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The potential of *Imbrasia belina* worm as a poultry and fish feed. A review

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ABSTRACT. This review is aimed to present the potential of *Imbrasia belina* as poultry and fish feed. *Imbrasia belina* worms contain substantial amounts of proteins, fats, essential amino acids, fatty acids, minerals and carbohydrates useful for the animal health. The worm as a source of protein could be utilised to minimise inadequate nutrition in poultry and fish. It has been documented as feed for such animals as fish, broilers, layers and guinea fowl. *Imbrasia belina* worm is an alternative source of animal protein, which is locally available, accessible and acceptable as food and feed source. However, using *Imbrasia belina* worm as animal feed has also some disadvantages as: chitin, the risk of being over exploited, unpalatability and a chance of indigestibility at higher inclusion levels in diets. Therefore, in this review the potential of *I. belina* worm as poultry and fish feed is assessed.

Introduction

Livestock feeding is known as a chief contributor to climate change, energy use, water dependence and land occupation (Mungkung et al., 2013). The production of soybean and fish meal rises these problems. Monogastric species like fish and poultry require high values and amounts of protein in their diet (Sánchez-Muros et al., 2014). From nutritional perspective, protein sources ought to have high-protein content, an adequate amino acid profile, high digestibility, good palatability and no anti-nutritional factors (Barrows et al., 2008). Hence fish and soybean meal are the main valuable protein sources in fish and poultry diets (Sánchez-Muros et al., 2014).

Furthermore, Sotak-Peper et al. (2017) pointed that soybean meal is a high digestible and high quality protein with favourable amino acid profile that can be used in animal feeding. However, it has several unfavourable traits, which include disparities between dispensable and indispensable amino acids, anti-nutritional factors, low palatability and high proportions of fibre and non-starch polysaccharides limiting the percentage inclusions in the diet (Sánchez-Muros et al., 2014). As a result, it is necessary to complete the diet by adding amino acids or high value protein source such as fish meal having also excellent nutritive properties. These benefits, together with the present regulations forbidding the usage of meat meals due to problems of food security, enable fish meal to be highly utilised. However, the massive use of soybean poses severe environmental issues, such as deforestation of high biological value areas, high water usage (Steinfeld et al., 2006), utilisation of insecticides, fertilisers and varieties whose genes have been artificially inserted (Garcia and Altieri, 2005) causing environmental deterioration. While fish meal is a resource that is governed on catch, hence its manufacture is quantitative and qualitatively variable (FAO, 2012). The stock has been declining due to global climate change leading to reduction in the manufacture of fish meal and price escalation of varieties whose genes have been artificially inserted. This situation is likely to linger (International Monetary Fund, 2010) with consequent repercussions on animal production. Hence this situation calls for alternative sources of proteins, which are vital for fish and poultry diets (Manzano-Agugliaro et al., 2012). Such potential protein source can be *Imbrasia belina* worm which can cater for amino acids deficiency in soybean. *Imbrasia belina* worm meal is highly digestible and has good balance between essential and non-essential amino acids (Sánchez-Muros et al., 2014).

Currently worms like *I. belina* are a novel protein source for poultry and fish (Premalatha et al., 2011; van Huis et al., 2013). When utilising insects as livestock feed, factors including the natural feeding habit of many species such as poultry and cultivated species of fish are considered. Conversely, there is limited documentation on *I. belina* being utilised as poultry and fish meal, despite its nutritive value potential. This review seeks to divulge the potential use of *I. belina* as poultry and fish feed.

Description and life cycle of *I. belina* worm

Imbrasia belina worm is a larval stage of mopane worm moth. Its common name mopane is derived from the host plant, *Colophospermum mopane* (Makhado et al., 2009; Dube and Dube; 2010; Moreki et al., 2012). It is found mainly in developing countries in the southern region of Africa, and widely distributed in South Africa, Namibia, Botswana, Zambia, Angola, Mozambique, Botswana, Zimbabwe, and Malawi (Makhado et al., 2012). Its exoskeleton is tough and covered by black or dark reddish brown spines, which during harvesting cause pain, lacerations, and associated hairs have a slight rusticating effect. In addition, Gondo et al. (2010) indicated that when the larvae are handled, they release a slimy green fluid through their mouth.

