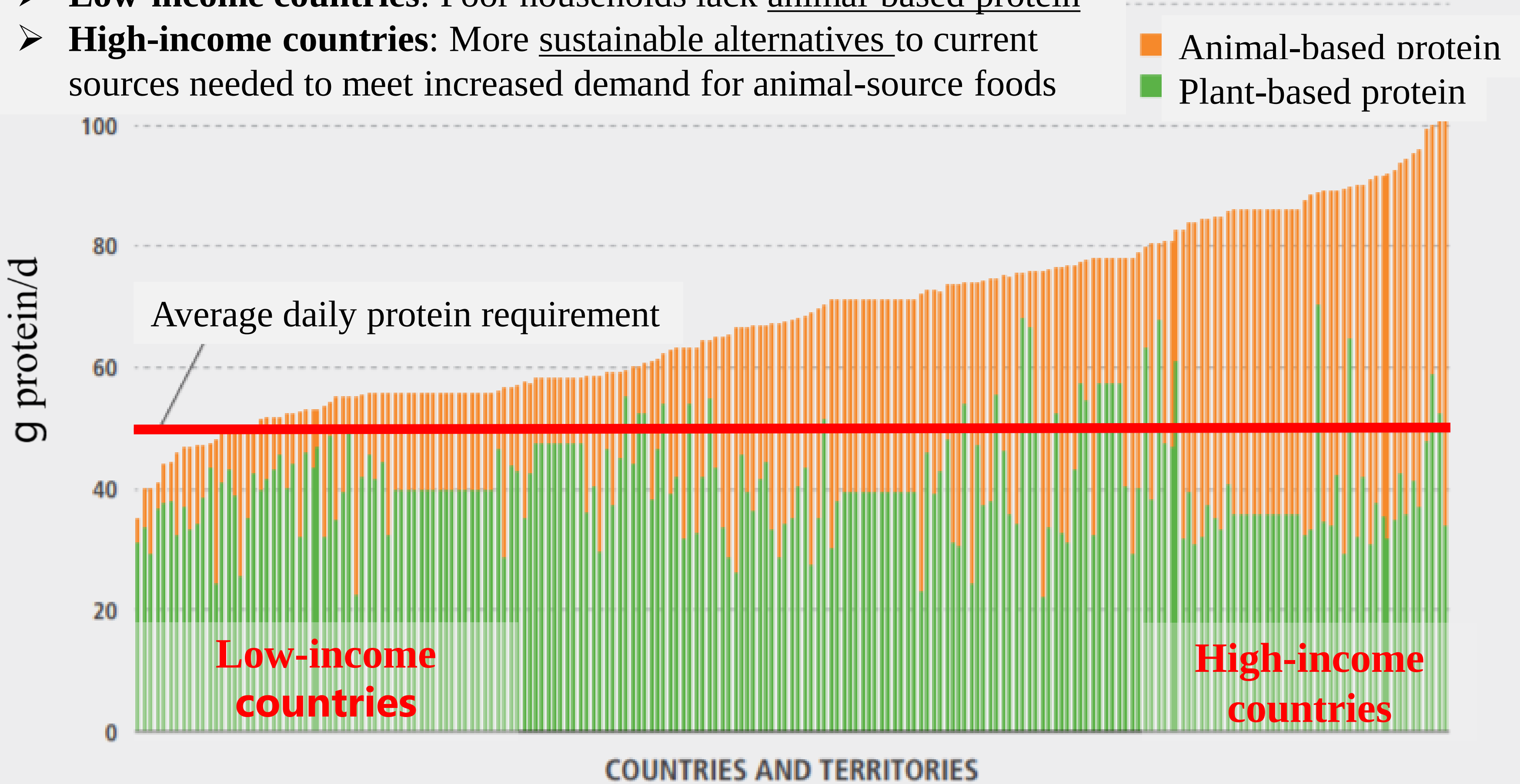
Insects are animals-source foods = source of protein, fat and micronutrients

