EARTHWORM MEAL: A NOVEL NON-CONVENTIONAL FEED INGREDIENT FOR SUSTAINABLE POULTRY PRODUCTION

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ABSTRACT: The poultry industry is one of the most important/vibrant sectors in the livestock industry. Feed economics is highly important in the production of poultry, especially in intensive farming. Protein intake is the key factor for the sustainable production process and growth rates. Mainly soybean and fish meal is used to fulfill the protein requirements in poultry feed, however, currently, soybean meal and other conventional protein ingredients are facing the problem of shortage supply resultantly increasing in prices. So, there is an urgent need to explore other alternatives and cheaper protein sources. In the past 20 years, amongst different alternative protein sources, private companies and research institutes have focused on the use of algae, insects, and other invertebrates in poultry diets whereas particular attention needs to be paid to the dietary use of earthworms as it is a good and palatable source of protein. Earthworms can be successfully used as an alternative protein source for poultry and aquaculture as an environmentally friendly protein feed ingredient. In this review, we summarize the suitability, productivity, and effectiveness of earthworm meals as an alternative protein ingredient in poultry diets The research has investigated the use of earthworm meal in fish and poultry feed and exhibited an increase in body weight, feed conversion ratio, feed intake, and growth rates in broilers as well as an increase in egg production in layers. The research has shown dietary inclusion level of earthworm meal in the fish diet is successfully up to 25-30% whilst its inclusion level in the broiler diet should not go beyond 15%. Supplementation of earthworm meals in broiler and aquaculture diets may trigger production performances without affecting the quality of the final product. The goal of this review is to deliver the recent scenario of research on earthworm meal; to offer a better understanding of its use as a novel feed ingredient for sustainable poultry production.

Key words: Earthworm meal; soybean meal; fish meal; poultry.

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INTRODUCTION

Poultry meat is an important animal protein source worldwide. The extension of poultry production is increasing the demand for feed and feed ingredients as feed is the most expensive part of the poultry industry (Thirumalaisamy *et al.* 2019). Increased human population has put pressure on feed resources causing a gap between the demand and supply of critical feed ingredients which is expected to increase in the future. Therefore there is a dire need to explore new low-cost high-quality feed ingredients for sustainable and profitable protein production. Most protein sources of poultry feed i.e. fish meal, soybean meal, canola meal, and meat meal, etc. have become expensive and even rare in some regions of the world. For this reason, there is an urgent need to explore other cheaper and readily available protein sources for poultry feed formulations (Ibáñez *et al.* 1993) and a promising protein source that is being considered is earthworms' meal.

Common names of earthworms are worms, nightcrawlers (USA), lobworms, grandaddy earthworms in Canada, and dew worms. They have about 4000 species on earth. Few species of earthworms are used for vermicomposting because these have certain characteristics like resistance to a range of environmental conditions, high reproductive rate, short life cycles, and good composting rate. Species used for vermicomposting are *Eudrilus eugeniae, Perionyx excavates, Eisenia fetida, Eisenia Andrei, and Dendrobaena Veneta* (Dominguez and Edwards, 2011). Nowadays, the major usage of earthworms is to produce vermin compost used as a source of protein for large animals, fish, and poultry farming (Deane, 2020). Earthworms are also eatable and can be cooked, roasted, fried, sautéed, and put on meat dishes over the world.

Habitat: Earthworm families live anywhere in soil and dead plant materials. Nightcrawlers generally live in stormy timberland regions and fresh water. Nightcrawler species require soggy soil conditions to grow. A few animal-type earthworms arise on the upper surface, especially in the evening times. They go deep in the dry or winter seasons. Few species of earthworms ever grow to the upper surface of the earth and spend their whole life in meters underneath the surface almost 16.5 ft.

Feeding: Nightcrawlers eat dead and decaying plant material, by and large leaves, yet likewise microscopic roots and various pieces. A couple of creature bunches live down someplace in the soil and eat dead plant roots (Curry and Schmidt, 2007).

Nutrient composition of earthworms: The nutrient composition of worms is compatible with other sources of protein that are mostly used in industry, especially fish meal and soybean meal (Dominguez and Edwards, 2011). Earthworms contain 5-21% carbohydrates, 10.5% crude protein, 1.6% fat, 2-3% minerals, and a variety of vitamins on a dry matter basis. Earthworms are rich in amino acid contents that are essential for animal bodies, especially methionine and lysine, as compared to other animal meals i.e. meat meal or fish meal (Finke, 2002).

