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Insect-Based Diet, A Promising Protein Source for Monogastric, Affects Human Health and Poultry Performance: A Case Study on Black Soldier Fly Lavae

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ABSTRACT

This review was commenced to high spot the potential of insect based protein rations in monogastric livestock and consumers as technical substitute for the increasingly expensive fish based protein diets. A systematic literature review was carried out targeting original articles evaluating the utilization of insect based diets for livestock taking broiler poultry as a case study. The authors performed a systematic search using Pubmed, EMBASE, and Web of Science databases (published in a period from 1994 to January 2023 to identify the studies that reported the association between performance parameters and levels of substituition of insects based proteins for fish. Countless studies indicated a high potential in the utilization of insect based diets although after defatting the insect lavae meals. The reported sustained performance is a consequence of comparable protein content as well as biological value. As a consequence of such responses, it was commended that for optimal productivity in terms of body weight gain, body condition score, quality carcass production, and improved economic returns, insect based protein can be used to substitute the fish meal provided the limiting amino acids are identified and made up using synthetic sources. Therefore, high crude protein content of insect meal based diets justifies utilization of the larvae meal as a substitute for fish meal in poultry diets. However, the differences in amino acid profile from that of FM, presence of chitin, and high crude fat content of BSLM could have an impact on feed utilization and the general performance of birds and quality of meat. In addition to affecting performance, attributes of BSLM for example antimicrobial peptides and the fatty acid profile gives BSLM the anti-bacterial, anti-viral and anti-fungal activities could improve the immune response of birds. In general effects of BSLM on performance, meat quality, gut integrity and microbiology and immune response of birds is not fully studied especially at higher inclusion levels.

Keywords: Human Health; Poultry; Insect Protein; Black Soldier Fly Protein Requirements of Broiler Chickens and Their Effect on Growth Performance

Abbreviations: FCR: Feed Conversion Ratio; PUFA: Unsaturated Fatty Acids; MUFA: Monounsaturated Fatty Acid; SFA: Saturated Fatty Acids

Introduction

As a means to increase productivity through improvements in health, feeding and daily management poultry should explore alternative nutrient resources especially for economically challenging nutrients like proteins and energy [1]. However, for most of the crop waste and industrial residues have the key nutrients complexed with inert compounds like lignin making the unavailable to non-ruminant livestock and poultry [1]. On the other hand, nature has provided readily available resources inform of insect based ingredients particularly black soldier fly larvae have been approved to be used as feed in monogastric livestock especially poultry piggery and fish [2]. Defined as a protein rich larvae meal is a protein-rich feed ingredient Black soldier fly lavae meal can replace the fish meal in both monogastric livestock and aqua feeds as it competes favorably with plant based sources like lablab [3]. This is attributed to the fact that the demand and price for the protein feed ingredients and fish meal increase in the market, necessitates the need for alternative protein feedstuff used as a substitute for the fish meal [3]. From the various studies conducted, it can be concluded that the black soldier fly larvae meal can effectively replace fish meal up to 50% in the fish feed without having any adverse effect on the fish body [4]. Thus, the use of black soldier fly larvae meal as an alternative source of protein can reduce the production cost in the aquaculture industry without reducing fish's quality. Besides being a promising fish meal substitute monogastric livestock species on the other hand reproduced appealing carcass composition, antioxidant enzyme activities, as well as digestive enzyme activities [5].

Whereas 50% replacement of fish meal with black soldier fly larvae meal in the diet showed positive effects without causing adverse effects on growth and feed utilization parameters several authors reported negative effects beyond 75% replacement [1,2]. Insects have been found to improve animal health. The chitin, antimicrobial peptides and fatty acids that are contained in insect meal have been reported to boost immune response in livestock [3]. (Xiao, et al. [4]) reported an increase in immune response of fish fed diets in which FMP was substituted with BSLMP through increased serum lysozyme activity. (Park, et al. [5]) reported a high antibacterial activity of black soldier larvae extracts in a study were the larval extract was tested on a broad spectrum of bacteria species. However, the dearth of information regarding effects of black soldier fly meal substitution of public health warrants further investigation.

