Trakia Journal of Sciences, No 4, pp 320-326, 2024

Available online at:
https://trakia-uni.bg

ISSN 1313-3551 (online) doi:10.15547/tjs.2024.04.005

Review

INSECTS IN MONOGASTRIC NUTRITION – CHALLENGES AND FUTURE

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ABSTRACT
The earth's population growth has stimulated the demand for animal protein for human consumption, boosting the exploitation of natural resources. In recent years, insects have been increasingly cultivated for human and animal food, emphasising the advantage of using less land and water, as well as creating lower emissions and greenhouse gases. Providing alternative protein sources in the feeding of monogastric animals is a challenge and a scientific priority for scientists. The review includes studies on insect meal (IM) addition in compound feeds and its influence on poultry and swine productivity, health and environmental effects. The questions remain open for research on the optimal level of inclusion of IM to different production categories, product quality, standardising IM rendering and production methods and the impact on the physiological and health status of animals.

Key words: insect meal, monogastric animals, nutrition, productivity

Until a decade ago, the use of edible insects in human food was considered unusual for the Western menu, and popular only in tropical areas. In recent years, there has been a growing interest in insect consumption, which can alleviate existing environmental problems by facilitating lower greenhouse gas emissions and ammonia, decreasing the consumption of water and the use of less land for their cultivation. Additionally, it curbs the increasing demand for meat (1). However, traditional animal food for many remains the main source of the necessary nutrients. As the world population could exceed more than 10 billion by 2050, consumption of chicken and pork is also expected to increase from 2010 to 2050 by 173% and 105%, respectively (2). Protein is the most expensive and limiting ingredient in compound feeds for pigs, and the cost of traditional protein sources has risen significantly due to the supply and competition between humans and animals (3). The livestock industry relies heavily on the production of staple food crops such as cereals, which are at the same time threatened by climate change, as well as the scarce or limited protein sources that augment cereals to help achieve a balanced compound feed for animals (4). Increased meat production requires a solid feed resource to feed animals. The Food and Agriculture Organization (FAO) recommends alternatives to conventional animal feed ingredients in order to reduce competition between humans and animals for limited food chain resources (5).

As protein raw materials, insects such as BSFL, mealworm larvae (*Tenebrio molitor L.*) and crickets (Orthoptera: Gryllidae) are the objective of scientific research and are used as alternative sources of nutrients in poultry and pig feeds as they contain almost 100 percent of the edible portion of the protein (6).

However, there is still a lack of systematic studies and approaches on the use of insect meal (IM) as an alternative component in compound feed for fattening pigs, on establishing the effectiveness, mode of action on productive indicators, digestibility of energy and nutrients and oxidative stress of the body affecting animal health. This provoked our scientific interest in searching for alternative feeds in pig breeding, ensuring good health and welfare, good functioning of the digestive system, as

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well as achieving better digestibility of nutrients, leading to higher productivity in growing pigs.

INSECT MEAL IN COMPOUND FEEDS FOR PIGS

The main source of protein in monogastric animals is soybean meal (SBM). No adverse effects have been identified when using first-generation GMO plant feed. However, foods containing or produced by GMOs are not perceived as safe (7). Alternative sources of protein have been sought in recent years in order to reduce the content of SBM in feeds. One of these potential alternatives is the use of IM. Insect larvae require less water, land and resources for production, compared to convective plant feed ingredients (8). The International Insect Platform for Food and Feed (IPIFF) predicts that IM production will increase to 200,000 tonnes in 2020 and 1.2 million tonnes in 2025 (9).

The largest markets for edible insects are the countries of the Asia-Pacific region. In the USA and EU (as of 2017) the BSF is authorized for use as feed in aquaculture; *Hermetia illucens* (2).

Insects are becoming increasingly important as an alternative ingredient in animal feed, and research in this direction is expected to expand. More than 1,900 species of edible insects have been identified and research on feeding resources has been conducted (10). Unfortunately, consumers have a negative perception of edible insect consumption (11).

Insects are a good source of fat and protein, have high digestibility and are palatable (2). They grow very quickly, have a short life cycle and can feed on organic waste, manure, garbage and plastics (12).

A number of studies have found that BSFL feed on organic resources such as fruit residues, animal manure, vegetables, and brewer's spent grains (13-18) and convert these resources into high-quality insect protein and fat. In their studies (19, 20), found that the black soldier fly has the ability to reduce the quality and content of organic waste in pig manure with an efficiency similar to that of poultry manure, which is of benefit to improve farm hygiene. A significant economic indicator is that the waste obtained from insect production is a valuable source of organic fertilizer that can be used in crop production (21).