Production of Earthworm meal: Earthworms' meal is a source of good protein for the poultry and livestock feed industry but practical production of earthworm meal involves the use of technology for large-scale production. This technology is used to separate earthworms from organic wastes where they are cultivated, that's why impeding the use of worm meal in advanced countries of the world. However, there is great potential for making worm meal in developed countries because employment costs are less. Yet, special care is required when we grow earthworms for the use of animal protein in feeds. One issue is that pollutants and heavy metals present in the earthworms can be transferred into the birds' digestive tract by ingesting the earthworm meal (Sharma *et al.* 2005). Therefore, it is important that what materials are used in the production of earthworm meals.

Table 1. Nutrient (percentage) composition of earthworms (*Lumbricus terrestris*).

Nutrient	Percentage
ME (Kcal/kg)	708 Kcal/kg
CP	10.5%
Fat	1.6%
Moisture	83.6%
Arginine	0.61%
Ash	0.6%
Sodium	965 mg/kg
Potassium	1820 mg/ kg
Methionine	0.19 %
Phosphorus	1590 mg/kg
Magnesium	136 mg/kg
Lysine	0.66 %
Threonine	0.47 %

Nutrient composition of earthworm meal: Worms meal is used as a source of alternative protein in the livestock feed industry (Sogbesan *et al.* 2007). It contained high protein contents i. e 54.6%. Earthworm meal contained all dietary essential amino acids like isoleucine i. e. 1.98% on a dry matter basis (Istiqomah *et al.* 2009). Earthworm meal that contained L. rubellus has antibacterial activity (Salzet *et al.* 2007). The amino acid that is used as a protein source is an important part of structural tissues, in which feathers, skin, bones, ligaments, also organs, and muscles are included. Amino acids are used in livestock feed as supplements for optimal growth, performance and animal health ('National Organic Standards Board Technical Advisory Panel Review for the USDA National Organic Program 2001).

Table 2. Chemical composition of Earthworm meal.

Nutrients	Contents
ME (Kcal/kg)	2990
DM %	90.6
CP%	54.6
FAT %	7.34
ASH %	21.2
Ca %	1.55
P %	2.75

Use of earthworm meal in poultry feed: There is little research data for the usage of worm meal in feeds. One study presented that 10% use of worm meal can be substituted with a fish meal in poultry feed has no negative effect on feed intake and weight gain but the

efficiency of feed was affected at the level of 15% (Prayogi and Prayogi, 2011).

Effect of earthworm meal on broilers: Several studies showed that the addition of earthworm meal in broiler feed affects broiler performance, weight gain, FCR, and feed consumption. Adding earthworm meals to the broiler diet can also affect final weight (g/per bird), respectively (Dauda *et al*, 2014). Another study showed that using varying levels of earthworm meal affects feed consumption, live body weight gain, and FCR. Tuleun *et al.* (2013) observed a positive effect on the body weight gain of broilers fed diets containing earthworm meal at the levels of 0.5, 0.10, and 0.15%, respectively for twelve successive days affecting live body weight gain of broilers @ 308, 350, and 358 grams and 25 days old 1,129, 1,272 and 1,253 grams respectively. According to Cohort (2008), the addition of soybean meal @ 29.6 percent in the meal of earthworms had shown a positive effect on the performance of broilers. Earthworm meal has shown improved feed conversion ratio values in broilers (2.1 to 1.9) when 0% to 10%. Moreover, it did not reveal any harmful effects on domestic chickens (Gomez and Gomez,2007; Sharma *et al.* 2005).

Figure 1 production of earth worm meal

The addition of earthworm meal up to 10% on a dry matter basis in sorghum and soybean diets had shown non-significant effects on feed consumption, weight gain, and feed efficiency in broilers. Using earthworm meals in poultry diets increased the palatability of feed (Ramos-Elorduy *et al.* n.d.). Results of another study revealed that adding 25% earthworm meal as a surrogate for feed was found to have a beneficial effect on the growth performance of broilers (Schiavone *et al.* 2014; Schiavone *et al.* 2017). Coturnix *japonica* (Japanese quails) when fed earthworm meal @ 22.5 and 30 g/kg of basic diet revealed good feed conversion ratio, body weight gain, meat quality, carcass yield, and jejunal histopathology (Yoo *et al*., 2005). Loponte *et al.* (2017) investigated that the addition of 250-500 grams of earthworm meal per kg feed of partridges increased the growth performance of the bird.

Nutritional significance and antimicrobial activity of earthworm meal: Earthworms are commonly used in free-range poultry systems (‘Blair, 2008). The amino acids profile of the earthworm meal is high and comparable with poultry diet requirements. It contains essential amino acids like methionine, threonine, and lysine and it is closely related to fish meal in nutrient profile. Digestibility of the earthworm is reported to be good (‘Blair, 2008; Rezaeipour *et al*., 2014; Son, 2009). One specie of earthworm namely, L. *rubellus* have ‘lumricin I’ which has anti-bacterial properties and is part of that peptide group consisting of 62 amino acids (Salzet *et al.* 2007). Innate immunity in lophotrochozoans: The annelids Current Pharmaceutical Design 12 1-8. Amino acids parts of proteins are the building blocks of the structural and functional tissues like ligaments, bones, feathers, muscles, and organs (‘Ministry of National Food Security & Research - Wikipedia’).

