Insects as an Alternative Protein Source for Animal Feeding: A Short Review about Chemical Composition

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Abstract

Currently, insects are considered as a potential substitute for fishmeal and soybean meal in feeding mixtures for farm animals. However, detailed information regarding insects' nutritional values is available only for some species. We suggested criteria for insect suitability to mass production and found 15 species from 5 orders which meet our requirements: Blattaria: *Blattella germanica*, *Blattella lateralis*, *Eublaberus distanti*, Coleoptera: *Alphitobius diaperinus*, *Tenebrio molitor*, *Zophobas morio*, Diptera: *Hermetia illucens*, *Musca domestica*, Lepidoptera: *Antheraea assamensis*, *Bombyx mori*, *Galleria mellonella*, *Samia ricini*, Orthoptera: *Acheta domestica*, *Locusta migratoria*, *Zonocerus variegatus*. We have collected available information about their nutritional composition and compared it to soybean meal and fishmeal. Protein content was found to be similar to (or slightly higher than in) soybean and fish meals. In terms of protein quality, it was found that insect protein composition is more similar to soybean protein or fishmeal with low protein concentration, than to that of high concentration fishmeal or casein. Due to highest lysine and methionine contents, we recommend *Musca domestica* and *Samia ricini* as most suitable protein sources for poultry and pigs feeding.

Keywords: *alternative protein source, amino acid, insects, nutrient content.*

Abbreviations: DM – dry matter, CP – crude protein, CF – crude fat, NFE – nitrogen free extracts, ADF – acid detergent fiber, NDF – neutral detergent fiber, BE – gross energy

INTRODUCTION

The world population is constantly increasing and human eating habits are globally changing as well. Therefore, sufficient production of meat represents a serious challenge for the future. In regard to production optimisation, it is necessary to provide sufficient quantities of quality feed to unlock maximal genetic potential of animals.

All monogastric livestock (and fish in aquaculture as well) need high quality protein.

Since November 2000, meat bone meals can no longer be used in diets of animals for human consumption (Deydier *et al.*, 2005). Because of this fact, soybean meal and fishmeal are now the most widely used protein sources in animal feeding. Unfortunately, obtaining both of the above mentioned meals leads to local environmental degradation. It is therefore essential to find alternative protein sources.

Insects are currently, considered to possibly be one of such sources, mainly due to their high protein content, cultivation on industry by-products and organic waste, high feed conversion, high fecundity and low space requirements in the rearing process (Rumpold and Schlütter, 2013).

Several papers and summaries, dealing with this issue, have recently been published (for all, see Makkar *et al.* 2014, Sánchez-Muñoz *et al.* 2014). Both of these reviews consider insects as future food source and discuss pros and cons of the prospect. They also contain detailed information about their nutritional composition. However, the first review only focuses on four most common orders of insects used as food.

The other study is more thorough and provides a comprehensive list of 150 commercially available insect species, and also provides nutritional values of several dozen insect taxa. Although Sánchez-Muñoz *et al.* (2014) report nutrient composition of a wide range of species, only a minority of them are commercially available in the required quantity (or only for a few is there a known methodology of controlled mass production).

The other reported species were obtained in different ways, such as collection from nature, etc., which means that they could not be used as standardised food for animals. It is also appropriate to point out that the nutritional composition of the most common insect species (used for this purpose) is available in several papers, but there are significant differences between reported results.

The aim of our study was to find out which easily cultivable insect species could be used as a full-fledged replacement for the most common protein sources used for animal feeding (fishmeal and soybean meal).

MATERIALS AND METHODS

In this review, we focused on insect species which could be considered as a possible future protein source for farm animals. We have gathered available information not only about quantity of basic nutrient content (DM, crude protein, crude fat, chitin, NFE, ADF, NDF, Ca/P ratio, BE), but also about the quality of proteins (amino acid composition) and lipids (fatty acid composition).

1. The selection of the insects was based on the following criteria:
2. The species must be commercially available and could be ordered or purchased from specialised mass production companies;

3. The species is bred and produced in multiple countries, and/or the breeding technology is more or less known and publicly available;
4. The species is used as a food source for animals (including companion animals);
5. The information about nutritional composition of the species is available from at least two sources;
6. Papers mentioning the nutritional value of the species have been published during the last ten years.

The information collected about the chemical composition of insect species which meet the required criteria has been put into tables. For species evaluated by several authors, we compiled tables with arithmetic means of available values. NFE negative values (reported by one of the sources) were excluded from arithmetic means calculations. The g/kg units were used intentionally in all the tables (only the fatty acids contents are shown in g/100 g). Knowledge about dry matter quantity enables us to more easily assess the quality of insect meal. For comparison, we also added average composition of soybean meal, fishmeal (Banaszkiewicz, 2011; Heuzé *et al.*, 2015a,b), and milk protein (Young and Pellet, 1991).

RESULTS AND DISCUSSION

Based on the aforementioned criteria, we found 15 species from 5 orders which meet our requirements. We list them in an alphabetical order according to the orders and species: Blattaria: *Blaptica dubia* (Serville, 1838), *Blatta lateralis* (Walker, 1868), *Eublaberus distant* (Kirby, 1903), Coleoptera: *Alphitobius diaperinus* (Panzer, 1797), *Tenebrio molitor* (Linnaeus, 1758), *Zophobas morio* (Fabricius, 1776), Diptera: *Hermetia illucens* (Linnaeus, 1758), *Musca domestica* (Linnaeus, 1758), Lepidoptera: *Antheraea assamensis* (Helfer, 1837), *Bombyx mori* (Linnaeus, 1758), *Galleria mellonella* (Linnaeus, 1758), *Samia ricini* (Anderson, 1788), Orthoptera: *Acheta domestica* (Linnaeus, 1758), *Locusta migratoria* (Linnaeus, 1758), *Zonocerus variegates* (Linnaeus, 1758).

