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Insects as an Option to Conventional Protein Sources in Animal Feed: A Review Paper

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Keywords: *insects, feed, inclusion, constituents, animal feed.*

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Insects as an Option to Conventional Protein Sources in Animal Feed: A Review Paper

Nazif Amza [α] & Metekia Tamiru [σ]

Abstract- Intensification of Livestock production and the growing world population posed heavy pressure on limited resources which requires urgent attention to reduce its effect on climate change and feed scarcity. Protein-rich insects are one of the options to conventional protein sources. Africa is one of the most important hotspots of edible insects' biodiversity comprising 524 species. The most widely used insects in animal feeds are the larvae of the black soldier fly, the maggot and pupae of common housefly, the yellow mealworm or larvae of the beetle as well as blue bottle, termites, blow flies and insect families belonging to the order Orthoptera including, grasshoppers, crickets and katydids. The chemical composition of insects varies between species, growth stage and management conditions. The Crude protein (CP %) ranges from 41.1-76.1, crude fiber (CF %) from 3.8-15.7, the extract (EE %) from 5.4- 37.2, ash% from 2.2-26.6 and gross energy (GE) from 19.8- 27.2. Based on the nutritive values, Insect meal is an excellent and important substitute of poultry diet replacing wide range of feed stuffs. Insect protein as supplement or substitute on aquaculture production improves fish productivity which could replace 50 % fish meal without adverse effect on weight gain, Specific growth rate and feed conversion ratio. Utilization of insect as a substitute or supplement in Pig has no adverse effect on growth performance and carcass quality. Despite the above benefits, all insects are not safe to use in animal feed. Just as it applies for plant and animal food Products some insects cause allergic reactions, botulism, parasitizes and food poisoning. All these health risks can be prevented by the utilization of scientifically recommended insect species reared on pollutant-free feed either harvested in the wild or on farms with proper processing, handling, and storage. Although utilization of insects as animal feed have been given due attention, insects are being reared at a small scale. So that there is a need for establishing cost-effective well-optimized mass insect rearing facilities up on utilization of bio-waste and organic side stream for a defined quality of animal product.

Keywords: insects, feed, inclusion, constituents and animal feed.

I. Introduction

World's population will grow to around 9 billion people in 2050 resulting in a higher consumption of food from animal origin and an increased demand for protein to feed livestock(Alexandratos and Bruinsma, 2012). Livestock production which accounts 70% of agricultural land and world population increase place heavy pressure on limited resources which require urgent attention in causing climate change and feed scarcity (Fao, 2009a). The livestock sector contributes approximately 14.5% of all anthropogenic greenhouse gas (GHG) emissions (7.1 Gigatons of CO_2-equivalent per year) (Gerber *et a*l., 2013) and animal products have a much higher water footprint than plant-based foods(Mekonnen and Hoekstra, 2012). Making better use of low-impact feed sources such as grasses, insects or worms can lower global footprint due to animal products (Soil Association, 2013). To reduce the environmental impact for Production of protein from animal sources and diet costs, protein-rich insects are one of the options to conventional protein sources (Khusro *et al*., 2012).

Feed-to-meat and milk conversion varies widely depending on the feed type, class of the animal and the production practices used (Pimentel and Pimentel 2003). Typically, 1 kg of live animal weight requires 2.5 kg for chicken, 5 kg for pork and 10 kg for beef in a typical United States production system(Smil, 2002).However, the production of 1 kg of live animal weight of crickets requires as little as 1.7 kg of feed(Collavo *et al.*, 2005). The growing of fish product importing in world requires a more interesting solution to benefit the producers on the use of insect meal to substitute fish and soybean meal at low costs (Van Huis, 2013). Fortunately, increasing demand for food (particularly meat, fish and eggs) has led to an urgent need for new and safe supplies of protein from insect which provides a potential alternative to animal feed protein from plant sources(Charlton *et al*, 2015).The important role of insects in assuring food and feed security is due to; their short life spans compared to most vertebrates, capacity to colonize new niches, ability to feed on nearly all species of plants with animals, easily reared on organic side streams (e.g. manure, pig slurry, industrial by product and compost), independency of arable land resources and non-competing with human nutrition(Cassidy *et al*., 2011, Veldkamp *et al.*, 2012).