	INSECT ORDER	PROTEIN (% dry matter)	FAT (% dry matter)
	**Orthoptera**		
	Crickets		
	Acheta domesticus	60-75	7-20
	Gryllodes sigillatus	60-75	7-20
	**Grasshoppers/locusts**		
	Locusta migratoria	40-60	10-25
	Schistocerca americana	40-60	10-25
	**Diptera (flies)**		
	Musca domestica	55-70	10-25
	Hermetia illucens	40-60	20-40
	**Coleoptera (beetles)**		
	Tenebrio molitor	45-55	25-35
	Zophobas atratus	40-50	40-45
	Alphitobus diaperinus	45-60	25-30
	**Lepidoptera (moths)**		
	Galleria mellonella	35-45	40-60
	Achroia grisella	35-45	40-60
	Bombyx mori	50-70	8-10

Ranges for fat and protein compiled by N Roos from various sources

Are food systems deficient in protein?

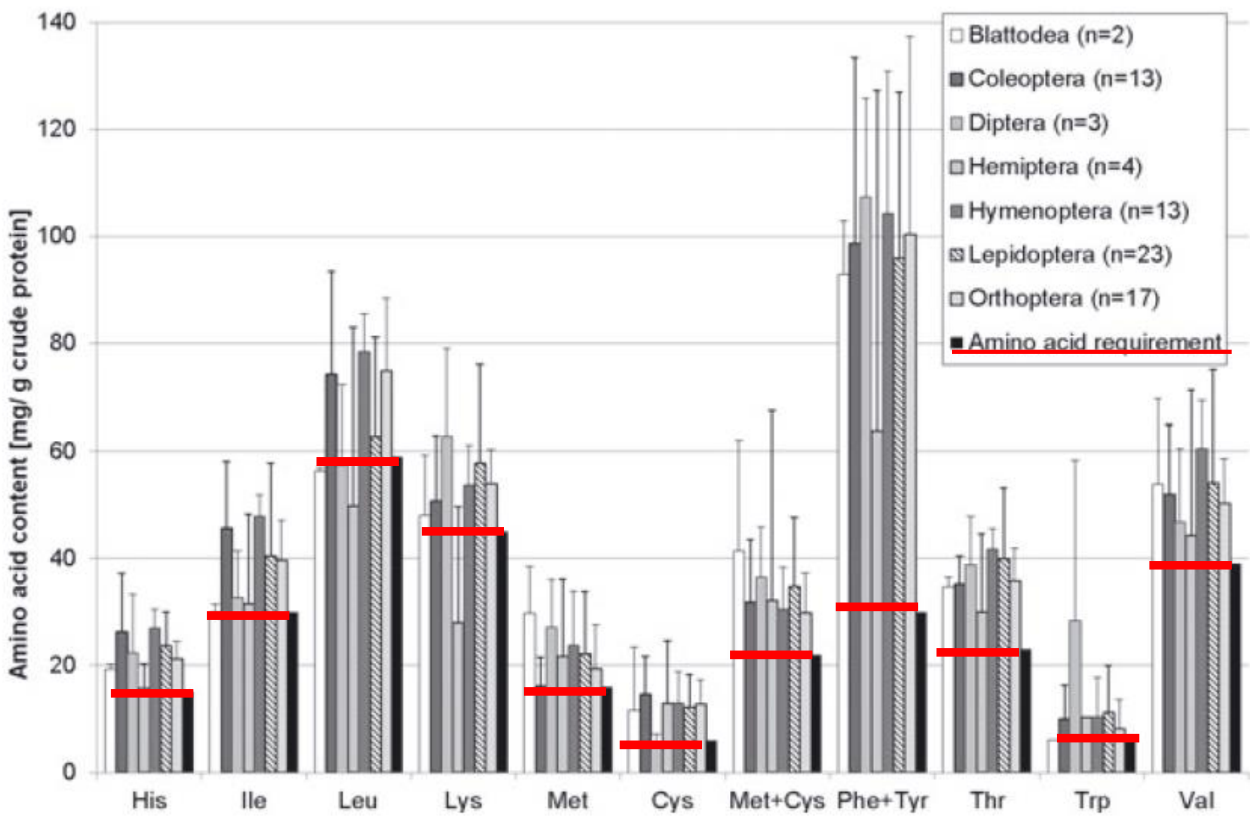
- **Total protein supply:** sufficient in most food systems
- **Low-income countries**: Poor households lack animal-based protein
- **High-income countries**: More sustainable alternatives to current sources needed to meet increased demand for animal-source foods