The information about the nutritional value of these species is shown in Tables 1–3. The average values are displayed in Tables 4 and 5.

According to our findings, the protein content of most of the reviewed insect species is

Tab. 1 Chemical composition of the investigated insect species, soybean meal and fishmeal (sources are shown in table).

Order	Scientific name	References	Stage	Basic nutrients										
				DM g/kg	CP g/kg	CF g/kg	Chitin g/kg	Ash g/kg	NFE g/kg	ADF g/kg	NDF g/kg	BE MJ/kg	Ca/P	
Blattaria	<i>Blaptica dubia</i>	Bosch <i>et al.</i> , 2014	adult females	x	644.0	245.0	x	44.0	x	x	x	x	x	x
		Kulma <i>et al.</i> , in prep.	adult	374.0	630.0	214.0	64.0	49.0	43.0	x	x	19.30	0.05	
		Yi <i>et al.</i> , 2013	adult	326.0	592.0	236.2	x	x	x	x	x	x	x	
		Kulma <i>et al.</i> , in prep.	nymph	422.0	525.0	328.0	65.0	40.0	42.0	x	x	21.90	0.05	
		Kulma <i>et al.</i> , in prep.	adult	307.0	584.0	145.0	59.0	51.0	161.0	x	x	17.90	0.53	
	<i>Blatta lateralis</i>	Kulma <i>et al.</i> , in prep.	nymph	360.0	470.0	363.0	53.0	37.0	77.0	x	x	22.80	1.72	
		Ooninx and Dierenfeld, 2012	nymph med.	283.0	628.5	265.0	x	68.9	x	127.5	127.6	x	0.20	
		Ooninx and Dierenfeld, 2012	nymph sm.	208.0	760.5	144.5	x	78.8	x	108.7	114.1	x	0.19	
		Bosch <i>et al.</i> , 2014	adult	x	663.0	251.0	x	36.0	x	x	x	x	x	
		Ooninx and Dierenfeld, 2012	adult	434.5	605.0	312.5	x	38.0	x	x	x	x	0.18	
Coleoptera	<i>Eublabeus distanti</i>	Ooninx and Dierenfeld, 2012	nymph lar.	492.0	382.8	544.8	x	19.6	x	x	x	x	0.16	
		Bosch <i>et al.</i> , 2014	larvae	x	648.0	222.0	x	36.0	x	x	x	x	x	
		Yi <i>et al.</i> , 2013	larvae	355.0	580.3	239.5	x	x	x	x	x	x	x	
		Bernard <i>et al.</i> , 1997	adult	386.0	637.0	184.0	x	31.0	x	161.0	x	24.20	0.09	
		Finke, 2002	adult	363.0	652.9	148.8	x	33.1	-38.6	203.9	316.8	16.00	0.08	
	<i>Tenebrio molitor</i>	Ooninx and Dierenfeld, 2012	adult	388.3	676.5	177.0	x	72.0	x	176.3	320.5	x	0.08	
		Bernard <i>et al.</i> , 1997	pupae	390.0	546.0	308.0	x	34.0	x	51.0	x	26.90	0.10	
		Ramos - Elorduy <i>et al.</i> , 2006	pupae	x	531.3	366.5	x	31.9	19.0	51.0*	23.00	x	x	
		Barker <i>et al.</i> , 1998	larvae	371.0	518.7	311.0	x	43.0	x	x	145.0	x	0.08	
		Bernard <i>et al.</i> , 1997	larvae	376.0	527.0	328.0	x	32.0	x	57.0	x	27.10	0.14	
Diptera	<i>Hermetia illucens</i>	Bosch <i>et al.</i> , 2014	larvae	x	520.0	339.0	x	39.0	x	x	x	x	x	
		Finke, 2002	larvae	381.0	490.8	351.7	x	23.6	70.9	65.6	149.6	22.57	0.06	
		Ramos - Elorduy <i>et al.</i> , 2006	larvae	x	477.6	382.9	x	27.7	42.4	69.1*	23.10	x	x	
		Yi <i>et al.</i> , 2013	larvae	365.0	523.3	271.2	x	x	x	x	x	x	x	
		Finke, 2002	giant mealworm	390.0	471.8	430.8	x	30.8	2.6	64.1	74.4	24.10	0.06	
	<i>Zophobas morio</i>	Ooninx and Dierenfeld, 2012	adult	382.1	680.5	142.5	x	61.6	x	320.6	501.4	x	0.08	
		Barker <i>et al.</i> , 1998	larvae	430.0	431.3	408.0	x	130.0	x	x	130.0	x	0.14	
		Bosch <i>et al.</i> , 2014	larvae	x	470.0	339.0	x	39.0	x	x	x	x	x	
		Finke, 2002	larvae	421.0	467.9	420.4	x	23.8	26.1	64.1	92.6	24.10	0.07	
		Yi <i>et al.</i> , 2013	larvae	401.0	516.2	399.0	x	x	x	x	x	x	x	
<i>Hermetia illucens</i>	Kroeckel <i>et al.</i> , 2012	pre-pupae	x	476.0	118.0	96.0	159.0	151.0	x	x	21.10	x		
	Sealey <i>et al.</i> , 2011	pre-pupae	x	x	x	x	x	x	x	x	x	x		
	Arango Gutiérrez <i>et al.</i> , 2004	maggot	x	411.0	209.0	x	194.0	x	x	x	x	x		
	Newton <i>et al.</i> , 1977	larvae	x	421.0	348.0	x	146.0	14.0	70.0*	x	3.30	x		
	St-Hilaire <i>et al.</i> , 2007	larvae	x	476.0	361.4	x	169.2	x	x	x	x	x		