Earthworm meal as a feed additive in poultry diets

Table 1: Study and their results on earthworm meal as a feed additive in poultry diets.

Year	Work/study	Results	Reference
2009	To determine the value of the essential amino acid index and	Histidine (0.63% of the dry matter basis) dominated the essential amino acid of the earthworm, while isoleucine	Istiqomah *et al.*

	to evaluate the essential amino acid profile of earthworms and earthworm meal	(1.98% of the dry matter basis) dominated the earthworm meal. Glutamic acid (1.52% and 3.60% of the dry matter base, respectively) predominated among the non-essential amino acids in both earthworms and earthworm meals. The essential amino acid index value found in earthworm meal was greater (58.67%) than those from earthworms, 21.23%).	(2009)
2014	In two tests with broiler chicks, the protein quality of earthworm meal was assessed and contrasted with that of soybean meal.	According to experiment 1's findings, there were no appreciable variations in PER or NPR between earthworm meal and soybean meal, however, broilers were given earthworm meal diets considerably ($p<0.05$) increased the weight of their breast muscles.	Rezaeipour *et al*. (2014)
2011	To replace the use of fish meals, evaluate the effects of supplementing different levels of earthworm meal feed consumption on body weight gain and feed conversion.	The outcome demonstrated that a larger percentage of earthworms in the feed caused a decrease in feed consumption, which was significantly different ($p<0.01$) from the control group. When the fish meal was absent from the diet or there was a higher percentage of earthworms (15%), the BW increase was drastically reduced.	Prayogi, (2011).
2020	This study's objective was to assess how Se-enriched earthworm powder (SEP) affected the laying hens' capacity for oxidative defense and immunity.	They discovered that hens' total protein, albumin, glutathione peroxidase, superoxide dismutase, IgG, and IL-2 were elevated by SEP with 1.0 mg/kg of Se while their triglycerides, total cholesterol, hyperglycemia, and nitric oxide were downregulated.	Sun *et al*. (2020).
2018	This research was done to find out if feeding earthworm powder to broiler pullets was safe.	When 3% and 5% of earthworm powder were introduced, the feed conversion ratios improved by 12.64% and 22.45%, respectively ($P = 0.02$). The growth of pullets was unaffected by the addition of 5% earthworm powder to the meal, and the liver's antioxidant enzyme activities increased ($P<0.05$).	Zang *et al*. (2018)
2021	A study was done to determine the impact of adding EWM made from dried *Eudrilus eugeniae* to broiler chicken diets on growth performance, carcass characteristics, and meat quality.	EWM supplementation had no impact on the pH or drip loss of the meat of broiler chickens. The EWM may be a viable alternative to fish meals and an acceptable source of protein for the production of broiler chicks.	Nalunga *et al*. (2021).
2012	The goal of this study was to examine the nutritional makeup of termites and earthworms and assess their potential utility as substitute sources of animal protein in the diets of chickens.	It has been demonstrated that termites and earthworms nutritionally outperform fish meal, the primary animal protein source in poultry diets. Given the great nutritional content of termites and earthworms, it would appear that substantial research on their production is required before their usage in smallholder poultry production can be made possible.	Moreki and Tiroesele, (2012).

Earthworm meal has a significant effect because this meal contains chitin, chitin cannot be digested and absorbed in the small intestine however, it goes into the large intestine where can be digested by microorganisms and changes into probiotics (Brownawell *et al.* 2012). So, using chitin can improve the health of the large intestine and balance microbial colonies. (Sizmaz, 2018). Research studies have shown that chitosan made from insect chitin when used as an additive in broiler feed acts as a natural antimicrobial. Yet excessive intake of chitin may reduce the performance, however, the Chitinase enzyme present in the digestive system of chicken helps in the degradation of chitin, but it is secreted in limited amounts. Chitin can be separated physically, in the sun drying method, and by extraction using caustic soda and chitinase enzyme.

Hidayat (2018) reported that earthworm meal can be used in poultry feed as an additive and can place as an antibiotics growth promoter (AGP). Islam and Yang (2017) observed that the addition of earth-4worms meal and super earthworms meal (Zophobas morio) can be used as a substitute for antibiotics in poultry feed supplemented with E. coli and Salmonella. Other studies reported antimicrobial peptides of earthworm meal which are free from hemocytes and help in protein secretion and convert peptides into hemolymph. Earthworm meal acts

on the cells of the digestive system by diffusing with the infection area. These are mostly known as AMPs i. e. lantibiotics, colchicine, and microcline. Salmonellae species are inhibited by these microcytes, so due to this their importance increasing in poultry (Sizmaz and Dubai, 2018). A previous study on earthworm meal as a feed additive in poultry diets is shown in Table 1.