IFPRI (2016) Global Food Policy Report

Insect protein: Essential amino acids composition in edible insects generally meets human requirements

Mol. Nutr. Food Res. 2013, 57, 802–823



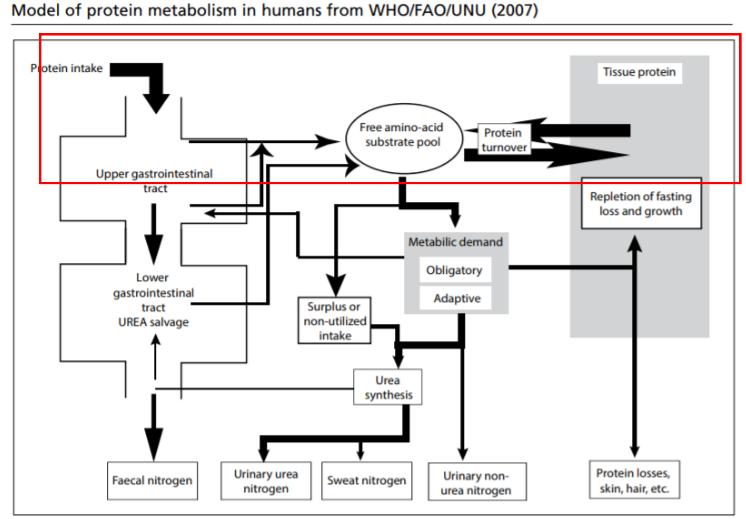
Histidine
Isoleucine
Leucine
Lysine
Methionine
Cysteine
Phenylalanine
Threonine
Tryptophan
Valine

Rumpold & Schlüter 2013

Protein quality: protein digestibility

- Good digestibility indicated in *in vitro* and rat studies (PDCAAS - Protein Digestibility-Corrected Amino Acid Score)
- Only few insect species assessed
- DIAAS (Digestible Indispensable Amino Acid Score) assessed in pigs is the accepted method to fully evaluate protein quality in humans

Model of protein metabolism in humans from WHO/FAO/UNU (2007)



Dietary protein evaluation in human nutrition, FAO 2013

Available PDCAAS values for insects

Edible insects	
Crickets (*Acheta domisticus*):	84 (1)
Mealworm (*Tenebrio molitrix*):	86 (1)
Mealworm (*Tenebrio moitrix*):	76 (2)
Mealworm (*Alphitobius diaperinus*)	82 (2)

- Leucine limiting amino acid for cricket
- Sulfur amino acids (cystine-methionine) limiting amino acids for mealworms
- PDCAAS indicates edible insects as high-quality protein sources. More DIAAS values needed.

(1) Poelaert et al. JIFF 2018

(2) Jensen et al.JIFF 2019

Other animal foods	
Beef	92
Egg	118 *
Milk powder	124*
Fish	82
Plant protein sources	
Maize	52
Wheat	54
Rice	65
Rapeseed	46
Soybean	90

Reviewed by Michaelsen et al. FNB 2009

* PDCAAS are commonly truncated to 100. These are un-truncated values recalculated from original data

Fat quality in human nutrition and health

PUFA (polyunsaturated fatty acids) are healthy compared to saturated fats

Essential fatty acids need to be supplied from diet:

Omega-6: Linolic acid (LA, 18:2 n-6)

Omega-3: α-Linolenic acid (ALA, 18:3 n-3)