Dry matter of BSFL contains 37% to 63% crude protein, 7% to 39% fat (22, 23), 8% calcium, 1% to 2% phosphorus 0.1% to 0.3% sodium and 0.4% to 1% magnesium (23-26). The content of unsaturated fatty acids, such as omega-3 and omega-6 are found in large quantities in mealworm larvae and has similar values to fish (27).

Although the inclusion of insect products in pig nutrition is new and not yet applicable, a small number of scientific studies with different categories of pigs have been published in recent years (28-32).

NUTRITIONAL VALUE OF INSECT MEAL

Studies conducted to evaluate the nutritional value of insect products to replace SBM show great potential for the use of IM as an alternative source of protein in pig breeding. Crosbie (33) found that both full-fat meal and defatted black soldier fly meal could be suitable protein alternatives for inclusion in pig rations. Both flours have high standardized ileal digestibility for most amino acids.

According to Crosbie (33), both defatted and full-fat black soldier fly meals have a rich amino acid profile and are therefore considered a more sustainable protein source than soy and fish meal. The most abundant essential amino acids are leucine (mean 44.6 g/kg, from 27.8 g/kg to 78.3 g/kg), lysine (mean 38.8 g/kg, from 23.0 g/kg to 68.2 g/kg) and valine (mean 40.1 g/kg, ranging from 28.2 g/kg to 67.9 g/kg). The content of these three amino acids is higher than that of SBM, and the valine content is higher than that of fishmeal, Council (34). The essential amino acids methionine and tryptophan amount to the least quantity, and are comparable to SBM, but in much lower concentrations in fish meal (34).

Among edible insects, the mealworm larva (*Tenebrio moiltor*) contains high protein and fat content, while the carbohydrate content is relatively lower than that of other edible insects (35). Unsaturated fatty acids, such as omega-3 and omega-6 have been found in large amounts in mealworm larvae and are as high as in fish (27). Meyer (36) conducted a study on the influence of *Tenebrio molitor L.* meal as a protein source on intermediate metabolism in growing pigs. In a 4-week experiment, 5-week-old pigs were placed in three experimental groups - control and experimental - with 5% and

10% IM in the combined feed. Lower ileal digestibility was observed by 6.7 to 15.6% in EB (10%) compared to the control. Regarding plasma metabolomics, higher concentrations of alanine glutamate, proline, serine, tyrosine and valine and lower concentrations of asparagine were found in EB 10 compared to the control. Plasma concentrations of the main types of carnitine and bile acids did not differ between groups. As a conclusion of the study, the authors propose the use of *Tenebrio molitor L.* meal as a dietary source of protein in pigs that does not cause an adverse effect on metabolism.

INSECT MEAL AND PRODUCTIVITY IN MONOGASTRIC ANIMALS

Studies by a number of scientists (37-39, 31) in feeding broilers and pigs show that replacing conventional protein sources such as SBM with IM does not impair growth when the limiting amino acids are provided. Some broiler studies (37-39, 31) found that animal health was not negatively affected by IM. The use of BSFL meal (Hermetia illucens) in the diets of salmonids, trout, tilapia and poultry (including chickens, ducks, turkeys and geese) has been approved by regulatory authorities (40).

Yu (41), found that the addition of 4% BSFL increased the microbiome of the following strains: Lactobacillus, Vibrio pseudo-oil, Rosella and faecalibacterium in the intestinal tract of pigs, while the number of streptococci decreased. In their conclusions (31), summarized that partially defatted BSFL meal can be used as a feed ingredient in diets for weaned piglets without negatively affecting their growth, nutrient digestibility, blood profile, the histological and morphological characteristics of the intestine. In pigs, however, little is known about the influence of IM on animal metabolism.

Replacing a portion of SBM in the rations of broiler chickens with soldier fly meal did not affect daily feed intake, average daily gain, feed conversion ratio and slaughter performance of the carcasses (42). Based on these results, the authors discuss prospects for the promotion of enterprises for the mass production of insects for animal feed protein.

