From Waste to Wealth: Insect-Based Feeds for Sustainable Livestock and Aquaculture in India

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Introduction:

The search for sustainable, cost-effective and nutritionally balanced feed resources has gained global momentum, particularly in the livestock and aquaculture sectors. Among the emerging alternatives**,** insects, especially the Black Soldier Fly (BSF**;** *Hermetia illucens***)** larvae meal, have shown significant promise. BSF larvae meal is characterized by its high nutrient density, typically containing 40–60% crude protein (with even higher values in defatted meals), a balanced amino acid profile, medium-chain fatty acids such as lauric acid, essential minerals and functional polysaccharides like chitin**,** which can enhance gut health and immunity. Recent meta-analyses (2024–2025) reported improved feed efficiency and growth performance in broilers, along with positive impacts on egg quality indices in layers when BSF meal was included at practical dietary levels (Chhetri et al., 2025).

In addition to its nutritional benefits, BSF production contributes to circularity and waste valorization. The larvae can convert a wide range of food and organic wastes into high-value protein and frass, the latter serving as a biofertilizer or soil amendment. Studies indicate that BSF rearing can achieve up to 70% reduction in waste mass within two weeks, thereby easing landfill pressure and reducing greenhouse gas emissions (SCF). Equally important are the environmental advantages of BSF meal compared to conventional protein sources like soybean meal and fishmeal. Independent industry and policy reviews recognize BSF as a viable solution to reduce the livestock sector's dependence on deforestation-linked soy production and overexploited fisheries, making it particularly relevant for poultry and pig production systems (Joly and Nikiema, 2019).

BSF Meal in Ruminant

Recent studies highlight the potential of black soldier fly (BSF, *Hermetia illucens*) larvae as an alternative protein and fat source in ruminant diets. Reviews emphasize BSF's nutritional value and applications across livestock systems. Defatted BSF meal has been successfully tested as a substitute for soybean meal in lactating dairy cows without adverse effects on production (Braamhaar et al., 2025), while BSF oil showed comparable outcomes to hydrogenated palm fat in dairy nutrition. Trials with cattle consuming forage indicate BSF and mealworm larvae can partially replace conventional protein sources. In small ruminants, inclusion of BSF meal in sheep and goat diets supported rumen function and performance without negative impacts. In vitro studies further confirmed that defatted BSF meal can replace up to 20–40% of total mixed rations with good digestibility (Kahraman et al., 2023). However, frass and chitin fractions may reduce nutrient digestibility in sheep and goats, highlighting the need for careful processing and inclusion control.

ICAR's BSF-Based Fish Feed Innovations:

The Central Marine Fisheries Research Institute (CMFRI) announced the development of an eco-friendly fish feed using Black Soldier Fly (BSF) larvae meal**.** This innovation is aimed at reducing the heavy dependence on conventional fishmeal in marine aquaculture. By partially replacing fishmeal with BSF protein, the formulation helps in lowering costs and promoting sustainability, while maintaining good growth and health performance in cultured marine fish (CMFRI, 2025). The Central Inland Fisheries Research Institute (CIFRI), in collaboration with other ICAR institutes, formulated a nutrient-rich fish feed containing BSF prepupae reared on organic waste**.** This approach provided a dual benefit: it served as a cost-effective alternative protein source for aquaculture feeds and simultaneously contributed to bioremediation of organic waste. The study demonstrated that BSF meal could be safely and efficiently included in carp diets without compromising performance (Aquaculture Nutrition, 2022 – ICAR-CIFRI).

Practical Inclusion Levels of BSF in Poultry Diets

Indian researchers have reported encouraging results on the use of Black Soldier Fly (BSF) meal in livestock and aquaculture. In poultry, BSF larva meal can be safely included up to about 5% in broiler diets, especially in the early growth phase, with positive effects on performance, though the nutrient profile may vary depending on the source and processing (Raju et al., 2024). For layer birds, BSF inclusion can improve feed efficiency and egg quality indices, without negatively affecting overall production (Fikari et al., 2024).

Processing Matters in BSF Meal Production

The way Black Soldier Fly (BSF) larvae are processed has a direct impact on their nutritional value, safety and suitability for animal feed.