Defined as fast growing avian species broiler as compared the egg type chickens and therefore correspondingly have higher protein requirements ranging between 18 and 23% on dry matter basis depending on age they offer the best case study on assessing the feeding values of protein substitutes in monogastrics. Since optimal growth is only attained when amino acids are provided in their adequate and right ratios [6] for example lysine and methionine should be maintained in a ratio of about 1:2.5 [7]. It implies that it is not just the protein content of the feed but the amino acid composition that is most crucial in monogastric nutrition [5]. Therefore, the quality of protein and hence its biological value is determined by the way essential amino acids are balanced. Specifically, as reported by several authors, increasing the ratio of sulphur amino acids to lysine from 50 to 77 increased weight gain in broiler chickens [8]. Such responses are attributable to the fact that amino acid profile of diet affects feed intake, feed utilization efficiency and body weight gain in monogastric livestock [9]. In addition, slight deficiencies in dietary methionine trigger detrimental reduction in feed intake and growth of birds [5,10] while optimizing sulphur amino acids improves growth and feed utilization [11]. Therefore, balancing monogastric diets does not only call for providing adequate protein content but also the amino acids and their ratios.

Ingredients used as protein sources in poultry diets differ in their amino acid profiles (composition) and thus their quality. For example sulfur amino acids and lysine are the most limiting in plant protein sources but abundant in animal protein sources [12]. Reduced growth performance and feed efficiency has been reported in studies where chickens were fed on diets without an animal protein source [13]. Therefore, animal protein sources should be considered while formulating poultry diets so as to balance the amino acid profile and thus improve growth performance and feed efficiency of birds.

Alternative Protein Sources to FM in Broiler Chicken Diets

Protein as a nutrient required by broiler chickens is supplied by various ingredients majorly cotton seed cake, soybean meal and FM which have an impact on the quality of protein in the diet and thus the performance of birds. Fish is and has always been the major animal protein source in broiler diets [14]. Fish has a high crude protein content and well balanced amino acid profile [14] and is a good source of phosphorus and calcium [6]. However, its availability for inclusion in poultry diet is limited by the several users of the product, thus a need to explore other animal protein sources that can be used as alternatives. Other ingredients used to substitute fish include both plant protein sources and animal protein sources [7]. In addition to the fact that a few plant protein sources have been explored as substitutes for FM, reduced performance has been reported when plant protein sources were used to substitute FM due to imbalances in the amino acid profile and high fiber content [8]. Among the animal protein sources that have been used to substitute fish include earth worm and insects from several orders [14,9]. However, studies have not fully exploited the use of these nonconventional protein sources either as sole protein sources or as substitutes for FM. Therefore, there is need for further research on use of insects as substitutes for FM.

Insects have been identified as a potential source of protein in poultry rations many years ago [10] and their use is still investigated up to date [11]. Several insect species under a number of orders have been studied for their potential to feed poultry [11] with order Diptera being the most widely studied. Insect species studied and so far used as protein sources under the order Diptera include house fly (Musca domestica) [10,11], blow fly (Chrysomya megacephala) 13 blue-bottle fly (Protophormia terraenovae) among others. Despite the potential of BSLM reported in previous studies questions still arise on the quantity that can substitute FM, effect on growth, feed utilization, feed cost, carcass quality and poultry physiology.

Nutritional Composition of Insect Meals Used for Animal Feed

Protein is one of the key and most expensive feed nutrient in non-ruminant livestock nutrition. With numerous insect species having an equivalent protein content as fish [12], insect based feed ingredients are a good source of proteins. Interestingly, other insect based proteins have even more protein content than fish [6,15,16]. Specifically, several authors have reported house cricket meals, field cricket, house fly maggots, grass hopper and black soldier flies meals to contain 60.4%, 58.3%, 60.4%, and 60% crude proteins, respectively [17-20]. Therefore, since some insects like silk worm larvae have substi-

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tuted fish without adverse effects on nutrition related performance of the monogastrics especially poultry and piggery [21], the high crude protein content makes many insects a potential source of protein in poultry diets. However, with no amino acid synthesis mechanisms, monogastric livestock, poultry and fish utilize the primary building blocks of proteins. This implies that the quality of proteins in monogastric and poultry feeding perspective primarily depend on the sequence of the amino acids as well as their bioavailability [5]. Interestingly, basing on the protein biological value, insect larvae especially from order diptera have high quality protein that compares well with that of fish and soybean meal [7,12]. (Wang, et al. [22]) noted a higher amino acid profile of field cricket than that of fish with an exception of histidine, whereas [21] also found silkworm to be superior in most essential amino acids than fish meal. In comparison to fish meal, insect meals are deficient in histidine, lysine and threonine amino acids [7] but seem to have a higher content of tyrosine and valine [23].