Lalev (43), found that inclusion of up to 10% SW and BSFd meal in the diet of broiler chickens improved their productive performance. A higher final live weight, better daily weight gain, better feed conversion and slaughter traits were found out. The study demonstrated that the inclusion of IM influenced the amino acid and fatty acid profile of meat, with no negative effect on chickens' immunity and health. The findings suggested that SW and BSFd meals may be a good alternative to SBM in broiler chicken nutrition. However, performing meta-analysis of published data, Moula and Detilleux (44) showed that the daily weight gain in broiler studies starts decreasing above 10% insect meal inclusion. Chobanova (45) found decrease in broiler performance when completely replacing SBM with 16% IM in diets. The reduced performance after high IM inclusion level may be associated with its chitin content. Despite the many functional benefits associated with chitin (e.g. as a potential prebiotic, as well as antimicrobial, antiviral and antifungal agent), it has often been characterised as an anti-nutritional factor (46). Although chickens have been shown to produce chitinase in the proventriculus and hepatocytes (47), the digestibility of chitin seems to be limited (48), particularly in young birds (49). Additionally, chitin comprises 3.0% to 6.8% non-protein nitrogen (NPN), meaning that the standard 6.26 N-to-CP conversion factor overestimates protein (50). The feeding value of IM will also depend on substrate fed to the larvae, larvae age, production, drying and milling techniques.

INSECT MEAL AND SWINE HEALTH

In studies with suckling pigs, with included 3.5% larval meal, Driemeyer (51) found that haemoglobin and haematocrit values increased. According to the author, these results are probably due to immunological stress.

Biasato (31) investigated haematological, biochemical, morphometric and histopathological parameters in weaned piglets given a compound feed with included IM of BSF-0, 5 and 10% replacing SBM. Evaluated haematological and biochemical parameters were not affected, except for the monocytes and neutrophils. Gut morphology and histological future were not affected.

Summarizing the research of multiple authors, Veldkamp and Vernooij (52) concluded that the values of haematological, biochemical and intestinal parameters were not affected by the inclusion of insect products. In only one study, the addition of 2% BSFL meal (replacing 50% of the fishmeal) affected the ileal and caecal

bacterial population and metabolic profile in weaned pigs.

Biasato (53) reported the influence of the HI (Hermetia illucers)-based diets in weaned pigs on gut health. The gut of the piglets fed the HI (Hermetia illucers)-based diets showed greater neutral mucin percentage than the Control ($P < 0.05$), with the intestinal neutral mucins of the HI-fed animals being also higher than the sialomucins and the sulfomucins found in the gut of the C group ($P < 0.05$). Furthermore, the piglets fed the HI-based diets displayed lower histological scores in the jejunum than the other gut segments (ileum [HI-5%] or ileum and duodenum [HI-10%], $P < 0.05$).

Insects emit less greenhouse gases and ammonia, have a small carbon footprint, compared to other animals (54, 55).

The study by Smetana (56) showed that insects have a high nutritional value, are rich in protein, vitamins and minerals and potentially have a lower environmental impact than traditional farm animals and thus can be an alternative source of protein to address the problems of sustainability associated with current food systems.

The present review demonstrated that IM products contain CP comparable to and available energy higher than those in SBM. Thus, they turn insect products into attractive components for sustainable diet formulations. Although IM shows good potential as alternative to SBM protein feed for monogastric animals, more research needs to be done on the optimal inclusive dietary level. Care must also be taken when choosing insect products for dietary formulation diets based on knowledge of their rendering technique, to ensure nutritional value is preserved as formulated. Further research into standardising insect rendering and production methods should be prioritised by the industry.