Insects are a class of animals within the arthropod group that have a Chitin exoskeleton and a three-part body (head, thorax and abdomen) (Harpe and McCormack, 2001). They are the most diverse groups of organisms in the history of life (Scaraffia and Miesfeld, 2012). Although, insects are the least studied

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of forest organisms (Johnson, 2010), they provide essential ecosystem services such as pollination, composting, wildfire protection, pest control, as human consumption and feed for animals(Losey and Vaughan, 2006). Scientists consider the insect meals a valid alternative source of animal protein and have studied the nutritional features, in terms of protein, mineral, energy value and composition of fatty acid for different livestock classes. Consequently, their conservation and the habitats they occupy are of an enormous benefit (Belluko, *et al.,* 2013, DeFoliart, 2005, Samways, 2007).

In recent years much attention has been devoted to antimicrobial peptides (AMPs) present in insects called natural antibiotics due to the increasing global problem of bacterial, fungal, certain parasitic and viral resistance to antibiotics. AMPs mechanism of insect doesn't induce bacterial resistance and involves the destruction of the bacterial cell envelope (Park *et a*l., 2015). However, there are possibilities of using in agriculture including animal nutrition as well as the pharmaceutical industry (Yi *et al*., 2014). Moreover, insects from the Diptera order, e.g. the larvae of the housefly and black soldier fly have a great ability to utilize organic waste material that contain moisture (60–80%) converting it to valuable insect protein in such a way that they reduce the accumulation of poultry manure by 50% and reduce bacterial growth in the manure that results in a reduced odor development and the growth suppression of significant pathogens (Čičkova *et al*., 2015, Diener et al., 2011). In addition, if insects are fed as alternative food sources, they may add value to other agricultural industries and contribute to mitigating the impact of climate (Khusro *et a*l., 2012, Saxe *et a*l., 2013).

Various insect species have a higher proportion of protein content compared to conventional fish and soybean meals and also have efficient food conversion factor (Anand *et al*., 2008).Animal feeding studies across insect species and animal production have shown that palatability of insects is good and they can replace 25-100% of soy meal or fishmeal depending on the animal and insect species (Makkar *et al*., 2014). Insects contain between 30% and 70% of protein on DM basis and rich in fats, minerals and vitamins (Veldkamp *et al*., 2012). Some insects can accumulate high levels of lipids and the extracted oil can be used for various applications including biodiesel production (Makkar et al., 2014). The nutritional contribution of more than 2,000 recorded edible insect species as food and feed is highly variable between species and morphological stages (eggs, larvae, pupae and adults) (Van Huis, 2013).

Insects such as the black soldier fly (*Hermeticaillucens* Linnaeus), common housefly (*Muscadomestica),* Linnaeus, (termites) and yellow mealworm (*Tenebriomolitor)* can play dual roles of recycling of organic by-products into high quality compost-fertilizers as well as utilization of the maggots directly as animal feed (Čičkováe*t al.*, 2015).The objective of this paper is to review utilization of insects as protein source in animal feed.

II. Potential Insect Species as Animal Feed

Insects are the most popular species comprising 70% of animal species and their biomass can be very high in some ecosystems (Chapman, 2009). Most insects are native from the tropical and subtropical of the world. However, insects are now wide spreading in tropical and warmer temperate regions between about 45°N and 40°S (Diener*et al*., 2011). There are insect species that are extremely resistant capable of dealing with demanding environmental conditions such as drought, food shortage or oxygen deficiency like black solder flies larvae (Diener*et al*., 2011).

In recent assessment Van Huis*et al.* (2013) reported 246 species of edible insects from 27 countries in Africa. Later, Ramos-Elorduy (2005) noted that Africa is one of the most important hotspots of edible insects biodiversity in the world with 524 species reported from 34 African countries. In Kenya, Nigeria, Tanzania, South Africa and Uganda, researchers are testing the feasibility of using insects rather than soybeans and fish meal for raising poultry and fish.