During the first three instar stages, the mopane worms are gregarious and forage in groups of 20 to 200 caterpillars (Akpalu et al., 2007), while worms of the remaining two instar stages tend to be solitary (Gondo et al., 2010). At the end of the larval stage, the fifth instar caterpillars descend from the tree and burrow 10–15 cm into the ground where they undergo metamorphosis (Akpalu et al., 2007; Dube and Dube, 2010; Gondo et al., 2010) as shown in Figure 1. The mopane moth is bivoltine throughout the most of its distribution, meaning there are usually two generations each year (Akpalu et al., 2007). Generations of the moth emerge during the summer months when temperatures are typically high, rainfall is most likely to fall and mopane trees are in leaf (Thomas, 2013). Depending on the generation, pupae remain underground for six to seven weeks (first generation) or experience a period of diapause and emerge six to seven months later (Gondo et al., 2010). The life cycle of the first generation of the species for the season begins when adult moths from the previous season mate and lay eggs, usually between October and January, and the first generation of adults then gives rise to the second generation of eggs between February and May (Dube and Dube, 2010) as shown in Figure 2. In the case of bivoltine populations, the first generation tends to be more abundant than the second, but the size of the population for both generations is greatly variable from year to year and is dependent on factors such as food availability and

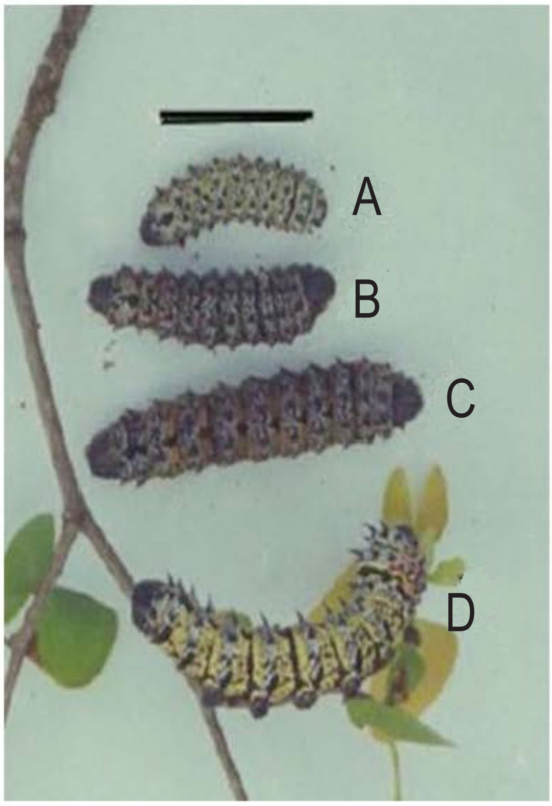

Figure 1. *Imbrasia belina* at different stages of development: (A) worm 5 weeks after hatching, (B) worm 6 weeks after hatching, (C) full grown worm ready to bury itself underground and (D) worm 7 weeks after hatching; scale bar = 6 cm (Dube and Dube, 2010)

rainfall (Thomas, 2013). In some more arid areas, the species are univoltine (Akpalu et al., 2007), so only one emergence of moths occurs each year in summer.

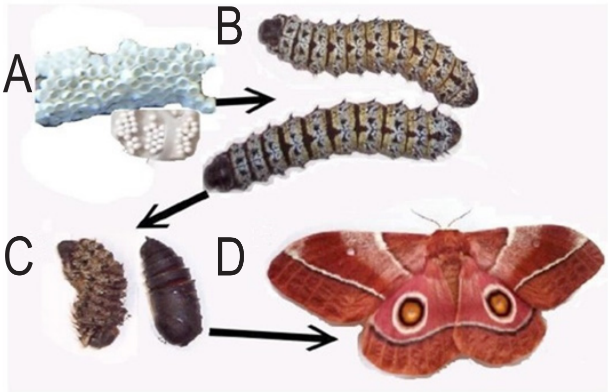

Figure 2. The life cycle of *Imbrasia belina*: (A) eggs, (B) larva, (C) pupa and (D) adult female (Dube and Dube, 2010)

Availability of *I. belina* worm

According to Makhado et al. (2009) and Makhado et al. (2012), *I. belina* worm prevalence is highly affected by some factors that include prevailing weather conditions, predatory and pressure at harvesting. In addition, rainfall plays a major role in promoting egg-laying by the emperor moth. Erratic, low and irregular rainfalls significantly lower the population of *I. belina* worms (Lucas, 2010). Hence, climate is a very important factor allowing worms to survive from hatching to pupation; the first generation is mostly affected by adverse weather conditions (Greyling and Potgieter, 2004). *Imbrasia belina* worm requires ecological harvesting so as to ensure a good crop for the following season (Akpalu et al., 2007). Pitiable harvesting practices of *I. belina,* due to competition among harvesters, put pressure on mopane worm population leading to decline in in the next generation (Makhado et al., 2009). Furthermore, the various growth stages of the worm life cycle provide food for natural predators (Greyling and Portigieter, 2004), and this predation can have significant impact on *I. belina* worm yield. As already indicated, the availability of *I. belina* worm may change due to biotic and abiotic conditions of the environment (Melo et al., 2011). Hence, this implies that availability of *I. belina* worm cannot be guaranteed. As a result, Dube and Phiri (2013) pointed out that there is need to understand the consequences of such factors on worm availability.