REFERENCES

1. van Huis, A. Prospects for insects as human food. *J Consum Prot Food Saf* 18, 105–106, 2023. https://doi.org/10.1007/s00003-023-01438-9
2. Jinsu Hong and Yoo Yong Kim. Insect as feed ingredients for pigs. *Anim Biosci*. 2022 Feb; 35(2): 347–355, 2022. doi: 10.5713/ab.21.0475
3. Arnold Van Huis. New Sources of Animal Proteins: Edible Insects, Woodhead Publishing Series in Food Science, Technology and Nutrition, Pages 443-461, 2017
4. Opoku Mensah, S., T.A.B. Akanpabadai, S.K. Diko, S.A. Okyere, and C. Benamba. Prioritisation of climate change adaptation strategies by smallholder farmers in semi-arid savannah agro-ecological zones: insights from the Talensi District, Ghana. *Journal of Social and Economic Development* 25: 232–258, 2023a.
5. Mottet A, de Haan C, Falcucci A, Tempio G, Opio C, Gerber P. Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Glob Food Sec*., 14:1–8, 2017.
6. Schiavone, A., De Marco, M., Martinez, S., Dabbou, S., Renna, M., Madrid, J., Hernandez, F., Rotolo, L., Costa, P., Gai, F., and Gasco, L. Nutritional value of a partially defatted and a highly defatted black soldier fly larvae (Hermetia illucens L.) meal for broiler chickens: apparent nutrient digestibility, apparent metabolizable energy and apparent ileal amino acid digestibility. *J.Anim. Sci. Biotechnol*. 8: 51, 2017.
7. Sorita, M., A. Rekiel, J. Wiecek, M. Batorska, K. Puppel. Alternative Protein Sources vs. GM Soyabean Meal as Feedstuffs for Pigs- Meat Quality and Health- Promoting Indicators. *Animals* (Basel) 2021 Jan 13;11(1):177. doi: 10.3390/ani11010177
8. Wang Y.-S., and Shelomi M. Review of black soldier fly (*Hermetia illucens*) as animal feed and human food. *Foods* 10:91, 2017. doi: 10.3390/foods6100091
9. IPIFF, 2019 IPIFF
10. Van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir, G, Vantomme P. Edible insects: Future prospects for food and feed security. 2013 Online: https://www.fao.org/3/i3253e/i3253e.pdf. Accessed 12 April 2023
11. Sogari G, Amato M, Biasato I, Chiesa S, Gasco L. The potential role of insects as feed: a multi-perspective review. *Animals*, 9:119, 2019.
12. Veldkamp T, Van Duinkerken G, Van Huis A, et al. Insects as a sustainable feed ingredient in pig and poultry diets: a feasibility study. Insecten als duurzame diervoedergrondstof in varkens-en pluimveevoeders: een haalbaarheidsstudie,

(No. 638). Wageningen, The Netherlands: Wageningen UR *Livestock Research,* 2012.
13. Sheppard, D.C.; Newton, G.L.; Thompson, S.A.; Savage, S. A value-added manure management system using the black soldier fly. Bioresour. Technol. 1994, 50, 275–279.
14. Nguyen, T.T.X.; Tomberlin, J.K.; Vanlaerhoven, S. Influence of resources on Hermetia illucens (Diptera: Stratiomyidae) larval development. *J. Med. Entomol*. 2013, 50, 898–906. [Google Scholar] [CrossRef] [PubMed]
15. Meneguz, M.; Schiavone, A.; Gai, F.; Dama, A.; Lussiana, C.; Renna, M.; Gasco, L. Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (Hermetia illucens) larvae. *J. Sci. Food Agric*. 2018, 98, 5776–5784.
16. Salomone, R.; Saija, G.; Mondello, G.; Giannetto, A.; Fasulo, S.; Savastano, D. Environmental impact of food waste bioconversion by insects: Application of life cycle assessment to process using Hermetia illucens. *J. Clean. Prod*. 2017, 140, 890–905.
17. Chia, S.Y.; Tanga, C.M.; Osuga, I.M.; Mohamed, S.A.; Khamis, F.M.; Salifu, D.; Fiaboe, K.K.; Niassy, S.; van Loon, J.J.; Dicke, M.; et al. Effects of waste stream combinations from brewing industry on performance of black soldier fly, Hermetia illucens (Diptera: Stratiomyidae). *PeerJ*, 6, e5885, 2018.
18. Pinotti, L.; Giromini, C.; Ottoboni, M.; Tretola, M.; Marchis, D. Review: Insects and former foodstuffs for upgrading food waste biomasses/streams to feed ingredients for farm animals. *Animal* 2019, 13, 1365–1375.
19. Nguyen, T.T.; Tomberlin, J.K.; Vanlaerhoven, S. Ability of black soldier fly (Diptera: Stratiomyidae) larvae to recycle food waste. *Environ. Entomol*. 2015, 44, 406–410, 2015.
20. Zhou, F.; Tomberlin, J.K.; Zheng, L.; Yu, Z.; Zhang, J. Developmental and waste reduction plasticity of three black soldier fly strains (Diptera: Stratiomyidae) raised on different livestock manures. *J. Med. Entomol*., 50, 1224–1230, 2013.
21. DiGiacomo K and Leury. K. Review: Insect meal: a future source of protein feed for pigs? *The Animal Consortium.* Pages 3022-3030, 2019.
22. Bosch, G.; Zhang, S.; Oonincx, D.G.A.B.; Hendriks, W.H. Protein quality of insects as potential ingredients for dog and cat foods. *J. Nutr. Sci*., 3, e29, 2014.
23. Barragan-Fonseca, K.B.; Dicke, M.; van Loon, J.J.A. Nutritional value of the black soldier fly (Hermetia illucens L.) and its suitability as animal feed—A review. *J. Insects Food Feed*, 3, 105–120, 2017.
24. Newton, G.L.; Sheppard, D.C.; Watson, D.W.; Burtle, G.J.; Dove, C.R.; Tomberlin, J.K.; Thelen, E.E. The black soldier fly, Hermetia illucens, as a manure management/resource recovery tool. *Symp. State Sci. Anim. Manure Waste Manag,* 2005.
25. Dierenfeld, E.; King, J. Digestibility and mineral availability of phoenix worms, Hermetia illucens, ingested by mountain chicken frogs, Leptodactylus fallax. *J. Herpetol. Med. Surg.* 2008, 18, 100–105.
26. Finke, M.D. Complete nutrient content of four species of feeder insects. *Zoo Biol*. 2013, 32, 27–36, 2013.
27. Van Huis, A. Potential of insects as food and feed in assuring food security. *Annual Review of Entomology,* 58, 563–583, 2013. 10.1146/annurev-ento-120811-153704 [PubMed]
28. Spranghers T, Michiels J, Vrancx J, et al. Gut antimicrobial effects and nutritional value of black soldier fly (Hermetia illucens L.) prepupae for weaned piglets. *Anim Feed Sci Technol,* 235:33-42, 2018.
29. Nekrasov R, Zelenchenkova A, Chabaev M, Ivanov G, Antonov A, Pastukhova N. PSIII-37 Dried Black Soldier Fly larvae as a dietary supplement to the diet of growing pigs. *J Anim Sci*., 96:314, 2018.
30. Altmann BA, Neumann C, Rothstein S, Liebert F, Mörlein D. Do dietary soy alternatives lead to pork quality improvements or drawbacks? A look into micro-alga and insect protein in swine diets. *Meat Sci* 2019; 153:26-34, 2019.
31. Biasato I, Renna M, Gai F, Dabbou S, Meneguz M, Perona G, Martinez S, Lajusticia ACB, Bergagna S, Sardi L, et al. Partially defatted black soldier fly larva meal inclusion in piglet diets: effects on the growth performance, nutrient digestibility, blood profile, gut morphology and histological features. *J Anim Sci Biotechnol*. 10:12, 2019.
32. Kar SK, Schokker D, Harms AC, Kruijt L, Smits MA, Jansman AJM. Local intestinal microbiota response and systemic effects of feeding black soldier fly larvae to replace