Processing of Earthworms for preparation of meal at small scale: Earthworm meal can be made first by drying the earthworm and then grinding the dried worms. On small scale drying of the earthworms is usually done by using the sun heat or sometimes through artificial heating however, washing can also be used before drying. Heating the earthworm meal at 120°C for one hour has been reported to reduce the bacterial count with improved growth rate. Different techniques are applied to separate residual undigested content from the earthworms such as washing the earthworm and keeping them in a bowl for 30 min then rinsing them in hot water and oven drying for 3 hours at 80°C. Heat-dried worms then are grounded with a hammer mill to convert into powder form which is packed into air-dried plastic bags and stored at 0 to 20°C for further use in diet (Sogbesan *et al.* 2007). The earthworm can be preserved with formic acid and it can be used with molasses and sorghum or only with molasses (Ortega *et al*., 1996).

Effect of earthworm meal in layers: Earthworm meal is a source of high protein and can be successfully used in the diet of laying hens. Various researchers have reported the beneficial effect of the dietary inclusion of earthworm meals on the production performance of layers. Supplementation of earthworm meal ranging from 0.2 to 0.6% in layers feed improves layer performance, and better egg quality especially the ratio on-3 fatty acids and egg yolks reported by Son, 2009. Cr, Cd, As, and Pb was found at a level of 1.18, 1.23, 4.41, and 3.39 ppm in earthworm meal respectively, but these heavy metals were not found in chicken eggs and meat. Hence, the inclusion of 0.6% of earthworm meals in the chicken diet did not affect egg and meat safety (Son, 2009).

The use of fresh earthworms 5% in the diet based on DM, can maintain the performance of the laying hens. Egg quality is not affected by the use of earthworm meal ('Mekada *et al*., 1979. Japan. Poult. Sci., 16: 293-297 | Feedipedia' n.d.). The use of earthworm meal 1 to 5% in growing hens, slightly enhances the FRC and growth rate. The concentration of heavy metals is a bit higher in earthworm meals and found in the liver of growing hens but not in muscles. So, earthworm meals can be safe to use in diet (Zang *et al.* 2018).

Other studies conducted to investigate the effect of supplementing earthworm meal on the egg quality and performance of layers. The results of these studies showed that 0.3 and 0.6% of earthworm meal affects egg production and daily egg mass (Son, 2009). Experimentally, earthworm meal fed to rats at the rate of 10% shows no sign of health hazards, mortality, and morbidity. So, earthworm meals can be used safely in animal diets (Ibáñez *et al.* 1993).