The most promising insects in animal feeds are the larvae of the black soldier fly (Hermetiaillucens), the maggot and pupae of common housefly (Muscadomestica), the yellow mealworm or larvae of the beetle (Tenebriomolitor) as well as blue bottle (Calliphoravomitoria), termites, blow flies and insect families belonging to the order Orthoptera including grasshoppers, crickets and katylids(Ghaly and Alkoaik, 2009). However, insects of the order Blattodea like American (Periplaneta Americana), German (Blattellagermanica) and Asian (Blattellaasahinai) cockroaches are also interesting candidates (Charlton *et al*, 2015).

Table 1: Distribution of insects in some parts of the world

Insect	Distribution
Black soldier fly	Tropical, subtropical and warm temperate of the world
Housefly	Word wide
Mealworm	Indigenous to Europe and now distributed worldwide
Grasshoppers and crickets	Africa, South America and Asia.
Silkworm	Worldwide, mostly Asia and silk producing countries(China, India, Uzbekistan, Brazil, Thailand and Vietnam)

Sources; (Longview al., 2011 and FAO, 2012).

III. Chemical Constituents of Insects at Different Developmental Stages

Most insects have a high-value feed source rich in protein, mineral, vitamin and fat. The amount of fat is extremely variable and depends on the type of diet which is 15-25% for larvae fed on poultry manure (Arango Gutierrez *et al*., 2004), 28% on swine manure (Newton *et al*., 2005), and 35% on cattle manure and 42-49% on oil-rich food waste for black solder fly larvae (Barry, 2004).

Table 2: Chemical constituents of insects in DM% reported by different authors

Types of insect	Chemical Composition					Reference
	CP	CF	EE	Ash	GE (MJ/kg)	
Black solder Fly larvae	42.1±1	7	26.0 ±8.3	20.6 ± 6	22.1	St-Hilaireet *al*. 2007
Housefly maggot meal	50.4 ± 5.3	5.7 ± 2.4	18.9 ± 5.6	10.1 ± 3.3	22.9 ± 1.4	Adesinaet *al*. 2011
Housefly pupae meal	70.8 ± 5.3	15.7	15.5 ± 1	7.7 ± 2.1	24.3	Pretorius (2011
Mealworm	52.8 ± 4.2	-	36.1 ± 4.1	3.1 ± 0.9	26.8 ± 0.4	Finke, 2002
locust or grasshopper meal	57.3 ± 11.8	8.5 ± 4.1	8.5 ± 3.1	6.6 ± 2.5	21.8 ± 2	Alegbeleye *et al*., 2012
House cricket	63.3 ± 5.7	-	17.3 ± 6.3	5.6 ± 2.4	-	Finke, 2002
silkworm pupae meal (non-defatted)	60.7 ± 7	3.9 ± 1.1	25.7 ± 9	5.8 ± 2.4	25.8	Jintasataporn, 2012

Note that DM is dry matter. Values are mean ± standard deviation and values without SE is when =1

According to St-Hilaireet *al*.2007, Adesinaet *al* 2011, Pretorius 2011, Finke, 2002 and Jintasataporn, 2012, the chemical composition of insects varies between species, growth stage and management conditions and the crude protein (CP %) ranges from 41.1-76.1, crude fiber (CF %) from 3.8- 15.7, Ether extract (EE%) from 5.4- 37.2, ash% from 2.2-26.6 and gross energy(GE) from 19.8- 27.2 (Table2).

The protein content of insect meals varies considerably from around 41.1- 76.1 even when the meals are based on the same insect species (Table2). The same holds true for the fat content. However, it is important to note that insect meals compared to fishmeal contain lower concentration of Methionine and Calcium which has to be considered when formulating diets based on insect proteins (Van Broekhovenet *al*., 2015, De Marco et al., 2015, Makkaret *al*., 2014).The fat content of mealworms fed low protein diets was significantly lower as compared to high protein diets (18.9 vs. 26.3 %) (VanBroekhovenet *al*., 2015).