soybean meal in growing pigs. *Sci Rep*, 11:15088, 2021. https://doi.org/10.1038/s41598-021-94604-8 35.
33. Crosbie, M., Zhu, C., Shoveller, A.K. and Huber, L.-A. Standardized ileal digestible amino acids and net energy contents in full fat and defatted black soldier fly larvae meals (Hermetia illucens) fed to growing pigs. *Translational Animal Science* 4, 2020: txaa104
34. Council, N.R. Nutrient Requirements of Swine; Natl Acad Press: Washington, DC, USA, (2012).
35. Rumpold, B. A., & Schlüter, O. Insect-based protein sources and their potential for human consumption: Nutritional composition and processing. *Animal Frontiers*, 5(2), 20-24, 2015.
36. Meyer S, Gessner DK, Braune MS, Friedhoff T, Most E, Höring M, Liebisch G, Zorn H, Eder K, Ringseis R. Comprehensive evaluation of the metabolic effects of insect meal from Tenebrio molitor L. in growing pigs by transcriptomics, metabolomics and lipidomics. *J Anim Sci Biotechnol*. 11:20, 2020.
37. Bovera F, Loponte R, Marono S, Piccolo G, Parisi G, Iaconisi V, Gasco L, Nizza A. Use of larvae meal as protein source in broiler diet: effect on growth performance, nutrient digestibility, and carcass and meat traits. *J Anim Sci*. 94:639–647, 2016.
38. Jin XH, Heo PS, Hong JS, Kim NJ, Kim YY. Supplementation of dried mealworm (Tenebrio molitor larvae) on growth performance, nutrient digestibility and blood profiles in weaning pigs. *Asian-Australas J Anim Sci*. 29:979–986, 2016.
39. Schiavone A, Dabbou S, De Marco M, Cullere M, Biasato I, Biasibetti E, Capucchio MT, Bergagna S, Dezzutto D, Meneguz M, et al. Black soldier fly larva fat inclusion in finisher broiler chicken diet as an alternative fat source. *Animal*. 12:2032–2039, 2018.
40. (AAFCO) The Association of American Feed Control Officials, (2016)
41. Yu M., Li Z., Chen W., Rong T., Wang G., Ma X. *Hermetia illucens* larvae as a potential dietary protein source altered the microbiota and modulated mucosal immune status in the colon of finishing pigs. *J. Anim. Sci. Biotechnol*.;10:50, 2019. doi: 10.1186/s40104-019-0358-1.
42. Onsongo V O, Osuga I M, Gachuiri C K, Wachira A M, Miano D M, Tanga C M, Ekesi S, Nakimbugwe D, Fiaboe K K. Insects for income generation through animal feed: effect of dietary replacement of soybean and fish meal with black soldier fly meal on broiler growth and economic performance. *Journal of economic entomology*, Volume 111, Article #4, 2018. https://academic.oup.com/jee/article-abstract/111/4/1966/4990642
43. Lalev, M., Hristakieva, P., Mincheva, N., Oblakova, M. & Ivanova, I. Insect meal as alternative protein ingredient in broiler feed. *Bulg. J. Agric. Sci*., 28 (4), 743–751, 2022.
44. Moula, N.; Detilleux, J. A meta-analysis of the effects of insects in feed on poultry growth performances. Animals. 2019, 9, 201.
45. Chobanova, S.; Karkelanov, N.; Mansbridge, S.C.; Whiting, I.M.; Simic, A.; Rose, S.P.; Pirgozliev, V.R. 2023. Defatted black soldier fly larvae meal as an alternative to soybean meal for broiler chickens. Poultry, 2023, 2(3), 430-441.
46. Hahn, T.; Roth, A.; Febel, E.; Fijalkowska, M.; Schmitt, E.; Arsiwalla, T.; Zibek, S. New methods for high-accuracy insect chitin measurement. J. Sci. Food Agric. 2018, 98, 5069-5073.
47. Suzuki, M.; Fujimoto, W.; Goto, M.; Morimatsu, M.; Syuto, B.; Toshihiko, I. Cellular expression of gut chitinase mRNA in the gastrointestinal tract of mice and chickens. J. Histochem. Cytochem. 2002, 50, 1081–9.
48. Hossain, S.; Blair, R. Chitin utilization by broilers and its effects on body composition and blood metabolites. Br. Poult. Sci. 2007, 48, 33–38.
49. Ijaiya, A.T.; Eko, E.O. Effect of replacing dietary fish meal with silkworm (Anaphe infracta) caterpillar meal on performance, carcass characteristics and haematological parameters of finishing broiler chicken. Pak J Nutr. 2009, 8, 850-855.
50. Janssen, R.H.; Vincken, J.P.; van den Broek, L.A.; Fogliano, V.; Lakemond, C.M. Nitrogen-to-protein conversion factors for three edible insects: Tenebrio molitor, Alphitobius diaperinus, and Hermetia illucens. J. Agric. Food Chem. 2017, 65, 2275-2278.
51. Driemeyer, H. Evaluation of black soldier fly (Hermetia illucens) larvae as an alternative protein source in pig creep diets in relation to production, blood and manure