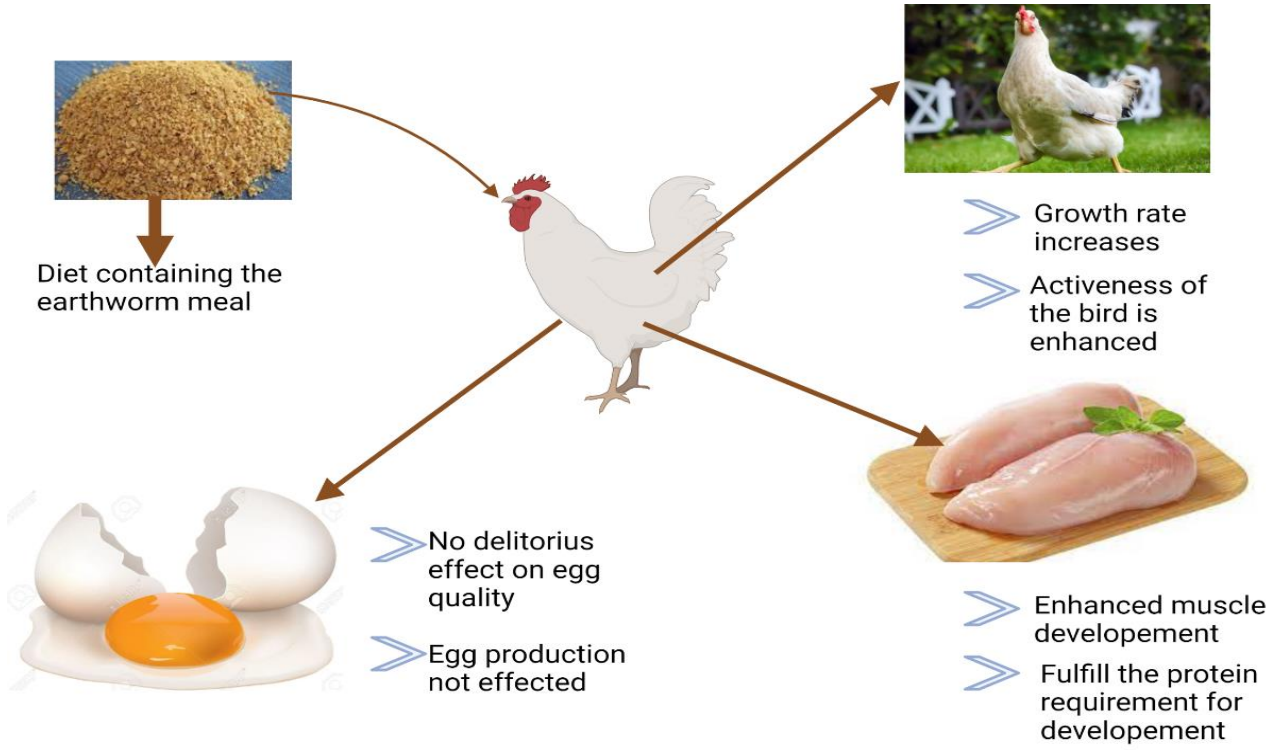

Figure 2 Dietary effect of earthworm meal on the production performance of poultry

A drawback of earthworm meals is that mostly it is grown in vermicomposting facilities, and these often receive industrial and domestic waste that is contaminated with heavy metals and medicines. Earthworms ingest and accumulate inside their body (Morgan, 2011). Heavy metals like Zn and Cu are mostly excreted while Pb and Cd have low excretion rates and they accumulate in earthworms (Spurgeon and Hopkin 1999). The amount of heavy matter can be lowered by pH or by using other additives (Li *et al*. 2010).

Earthworm meal is a good quality sustainable animal protein source: For the last few years, special attention is paid to vermiculture or intensive earthworm culture to overcome the severe problems linked with the management of the disposal of the huge amount of organic waste (Tedesco *et al.* 2019). An earthworm can be raised on the waste of vegetables and fruits. The processing of the fruits and vegetables required the expenditure of transport, chopping, and vermicomposting. The other process is to just grow the earthworm on fruits and vegetable waste and then oven dry to make feed (Tedesco *et al.* 2019).

Feeding earthworm increases the P and Ca level in the blood and decreases the cholesterol level. Earthworm feeding increases the antibodies of avian influenza. Earthworm feeding reduces the growth of intestinal E. coli while enhancing the growth of intestinal lactic acid bacteria (Z. *et al.* 2017). Because of these effects, it decreases the cost of minerals as we need to provide additional, and reduces the chances of heart diseases by lowering cholesterol levels thus reducing the cost of medicine. As it enhances the antibodies against viral disease hence saving the cost of medicine and bird loss. Many studies revealed that the high reproduction rate and composting ability of earthworms can be utilized to produce cost-effective animal-source protein diets for the poultry and fish industry worldwide (Istiqomah *et al.* 2009).