Razak et al also found the house cricket to have more tryptophan, tyrosine and valine amino acids than soybean and fish [24]. The most limiting essential amino acids, lysine and methionine were found to be higher in the maggot meal (6.04% and 2.28% respectively) when compared with those of other conventional protein sources including fish meal [25] (Aniebo, et al. 2008. When compared with fish meal, black soldier fly lavae meal contains higher quantities of histidine and valine but lower levels of methionine, threonine and cysteine [19,26,27]. Despite the lower levels of some amino acids, previous researchers have reported black soldier fly lavae meal to have sufficient crude protein and amino acid for broiler chickens [7,28]. Therefore, regardless of the quality of protein portrayed by insect meals the need for supplementation with other protein sources or with synthetic amino acids that could be deficient in insect meals in case insect meals are to be used as feed or feed ingredients is indispensable. Besides proteins, metabolizable energy plays a complimentary role in protein utilization especially during protein synthesis. For the case of insect meals, the energy component is largely contributed to by the crude fat fraction of the ingredient which varies with insect species [7]. Generally, insects have a high fat content of over 70% more than that of fish meal [9,11].

The high crude fat of larval insect meals is as a result of the extra deposition of fat during the larval stage of some insect species for use by the adults that do not feed due to absence of mouth parts. Specifically, black soldier fly lavae meal contains a crude fat content that ranges between 14% [29] and 39% [23], mealworm over 28% [26], housefly maggot meal 24% [30] among others. Furthermore, the fatty acid profile of insect larvae differs from that of fish meal [31]. Insects, black soldier fly lavae meal inclusive have higher levels Saturated Fatty Acids (SFA), high omega 6 and over three times lower omega 3 fatty acids as compared to FM [32,33]. Lauric acid is the most abundant SFA in black soldier fly lavae meal [31]. However, the high levels of Crude fat accounts for the reduced feed intake in insect meal based diets which leads to inadequate supply proteins and other nutrients. This implies that, the difference in the lipid profile of insect meal from that of fish meal can alter the dietary lipid profiles when used to substitute fish meal not only affects livestock and fish but also effects human nutrition health.

Factors that Affect Nutritional Composition of Insect Meals

Insect meals differ in their nutritional and mineral content and such variations are attributed to species differences, substrate or diet of the insect, age at harvest and method of drying and processing [34,35]. The growing substrate has a major influence on the nutrient composition of the resultant insect meal. The nutritional content of the substrate especially the crude protein influences the crude protein content of the insect larvae [23]. (Spranghers, et al. [36]) reported a 5% rise in crude protein and a 77% increase in crude fat of black soldier pre-pupae fed on substrates with correspondingly higher crude protein and crude fat respectively. Ramos-elorduy [9] also reported a difference in crude protein content of mealworm larvae with diet. On the other hand raising housefly maggots on different substrates each containing a proportion of poultry droppings did not change the crude nutritional composition of the resultant maggots [37]. The observed results could have been a result of the small variation in substrate composition. Therefore, the material selected for production of insect meals is very important as far as the nutritional composition of the resultant larvae is concerned. Nutritional composition of insects also differs with age at which they are harvested and the method used to process the insects or insect larvae [34].

Generally, the crude protein content of insect larvae reduces as they grow while the crude fat increases [7]. As the larva develops towards the pupa stage it stores more energy in form of fat which it utilizes in the later adult stage. Some adult insects for example BSF do not have mouth parts and thus do not feed but survive on the fat stores [38]. Aniebo and Owen [39] reported an increase in fat content and decrease in crude protein content of housefly larvae (Musca domestica Linnaeus) with age. (Singh, et al. [34]) reported higher concentrations of amino acids in the meal of blowfly maggots harvested one day after hatching than those harvested later. On the other hand, earlier studies reported a change in the composition of insect meals exposed to different processing procedures. Higher protein content (50.9%) and less fat (22.8%) was reported when maggots were oven dried as compared to sun dried maggots (47% CP and 26.4% CF) [7]. Therefore, variations in the nutritional content of insect larvae due to age and processing methods should be considered while choosing to incorporate insects in poultry diets.

