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Harnessing Nature’s Allies: Beneficial Insects and Biocontrol Agents in Sustainable and Integrated Farming Systems

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Abstract

Beneficial insects are integral to Integrated Farming Systems (IFS), where crops, livestock and other enterprises are linked so that one component's waste becomes another's input. This article categorizes these insects into four functional groups: productive insects (silkworms, honey bees, lac insects) that generate direct income through sericulture, apiculture and lac cultivation; pollinators, which raise yields of fruits, vegetables, oilseeds and forage crops by 15–600% depending on the crop; scavengers (dung beetles, termites, ants), which recycle organic waste and improve soil fertility; and biocontrol agents predators, parasitoids, weed-feeding insects and microbial bioagents (bacteria, fungi, viruses, nematodes) that suppress pests without synthetic chemicals. It also examines black soldier fly larvae and mealworms as an emerging insect-farming sector, converting organic waste into high-protein animal feed (40–61% crude protein) within 15–18 days. Overall, the article demonstrates that integrating these insect groups into farming systems diversifies income, reduces dependence on chemical inputs and strengthens nutrient cycling and ecological resilience, positioning beneficial insects as a core component of sustainable agriculture.

Keywords: Integrated Farming Systems; Beneficial insects; Sericulture; Apiculture; Biological control

Introduction

Ask most people what keeps a farm running and they'll say soil, water, seeds, maybe a good monsoon. Almost nobody says insects. Yet in an Integrated Farming System (IFS), a model that weaves together crops, livestock, fisheries and other enterprises so that one activity's waste becomes another's raw material, insects turn out to be some of the hardest-working, most cost-effective employees a farmer will ever have.

Not every insect earns it keep the same way. Broadly, they fall into a few job categories: productive insects that manufacture marketable goods, pollinators that make fruits and seeds possible, scavengers that clean up and recycle waste and biocontrol agent’s predators, parasitoids, weed-killers and microbes that guard crops without a drop of chemical pesticide. Together, this six-legged workforce is quietly one of the most valuable assets in sustainable agriculture.

Beneficial insects in Integrated Farming Systems can broadly be classified into:

1. Productive Insects in IFS

Productive insects directly generate commercially valuable products and provide supplementary farm income. Major productive insects integrated into farming systems include silkworms, honey bees and lac insects.

A. Sericulture

Sericulture the rearing of silkworms for raw silk is built on three linked activities: growing mulberry to feed the worms, rearing the worms themselves and reeling silk from their cocoons. It's a genuinely massive employer: around 60 lakh (6 million) people work across India's sericulture value chain and the industry generates roughly 11 person-days of work for every kilogram of raw silk produced, spread across the year. Encouragingly, about 56.8% of the industry's gross income flows straight back to the cocoon growers themselves, according to Central Silk Board figures.

The economics are unusually forgiving for a farm enterprise. An investment of roughly ₹12,000–15,000 (excluding land and rearing sheds) is enough to start mulberry cultivation and silkworm rearing on one acre of irrigated land. Mulberry takes just two months to establish before rearing can begin and once planted, a garden keeps producing for 15–20 years. Under tropical conditions, farmers can take six silkworm crops a year and a well-managed acre can bring in up to ₹50,000 net income per crop. Women make up more than 60% of the workforce in sericulture's downstream activities, making it an important engine of rural women's employment too.

Running a silkworm operation needs a few essentials: a dedicated rearing house, a mulberry garden nearby, rearing stands to hold the trays and mountages the structures onto which mature larvae climb to spin their cocoons. India also rears more than one kind of silk: alongside common mulberry silk, there's eri, muga and tasar silk, each from a different silkworm species and each with its own texture and market.

Turning Sericulture Waste into Farm Gold

What makes sericulture such a natural fit for an IFS is how little of it goes to waste.