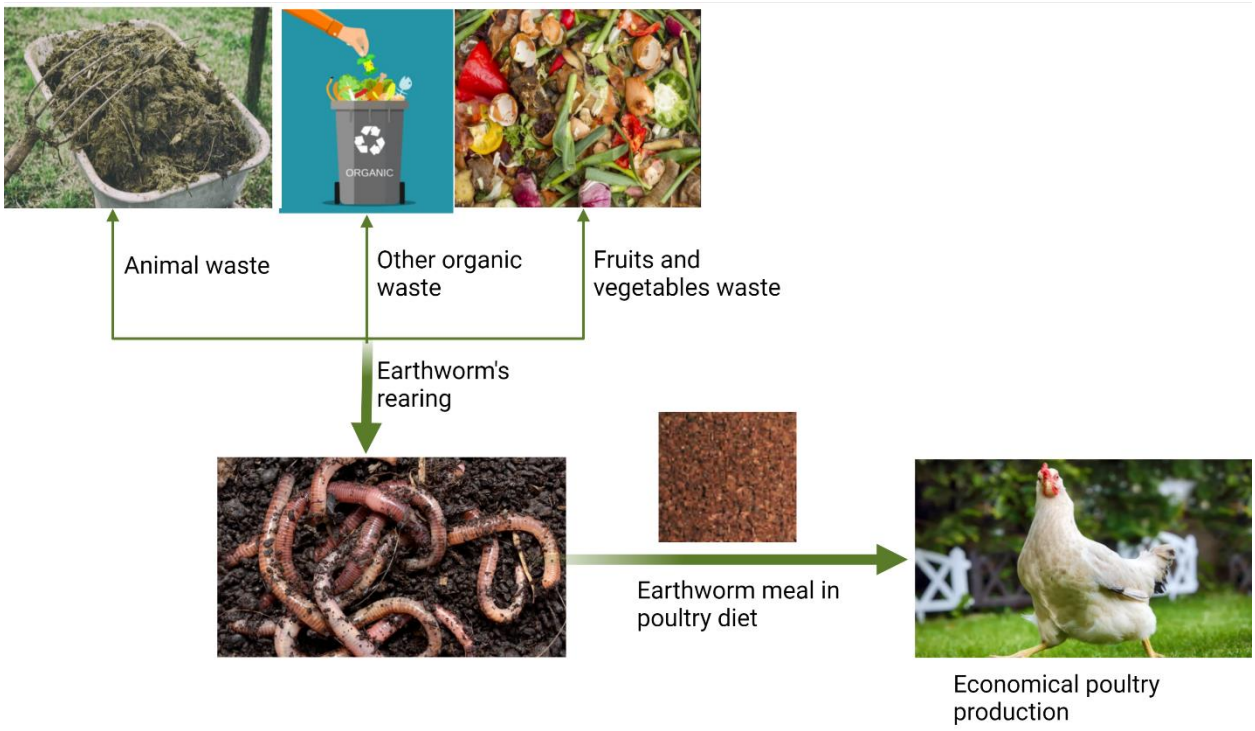

Figure 3 Earthworm meal: a novel feed ingredient and its prospects

Earthworm meal as an alternate source of protein in poultry feed has been studied for the last 30 years worldwide. Over the past few years, more concentration has been paying for use of earthworm meals as a substitute source of protein in the poultry and fish industry. Because of increasing the price of conventional protein resources.

There is little information about different species of earthworms and their growth rate potential on single and mixed substrates. Yet the identification of the high-

yield species of earthworms that could be used in fish and poultry diets, the nutrient profile of earthworm meals and toxic contaminants of the meal when reared on various substrates as well as the digestibility of meal and its adverse effects (if any) for poultry, livestock and aquaculture need to be addressed.

Future research should be done for the identification of the best substrate for the growth of earthworms. Yet, other factors like environmental, economic, and social benefits linked to the use and raising of earthworm meal as compared to the use of soybean and fishmeal need to be addressed. Need-based research is required to assess the environmental effects of earthworm cultivation with marine and crop-based ingredients and to explore the safety, quality, and security concerns of poultry/aquaculture/livestock feed containing earthworm meal. Moreover, additional work is needed to the awareness of people for their willingness to consume the meat of animals fed diets containing earthworm meal.

Conclusions: This review has plenty of scientific and technical information for use of earthworm meals as a substitute for conventional protein sources in poultry and aquaculture production. There is a dearth of research regarding earthworm production and their utilization is still less in terms of topographical area and timing required for the research trials to be performed in fish and poultry birds. Some research data have shown that earthworm meal can safely be used in poultry feed is up to 15% whereas in fish and aquaculture feed its inclusion level may go beyond 25% without affecting the quality of poultry and fish products.

REFERENCES

Blair (2008). CABI SERIES, CABI, WALLINGFORD, UK | Feedipedia. Accessed at http://books.google.com/books?id=9WZ9LJLoCZIC.

Brownawell, A. M., W. Caers, G. R. Gibson, C. W. C. Kendall, K. D. Lewis, Y. Ringel, J. L. Slavin. (2012). Prebiotics and the Health Benefits of Fiber: Current Regulatory Status, Future Research, and Goals. *The Journal of Nutrition* 142: 962–974.

Curry, J. P. and O. Schmidt (2007). The feeding ecology of earthworms - A review. *Pedobiologia* 50: 463–477.

Deane (2020). EATTHEWEEDS WEBSITE . Feedipedia. Accessed at http://www.eattheweeds.com/barnyard-grass/

Domínguez, J. and C. A. Edwards (2011). Biology and ecology of earthworm species used for vermicomposting. In: Edwards CA, Arancon NQ and Sherman RL (eds) Vermiculture Technology: Earthworms, Organic Waste and Environmental Management. Boca Raton, FL: CRC Press, pp.25–37.

Gomez, K. A. and A. A. Gomez (2007). Statistical procedures for agricultural research. A Wiley-intersclence Publication JOHN WILEY & SONS, New York . Chichester . Brisbane . Toronto . Singapore.

Hidayat, C. (2018). Pemanfaatan Insekta sebagai Bahan Pakan dalam Ransum Ayam Pedaging (The Utilization of Insects as Feedstuff in Broiler Diet) 28: 161–174.