Table 3: Mineral content of some insects reported by different authors

Types of insect	Ca	P	K	Na	Mg	Fe	Mn	Zn	Cu	Reference
Black solder Fly larvae	75.6 ± 17.1	9 ± 4	6.9	1.3	3.90	1.37	246	108	6	ArangoGutierrezetal.2004
Housefly maggot meal	4.7 ± 1.7	16± 5.5	5.7 ± 3.5	5.2 ± 2.4	3.4 ± 4	1± 0.44	114±91	27±6	119±118	Odesanya.*et al*. 2011
Mealworm	2.7 ± 1.9	7.8 ± 3.7	8.9	0.9	2.3 ± 0.4	57 ± 32	9.0 ± 4.0	116 ± 24	16 ± 1	Klasing.*et al*., 2000
House cricket	10.1 ± 5.3	7.8± 7.9	-	-	1.6 ± 0.8	116 ± 58	40.0 ± 10	215 ± 60	15± 7	Finke, 2002
silkworm pupae (non-defatted)	3.8 ± 3	6 ± 2.3			3.7 ± 2.5	326± 67	28± 9	224 ± 126	15 ± 12	Jintasataporn, 2012

Note that values are mean± standard deviation except at n=1, DM, dry matter and all values in g/kg DM except Mn, Zn, and Cu are in mg/kg DM.

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The major mineral content of studied insect were 0.8-92.7, 3.7-22.5, 2.2-9.2, 0.9-7.6 and 0.8-6.2 for Ca, P, k, Na and Mg in g/kg DM and also the micro was 0.56-393, 5-246, 19-275, and 1-237, for Fe, Mn, Zn and Cu mg/kg DM respectively. The mineral content of insects reviewed indicates that there is a need to think about feed of plant origin substitution by insects for animal at low cost .It is important that insect meals compared to fishmeal contain have lower concentration of ca which has to be considered when formulating diets based on insect proteins (Table3).

IV. Nutritional Value of Insects for Different Animal Species

Numerous studies have been conducted on the nutritive value and nutrient composition of different species insects confirming that insects are good sources of proteins, fat, energy, vitamins and minerals. The consumption of 100 g of caterpillars, for example, provides 76% of the daily required amount of proteins and almost 100% of the daily required amount of vitamins for humans and animals. And also Dried silkworm pupae are composed of about 50% proteins and 30% lipids (Mitsuhashi, 2010, Agbidye et al, 2009).

a) *Insect protein in poultry production*

The poultry industry is one of the fastest-growing agro-businesses but the use of expensive maize as a feed ingredient is threatening the survival of farmers. Feeding poultry with insect based is the best option for the survival (Krishnan *et al*. 2011).The insects were able to transform the low-nutritive waste products into a high-protein diet in particular as a replacement of soybean meal in poultry feed. Research conducted by Ramos Elorduy *et al.*, 2002 confirmed that insects could be utilized as protein source in poultry feed. More specifically, the amino acids derived from most insects‘are superior compared to those from plant supplements in poultry feed formulations (Bukkens, 2005). They are usually fed live but are also sold canned, dried or in powder form (Aguilar-Miranda et al., 2002, Hardouin and Mahoux, 2003, Veldkampet al., 2012).

Table 4(a): The role of insect in growing chicks and laying hens reported by different authors

Class of Animal	Insect Type	Feeding purpose	Result	Recommendation	Reference
In Chicks	Black solder fly larvae	As component of diet and substitute of soybean meal	Good growth and High feed conversion efficiency	Concentration up to 93% has significance / above 93% isn't recommended	Newton *et al*., 2005
Ruralchicken (Ghana and Togo)	Housefly maggot (larvae) meal	Supplementation	Higher growth rate, increased hatchability and clutch size	30-50g/d/bird	Dankwa *et al* .2002, Ekoue and Hadzi,2000
Laying hens	Mealworm	To replace fishmeal	Higher egg-laying ratio than that obtained with good quality feed.	2.4% and There is limited information	Giannone, 2003