The long-chained 'marine' PUFAs (EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid) are beneficial for health (lower risk of cardiovascular diseases) and brain development

'You are what you eat': Omega-3 in farmed insects reflects the content in the diet

Table 4 Proportions of saturated fatty acids (SFA), mono-unsaturated fatty acids (MUFA), poly-unsaturated fatty acids (PUFA), total omega 3 fatty acids, total omega 6 fatty acids, and their ratio in experimental diets, house crickets, lesser mealworms, and black soldier flies (mean ± SD; $n = 6$). Different letters in superscript in the same column indicate significant differences (Kruskal–Wallis test followed by Dunn–Bonferroni post hoc test; $P < 0.05$).

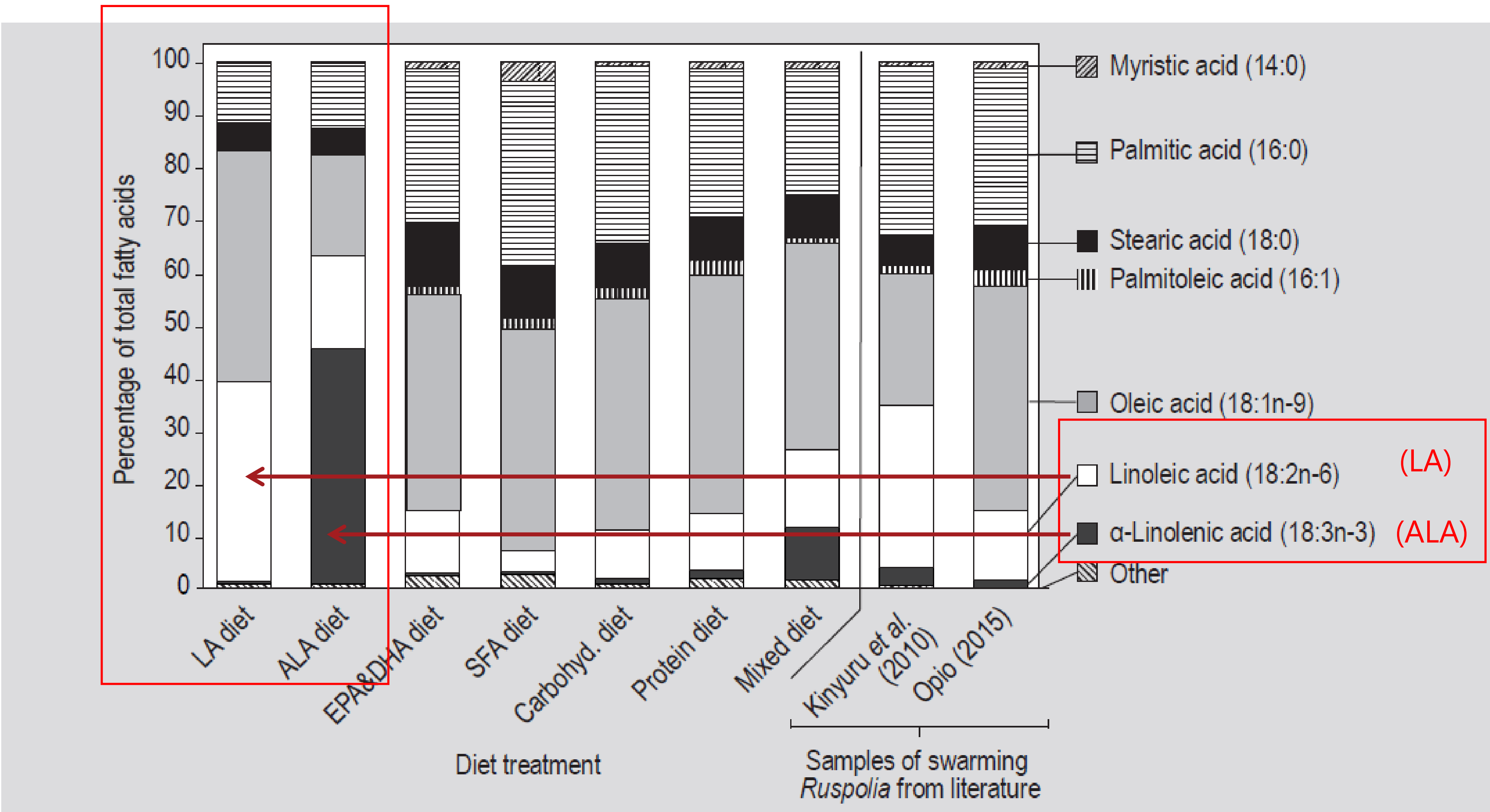
	Flaxseed oil	SFA	MUFA	PUFA	n-3	n-6	n-6/n-3
Diet	0%	29.1 ± 0.30^{a}	31.5 ± 0.12^{a}	38.3 ± 0.31^{a}	3.0 ± 0.05^{a}	35.0 ± 0.29^{a}	11.8 ± 0.22^{a}
	1%	24.4 ± 0.26^{ab}	29.2 ± 0.12^{a}	45.5 ± 0.24^{ab}	14.2 ± 0.21^{ab}	31.1 ± 0.30^{ab}	2.2 ± 0.05^{ab}
	2%	22.6 ± 1.42^{bc}	28.5 ± 1.92^{ab}	48.0 ± 3.38^{bc}	22.2 ± 1.48^{bc}	25.6 ± 4.82^{bc}	1.2 ± 0.27^{bc}
	4%	18.7 ± 0.39^{c}	25.9 ± 0.24^{b}	54.9 ± 0.56^{c}	30.5 ± 0.85^{c}	24.2 ± 0.34^{c}	0.8 ± 0.03^{c}