Ibáñez, I. A., C. A. Herrera, L. A. Velásquez, P. Hebel (1993). Nutritional and toxicological evaluation on rats of earthworm (Eisenia fetida) meal as protein source for animal feed. *Animal Feed Science and Technology* 42: 165–172.

Islam, M. M. and C. J. Yang (2017). Efficacy of mealworm and super mealworm larvae probiotics as an alternative to antibiotics challenged orally with Salmonella and E. coli infection in broiler chicks. *Poultry Science* 96: 27–34.

Istiqomah, L., A. Sofyan, E. Damayanti, H. Julendra. (2009). Amino acid profile of earthworm and earthworm meal (Lumbricus rubellus) for animal feedstuff. Journal of the Indonesian Tropical Animal Agriculture. 34.4.253-257.

Khan, S. H. (2018). Recent advances in role of insects as alternative protein source in poultry nutrition. *Journal of Applied Animal Research* 46: 1144–1157.

Li, L., Z. Xu, J. Wu, G. Tian (2010). Bioaccumulation of heavy metals in the earthworm Eisenia fetida in relation to bioavailable metal concentrations in pig manure. *Bioresource Technology* 101: 3430–3436.

Loponte, R., S. Nizza, F. Bovera, N. De Riu, K. Fliegerova, P. Lombardi, G. Vassalotti, V. Mastellone A. Nizza, G. Moniello (2017). Growth performance, blood profiles and carcass traits of Barbary partridge (Alectoris barbara) fed two different insect larvae meals (Tenebrio molitor and Hermetia illucens). Res Vet Sci. 115:183-188. doi: 10.1016/j.rvsc.2017.04.017. 03087833818.

Mekada, H., N. Hayashi, H. Yokota, J. Okumura (1979). Performance of growing and laying chickens fed diets containing earthworms (*Eisenia foetida*). Japan. Poult. Sci., 16: 293-297

Ortega Cerrilla, M. E., A. L. Reyes Ortigoz, G. Mendoza Martínez (1996). ARCH. LATINOAM. NUTR., 46 (4): 325-328.

Prayogi, H. and H. S. Prayogi (2011). The Effect of Earthworm Meal Supplementation in the Diet on Quail's Growth Performance in Attempt to Replace the Usage of Fish Meal. *Article in*

International Journal of Poultry Science 10: 804–806.

Ramos-Elorduy, J., E. A. Gonzalez, A. R. Hernandez, and J. M. Pino (2002). Use of *Tenebrio molitor (Coleoptera:Tenebrionidae)* to recycle organic wastes and as feed for broiler chickens. J. Econ. Entomol. 95 (1), 214-220.

Rezaeipour, V., O. A. Nejad, H. Y. Miri, (2014). Growth performance, blood metabolites and jejunum morphology of broiler chickens fed diets containing earthworm (*Eisenia foetida*) meal as a source of protein. Int. J. Adv. Biol. Biomedic. Res., 2 (8): 2483-2494.

Salzet, M., A. Tasiemski, E. Cooper (2007). Innate Immunity in Lophotrochozoans: The Annelids. *Current Pharmaceutical Design* 12: 3043–3050.

Thirumalaisamy G, Muralidharan J, Senthilkumar S, Sayee R, Hema and Priyadharsini M 2019 Cost effective feeding of poultry Int. J. Environ. Sci. Technol. 5 3997–4005.

Schiavone, A., Cullere, M., De Marco, M., Meneguz, M., Biasato, I., Bergagna, S., Dezzutto, D., Gai, F., Dabbou, S., Gasco, L. Zotte, A. D. (2017). Partial or total replacement of soybean oil by black soldier fly larvae (Hermetia illucens L.) fat in broiler diets: Effect on growth performances, feed-choice, blood traits, carcass characteristics and meat quality. *Italian Journal of Animal Science* 16: 93–100.

Schiavone, A., De Marco, M., Rotolo, L., Belforti, M., Martinez Miro, S., Madrid Sanchez, J., Hernandez Ruiperaz, F., Bianchi, C., Sterpone, L., Malfatto, V., Katz, H., Zoccarato, I., Gai, F. & Gasco, L., 2014. Nutrient digestibility of *Hermetia illucens* and *Tenebrio molitor* meal in broiler chickens. In. Proc. 1st Int. Confer. Insects to Feed the World, Wageningen, The Netherlands, 73.

Sharma, S., Satya, S., P. Vasudevan, K. Pradhan (2005) Potentiality of Earthworms for Waste Management and in Other Uses-A Review DRDO project View project Organic agriculture and waste management View project Potentiality of Earthworms for Waste Management and in Other Uses-A Review. *The Journal of American Science* 1.