Table 4(b): The Role of Insects in Broilers reported by different authors

Class of Animal	Insect Type	Feeding purpose	Result obtained	Recommendation	Reference
Broilers	Housefly maggot meal	Replacement for conventional protein sources and fishmeal	Have no distinctive organoleptic qualities and to be acceptable by consumers	Inclusion rate is ≤10% in the diet >10% result lower intake due to darker color of the meal	(Awoniyi, 2007).
120-day broilers (in Nigeria)	Maggot meal	Mixture of dried cassava peels and maggot meal for replacing 0-100% maize grain	Cassava peels-maggots' mixture could replace 50% maize (29% diet as fed) into save cost	With 4:1 ratio	Adesina *et al*., 2011

Table 4(c): The role of Insects in Broilers reported by different authors

Class of Animal	Insect Type	Feeding purpose	Result obtained	Recommendation	Reference
Broilers	Mealworm	For replacing soy meal or fishmeal.	Protein quality is like that of soy meal based broilers. But, low methionine and Ca content for poultry.	The addition of 8% $CaCO_3$ was found to be suitable to increase Ca.	Klasinget *al*., 2000. Anderson, 2000
	Dried Mealworm	Inclusion of broiler starter diet based on sorghum and soybean	Without negative effects on feed consumption, weight gain, feed efficiency, texture, palatability or inclusion level	Inclusion level is 25% mealworm, as a substitution of the basal diet	RamosElorduyet *al*., 2002 Schiavone *etal*, 2014
Broilers 1-28 days	grasshopper	As a substitute for fishmeal	Resulted in higher body weight gain, feed intake and feed conversion	Replace50% fishmeal protein with locust meal 1.7% in the diet.	Adeyemo *et al*, 2008

According to different studies conducted in the above (table4), insect meal is an interesting and important substitute of poultry diet potentially substituting wide range of feed staff like cassava peels, sorghum, fish meal, maize and soy meal. However, some insect species have no distinctive organoleptic quality which leads lack of consumer acceptance. Generally, when insects were included in poultry feed, the carcass quality, breast muscle portions, feed consumption, weight gain, feed efficiency, texture, palatability and higher egg-laying ratio was found to be better at a recommended levels of inclusion than other conventional good quality feed.

b) Insect protein in Aquaculture production

Recent high demand and consequent prices for fishmeal together with increasing production pressure on aquaculture has led to undertaking research into the development of insect proteins for aquaculture and making insects more cost-effective dietary fishmeal substitutes (Fao, 2012b).

Table 5(a): The role of insect in Aquaculture production reported by different authors

Fish species	Insect Type	Feeding purpose	Result obtained	Recommendation	Reference
Blue tilapia	Chopped black solder fly larva	Alone or in combination with commercial feed	Improve weight gain higher by 140% and 28%feed conversion	Not the same as tilapia in another fish(reduction of performance is observed)	Sealeyet *al*.,2011
Rainbow trout fishes	Mealworm	As replacement of fishmeal in a diet containing 45% Cp	Without a growth performance reduction, leading to a saving of fishmeal.	Inclusion level at 25% and can be used up to 50%	Gascoet *al*., 2014a
African catfish	Meal of adultgrasshopper	To replace fishmeal (weight basis	Resulted without any adverse effect on growth and nutrient utilization at the same protein level in the diet.	Inclusion>25%decreased digestibility, performance, a little shrinkage in gills, reduction in ovarian steroid genesis which may reduce fertility	Alegbeleye *et al*., 2012, Johri*et al*., 2010;Johri *et al*., 2011a, b

Table 5 (b): The role of Insects in Aquaculture Production

Fish species	Insect Type	Feeding purpose	Result obtained	Recommendation	Reference
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In aquaculture production for better economic benefit at low cost and quick returns, inclusion of insect meal is one of the alternative feed sources that can substitute Fishmeal, Soybean alone or in combination with commercial feed like cattle brain meal, feather meal and chicken offal meal at different level of inclusion for different fish species (Table5b).