House cricket	0%	37.3 ± 0.35^{a}	31.5 ± 1.25^{a}	29.8 ± 0.97^{a}	0.8 ± 0.04^{a}	28.8 ± 0.96^{a}	36.2 ± 1.32^{a}
	1%	37.0 ± 1.96^{a}	30.6 ± 1.40^{ab}	31.0 ± 1.22^{ab}	4.1 ± 0.18^{ab}	26.8 ± 1.17^{ab}	6.6 ± 0.38^{ab}
	2%	34.6 ± 0.66^{ab}	30.4 ± 0.76^{ab}	33.7 ± 1.31^{bc}	7.2 ± 0.36^{bc}	26.4 ± 1.01^{ab}	3.7 ± 0.12^{bc}
	4%	31.9 ± 1.36^{b}	28.4 ± 1.17^{b}	38.4 ± 2.23^{c}	12.7 ± 1.05^{c}	25.6 ± 1.27^{b}	2.0 ± 0.09^{c}
Lesser mealworm	0%	34.0 ± 4.68	36.0 ± 2.48^{a}	28.6 ± 2.30^{a}	1.2 ± 0.11^{a}	27.0 ± 2.22	21.7 ± 0.44^{a}
	1%	31.2 ± 2.27	35.6 ± 1.19^{ab}	31.9 ± 1.35^{ab}	4.4 ± 0.23^{ab}	27.2 ± 1.54	6.3 ± 0.63^{ab}
	2%	30.7 ± 3.24	34.5 ± 1.73^{ab}	33.6 ± 1.74^{b}	7.2 ± 0.26^{bc}	26.1 ± 1.59	3.6 ± 0.19^{bc}
	4%	31.0 ± 6.15	32.5 ± 2.02^{b}	35.2 ± 4.25^{b}	10.9 ± 3.04^{c}	24.0 ± 1.42	2.4 ± 1.03^{c}
Black soldier fly	0%	74.4 ± 1.04^{a}	15.1 ± 0.47	10.1 ± 0.72^{a}	0.5 ± 0.14^{a}	9.1 ± 0.84	18.3 ± 5.59^{a}
	1%	70.8 ± 1.60^{ab}	15.3 ± 0.64	13.3 ± 1.27^{ab}	3.3 ± 0.46^{ab}	9.7 ± 0.71	3.0 ± 0.24^{ab}
	2%	68.4 ± 2.91^{b}	15.3 ± 1.18	15.8 ± 1.84^{bc}	5.5 ± 0.59^{bc}	10.0 ± 1.21	1.8 ± 0.11^{bc}
	4%	63.5 ± 2.76^{b}	15.6 ± 1.21	20.3 ± 1.63^{c}	9.7 ± 0.87^{c}	10.4 ± 0.83	1.1 ± 0.02^{c}