Health Associated Benefits and Risks in Humans

Meat is the major source of fat especially SFA in human diet. Saturated Fatty Acids have been associated with some diseases like cardiovascular diseases and some types of cancers [40]. The incidence of such diseases is associated with both the amount and type of fat consumed. Therefore, there is need to assess the quality of the meat for human consumption in order to address the latest health con-

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cerns. Despite the number of studies conducted to assess the effect of inclusion of insect meals in diet of broiler chickens, results stop at describing effect on growth performance. Health benefits derived from meat are majorly dependent of the meat fat and fatty acid composition. Cardiovascular diseases are correlated to the level of Low Density Lipoprotein (LDL) cholesterol. Diets high in SFA for example lauric, myristic and palmitic acids contribute to the increase in both LDL and HDL cholesterol level while oleic and linoleic acids are said to increase HDL and lower LDL [41,42]. On the other hand Monounsaturated Fatty Acid (MUFA) and Poly Unsaturated Fatty Acids (PUFA) in particular long chain n-3 PUFA reduce the risk of coronary heart disease in humans through their effect on the level of LDL [43]. Further, lack of n-3 PUFA or an imbalance of n-6 and n-3 fatty acids in the diet can result into increased inflammatory and immune disorders [43,44].

Some fatty acids like linoleic, linolenic and arachidonic are essential fatty acids that should be supplied in the diet since the body cannot produce them. Strategies to modify the quality of meat through dietary modifications have been adopted of recent. In such strategies ingredients that are considered beneficial to human health have been added to diets of different animal species [45], after different studies have proved that the composition of the diet affects the resultant meat composition [46] Un like ruminants, in poultry dietary fatty acids are absorbed unchanged before incorporation in tissues and thus the content of the different fatty acids of muscles increase through increasing their content in the diet [47]. Plasma triglycerides and total cholesterol can be used in prediction the amount of carcass fat. Apart from the age of birds dietary composition also affects the plasma lipids [48,49]. For example including sugar beet pulp in diets of broiler chickens reduced the total serum cholesterol concentrations of the birds [48]. Inclusion of garlic in diet reduced the serum levels of cholesterol, low density lipoprotein and triglycerides but increased high density lipoprotein levels [46]. Insect meal, BSLM in particular has been reported to reduce plasma triglycerides and total cholesterol in chickens [4,50]. Dietary fat sources high in SFA increase plasma triglycerides and total cholesterol in poultry. Substituting FM with grass hopper meal increased total cholesterol in rabbits [18].

Utilization of BSLM in Livestock Feed and Impact on Growth, Feed Intake and Utilization

The BSLM is a potential protein source in fish [28,33], pig [36] and poultry rations [51]. Studies have assessed its potential either as a substitute for FM [51], soybean meal [52] or as a sole protein source [4,39,53]. Additionally BSLM has also been assessed as a fat source in broiler diets [39]. Despite the potential of BSLM as a protein source in poultry diets, effects of its inclusion at higher levels in broiler chicken diets are not known.

Different inclusion levels and forms of BSLM have been studied as feed or feed ingredient for livestock. BSLM has been added at lower levels in broiler chicken diets, the highest level being 50% in starter diets [54] and 55.5% in finisher diets [54]. However, with other poultry species up to 100% inclusion has been studied [54]. Some studies have assessed levels up to 15% only in broiler chickens and quails [39,55] in pigs levels of up to 8% inclusion have been assessed [36]. While in fish diets levels more than 50% have been studied [38]. In many of the studies the larval stage of BSF has been studied and in the processed form as a meal [56]. In some studies further processing of BSLM was done by either partially or fully defatting the meal [18]. Performance of livestock fed on diets containing BSLM varies with inclusion level, method of processing and stage of growth. Inclusion of up to 50% BSLM in fish diets did not affect feed intake and the feed conversion Ratio (FCR) but reduced weight gain in rainbow trout [57].

On the other hand, increasing the level of BSLM beyond 50% reduced feed intake, FCR and weigh gain of different species of fish [28,58]. In pigs, a higher feed intake was observed for a diet that contained BSLM compared to a soybean based diet [59], but lower levels up to 8% did not affect growth in weaned piglets [36]. Incorporating up to 50% BSLM in diets of quails increased feed intake by 7% and egg weight by 9% [60]. While complete substitution of soybean in diets of laying hens reduced feed intake, percentage lay, egg weight and egg mass [4]. Previous findings report similar or an increase in feed intake, FCR, growth performance and feed utilization of diets containing less than 55% BSLM [51,54,55,61]. On the other hand substituting soybean up to 50% with BSLM in broiler chicken diet reduced feed intake and weight gain when the amino acid profile of the diet was not balanced, however, balancing the amino acid profile increased feed intake and weight gain [29]. Partial defatting of BSLM in addition to increasing the CP content and digestibility of the meal, also improves performance among broiler chickens [18].