Diptera	<i>Musca domestica</i>	Bernard <i>et al.</i> , 1997	pupae	x	583.0	158.0	x	68.0	x	199.0	x	23.90	0.28
		Pretorius, 2011	pupae	x	762.3	143.9	x	x	x	157.1*	x	20.42	x
		St-Hilaire <i>et al.</i> , 2007	pupae	x	799.1	182.7	x	11.1	x	x	x	x	x
		Hwangbo <i>et al.</i> , 2009	maggot	x	675.6	256.7	x	54.5	13.2	x	x	23.25	1.52
		Ogunji <i>et al.</i> , 2007	maggot	x	389.0	205.0	x	240.0	203.0**	x	x	21.10	x
		Pretorius, 2011	maggot	x	603.8	140.8	x	x	x	85.8*	x	20.10	x
		Zuidhof <i>et al.</i> , 2003	maggot	x	593.0	x	x	x	x	x	x	x	0.40
		Aniebo and Owen, 2010	larvae	x	597.7	224.3	x	67.3	x	66.9*	x	x	x
		Bernard <i>et al.</i> , 1997	larvae	x	568.0	200.0	x	68.0	x	180.0	x	25.40	0.12
		Djordjevic <i>et al.</i> , 2008	larvae	x	594.8	66.6	x	142.4	80.8	x	x	x	5.70
		Deori <i>et al.</i> , 2014	pupae	286.2	542.0	166.6	x	14.5	16.2	30.5*	x	x	x
		Mishra <i>et al.</i> , 2003	pupae	337.5	426.7	503.7	x	27.0	39.1	4.1*	26.67	x	x
		Katayama <i>et al.</i> , 2008	pupae	148.0	x	x	x	x	x	x	x	x	x
		Mishra <i>et al.</i> , 2003	pupae	348.7	343.5	576.0	x	22.6	51.6	5.5*	28.39	x	x
Lepidoptera	<i>Bombyx mori</i>	Finke, 2002	larvae	173.0	537.6	80.9	x	63.6	254.3	63.6	63.6	16.18	0.07
		Barker <i>et al.</i> , 1998	larvae	381.0	412.5	514.0	x	33.0	x	x	121.0	x	0.05
		Bernard <i>et al.</i> , 1997	larvae	341.0	424.0	464.0	x	27.0	x	48.0	x	29.60	0.18
		Finke, 2002	larvae	415.0	339.8	600.0	x	14.5	-33.7	81.9	195.2	11.50	0.12
		Longvah <i>et al.</i> , 2011	pupae	274.5	596.7	262.0	x	38.0	37.7	34.5*	19.60	0.14	0.14
		Mishra <i>et al.</i> , 2003	pupae	298.6	534.8	371.4	x	45.5	40.5	37.7*	23.66	x	x
		Longvah <i>et al.</i> , 2011	prepupae	284.5	594.4	262.0	x	40.0	35.7	32.6*	19.30	0.13	0.13
		Barker <i>et al.</i> , 1998	adult	268.0	643.8	228.0	x	51.0	x	x	191.0	x	0.26
		Bernard <i>et al.</i> , 1997	adult	310.0	649.0	138.0	x	138.0	x	94.0	x	22.40	0.14
		Bosch <i>et al.</i> , 2014	adult	x	706.0	177.0	x	53.0	x	x	x	x	x
		Finke, 2002	adult	308.0	665.6	220.8	x	35.7	-26.0	103.9	220.8	19.16	0.13
		Yi <i>et al.</i> , 2013	adult	292.0	736.3	123.3	x	x	x	x	x	x	x
		Barker <i>et al.</i> , 1998	juvenile (nymph)	332.0	550.0	98.0	x	91.0	x	x	164.0	x	1.63
		Finke, 2002	nymph	229.0	672.5	144.1	x	48.0	39.3	96.1	157.2	17.50	0.11
Orthoptera	<i>Acheta domestica</i>	Nagasaki and DeFoliart, 1987	mix	x	654.0	79.0	x	48.5	x	73.8*	x	0.19	0.19
		Oonincx and VD Poel, 2011	adult	343.0	555.0	296.0	x	33.3	x	x	x	23.80	0.10
		Oonincx and VD Poel, 2011	subadult	291.0	555.0	247.0	x	37.3	x	x	x	23.30	0.09
		Alegbeleye <i>et al.</i> , 2012	mix	x	615.0	68.7	93.5	43.0	273.3	0.0*	x	x	x
		Olusola <i>et al.</i> , 2003	mix	x	580.0	155.0	x	x	x	124.0*	x	x	x
		Banaszkiewicz, 2011	44% NL	x	438-499	5.5-30	x	56-72	398.1	89-119	123-189	x	0.49
		Heuzé <i>et al.</i> , 2015b	low protein	879.0	518.0	20.0	8.0	71.0	94.0	83.0	137.0	19.70	0.56
		Heuzé <i>et al.</i> , 2015b	high protein	881.0	535.0	18.0	5.0	72.0	106.0	59.0	110.0	19.70	0.47
		Heuzé <i>et al.</i> , 2015a	high protein	921.0	754.0	110.0	x	136.0	x	x	x	21.90	1.18
		Heuzé <i>et al.</i> , 2015a	low protein	925.0	484.0	103.0	x	352.0	x	x	x	19.00	2.00
		Young and Pellet, 1991	milk protein	x	x	x	x	x	x	x	x	x	x
		Casein	milk protein	x	x	x	x	x	x	x	x	x	x
		Comparison	low protein	921.0	754.0	110.0	x	136.0	x	x	x	21.90	1.18
		Heuzé <i>et al.</i> , 2015a	high protein	921.0	754.0	110.0	x	136.0	x	x	x	21.90	1.18
		Heuzé <i>et al.</i> , 2015a	low protein	925.0	484.0	103.0	x	352.0	x	x	x	19.00	2.00