In addition, Akpalu et al. (2007) pointed that the first generation tends to be more abundant than the second, though quantities attained have not been noted yet. However, the size of population for both generations is greatly variable year to year, depending on factors like food availability and rainfall. Also, the accessibility of the *I. belina* worm depends on a tight synchrony of the availability of vegetative material on mopane trees and hatching of the moth eggs. Hence it would be worth discovering the opportunity of breeding mopane worms in confinement and freeing the butterfly to re-seed the mopane foliage when the environments are encouraging (Stack et al., 2003).

Sustainability in harvesting *I. belina* worms

When collecting a common, high valued worm from nature, one of the perils is overexploitation, which can threaten forthcoming produce. Over-harvesting mainly occurs when there is a food shortage or increase returns from sale. Consequently, in Zimbabwe, concerns in opportunities for small scale farming of *I. belina* worm arose (Hope et al., 2009). The absence of regulations for the collection of *I. belina* worm has also increased the competition for harvesting between local people and outsiders at the same time affecting the worm life cycle. Threats linked with harvesting include destroying the mopane trees whereby the trees are chopped down so as to make the worm reachable, incorrect timing and length of the harvesting period, taking too many, under-aged larvae, too many harvesters and adverse environmental impacts linked with harvesters such as trampling, fire wood collection and litter (Thomas, 2013). The use of fire to process the *I. belina* worm results in patches of veld being burnt, therefore its sequel is reduced grazing capacity of the veld. Nevertheless, traditional regulations may include: monitoring the caterpillar development, abundance, harvesting mature and bigger worms than the younger and smaller ones. Nevertheless, increased demand for mopane worm, apart from traditional control, calls for government legislation and permits to control harvesting (Dube and Dube, 2010). In communal areas regulation may involve harvesting permits that regulate the number of harvesters, the place of collection, the number and size of *I. belina* worms, and number of days spent on harvesting (Mufandaedza et al., 2015). In addition, government should establish also non-harvest areas as nature reserves, and areas harvested on rotational basis and sacred sites. It is important since the population of the *I. belina* worms not picked in one period would define abundance in the next period

(Akpalu et al., 2007). Furthermore, recognition of the property rights may also allow locals to manage and control their own land hence protecting them from outside harvesters.

Mass rearing and breeding of mopane worm

In most countries, wild harvesting is the most common way to collect the mopane worm. Furthermore, the worm may not be available all year round in the wild due to seasonal and geographical variations. In order to ensure all year-availability of mopane worm, mass rearing is currently being studied in Zimbabwe, South Africa and Botswana (Rapatsa and Moyo, 2017). Hence, the industrial scale worm production, assisted by sustainable worm breeding, farming and processing technologies, can ease the challenges of worm availability and lower the sale price of edible worms (Raheem et al., 2018). According to Gondo et al. (2010), the efforts to farm mopane worms in deliberately planted mopane forests in order to meet the increasing demand have met with varying success. What is more, Gardiner (2003) conducted a project demonstrating that it was possible to establish and maintain a captive breeding population of *I. belina* for over of three years. In addition, attempts to semi-cultivate and domesticate the mopane caterpillar as a food source has had positive results. However, such issues as susceptibility to viral and bacterial diseases of *I. belina* worms need to be addressed before their wider utilisation.

Nutritive value of *I. belina* worm

Proximate and mineral analysis

The inclusion level of protein in diets is one of the most crucial principles that needs to be taken into account when talking about feed protein sources (Sánchez-Muros et al., 2014). Studies regarding protein value of *I. belina* indicate that it has high quality and quantity of protein (Dube and Dube, 2010; Moreki et al., 2012; Manyeula et al., 2013) which is comparable with other commonly used protein sources as shown in Table 1. Furthermore, Johnson (2010) and Xiaoming et al. (2010) affirmed that most edible insects are nutritious and provide adequate proteins and other major nutrients needed by poultry and fish.

According to Akpalu et al. (2007), *I. belina* worm contains higher levels of protein, fat, carbohydrates and minerals than beef and chicken.