In conclusion, lower levels of BSLM have proved to be a potential protein source specifically in broiler chicken diets through improving performance. Several studies have reported a high digestibility of BSLM which increases the potential for utilizing the larvae meal in poultry diets. Apart from quails where a low (<50%) CP digestibility of a diet containing BSLM was reported [29] studies with fish [28], pigs [36] and chickens [55] have reported higher (>70%) CP digestibility of diets containing BSLM. The digestibility of BSLM was higher than that of mealworm among broiler chickens [29]. In addition, digestibility of BSLM is affected by method of processing [53]. In the same study BSLM dried at 1000C and that which was defatted had higher digestibility coefficients than full fat BSLM dried at 650C. Weaned piglets digested defatted BSLM better than full fat BSLM [36]. In addition, presence of chitin in BSLM could reduce digestibility of diets in which it is included [48]. Despite the higher digestibility of BSLM that has been reported, factors like the high fat content of the larvae meal, presence of chitin and drying temperatures could affect digestibility of diets in which BSLM is included.

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Effect of Diet on Immune Response of Livestock and Poultry

Immune response is the number one mechanism used by the body to fight against harmful organisms. The immune system can be categorized as humoral immunity which is mediated by the bursa dependent component by macromolecules such as antibodies or cell mediated immunity which involves the activation of phagocytes, leukocytes or White blood cells (WBC) majorly controlled by the thymus [62]. WBC are produced in the bone marrow, liver and lymphoid tissues which include the bursa, spleen and thymus [63]. Types of WBC include monocytes, lymphocytes, heterophils, eosinophils and basophils. Control of NCD and IBD in chickens starts right from proper health management of the parent stock. The parent stock at hatcheries is vaccinated against all diseases and thus chicks possess high levels of antibody at the time of hatching which they obtain antibodies from their parents. The maternal antibody level reduces thereafter with age and disappears by day 21 [34]. Immune response increases with age and reduction in maternal antibody in chicks. The reduction in antibody titers against inactivated NCD virus during the first week of age was attributed to the interference by maternal antibodies [64]. (Grozdanić, et al. [64]) reported the highest immune response on day 21 when maternal antibody had disappeared and lowest on day one when maternal antibody was highest. Dietary composition especially medicinal ingredients affect immunity of birds.

(Rahimi, et al. [65]) reported an increase in antibody titers in response to sheep red blood cells but not to new castle disease vaccine when chickens were fed on coneflower extract. In addition, supplementing the diets of broiler chickens with chromium methionine increased antibody titers against both NCD and Infectious Bronchitis Virus [66]. Including the sun mushroom in the diet of broiler chickens increased the percentage of eosinophils [67]. Heterophils are said to range from 30 -75%, lymphocytes 20 - 65%, monocytes 0-5%, basophils 0-5% and eosinophils 0-4% [67]. It has been demonstrated that the numbers of leukocytes in avian species change with physiological changes, disease and stress [68]. Dietary composition especially the fatty acid composition has an influence on the immune system of birds [69]. Fatty acids and their derivatives are known antimicrobial, antifungal and antiviral agents, promote development of lymphoid tissues and increase lymphocyte proliferation [70,71]. Researchers have studied the effect of fatty acids on the immune system and findings confirm the antifungal, antiviral and antimicrobial effect of different fatty acids [72]. Antiviral fatty acids at low concentrations act by affecting the cell envelope causing leakage while at higher concentrations they completely disintegrate the envelope and cell particles or even the cell membrane causing death [69]. Among all fatty acids lauric acid has been the most widely studied and reported for antibacterial, antifungal and antiviral activity [73-75].

In addition feeding chickens on diets containing lower omega 3 fatty acids increase lymphocyte proliferation [72]. Insects have been found to improve animal health. The chitin, antimicrobial peptides and fatty acids that are contained in insect meal have been reported to boost immune response in livestock [51]. Xio, et al, [76] reported an increase in immune response of fish fed diets in which FMP was substituted with BSLMP through increased serum lysozyme activity. Park et al reported a high antibacterial activity of black soldier larvae extracts in a study were the larval extract was tested on a broad spectrum of bacteria species [77].