Ooninckx et al. *Insect science*, 2019

- Fatty acid profiles should be considered in the formulation of diets for insects farmed for human consumption
- Insects can be a valuable source of essential fatty acids
- Contents of saturated fat should be sought minimized through breeding and feeding practices

Fatty acid profiles of *Ruspolia differens* fed different diets

Accumulation of linoleic (n-6) and linoleneic (n-3) acids reflects the diets



EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; LA, Linoleic acid; ALA, a-Linolenic acid

Lehtovaara et al, JIFF 2017

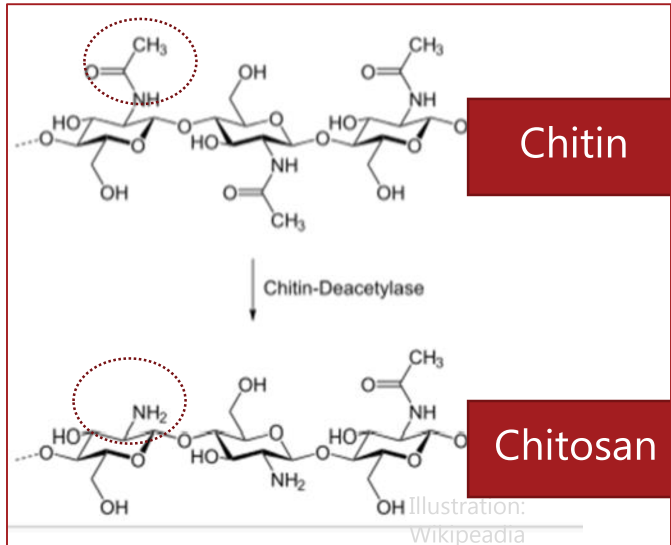
Chitin - nutrition or health value?

Nutrition

- Chitin is regarded as **indigestible fibre** in human diets
- Human chitinases are identified and some digestion may occur (Paoletti et al. 2007)

Health

- Inflammation and immune response: Exposures to chitin and chitosan activate multiple beneficial immune responses protective against inflammation (reviewed by Komi et al. Clin Rev Allerg Imm, 2018)
- Chitin induced immune activation may be harmful **allergic** reactions, (mainly reported for skin and lung reactions)
- Few reports of allergic reactions to consumption of insects



Chitosan is the deacetylated derivate of chitin

Chitin content varies between insect species and by stage in the lifecycle

Changes in composition of cricket (*Acheta domisticus*) over the first 10 weeks of age