Table 1. Chemical composition of *Imbrasia belina,* fish meal and soybean meal

Indices	*I. belina*	Ref	Fish meal	Ref	Soybean meal	Ref
Nutrient, %						
CP	54 – 59	b, c, e, f	65.5	d	40.1 – 46.8	a, d
ash	6.9 – 10.4	b, c, e, f	18.0	d	6.13	d
NDF	27.8	a	N/D	-	14.5	d
ADF	16 – 58.4	b, e, f	N/D	-	9.5	d
ADL	5.2	b	N/D	-	N/D	-
ADIN	0.9	b	N/D	-	N/D	-
fat	12.9 – 16.7	b, c, e, f	12.0	d	18.2–20	a, d
Minerals, mg/g						
K	1.1 – 35.2	b, e, f	0.5	d	19.85	d
Ca	0.7 – 16	b, e, f	3.9	d	3.12	d
P	0.45 – 14.7	b, e, f	2.6	d	6.64	d
Mg	4.1 – 54	b, e, f	0.0	d	2.72	d
Fe	11.6 – 12.7	b, e, f	0.2	d	N/D	-
Zn	1.9 – 2.1	b, e, f	0.0	d	N/D	-
Na	26.7 – 33.3	b, e, f	0.8	d	0.18 – 04	a, d

References: a – da Silva et al. (2009), b – Madibela et al. (2009), c – Dube and Dube (2010), d – Gümüş (2011), e – Moreki et al. (2012), f – Manyeula et al. (2013); ND – not detected; CP – crude protein; NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; ADIN – acid detergent insoluble nitrogen

In addition, Madibela et al. (2007) estimated that it contains 50% crude protein (CP). This could be attributed to the fact that mopane leaves (leaves on which *I. belina* feeds) are characterised by the high value of CP (Wessels et al., 2007). Furthermore, according to Madibela et al. (2009) removal of the gut content improves the CP concentration of the *I. belina* worm by 10%. This is because the gut content consists of plant material which is mainly built of carbohydrates. As a result, removal of carbohydrate rich content of the gut results in a relatively larger amount of the remaining constituent protein and fat (Lautenschläger et al., 2017). This could be attributed to the fact that tannins in the gut content can lower the level of available protein by antagonistic competition (Ekop, 2009). The mineral profile of *I. belina* depends to a large extent on its diet (Henry et al., 2015). Whilst Rapatsa and Moyo (2017) revealed that minerals in *I. belina* worm were much higher than those in fish meal (the phosphorous as the one exception). Despite the fact that calcium and phosphorus are required as structural components of the skeleton (McDonald et al., 2002). The *I. belina* worm meal is rich in sodium attributed by addition of salt during processing. Also high levels of iron were reported in these worms, which may be connected with the alkaline soils, rich in iron, on which mopane trees are usually found (Stack et al., 2003).

In a study by Rapatsa and Moyo (2017), acid detergent fibre (ADF) was taken as a surrogate measure of chitin. The increased growth performance of Mozambique tilapia (*Oreochromis mossambicus*) with higher *I. belina* worm inclusion levels suggests that chitin did not affect nutrient digestibility. Chitin is not hydrolysed in the intestinal tract of most fish due to the absence of chitinase, hence making it possible for *I. belina* worm to be utilised as fish meal (Rapatsa and Moyo, 2017). According to Madibela et al. (2013) concentration levels of CP was reduced by 9% in a study determining the suitability of *I. belina* worm as feed. Whereas, in an earlier study Madibela et al. (2009) noted an increase in the ADF, neutral detergent fibre (NDF) and lignin in degutted *I. belina* worm samples. Hence, Madibela et al. (2013) pointed that this could reflect that gut content of *I. belina* worm neutralises the CP content, while increases the concentration of lignin, ADF and NDF.

Amino acids

Livestock, particularly poultry and fish, do not have true protein requirements, but rather amino acid (parts of protein) needs (Teles et al., 2011). Hence, protein quality depends on the amino acid composition – mainly the balance among dispensable and indispensable amino acids is important (Sánchez-Muros et al., 2014). Amino acids are very crucial components in broiler diets, improper intake can cause detrimental effects on growth and production (Kim, 2010). Also, they play an imperative role in enzyme and tissue functioning (Li et al., 2011). *Imbrasia belina* worm contains greater concentrations of some indispensable amino acids, such as threonine, valine, tryptophan and phenylalanine than fish meal and soybean (Mojeremane and Lumbile, 2005). Thus its inclusion into the diet may balance the indispensable amino acids level. In addition, Nobo et al. (2012a) confirmed that levels of some essential amino acids like lysine and methionine in *I. belina* worm are comparable to fish meal. Whereas, according to Rapatsa and Moyo (2017) the levels of methionine in *I. belina* exceeded the catfish requirements. Furthermore, Rapatsa and Moyo (2017), pointed that *I. belina* worm is composed of all essential amino acids (Table 2) required by *O. mossambicus* and poultry. So, it can be utilised to be included into diet and/or substitute fish and soybean meal. This fact could reduce the usage of fish meal and soybean meal in the livestock diets, thereby causing the decrease in the price of fish and soybean meal. However, more research needs to be carried out on *I. belina* worm meal as an ingredient of poultry and fish diets.