- Defatting for Higher Protein Concentration
  - Fresh BSF larvae contain a significant amount of fat (30–40%).
  - When the larvae are defatted (oil removed through pressing or solvent extraction), the crude protein concentration rises to 50–65%, making the product closer to fishmeal in quality.
  - Defatting also makes the meal more stable during storage and reduces the risk of rancidity.
  - However, the removed oil is not wasted—it is rich in lauric acid and can be used separately in poultry, pig, or aquaculture diets for energy and antimicrobial benefits.
- Drying and Thermal Processing
  - Drying methods (sun-drying, oven-drying, or industrial drum-drying) and temperature profiles play a key role in digestibility.
  - High temperatures can denature proteins and destroy heat-sensitive vitamins, while under-drying risks microbial contamination.
  - Controlled drying at moderate heat ensures a balance between safety and nutrient preservation.
  - Grinding size also affects feed use—finer particle sizes improve digestibility and mixing in pelleted feed, whereas coarse grinding may reduce feed intake efficiency.
- Substrate Control: What the Larvae Eat Matters
  - The nutrient profile of BSF meal depends on the substrate (the waste or by-products larvae are reared on).
  - For example, larvae fed on brewery by-products may have a different amino acid and fatty acid composition compared to those reared on fruit/vegetable waste.
  - More importantly, substrates can influence safety risks:
    - Heavy metals (like lead, cadmium) may accumulate if the substrate is contaminated.
    - Microbes and pathogens can transfer from poorly managed waste streams.

Functional Benefits to Leverage

Lauric acid (C12:0) and chitin, two key bioactive components derived from insect meal and related substrates, provide multiple functional advantages in animal nutrition. Lauric acid has been widely recognized for its antimicrobial properties, particularly against gram-positive bacteria, thereby contributing to improved gut health and reduction of pathogenic load in poultry and aquaculture species. For instance, Spranghers (2017) reported that modest inclusion of insect-derived lipids rich in lauric acid enhanced gut microbial balance and reduced enteric pathogens in broiler chickens. Similarly, Nguyen et al. (2015) observed improved feed efficiency and reduced disease incidence in fish when diets were supplemented with lauric acid-containing insect meals.

Chitin, a structural polysaccharide present in the exoskeleton of insects, also exerts beneficial effects on gut health. It acts as a prebiotic, promoting the proliferation of beneficial gut microbiota such as *Lactobacillus* spp., while simultaneously strengthening the intestinal barrier. Beyond gut modulation, chitin has been shown to stimulate non-specific immune responses. Khempaka et al. (2011) demonstrated that broilers fed chitin-rich black soldier fly meal exhibited enhanced immune parameters and reduced susceptibility to infections. More recently, Shah et al. (2020) highlighted that moderate dietary inclusion of chitin improved disease resistance and stress tolerance in aquaculture species such as tilapia. Taken together, these findings suggest that lauric acid and chitin, when strategically incorporated at modest dietary inclusion levels, can provide synergistic benefits by enhancing gut health, suppressing pathogenic bacteria and modulating host immunity across different livestock and aquaculture systems.

Safety, Quality Assurance and Indian Regulatory Context

Feed safety relies on HACCP-based sourcing, microbial load control (via heat/steam), and heavy-metal testing, especially when larvae are reared on mixed waste. International data from shrimp and salmon show insect meals are safe when stringent QA is applied (MDPI; Frontiers).

In India (2024–2025), feed regulation spans DAHD, BIS (for approved feed ingredients) and state FDA/FSSAI (for some by-product streams). Dedicated insect meal standards are still under development, though ICAR is piloting BSF technologies and firms (e.g., Arthro Biotech) have achieved EU TRACES compliance, paving export pathways. For commercialization, alignment with BIS norms, full traceability and consultation with state AHD/Veterinary authorities on substrate use are advised.

Economics & Sustainability

Black soldier fly (BSF) meal shows economic competitiveness in regions where rearing substrates include waste streams with tipping fees or low-cost agro-industrial by-products. However, in the absence of such inputs, BSF products often face cost pressure compared to conventional protein sources such as soybean meal and fishmeal. Recent independent analyses (2023) emphasize that commercial viability depends heavily on scaling and strategic co-location with agro-industries, where integration of heat, CO_2 and waste management can deliver both cost savings and measurable carbon footprint reductions.

How to Implement (Actionable Roadmap)

- Substrate & Partners – Source traceable inputs from breweries, fruit/veg packers, starch, oil and poultry sectors; apply ICAR protocols.
- Process Flow – substrate prep → larvae rearing (7–12 d) → harvest → defat (if needed) → dry/mill → QC (microbes, metals, proximate, AA, FA) → formulate.
- Farm Trials –
  - Broilers: 0–7.5% BSF meal; monitor FCR, ADG, gut health. Use synthetic Met/Lys top-ups if needed. Indian literature supports 5% comfortably.
  - Layers: 0–6% defatted BSF meal; track egg quality and yield. Meta-analyses support quality gains at moderate levels
  - Fish: Replace 15–25% fishmeal protein; check growth, FCR, fillet FA profile. . Use fish-oil/algal-oil topping if PUFA targets matter
- By-products – Use frass as fertilizer/soil amendment within local regulatory norms.

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