Note: DM-dry matter; CP-crude protein; CF-crude fat; NFE-nitrogen free extracts; ADF-acid detergent fiber; NDF-neutral detergent fiber; BE-brutto energy

*authors do not refer the ADF and NDF values, but they report only the crude fibre content

** author refers to NFE as NFE+crude fibre

Tab. 2 Fatty acid composition of the investigated species (information is known only for 5 species). Sources are shown in table.

Order	Scientific name	References	Stage	Fatty acid composition g/100g DM							
				lauric	myristic	palmitic	palmitoleic	stearic	oleic	linoleic	arachidic
Coleoptera	<i>Tenebrio molitor</i>	Finke, 2002	adult	0.00	0.20	2.30	0.20	0.70	4.90	3.80	0.10
		Finke, 2002	larvae	0.00	0.80	6.00	0.90	1.00	14.10	9.10	0.10
		Finke, 2002	giant mealworm	0.20	1.30	6.50	1.20	1.00	17.00	12.60	0.10
	<i>Zophobas morio</i>	Finke, 2002	larvae	0.00	0.40	12.50	0.20	3.00	15.70	7.80	0.10
Lepidoptera	<i>Bombyx mori</i>	Finke, 2002	larvae	0.00	0.00	1.00	0.10	0.70	1.80	2.00	0.10
	<i>Galleria mellonella</i>	Finke, 2002	larvae	0.00	0.10	19.20	1.20	0.80	29.90	3.70	0.10
Orthoptera	<i>Acheta domestica</i>	Finke, 2002	adult	0.00	0.10	5.10	0.30	1.90	5.00	7.40	0.10
		Finke, 2002	nymph	0.00	0.10	2.70	0.10	1.30	2.80	4.80	0.10

Tab. 3 Amino acid content in dry matter (DM) of the investigated species, soybean meal and fishmeal (sources are shown in table).

Order	Scientific name	References	Stage	Amino acid content (g/kg DM)													
				Asp	Thr	Ser	Glu	Ala	Gly	Cys	Met	Ile	Leu	Tyr	Phe	His	Lys
Blattaria	<i>Blattella germanica</i>	Yi <i>et al.</i> , 2013	adult	39.66	18.90	20.10	56.90	42.00	31.40	13.60	18.40	33.20	55.10	13.60	25.50	27.20	28.40
		Bosch <i>et al.</i> , 2014	adult females	x	19.96	x	x	x	x	8.37	20.61	34.13	x	17.39	28.98	25.76	22.54
	<i>Eublaberus distanti</i>	Bosch <i>et al.</i> , 2014	adult	x	20.55	x	x	x	x	8.62	22.54	35.80	x	17.24	28.51	23.87	x
		Yi <i>et al.</i> , 2013	larvae	48.20	22.60	23.20	71.40	38.30	26.70	15.10	25.00	38.30	69.60	19.70	35.40	31.30	32.50
Coleoptera	<i>Alphitobius diaperinus</i>	Bosch <i>et al.</i> , 2014	larvae	x	25.92	x	x	x	x	8.42	29.81	43.42	x	25.27	31.75	42.12	31.10
		Finke, 2002	adult	45.73	22.31	27.00	62.81	49.86	55.10	4.41	8.26	28.37	53.99	21.76	17.08	18.73	28.93
	<i>Tenebrio molitor</i>	Bosch <i>et al.</i> , 2014	larvae	x	20.80	x	x	x	x	7.28	23.92	37.96	x	17.68	26.52	28.60	23.92
		Finke, 2002	larvae	39.90	20.21	25.20	55.38	40.42	27.30	4.20	6.30	24.67	52.23	35.96	17.32	15.49	26.77
Coleoptera	<i>Tenebrio molitor</i>	Yi <i>et al.</i> , 2013	larvae	41.90	20.40	23.00	57.00	36.60	26.20	13.60	22.50	38.20	52.30	15.20	28.30	28.30	34.50
		Finke, 2002	giant mealworm	41.54	16.41	23.33	58.46	35.13	25.38	3.85	6.67	22.05	36.67	36.67	19.23	16.67	28.72
	<i>Zophobas morio</i>	Bosch <i>et al.</i> , 2014	larvae	x	19.27	x	x	x	x	7.52	23.50	33.84	x	17.39	22.56	24.91	21.62
		Finke, 2002	larvae	37.53	18.53	21.85	57.48	33.97	22.57	3.56	4.99	22.09	45.37	32.54	16.15	14.25	24.47
Coleoptera	<i>Zophobas morio</i>	Yi <i>et al.</i> , 2013	larvae	42.30	20.60	21.70	65.60	35.10	24.80	12.40	23.70	36.70	57.30	16.00	54.00	27.90	28.90