Table 2. Amino acid in mopane worm *(Imbrasia belina),* fish meal and soybean meal

Amino acid	*I. belina*	Ref	Fish meal	Ref	Soybean meal	Ref
Methionine	1.5–2.2	a, b, e	1.5–2.26	a, d	0.54–0.8	a, d
Lysine	3.6–4.7	a, b, e	4.8–10.96	a, d	2.85–3.0	a, d
Tryptophan	0.7–1.1	a, c, e	0.7–0.97	a, d	0.6–0.64	a, d
Arginine	3.2	a	3.82–4.2	a, d	3.39	d
Tyrosine	3.6	a	4.6	a	N/D	-
Histidine	1.7–2.9	a, b, e	1.4–4.19	a, d	1.3–1.19	a, d
Threonine	2.7–7.3	a, b, e	2.5–5.28	a, d	1.78–1.9	a, d
Isoleucine	2.2–3.0	a, b, e	2.60–2.66	a, d	2.0–2.03	a, d
Leucine	3.5–7.1	a, b, e	4.5–8.31	a, d	3.49–3.5	a, d
Phenylalanine	2.5–5.1	a, b, e	2.9–5.52	a, d	2.22–2.3	a, d
Valine	3.2–4.1	a, b, e	3.22–3.1	a, d	2.02–2.2	a, d

References: a – McDonald et al. (2002), b – Lucas (2010), c – Harlıoglu (2012), d – Rapatsa and Moyo (2017), e – Lautenschläger et al. (2017); ND – not detected

Lipids and fatty acids

Feed rich in protein include some amount of lipids; hence determination of fatty acid composition of lipid is very crucial. This is because lipid contributions can meet the requirements of essential fatty acids or limit the biological function of fatty acids (Sánchez Muros et al., 2014). The ratio of total unsaturated fatty acid to total saturated fatty acid in *I. belina* was 54:49 with α-linoleic acid being the most abundant (Table 3). However, the worm lacked eicosapentaenoic acid (EPA) (C20:5n3) and docosahexaenoic acid (DHA) (C22:6n3), while fresh water fish like *O. mossambicus* requires polyunsaturated fatty acids (PUFA) in their diets (Tocher, 2010). In addition, EPA and DHA are sources of omega-3 fats in poultry diets (Cherian, 2015). Furthermore, Yeboah and Mitei (2009) reported that *I. belina* worm contains high levels of dietary α-linolenic and palmitic acids, which can be helpful to cure alleviating coronary heart disease and chronic ailments. Pharithi et al. (2004) reported that the *I. belina* worm and the mopane tree, from which it feeds on, have the same fatty acid profile. There is little information on lipid and essential fatty acid requirements for *O. mossambicus*, guinea fowl and broilers. Hence, *I. belina* worm meal appears to be a suitable lipid source to provide essential fatty acid. Dietary fat levels of *I. belina* worm meal are not significantly different than that in fish meal (Table 1).

Table 3. Fatty acid composition (g/100 g) of mopane worm (*Imbrasia belina*), fish meal and soybean meal

Fatty acids	*I. belina*	Ref	Fish meal	Ref	Soybean meal	Ref
Total polyunsaturated fatty acids (PUFA)	54	c	39.19	b	27.96–46.32	a, b
Total monounsaturated fatty acids	1.7	c	18.55–44.98	b, d	8.45–45.43	a, b, d
Total saturated fatty acids	49	c	40.17–52.43	b, d	4.10–53.00	a, b, d
n-3PUFA	N/D	-	36.54	b	0.77	b
n-6PUFA	N/D	-	2.65	b	45.55	b
n-3/n-6	N/D	-	13.78	b	0.14	b
Lauric acid C12:0	<0.1	c	0.11–0.19	b, d	0.18	e
Myristic acid C14:0	<0.1	c	2.77–4.48	b, d	0.21–3.89	a, b, d
Palmitic acid C16:0	3.2	c	27.28–27.48	b, d	12.31–27.32	a, b, d
Stearic acid C18:0	1.7	c	21.86–7.28	c, d	3.74–21.18	a, b, d
Arachidic acid C20:0	<0.1	c	N/D	-	0.04	a
Palmitelaidic C16:1	0.1	c	0.41	b	N/D	-
Elaidic acid C18:1n9c	1.6	c	N/D	-	N/D	-
Linolelaidic acid C18:3	3.7	c	N/D	-	N/D	-
α-Linoleinic acid C18:2n6c	<0.1	c	N/D	-	0.72–2.16	a, b
Arachidonic acid C20:4	<0.1	c	N/D	-	N/D	-
Linoleic C18:2	1.6	-	2.57	d	1.55–11.6	a, b, d
Oleic acid C18:1n9c	1.6	-	44.98	d	45.43	d