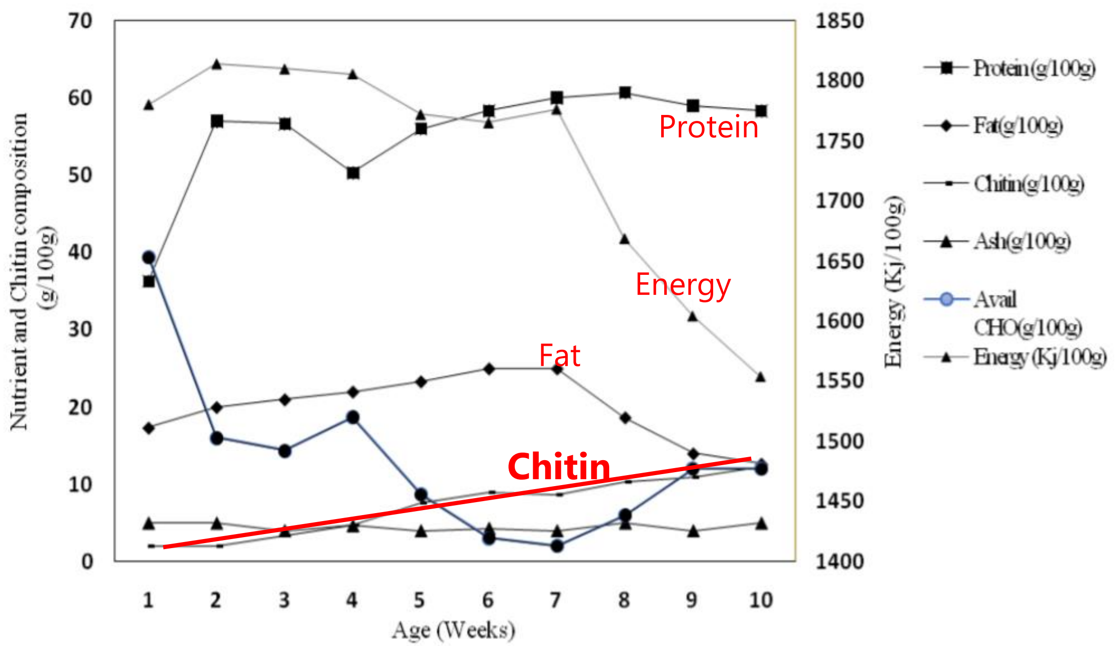


Figure 1. Proximate,chitin and energy content of crickets harvested at different ages.

Kipkoech et al. 2017 DOI: 10.5897/AJAR2017.12687

Minerals and vitamins

- Many insect species have relatively high contents of the important minerals **iron** and **zinc**
- **Iron** metabolism of insects is based on transferrin and ferritin, rather than haemoglobin (vertebrates)
- Few *in vitro* studies indicate iron from insects to be as bioavailable as from beef. **Human studies** are needed.
- Few studies of **vitamins** in insects
- Insects as **vitamin B12** source needs more research in scenarios of insects as meat replacement

Are there bioactive compounds in insects – and what is the evidence?

Antioxidants - protecting cell damaging?

- Antioxidative activity in organisms protect against cell damage and potentially against cancer
- Antioxidants have been measured in several **farmed insect** species using ***in vitro* methods** (f.ex. Zielińska et al. 2016)
- However, anti-oxidative activity must be measured directly in **humans or animal models** – activity in foods do not reflect anti-oxidative activity after digestion
- Anti-oxidative activity in foods may be beneficial for the preservation of foods – but do not transfer directly to health benefits

Are there bioactive compounds in insects – protect against hypertension?