Diptera	<i>Hermetia illucens</i>	Kroeckel <i>et al.</i> , 2012	pre-pupae	x	22.09	x	x	x	3.90	10.38	24.70	41.08	x	18.52	15.90	33.89	27.18	x	x	34.32		
		Sealey <i>et al.</i> , 2011	pre-pupae	40.90	15.80	13.70	44.20	24.50	17.20	x	7.70	18.30	26.60	22.20	18.30	7.60	20.50	17.80	x	x	29.90	
		Newton <i>et al.</i> , 1997	larvae	45.60	5.50	1.20	38.10	36.90	28.80	0.60	0.86	19.30	35.30	25.10	22.00	19.10	33.70	22.40	32.60	2.00	34.10	
		St-Hilaire <i>et al.</i> , 2007	larvae	37.20	17.80	16.80	37.80	30.20	22.80	x	7.40	20.30	31.00	30.80	20.00	11.80	26.20	26.50	23.90	x	27.90	
	St-Hilaire <i>et al.</i> , 2007	pupae	37.20	17.80	16.80	37.80	30.20	22.80	x	7.40	20.30	31.00	30.80	20.00	11.80	26.20	26.50	23.90	x	27.90		
	<i>Musca domestica</i>	Hwangbo <i>et al.</i> , 2009	maggot	22.10	22.70	56.30	57.10	48.50	32.70	4.20	23.40	14.60	29.00	45.50	35.70	19.80	25.40	36.30	15.80	31.70	29.20	
		Zuidhof <i>et al.</i> , 2003	maggot	50.20	23.70	23.10	72.70	34.20	24.90	4.60	14.80	22.10	35.30	34.70	30.90	21.20	38.70	28.70	22.40	8.50	29.00	
	Lepidoptera	<i>Bombyx mori</i>	Djordjevic <i>et al.</i> , 2008	larvae	x	x	x	x	x	4.60	15.00	x	x	x	x	x	44.10	x	x	x	x	
			Katayana <i>et al.</i> , 2008	pupae	x	x	x	x	6.00	6.90	x	4.20	4.70	7.50	7.10	5.40	5.10	8.00	5.90	5.40	x	6.30
			Finke, 2002	larvae	35.26	16.76	19.65	53.76	24.28	32.37	4.62	7.51	17.34	28.32	16.76	15.61	13.87	25.43	22.54	18.50	4.05	21.97
Finke, 2002			larvae	32.29	14.22	25.30	46.99	22.65	17.83	2.65	5.30	15.18	29.88	21.20	12.77	7.95	19.04	17.11	22.89	2.89	16.39	
<i>Galleria mellonella</i>		Longvah <i>et al.</i> , 2011	pupae	59.00	28.30	31.30	77.00	36.60	29.50	3.20	13.80	26.40	39.60	38.20	31.30	15.90	39.00	26.30	38.50	x	32.00	
		Longvah <i>et al.</i> , 2011	prepupae	58.00	26.60	28.30	76.70	36.00	33.50	3.10	12.60	25.70	38.80	37.60	30.70	16.60	38.90	27.90	35.80	x	31.40	
<i>Acheta domestica</i>		Bosch <i>et al.</i> , 2014	adult	x	25.42	x	x	x	x	x	11.30	28.24	46.60	x	22.59	24.00	40.95	40.24	x	x	40.24	
		Finke, 2002	adult	55.84	24.03	33.12	69.81	58.44	33.77	5.52	9.74	30.52	66.56	32.47	21.10	15.58	35.71	40.58	37.34	4.22	34.74	
		Yi <i>et al.</i> , 2013	adult	53.70	25.80	28.00	91.00	59.70	37.60	18.40	26.50	48.60	67.70	15.50	39.00	47.90	39.80	6.60	40.50			
		Finke, 2002	nymph	47.60	24.02	27.95	69.87	59.83	35.37	5.68	8.73	28.82	64.19	37.12	18.78	14.85	36.24	41.05	37.12	3.49	33.19	
<i>Zonocerus variegatus</i>	Nagasaki and DeFoliart, 1987	mix	31.13	15.71	18.28	45.69	39.13	23.13	x	5.71	18.85	41.98	24.28	12.28	9.71	23.70	26.85	24.28	2.28	21.70		
	Alegbeleye <i>et al.</i> , 2012	mix	x	17.84	x	x	25.22	28.91	3.08	14.15	23.99	34.44	22.14	14.15	11.69	20.91	22.76	12.92	4.67	26.45		
Comparison	<i>Soybean meal</i>	Banaszkiewicz, 2011	44% NL	x	18.90-20.30	x	x	x	6.60-7.50	6.00-6.90	21.50-27.80	36.60-39.90	x	23.50-30.00	12.10-13.20	29.90-32.20	34.90-37.80	x	6.60-7.50	22.40-26.70		
		Heuzé <i>et al.</i> , 2015b	low protein	58.53	20.20	25.90	91.69	22.79	21.76	7.77	7.25	23.83	38.85	18.13	25.90	13.47	31.60	38.33	25.38	6.73	24.86	
	<i>Fishmeal</i>	Heuzé <i>et al.</i> , 2015b	high protein	60.99	20.33	24.61	95.77	23.01	22.47	8.56	7.49	24.61	41.20	18.73	27.29	14.45	33.71	39.06	26.75	7.49	25.68	
		Heuzé <i>et al.</i> , 2015a	high protein	65.60	30.91	30.16	95.00	45.99	44.49	6.03	21.11	32.42	52.78	21.87	28.65	16.59	56.55	43.73	28.65	8.29	36.95	
	<i>Casein</i>	Heuzé <i>et al.</i> , 2015a	low protein	46.46	19.36	16.94	60.98	30.01	33.88	5.81	12.58	19.84	36.30	15.49	19.36	11.62	33.88	25.17	23.23	x	25.17	
		Young and Pellet, 1991	milk protein	x	42.00	x	x	x	x	35.00	54.00	95.00	111.00	32.00	85.00	x	x	14.00	63.00			