References: a – van Eys et al. (2004), b – Gümüş (2011), c – Rapatsa and Moyo (2017), d – Romero-Bernal et al. (2017); ND – not detected

Indigestibility components of *I. belina* worm

Chitin and strategies of overcoming it

Chitin is a polysaccharide present or found in the exoskeleton of arthropods. It is a polymer of β(1→4) joined by a β(1→4) glycosidic bond, a crude fibre (Lindsay et al., 1984) that is not digestible by monogastric animals. Furthermore, Kwiri et al. (2014) reported that 27% of *I. belina* dry weight is chitin, an exoskeleton component. Chitin impedes protein utilisation (Longvah et al., 2011) as it evades the access of digestive enzyme to hydrolyse protein, lipids, fat-soluble vitamins and minerals thus affecting their utilisation (Mahata et al., 2008). Nevertheless, its removal increases the net protein utilisation (NPU), improves the value of insect protein as some proteins are connected to it (Rumpold and Schuler, 2013). This fact should be taken into account when processing *I. belina* worm. Belluco et al. (2013) pointed out that elimination of chitin raises the value of insect protein to the level of vertebrate animal protein. However, this may lead to the additional costs connected with processing and removing chitin.

Species fed diets containing *I. belina* worm meal

Poultry

The main challenge in the poultry industry is to avail feeds containing all indispensable diet constituents for the birds to promptly mature (Oyegoke et al., 2006). What is more, the nutritive needs of monogastric species, particularly, broilers, layers, and guinea fowls include a high value and quantity of protein in the diet. From a nutritional point of view, protein sources must be characterised by a high-protein content with adequate amino acid profiles, high digestibility and good palatability (Barrows et al., 2008). *Imbrasia belina* worm was shown to possess most of the mentioned protein qualities.

According to Nobo et al. (2012b) guinea fowls fed a diet containing 4.5% of the *I. belina* worm had a higher feed intake compared to those fed a diet with a 13.5% additive and a control one. This could be due to the speculation that chitin in *I. belina* may influence the apparent digestibility coefficient of the total tract nutrient (De Marco et al., 2015) and render feed unpalatable and indigestible. In addition, as the energy in the diet increases, the feed intake decreases (Veldkamp et al., 2005). This is because the increase of dietary energy level improves feed conversion ratio, hence reducing feed intake (Dozier et al., 2006; Ghaffari et al., 2007). As a result, the increase in the diet levels does not contribute to the good performance of the guinea fowl. However, guinea fowl fed higher levels of *I. belina* worm diet had lower body weight during the study than other treatments. It shows that higher levels of *I. belina* worm have deleterious effects on guinea fowl growth performance, especially at its early stages of growth.

Furthermore, Mareko et al. (2010) revealed that weight of broilers fed 20% *I. belina* worm was significantly different in comparison with the control. At 6 weeks of age, control birds weighted 2.016 ± 0.042 kg whereas those fed *I. belina* worm 1.480 ± 0.042 kg. This is in agreement with the findings of Nsoso et al. (2006) who observed that broilers under commercial feeding at 6 weeks of age should weigh 2 kg. This could be attributed to the supplement characteristics, which fed at higher levels becomes unpalatable and as a consequence limits the feed intake. Nsoso et al. (2008) and Mareko et al. (2010) also stated that higher levels of *I. belina* worm render it unpalatability and hence its intake was lower in guinea fowl. Later, Nobo et al. (2012b) suggested that *I. belina* worm meal can be fed to guinea fowl at 4.5% without negative effects on growth performance. Nonetheless, further findings need to be done in order to determine inclusion levels at which the *I. belina* worm meal can be fed to guinea fowl without significant affection of weight gains. Mareko et al. (2010) revealed that sodium content in meat was higher in birds fed *I. belina* worm meal at inclusion of 20 to 40% in comparison to control group; however meat sodium level was still lower than that found by Nsoso et al. (2008). This variation may be attributed to different species raised under different housing systems and feed types. Furthermore, Mareko et al. (2010) stated significant amounts of phosphorous in meat of birds fed diet supplemented with 40% of *I. belina* worm or the control one.

Mareko et al. (2008) also revealed 0.72–0.92% of potassium content in meat of animals fed *I. belina*, whereas Mareko et al. (2010) recorded 1.52–1.57%. Potassium and sodium are very crucial minerals in osmotic regulation of the body fluids and an acid base-balance in animals. They also play a pivotal role in nerve and muscle excitability and in carbohydrate metabolism (Choi and Ha, 2013).

Furthermore, Manyeula et al. (2013) noted that layer chickens fed 18% *I. belina* worm meal had high average daily gains (ADG) (4.77 g) and low feed conversion ratio (FCR) (1.10 ± 0.16) (Table 4). Low FCR in hens fed *I. belina* worm diet could be attributed to lower feed intake due to possible unpalatability and indigestibility of the feed.