Effect of Diet on Gut Colonization, Structural Development and their Impact on Nutrient Digestibility and Health

At the time of hatching, chicks are exposed to microbes that exist at the surface of the egg shell. This originates both from the mother chicken gut and the environment. The microbial population continues to change and its composition and numbers is influenced by diet of birds [78,79] among other factors. Dietary factors that influence gut micro flora include the ingredient composition of feed, digestibility of feed, protein content and amino acid content of the diet and protein source [78,79] fatty acid profile [35]. The populations of Clostridium perfringens in the ileum and caecum increased with the level of protein content when birds were fed FM, meat meal, feather meal or potato protein concentrate as a sole protein sources but not with soybean meal, corn gluten meal or pea protein concentrate [78]. Gut microbial population changes with age and section of the GIT [80,81]. In addition the source of crude protein in the diet affects microbial population [78]. In the study, the population of Clostridiun perfringens in hind gut significantly increased when birds were fed FM instead of soybean meal. (Spranghers, et al. [35]) reported a reduction in streptococci and lactobacilli when weaned piglets were fed a diet containing 8% BSLM substituting soybean meal. Feeding laying chickens on a diet with BSLM as a protein source increased both the microbial diversity and abundance in the caeca compared to a soy bean meal based diet [50]. The caecum contains more bacterial population in terms of number than the ileum [82]. An adult chicken GIT is inhabited by up to 1013 bacteria [83].

The population grows rapidly within the first week post hatching. Previous studies reports the population to plateau within the first four days after hatching, however some changes occur throughout the entire life of broiler chickens [83]. One day post hatching, the bacterial numbers in the proximal and distal parts of the ileum is expected to be 108 and 1010 cells/g of digesta respectively, the maximum population of more than 109 in the ileum and 1011 in the caecum is obtained in less than seven days and there after the population of bacteria remains stable up to 30 days [83]. Bacteria in the gut of chickens have a positive effect on gut morphology and nutrition. Gut micro-biota help in digestion and synthesis of dietary compounds, are involved in gastrointestinal development, regulate intestinal epithelial proliferation, host energy metabolism and synthesizes vitamin K and most water soluble vitamins like biotin, cobalamin, folate nicotic acid pantothenic acid, riboflavin and thiamine [83]. Gut miro-biota of chickens also

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impact the immune system and the health of the chickens in general. Bacterial species in the gut keeps changing in composition and number until a stable ecosystem is obtained. Once a stable ecosystem is obtained bacterial subsequent growth occurs in synchrony with digesta passage rate keeping the bacteria density in each part of the GIT constant. The more stable the gut micro biota the more the bird can resist infections especially in the gut [50]. Stability of the gut bacterial population prevents colonization by pathogenic organisms. Micro-biota has an influence on the immune system through its influence on the intestinal wall, regulates intestinal epithelial proliferation, is involved in inflammatory immune responses and fills the microbiological niche that would in their absence be occupied by harmful enteric micro-organisms [83]. Bacteria in the gut provide a physical barrier to the gut epithelia from harmful invading micro-organisms. Gut microbes also produce short chain fatty acids which are bacteriostatic and some generate bacteriacins. Adding insects in diets of insects has proved to modulate gut microbes in chickens and improving immunity [84]. Dietary composition influences structural development of gut. An increase in jejunal villi, crypt depth and a reduction in goblet cell number was observed when broiler chickens were fed diets with varying level of methionine [85]. An increase in the villi height was observed in rats fed monounsaturated and polyunsaturated fatty acids compared to those fed saturated fatty acids. Feeding broiler chickens on a diet containing BSLM did not affect the structure of the duodenum and caecum with respect to villi length and crypt depth but increased the jejunum villi length by 17%. Therefore, the amount and composition of dietary fat affects the structure poultry gut, of which the composition of crude fat is influenced by the ingredients supplying the fat.

Conclusion

The high crude protein content of insect meal based diets justifies utilization of the larvae meal as a substitute for fish meal in poultry diets. However, the differences in amino acid profile from that of soybean and fish meal, presence of chitin, high crude fat content associated anti- nutrients and mycotoxins [5,86] could have an impact on feed intake and utilization hence the general performance of livestock and poultry and hence meat quality. In addition to affecting performance, attributes of insect based meals especially black soldier fly meals for example antimicrobial peptides [87] and the fatty acid profile gives BSLM the anti-bacterial, anti-viral and anti-fungal [77] activities could improve the immune response of birds. In general effects of BSLM on performance, meat quality, gut integrity and microbiology and immune response of birds is not fully studied especially at higher inclusion levels.

Data and Information Sources

The information utilized in this review came from manuscripts that were just published in a variety of journals. Electronic data sources like the Directory of Open Access Journals (DOAJ), Research Gate, Web of Science, Science Direct, Google Scholar, and PubMed were used to access databases. Furthermore, other pertinent articles were found by searching through the citations included in the articles from the databases. The search engines were used to find “poultry,” “edible insects,” and “insect meal.”

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