microbiology parameters. *Stellenbosch University, Stellenbosch,* 2016.
52. Veldkamp, A.G. Vernooij. Use of insect products in pig diets, *Journal of Insects as Food and Feed* 7(5):1-14, 2021.
53. Biasato I, Ferrocino I, Colombino E, et al. Effects of dietary Hermetia illucens meal inclusion on cecal microbiota and small intestinal mucin dynamics and infiltration with immune cells of weaned piglets. *J Anim Sci Biotechnol*, 11:64, 2020.
54. Oonincx DGAB, van Itterbeeck J, Heetkamp MJW, van den Brand H, van Loon JJA, van Huis A. An Exploration on Greenhouse Gas and Ammonia Production by Insect Species Suitable for Animal or Human Consumption. *PLoS ONE* 5(12): e14445, 2010. https://doi.org/10.1371/journal.pone.0014445
55. Mlček J, Adámková A, Adámek M, et al. Selected aspects of edible insect rearing and consumption–A review. *Czech J Food Sci*, 39:149-59, 2021.
56. Sergiy Smetana, Anita Bhatia, Uday Batta, Nisrine Mouhrim, Alberto Tonda. Environmental impact potential of insect production chains for food and feed in Europe, *Animal Frontiers*, Volume 13, Issue 4, August 2023, Pages 112–120, 2023. https://doi.org/10.1093/af/vfad033