Tab. 4 Chemical composition of the investigated insect species (average values)

Order	Scientific name	Stage	DM	Basic nutrients							Ca/P		
			(g/kg)	CP	CF	Chitin	Ash	NFE	ADF	NDF		BE	
Blattaria	<i>Blaptica dubia</i>	adult	350.0	622.0	231.7	64.0	46.5	43.0	x	x	19.30	0.05	
		nymph	422.0	525.0	328.0	65.0	40.0	42.0	x	x	21.90	0.05	
	<i>Blatta lateralis</i>	adult	307.0	584.0	145.0	59.0	51.0	161.0	x	x	17.90	0.53	
		nymph	283.7	619.7	257.5	53.0	61.6	77.0	118.1	120.8	22.80	0.70	
	<i>Eublaberus distanti</i>	adult	434.5	634.0	281.7	x	37.0	x	x	x	x	0.18	
		nymph	492.0	382.8	544.8	x	19.6	x	x	x	x	0.16	
Coleoptera	<i>Alphitobius diaperinus</i>	larvae	355.0	614.5	230.8	x	36.0	x	x	x	x	x	
		adult	379.1	655.5	169.9	x	45.4	x	180.4	318.6	20.10	0.08	
	<i>Tenebrio molitor</i>	pupae	390.0	538.6	337.3	x	33.0	19.0	51.0	x	24.95	0.10	
		larvae	373.3	509.6	330.6	x	33.1	56.6	61.3	147.3	24.26	0.09	
		giant mealworm	390.0	471.8	430.8	x	30.8	2.6	64.1	74.4	24.10	0.06	
		adult	382.1	680.5	142.5	x	61.6	x	320.6	501.4	x	0.08	
Diptera	<i>Zophobas morio</i>	larvae	417.3	471.3	391.6	x	64.3	26.1	64.1	111.3	24.10	0.10	
		pre-pupae	x	476.0	118.0	96.0	159.0	151.0	x	x	21.10	x	
	<i>Hermetia illucens</i>	larvae	x	436.0	306.1	x	169.7	14.0	70.0	x	x	3.30	
		pupae	x	714.8	161.5	x	39.6	x	199.0	x	22.16	0.28	
	<i>Musca domestica</i>	larvae	x	574.6	182.2	x	114.4	47.0	180.0	x	22.46	1.93	
		pupae	311.8	484.3	335.1	x	20.7	27.6	17.3	x	26.67	x	
Lepidoptera	<i>Antheraea assamensis</i>	pupae	248.3	343.5	576.0	x	22.6	51.6	5.5	28.39	x	x	
		larvae	173.0	537.6	80.9	x	63.6	254.3	63.6	63.6	16.18	0.07	
	<i>Galleria mellonella</i>	larvae	379.0	392.1	526.0	x	24.8	x	64.9	158.1	20.55	0.12	
		prepupae	284.5	594.4	262.0	x	40.0	35.7	32.6	19.30	0.13	0.13	
	<i>Samia ricini</i>	pupae	286.5	565.1	316.7	x	41.7	39.1	36.1	21.63	0.14	0.14	
		adult	294.5	680.1	177.4	x	69.4	x	99.0	205.9	20.78	0.18	
Orthoptera	<i>Acheta domestica</i>	nymph	280.5	611.3	121.0	x	69.5	39.3	96.1	160.6	17.50	0.87	
		mix	x	654.0	79.0	x	48.5	x	73.8	x	x	0.19	
	<i>Locusta migratoria</i>	adult	343.0	555.0	296.0	x	33.3	x	x	x	23.80	0.10	
		subadult	291.0	555.0	247.0	x	37.3	x	x	x	23.30	0.09	
		<i>Zonocerus variegatus</i>	mix	x	597.5	111.8	93.5	43.0	273.3	62.0	x	x	x

Note: DM-dry matter; CP-crude protein; CF-crude fat; NFE-nitrogen free extracts; ADF-acid detergent fiber; NDF-neutral detergent fiber; BE-brutto energy

Tab. 5 Amino acid content in dry matter (DM) of the investigated species, soybean meal and fishmeal (average values).