Table 4. Growth and laying performance of Tswana hens fed on three protein sources (*Tylosema esculentum, Vigna subterranean* and *Imbrasia belina*) from 25–38 week of age (according to Manyeula et al., 2013)

Parameters	Control	*T. esculentum*	*V.subterranean*	*I. belina*
FI, g	84.6 ± 7.9[a]	54.9 ± 7.9[b]	59.3 ± 7.9[b]	59.6 ± 7.9[b]
FCR	1.76 ± 0.16[b]	1.61 ± 0.16[b]	1.23 ± 0.16[a]	1.10 ± 0.16[a]
ADG, g/d	3.27 ± 1.16[a]	0.82 ± 1.60[b]	3.13 ± 1.51[a]	4.77 ± 1.31[a]
HDEP, %	90 ± 0.87[a]	41 ± 0.87[d]	67 ± 0.87[c]	75 ± 0.87[b]

FI – feed intake per hen per day; FCR – feed conversion ratio; ADG – average daily gain per hen; HDEP – hen day egg production; [abcd] – means with different superscript in the same row are significantly different at $P < 0.05$

The findings also indicate that low FCR could result in increased weight gain from consumption of little feed of good quality (Haryanto et al., 2016). Hence, less consumed feed reduces the cost of production. Madibela et al. (2006) reported that *I. belina* worm meal is superior in essential amino acids content compared to soybean and fish meal. Furthermore, Nobo et al. (2012a) reported no significant differences in feed intake, ADG, FCR and dressing percentage between guinea fowl fed fish meal (control diet) and 4.5% *I. belina* worm meal. The differences in Manyeula et al. (2013) and Nobo et al. (2012a) studies could be ascribed to the used Tswana birds and guinea fowls and their sex differences. Layers fed *I. belina* worm and control diet produced 11 and 14 eggs/clutch/year, respectively. These findings are in agreement with the study of Moreki et al. (2010). In addition, a hen day egg production (HDEP) from those animals fed *I. belina* worm was 75 ± 0.87 (Manyeula et al., 2013). This could be attributed to the fact that *I. belina* worm contains adequate amounts of amino acids and minerals like phosphorus and calcium to support egg production, however other essential ingredients could have contributed to it as well.

In the study of Chiripasi et al. (2013) it was revealed that guinea fowl birds fed 4.5% *I. belina* worm diet had lower bone width in comparison to other treatment diets. In addition, bone width in birds fed control diet, 9 and 13% *I. belina* worm meal did not significantly differ. Furthermore, bone weights were negatively influenced by 9% *I. belina* worm meal. Therefore, it is suggested that the diet containing 4.5% *I. belina* worm meal promoted more bone mineral deposition resulting in heavier weights than the other treatment diets. Furthermore, Chiripasi et al. (2013) reported that guinea fowls fed 4.5% *I. belina* were characterised by higher bone mineral composition of phosphorus (3536.2 mg/l), sodium (1332.96 mg/l) and potassium (1841 mg/l) than those fed control, 9 and 13.5% inclusions. Higher bone mineralisation is recorded at lower *I. belina* inclusion levels because increase in inclusion levels render the feed unpalatability and indigestibility (Madibela et al., 2007) leading to reduced feed intake and bone mineralisation. In addition, bones of birds fed 13.5% *I. belina* worm meal diet had the lowest copper content, whereas 4.5 and 9% inclusion levels did not influence this indicator significantly. This finding is supported by the estimation that copper level in *I. belina* is 8–12 mg/l (Pillay, 2015). Therefore, increasing inclusion levels of *I. belina* in the diet results in low levels of copper consumed by the bird.

Furthermore, according to Chiripasi et al. (2013) the content of magnesium in bones of birds fed control, 9 and 13.5% *I. belina* meal diets did not significantly differ and amounted 655.82–658.84 mg/l. On the other hand, the content of iron in bones was the highest in birds fed 13.5% *I. belina* worm meal (204.64 mg/l) and this is inconsistent with Moreki et al. (2011) who reported that the content of iron in bones amounted 95.07 mg/l. These findings could be related to the relatively high daily mineral intakes of 0.1577 to 0.2347 g/day and also the high levels of iron present in mopane tree leaves (Pillay, 2015). Furthermore, it was revealed that in guinea fowls fed 4.5, 9 and 13.5% of *I. belina* worm meal bone mineral composition was almost the same. Therefore, it could be stated that increasing *I. belina* worm meal concentration to 13.5% do not lead to better bone mineralisation. Even 4.5% inclusion could be enough to maintain possible optimum level for bone mineralisation. Chitin present in *I. belina* worm meal makes it highly unpalatable and poorly digestible (Madibela et al., 2007), and as a result leads to reduced feed intake and reduced bone mineralization especially at 13.5% inclusion. McDonald et al. (2002) alluded that calcium, potassium and magnesium are required as structural components of the skeleton and these components were found in high concentration in a study by Chiripasi et al. (2013). Also, these authors observed that *I. belina* worm meal can replace fish meal by up to 9% without affecting mineral intake, retention and utilisation. Inclusion of *I. belina* worm into poultry diets caused various results of bone mineralisation and bone width, therefore the effect of *I. belina* worm meal intake on poultry bone density and strength needs to be studied in detail.