Insect protein as supplement or substitute on aquaculture production improves fish productivity which could replace 50 % fish meal without adverse effect on weight gain, specific growth rate and feed conversion varying between fish species and inclusion level. However, inclusion rate ≤7.5% is unnecessary and chopping is recommended in channel fish. Maggot meal gave better performance than soy meal and lower performance than cattle brains in African catfish (Table5 b).

c) *Insect protein in Swine production*

According to (Adenji, 2008, Medhi et al., 2009a, b) insects were able to transform the low-Nutritive waste products into a high-protein diet as a replacement of soybean meal in swine feed.

Table 6: Pig performance evaluation under diet inclusion with insect meal

Class of Animal	Insect Type	Feeding purpose	Result obtained	Recommendation	Reference
Growing pigs	Black solder fly larvae	As replacement of soy meal	Good performance without supplementation of Ca and P	High ash content, require attention	Newton *et.al*,2005
Weaned Pig	Black solder fly larvae	Without Amino acid supplement	Gave better performance at 50% mix	Cuticle removal and rendering is necessary	Newton *et.al*,2005
	House fly larvae	Processed and as replacement of wheat offal	No adverse effect on performance	At ratio of 3;1 or at 10% inclusion	Adenji,2008
Finishing pigs	Silkworm pupae non-defatted silkworm	To replace up to 100% of soy meal	no adverse effect on growth performance, carcass characteristics and blood parameters	≥50% have negative effect on intake	Medhi*et al.*, 2009a, b Medhi, 2011.
		To replace up to 100% fish meal	no adverse effect on growth performance, carcass characteristics and blood parameters	Could fully replace fishmeal	
	Silkworm litter	To replace fish meal	no adverse effect on growth performance, carcass characteristics and blood	inclusion rate is about 7% but, shouldn't ≥ 10%	Wang *et al.*, 2007

In different classes of pigs' utilization of insect as a substitute or supplement have no adverse effect on growth performance, carcass quality and interest of consumers within recommended inclusion level for specified species of insects (Table6).

V. Insect Meals vis-à-vis Fishmeal and Soy Meal in Animal Feed

Insect meals are the important dietary substitutes of plant origin. Because plant production competes with human food and expensive compared with insect production and have environmental impact. Moreover, chemical constituent of fish meal and soy meal is less or equal to insects.

Table 7: Comparison of some insect's meal with soy meal and fish meal

Constituents % in DM)	Housefly maggot meal	Silkworm pupae meal	Fishmeal	Soy meal
Crude protein	50.4 - 62.1	60.7 -81.7	70.6	51.8
Lipid	18.9	25.7	9.9	2.0
Calcium	0.47	0.38	4.34	0.39
Phosphorus	1.60	0.60	2.79	0.69

Source FAO, 2011 and 2013

VI. Barriers for Inclusion of Insect Protein in Animal Feed

Not all insects are safe to use in animal feed. Just as it applies for plant and animal food Products some insects cause allergic reactions, botulism, parasitizes and food poisoning (Yen, 2010). For example, the pupae of the African silkworm (Anaphevenata) contains a thiaminase and can cause thiamine deficiency and responsible for a seasonal ataxic syndrome (Okazaki & Akai, 2000).

However, all these health risks can be prevented by utilization of scientifically recommended insect species reared on pollutant-free feed either harvested in the wild or on farms with proper processing, handling and storage facilities (Schabel, 2010).

VII. The Role of Insects in Reducing the Environmental Impact of Livestock Intensification

About 20 percent of the world's pastures and rangeland have been degraded to some extent and the proportion may be as high as 73 percent in dry areas (UNEP, 2004). To reduce the environmental impact (through deforestation) due to intensification of livestock production, the protein-rich insects are one of the options which are being considered as an alternative to conventional protein sources (Khusro*et al*., 2012).

Among insect species only cockroaches, termites and beetles produce CH4 which originates from bacterial fermentation by Methanobacteriaceae in the hindgut (Egert *et al*., 2003). More importantly insect's species such as mealworm larvae, crickets and locusts which are favorably lower by a factor of about 100 with pigs and beef cattle in their GHG emissions (Oonincx *et al*., 2010) suggesting that they are the inevitable option in reducing GHG emission.