Order	Scientific name	Stage	Amino acid content (g/kg DM)																	
			Asp	Thr	Ser	Glu	Ala	Gly	Cys	Met	Ile	Leu	Tyr	Phe	His	Lys	Arg	Pro	Trp	Val
Blattaria	<i>Blaptica dubia</i>	adult	39.66	19.40	20.10	56.90	42.00	31.40	x	8.37	19.50	33.70	x	17.39	21.29	25.63	24.87	28.40	4.70	32.79
	<i>Eublaberus distanti</i>	adult	x	20.55	x	x	x	x	x	8.62	22.54	35.80	x	17.24	28.51	28.51	23.87	x	x	37.13
	<i>Alphitobius diaperinus</i>	larvae	48.20	24.26	23.20	71.40	38.30	26.70	x	8.42	27.40	40.86	x	25.27	25.72	38.76	31.20	32.50	7.00	35.96
Coleoptera		adult	45.73	22.31	27.00	62.81	49.86	55.10	4.41	8.26	28.37	53.99	21.76	17.08	18.73	28.93	28.10	41.32	7.16	41.32
	<i>Tenebrio molitor</i>	larvae	40.70	20.47	24.10	56.19	38.21	26.75	4.20	6.97	23.70	42.80	35.96	17.50	19.07	27.89	25.89	34.31	5.12	31.18
	giant mealworm		41.54	16.41	23.33	58.46	35.13	25.38	3.85	6.67	22.05	36.67	36.67	19.23	16.67	28.72	26.41	31.03	4.36	31.28
Diptera	<i>Zophobas morio</i>	larvae	39.91	19.47	21.77	61.54	34.53	23.68	3.56	6.25	23.10	38.64	32.54	16.92	17.60	34.46	24.11	27.27	5.74	29.17
	<i>Hermetia illucens</i>	pre-pupae	40.90	18.94	13.70	44.20	24.50	17.20	3.90	9.04	21.50	33.84	22.20	18.41	11.75	27.19	22.49	x	x	32.11
		larvae	41.40	11.65	9.00	37.95	33.55	25.80	0.60	4.13	19.80	33.15	27.95	21.00	15.45	29.95	24.45	28.25	2.00	31.00
Lepidoptera	<i>Musca domestica</i>	pupae	37.20	17.80	16.80	37.80	30.20	22.80	x	7.40	20.30	31.00	30.80	20.00	11.80	26.20	26.50	23.90	x	27.90
		larvae	36.15	23.20	39.70	64.90	41.35	28.80	4.47	17.73	18.35	32.15	40.10	33.30	20.50	36.07	32.50	19.10	20.10	29.10
	<i>Bombyx mori</i>	pupae	x	x	x	x	6.00	6.90	x	4.20	4.70	7.50	7.10	5.40	5.10	8.00	5.90	5.40	x	6.30
Orthoptera	<i>Galleria mellonella</i>	larvae	35.26	16.76	19.65	53.76	24.28	32.37	4.62	7.51	17.34	28.32	16.76	15.61	13.87	25.43	22.54	18.50	4.05	21.97
	<i>Samia ricini</i>	prepupae	32.29	14.22	25.30	46.99	22.65	17.83	2.65	5.30	15.18	29.88	21.20	12.77	7.95	19.04	17.11	22.89	2.89	16.39
		pupae	52.90	24.28	25.80	69.92	32.79	30.51	2.82	11.49	23.47	35.34	34.25	28.02	15.12	35.45	25.42	32.68	x	28.67
Comparison	<i>Acheta domestica</i>	pupae	54.00	25.94	28.67	70.43	33.52	26.97	2.89	12.61	24.13	36.20	34.94	28.61	14.58	35.71	24.08	35.27	x	29.27
		adult	54.77	25.08	30.56	80.40	59.07	35.68	5.52	10.52	28.42	54.59	32.47	21.84	18.36	38.55	42.91	38.57	5.41	38.49
		nymph	47.60	24.02	27.95	69.87	59.83	35.37	5.68	8.73	28.82	64.19	37.12	18.78	14.85	36.24	41.05	37.12	3.49	33.19
Comparison	<i>Zonocerus variegatus</i>	mix	31.13	15.71	18.28	45.69	39.13	23.13	x	5.71	18.85	41.98	24.28	12.28	9.71	23.70	26.85	24.28	2.28	21.70
		mix	x	17.84	x	x	25.22	28.91	3.08	14.15	23.99	34.44	22.14	14.15	11.69	20.91	22.76	12.92	4.67	26.45
		44% NL	x	18.90-20.30	x	x	x	x	6.60-7.50	6.00-6.90	21.50-27.80	36.60-39.90	x	23.50-30.00	12.10-13.20	29.90-32.20	34.90-37.80	x	6.60-7.50	22.40-26.70
Comparison	<i>Soybean meal</i>	low protein	58.53	20.20	25.90	91.69	22.79	21.76	7.77	7.25	23.83	38.85	18.13	25.90	13.47	31.60	38.33	25.38	6.73	24.86
		high protein	60.99	20.33	24.61	95.77	23.01	22.47	8.56	7.49	24.61	41.20	18.73	27.29	14.45	33.71	39.06	26.75	7.49	25.68
	<i>Fishmeal</i>	high protein	65.60	30.91	30.16	95.00	45.99	44.49	6.03	21.11	32.42	52.78	21.87	28.65	16.59	56.55	43.73	28.65	8.29	36.95
Comparison		low protein	46.46	19.36	16.94	60.98	30.01	33.88	5.81	12.58	19.84	36.30	15.49	19.36	11.62	33.88	25.17	23.23	x	25.17
	<i>Casein</i>	milk protein	x	42.00	x	x	x	x	35.00	54.00	54.00	95.00	111.00	32.00	85.00	x	x	x	14.00	63.00

similar to that of conventional commercial protein sources – fishmeal and soybean meal. In terms of protein quality, it was found that insect protein composition is more similar to soybean protein or fishmeal with low protein concentration, than to that of high concentration fishmeal or casein.