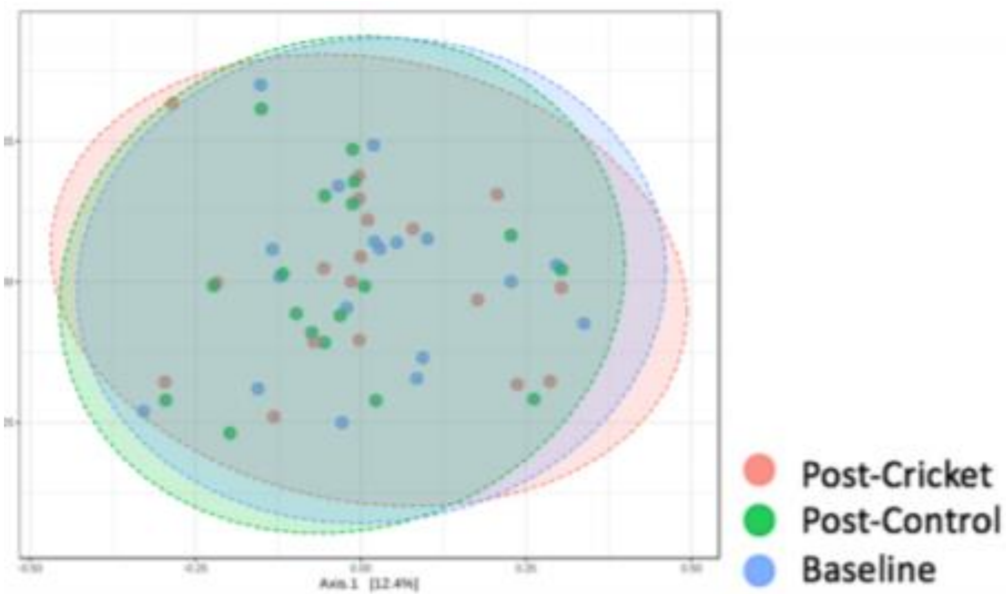
- Foods containing **Angiotensin-converting enzyme (ACE) inhibitors** (peptides) may protect against the vascular contradictions causing hypertension.
- *in vitro* ACE activity are found in six insect species:
  - African cotton leafworm (*Spodoptera littoralis*);
  - Yellow mealworm (*Tenebrio molitor*)
  - Desert locust (*Schistocerca gregaria*)
  - Silkworm (*Bombyx mori);*
  - Green tree ant (*Oecophylla smaragdina*);
  - Fruit fly (*Drosophila melanogaster*)

(reviewed by Cito et al, JIFF 2017)

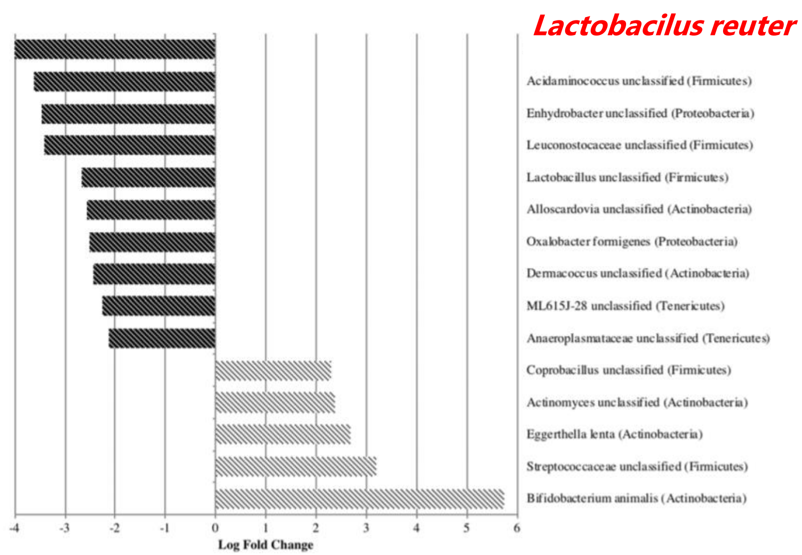
- ACE activity **confirmed in animal models in two species**
- Needs to be confirmed for relevant imapct in humans

Edible insects can modify gut microbiota – what are the impacts on health?

- Human **pilot study** by Stull et al. (Scientific reports, 2019): 2 weeks daily consumption of **25 g cricket** (*Gryllodes sigillatus)* powder **changed** the gut microbiota
- The **density of *Lactobacillus*** was enhanced, **indicating** potential positive health impact



Principle Coordinates Analysis (PCoA) projecting Bray-Curtis distances.



Main microbial taxa groups contributing to the microbiota difference between cricket and control group

Are insects 'superfoods'?

- **YES**: Insects can contribute **high quality protein** and (possibly) bioavailable minerals, and nutritionally substitute meat in diverse diets

- **YES**: Insects can provide essential fatty acids (linoleic and linoleneic acids); though not the long-chained 'marine' fatty acids (DHA/EPA)

- **MAYBE**: Insect species have potetials for bioactive qualities BUT all indications needs to be documented in human studies

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