Furthermore, in the study of Chiripasi et al. (2013) it was shown that meat from guinea fowl fed diet containing 4.5% of *I. belina* worm meal was characterised by significantly higher calcium content than 9 and 13.5% *I. belina* worm inclusions and control diet. The calcium mean value (10.29 mg/100 g) obtained by Chiripasi et al. (2013) corresponded to the value of 15.87 mg/100 g obtained by Tlhong (2008). These differences may be due to the differences in treatment diets used in both studies and animals used. Mareko et al. (2008), reported calcium and phosphorus values ranging from 0.14 to 0.16% and 1.81 to 2.55%, respectively. Hence calcium content in guinea fowl meat was lower than in the bone. It has been observed that *I. belina* worm meal inclusion into poultry diet influenced bone mineralisation and meat characteristics. So, it is necessary to study its impact on egg quality (shell strength, egg composition and yolk colour) when fed to poultry layers.

Fish

Utilised widely, fish meal is highly valuable for aquaculture and, as a result, it is becoming gradually rare and expensive. Increasing fish meal prices promoted the use of low inclusion levels; however, it is counterbalanced by the fast development of aquaculture sector (Olsen and Hasan, 2012; World Bank et al., 2013). Such situation promotes the exploration of substitute sources, for example the use of *I. belina* worm meal.

Rapatsa and Moyo (2017) noted a significant difference in growth parameters of *O. mossambicus* fed different levels of *I. belina* worm diets. The best growth rate performance was observed in control animals, however the specific growth rate (SGR), thermal unit growth coefficient (TGC), and apparent digestibility coefficient were increased at 60% *I. belina* worm inclusion level. However, this report differs from other studies where growth performance was declined with higher inclusion levels of the test ingredient (Sánchez-Muros et al., 2014). This is also inconsistent with the findings of Mwimanz and Musuka (2014) indicating not impressive results under 50% inclusion level. This could be attributed to the observation that *I. belina* worm is possibly rich in other anti-nutritional factors like condensed tannins and phenols (Wessels et al., 2007) other than chitin. It may be also stated that the amino acid profile of *I. belina* worm was not appropriate for *Oreochromis macrochir* at that inclusion level. However, according to Mwimanz and Musuka (2014) there are no studies conducted on the amino acids requirements of *O. macrochir* hence there is a need to conduct such. Interestingly the inclusion levels of 50, 75 and 100% used by Mwimanz and Musuka (2014) are already too high in comparison to Rapatsa and Moyo (2017). Anyway, more detailed research connected with *I. belina* worm that possibly could replace fish meals is needed.

Conclusions and future perspective

Imbrasia belina worm is a potential and equal protein substitute, which can be utilised in livestock feed preparations. It is known to be a source of animal protein, fat, minerals, fatty acids and amino acids, which contribute greatly to the growth performance of fish, broilers and guinea fowls. It is well documented that it can be utilised for animal feed, when compared with the control. Furthermore, this review revealed that *I. belina* lacks polyunsaturated omega-3 fatty acids, eiocosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in its fatty acid profile. There is need, of course, for further possibilities of using *I. belina* worm as a substitute to fish meal and fish oil in poultry and fish meal. However, this worm is overexploited during harvesting, hence there is a need to enforce traditional and government regulations so as to sustainable harvest *I. belina* worm.

Despite positive outcomes on the potential use of *I. belina* worm as poultry and fish diets to increase their performance and product quality there is yet a challenge of chitin that could limit the inclusion level. However further research on the enzyme additives (chitinase) to enrich *I. belina* worm should be considered in order to increase the inclusion level of *I. belina* worm meal and to improve nutrient digestibility. Currently, the chitin content and digestibility seem to prevent the inclusion of *I. belina* in poultry diet at levels higher than 20–30%. Research focusing on the nutritional composition of *I. belina* worm instar growth stages and the worm without exoskeleton would be of paramount importance. *Imbrasia belina* worm has been consumed by human beings, poultry and fish, therefore research focusing on its effect on ruminants would be interesting as no or little has been reported till now. Despite *I. belina* nutritional properties, its effect on broiler meat quality has not been determined.

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