Although many authors deal with this topic, complete information about the nutritional value of the reviewed species is rather unavailable. Despite the fact that the basic nutritional composition of most species is well known (see Table 1), the information about quality of their proteins (see Table 2) and lipids (see Table 3) is unfortunately insufficient. Detailed chemical analyses of other insect species are also available, but those specimens have been obtained from nature (by collecting, etc.), which means we do not consider them as suitable for mass production (Adeyeye and Awokunmi, 2010; Wang *et al.*, 2005).

Breeders of insectivorous companion animals rear many more insect species, especially to improve the animals' diet, but also as a kind of enrichment. Due to the high cost of inputs, the price of small scale reared insects is several times higher than it is supposed to be in mass production. Therefore, developing technologies for rearing intensification purposes is essential.

Based on available data, the nutritional value of the insects varied among individual orders, species and developmental stages. The available information indicates that the amount of nutrients could also vary according to the breeding methodology (e.g. diet composition, temperature, gut loading, etc.). There were instances where the published results for the same species differed substantially (e.g. Ca/P ratio in *M. domestica* by Bernard *et al.*, 1997 and Djordjević *et al.*, 2008).

Regarding Table 1, the protein content of most of the reviewed insect species ranged between 339.8 – 799.1 g/kg DM, which could be considered as similar to or slightly higher than in soybean (438 – 535 g/kg DM) and fish meals (484.0 – 754.0 g/kg DM). The exception for this criterion (i.e. crude protein content lower than 438 g/kg) were two species of the Lepidoptera order – *G. mellonella* larvae, *B. mori* pupae; one Diptera species – *H. illucens* larvae, and nymphs of *E. distantii*, Blattaria. On the other hand, the average protein contents of adult *A. domestica* or pupae of *M. domestica* were almost equal to that of high concentration fishmeals.

Most farm animal requirements are not specified in protein quantity, but in its quality. Knowledge of amino acid composition is therefore necessary. In terms of animal feeding, the most important aspect is the content of limiting amino acids. The most frequent farm animal species associated with using insect meal as an alternative protein source are pigs (Adeniji, 2008; Coll *et al.*, 1992) and poultry (Ramos-Elorduy, 2002; Tas, 1985; Téguia *et al.*, 2002).

The limiting amino acid in pig nutrition is lysin (Subcommittee on Swine Nutrition *et al.*, 1979). As shown in Table 5., the average lysin content in insects has been found to be significantly lower than in casein or high protein fishmeals, but similar to that of soybean meal (12 groups) or low protein fishmeal (7 groups). The lowest level (8 g/kg DM) of lysin was found in *B. mori* pupae. The average level of methionin (see Table 5) which is limiting amino acid in poultry nutrition (Subcommittee on Poultry Nutrition *et al.*, 1994), in most insects was similar to or slightly higher than in soybean meal. Only 3 species (*M. domestica* larvae, *S. riciini* pupae and a stadium mix of *Z. variegatus*) had the same methionin content as low protein fishmeal. None of the reviewed species neared methionin values of high protein fishmeals or milk protein. The same situation occurred with almost all essential amino acids (see Table 3 and Table 5), except leucin. Average leucin level was unexpectedly higher in both nymphs and adults of *A. domestica* than in high protein fishmeal.

The insects also contain high levels of lipids (see Table 1), ranging from 66.6 to 600.0 g/kg DM. These contents are several times higher than that of soybean meal and fishmeal. The lowest average lipid levels were found in two Orthoptera species: *Z. variegatus* and *A. domestica*, which both may be considered similar to fishmeal in terms of fat content. The highest average lipid levels have been conversely found in Lepidoptera species *B. mori* (pupae) and *G. mellonella*. Both these groups were actually the only investigated insects with higher lipid than protein content. The quality of lipids is expressed by fatty acid composition. Unfortunately, the information about that is limited (see Table 2), but it is known that fatty acid composition is influenced by its composition in the insect's diet (Stanley-Samuelson *et al.*, 2005), so we assume that these values may vary greatly.

An anti-nutritional factor contained in the insects is polysaccharide chitin. Information about its content in insects is very limited, but the available results indicate that it reaches levels many times higher than indigestible polysaccharide lignin levels contained in soybean meals.

The gross energy (see Table 1) content was 11.5–29.6 MJ/kg DM, most of the investigated groups (10) exhibiting higher average energy content than both fishmeal and soybean meal. On the other hand, seven groups of insect containing slightly lower energy amount have also been found.

The ash content (see Table 1) in insects was found in a large variety of 11.1–240.0 g/kg DM. Except for a few Diptera species, the reviewed insects contained similar amounts of ash as there is in soybean meal. However, the ratio of the most important macroelements Ca:P is generally significantly lower than in fishmeal and soybean meal. The only investigated groups containing more calcium than phosphorus were the maggots of two Diptera species.

The studied insects expectedly contained low levels of NFE (see Table 1), probably formed only by feed residues. Only three exceptions with NFE content higher than 100 g/kg DM were found in sources – adult *B. lateralis* (Kulma *et al.*, in prep), *H. illucens* (Kroeckel *et al.*, 2012) and *B. mori* (Finke, 2002). On the other hand, negative values have been reported by Finke (2002) as well.

CONCLUSION

The collected data indicate that insect meals could be considered as a potential future substitute for currently used protein sources in agriculture. Further research including more aspects (mass production, economy, rearing techniques, possibilities of nutrient content manipulation, etc.) of using insect meals is undoubtedly needed.

Based on the highest lysin and methionin content, we propose *Musca domestica* larvae and *Samia ricini* as the best alternatives to commonly used protein sources for poultry and pig feeding.

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