Table 8: Production of GHG and Ammonia in three insect species, pig and beef

Emission	Meal worm	Cricket	Locust	Pig	Beef
GHG	50 (insignificant)	50(insignificant)	100	200-1000	2500-2800
Ammonia	10 (insignificant)	100	50	1100	Not specified

NB.The unit used in measuring emission was; for GHG=g/kg mass gain and mg/day/kg mass gain.

Source (Ooninck. et al., 2010)

VIII. Summary and Conclusion

- Based on the comprehensive research finding obtained from different researchers, it is possible to come up with concrete conclusion that insect meals are a valid, cost effective and highly nutritive alternative source of animal protein potentially utilized as a supplement and or sole source of nutrients particularly protein meeting the overall nutrient requirements of various animal species.
- According to the current reviews, various insect species have 30% -70% of protein on DM basis and rich in fats, minerals and vitamins content and have efficient food conversion factor compared to conventional fish and soybean meals which are reported to be very expensive and unaffordable for small scale farmers engaged in livestock rearing.
- The palatability of the diets containing insect meals is good and can replace soybean and fishmeal in the diets of poultry, fish and pig based on feeding studies conducted by different researchers. However, in the future further availability of different species of insect meals should be conducted to provide impetus for upcoming detailed research on evaluation of insects as alternative feed resources in ruminant livestock as well.
- In laying hens maggots could replace up to 50% of fishmeal at inclusion 5% in diet without any adverse effects. However 100% replacement produced negative effects on egg production. For broilers, the optimum level of their inclusion is generally ≤ 10% like meal worm without any adverse effects; however it is important to note that insect meals compared to fishmeal contain lower concentration

of Methionine and Ca which has to be considered when formulating diets based on insect proteins. It appears that grasshopper meal could be added into the diets of broilers at 2.5% (as a substitute for fishmeal). Mormon cricket can be up to 30% without any adverse effects.

- In fish species 25-40% replacement of insect meal as substitute of fishmeal does not affect growth performance in catfish. In various fish species (African catfish, walking fish and Nile tilapia) the studies suggested that 25% of fishmeal can be replaced with grasshopper meal without any adverse effects and for some species inclusion up to 40% is recommended. From the output of experiments conducted in growing and finishing pigs, it could be concluded that defatted silkworm meal could replace 100% of soy meal or fishmeal.
- Some insect meals, for example (black soldier fly larvae, housefly maggot meal, mealworm and silkworm) contain as high as 36% oil which can be used for the preparation of biodiesel. However, high content of oil could decrease fiber digestion in the rumen in such a way that it creates unfavorable condition for optimum rumen fermentation. Therefore, such species of insects should be defatted to ensure normal rumen fermentation.
- Insect meals (e.g. black soldier fly larvae) contain high levels of ash and hence their higher levels of inclusion in the diet, especially of mono-gastric, can decrease its intake and cause other adverse effects. Furthermore, black solder fly larvae has high content of Ca which is around (7.5%) and other insects containing low content of Ca which need be supplemented with Ca in the ration.

IX. The Way Forward

- Currently, insect rearing is done at a small scale. So that, there is a need for establishing cost-effective well-optimized mass insect rearing facilities for a defined quality of animal product.
- To use insects as alternative sustainable protein rich ingredient in poultry, Fish and pig diets, it requires production of insect at large scale up on undertaking utilization of bio-waste and organic side stream.
- There is a need in developing countries to establish intensive insect rearing to enhance livestock productivity ultimately ensuring food security. This can be achieved when different stakeholders share
- Coordinated responsibilities. First the Government should create awareness on how to establish insect rearing farms up on utilizing of locally available insects species, biowates and organic side streams to different stakeholders engaged in livestock rearing and collaborately working with various governmental and nongovernmental such those working in agriculture, livestock resource, fishery developments, health and environment.
- For obtaining safe insect meals in animal feed, setting up of sanitation procedures on bio-wastes, disease management, application of heavy metals and pesticides needs to be considered.
- While feeding insects' meal to livestock, we should also consider its impacts on animal and human health point of view.
- To reduce environmental effect of protein rich animal feed derived from plant and animal sources, insect should be encouraged as substitute or supplementation.

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