Sizmaz, O. and P. S. I. Dubai (2018). Relationships Antimicrobial Peptide with Mealworm Used in Poultry Nutrition. *researchgate.net*.

Sogbesan, A. O., UGWUMBA, and C. T. MADU (2007). Productivity potentials and nutritional values of semi-arid zone earthworm (Hyperiodrilus euryaulos; Clausen, 1967) cultured in organic wastes as fish meal supplement. *Pakistan Journal of Biological Sciences* 10: 2992–2997.

SON, (2009). The study on treatment of poultry waste by earthworms, and the effect of feeding earthworms meal on the performance of broilers and laying hens, and safety of meat and egg. Korean J. Organic Agric., 17 (1): 63-82.

Spurgeon, D. J. and S. P. Hopkin 1999. Comparisons of metal accumulation and excretion kinetics in earthworms (Eisenia fetida) exposed to contaminated field and laboratory soils. *Applied Soil Ecology* 11: 227–243.

Sugimura, K., E. Hori, Y. Kurihara, S. Itoh (1984). Nutritional value of earthworms and grasshoppers as poultry feed. *Japanese poultry science* 21: 1–7.

Tedesco, D. E. A., C. Conti, D. Lovarelli, E. Biazzi, J. Bacenetti (2019). Bioconversion of fruit and vegetable waste into earthworms as a new protein source: The environmental impact of earthworm meal production. *Science of The Total Environment* 683: 690–698.

Finke, M. D. (2002) Complete Nutrient Composition of Commercially Raised Invertebrates Used as Food for Insectivores. Zoo Biology, 21, 269-285.https://doi.org/10.1002/zoo.10031.

Tuleun, C. D., A. Y. Adenkola, and F. G. Yenle (2013). Performance and Erythrocyte Osmotic Membrane Stability of Laying Japanese Quails (Coturnix coturnix japanica) Fed Varying dietary Protein Levels in a Hot-Humid Tropics. Agriculture and biology journal of north America. 4(1): 6-13. doi:10.5251/abjna.2013.4.1.6.13

Velásquez, L., C. Herrera, I. Ibáñez(1986). Harina de lombriz. I Parte: Obtención, composición química, valor nutricional y calidad bacteriológica. Alimentos, 11 (1): 15-21.

Zang, Y. T., S. Bing, Y. Z. Zhang, X. W. Sheng, D. Q. Shu (2018). Effects of Dietary Supplementation With Earthworm Powder on Production Performance, Blood Characteristics, and Heavy Metal Residues of Broiler Pullets. *Journal of Applied Poultry Research* 27: 609–615.

Cohort, (2008). CoSTAT Version 6.400 Cohort Software 798 (Monterey)

Dauda, G., O. M. Momoh, N. I. Dim D. M. Ogah (2014). Growth, production and reproductive performance of Japanese quails (Coturnix coturnix japonica) in humid environment Egypt. Poult. Sci. 34 :381-95.

Zang, Y. T., S. Bing, Y. Z. Zhang, X. W. Sheng, D. Q. Shu (2018). Effects of dietary supplementation with earthworm powder on production performance, blood characteristics, and heavy metal residues of broiler pullets. *Journal of Applied Poultry Research*, *27*(4), 609-615.

Prayogi, H. S. (2011). The effect of earthworm meal supplementation in the diet on quail's growth

performance in attempt to replace the usage of fish an meal. *International Journal of Poultry Science*, *10*(10): 804-806.

Istiqomah, L., A. Sofyan, E. Damayanti, H. Julendra (2009). Amino acid profil of earthworm and earthworm m al (Lumbricus Rubellus) for animal f dstuff. *Journal of the Indonesian Tropical Animal Agriculture*, *34*(4), 253-257.

Rezaeipour, V., O. A. Nejad, and H. Y. Miri (2014). Growth performance, blood metabolites and jejunum morphology of broiler chickens fed diets containing earthworm (Eisenia foetida) meal as a source of protein. *International Journal of Advanced Biological and Biomedical Research*, *2*(8), 2483-2494.

Sun, X., S. Z Yue, Y. H. Qiao, Z. J. Sun, C. Wang, and H. F. Li (2020). Dietary supplementation with selenium-enriched earthworm powder improves antioxidative ability and immunity of laying hens. *Poultry science*, *99*(11), 5344-5349.

Nalunga, A., A. J. Komakech, J. Jjagwe, H. Magala, J. Lederer (2021). Growth characteristics and meat quality of broiler chickens fed earthworm meal from Eudrilus eugeniae as a protein source. *Livestock Science*, *245*, 104394.

Moreki, J. C. and B. Tiroesele (2012). Termites and earthworms as potential alternative sources of protein for poultry. *Intern* J Agro Veter Med Sci, 6, 368-76.