- **From the mulberry plant:** Excess leaves feed cattle, goats and rabbits, being rich in protein, minerals and digestible nutrients; twigs and stems become fuelwood, paper pulp, particle board, handicrafts or compost; and the fruit, high in antioxidants, is eaten fresh or turned into juice, jam, wine and pharmaceutical extracts.
- **From the rearing process:** The leftover bedding from rearing trays makes excellent organic manure and vermicompost, while the silkworms' excreta (frass) is rich in nitrogen, phosphorus and potassium and doubles as a biofertiliser for mulberry gardens and vegetable crops.
- **From the pupae:** Roughly 55–60% protein, pupae are used in poultry and fish feed and in some countries even as human food. Pupal oil, rich in unsaturated fats, is extracted for pharmaceuticals, cosmetics, soaps, paints and lubricants and researchers are exploring it as a potential biodiesel source.

Put together, sericulture by-products help build a genuinely zero-waste farming approach feeding into dairy, poultry, fisheries and organic farming components of an IFS, while adding an extra income stream for the farmer.

Apiculture: Bees and their usefulness have been recognised since prehistoric times references to bees and honey appear in the Vedas and in the Ramayana. India is home to five economically important honey bee species, each with a strikingly different honey yield (Table 1).

Table 1. Honey yield of different honey bee species under colony/year basis

Species	Common name	Honey yield / colony / year
Apis dorsata	Rock bee	≈37 kg
Apis florea	Little bee	0.5–1 kg
Apis cerana indica	Indian hive bee	2–5 kg
Apis mellifera	European/Italian bee	45–180 kg
Tetragonula (Melipona) iridipennis	Dammer / stingless bee	Small, but valued honey

Beekeeping isn't just about honey. It also yields beeswax, bee pollen, propolis, royal jelly and bee venom all valuable products in their own right and its pollination service raises crop yields directly. Recognising this, the Government of India launched the National Beekeeping and Honey Mission (NBHM) under the "Sweet Revolution" to promote scientific beekeeping and boost farmers' incomes.

Importance of Apiculture in Integrated Farming Systems

Bee pollination alone can lift seed and fruit yield by 15-50% across many crops' fruits and nuts like almond, apple, apricot, peach, strawberry, citrus and litchi; vegetables and vegetable-seed crops like cabbage, cauliflower, carrot, coriander, cucumber, melon, onion, pumpkin, radish and turnip; oilseeds like sunflower, niger, rapeseed, mustard, safflower and sesame; and forage crops like lucerne and clover.

India's scale of opportunity here is striking: around 50 million hectares of bee-dependent crops would ideally need 150 million bee colonies (at 3 colonies per hectare), yet the country currently has only about 1.2 million colonies in place leaving enormous room for beekeeping to expand purely as a pollination service. The recommended stocking rate is 3 colonies per hectare for Italian bees and 5 per hectare for Indian honey bees.

Case studies bring the numbers to life. Sunflower, a self-incompatible, cross-pollinated crop, can see yields rise by up to 600% with the help of three Apis mellifera colonies, along with a 6.5% jump in oil content. Cucurbit vegetables see fruit set increase 30–100%. Alfalfa needs bees to physically "trip" its keel petals and release pollen; without that mechanical trigger, seed set simply doesn't happen. Coriander yields rise by up to 187%, cardamom by 21-37% and sesame (gingelly) by around 25%. Apples are perhaps the clearest case of all: without bee-mediated pollination, seed set fails and fruit that does form around an incomplete seed set turns out lopsided and less marketable.

Lac cultivation

Lac is a scarlet resin secreted by scale insects, most notably *Kerria lacca* (also called Laccifer lacca), which feed on the sap of specific host trees. India is a major global producer of the processed resin, known as shellac. The insect itself is a minute crawling scale that inserts its proboscis into plant tissue, feeds and secretes resin from its body without harming the host tree's overall health, though the process is costly in insect terms: producing just 1 kg of lac resin requires around 300,000 insects.

Good lac cultivation depends on choosing the right site and host trees. Farmers need open areas with good air circulation (to avoid fungal problems and fire risk), well-drained, mildly acidic-to-alkaline soils and a sub-humid climate. Jharkhand and Chhattisgarh are classic lac belts. Popular host trees include palas (*Butea monosperma*), ber (*Ziziphus jujuba*), kusum (*Schleichera oleosa*), khair (*Acacia catechu*), arhar (*Cajanus cajan*), peepal (*Ficus religiosa*) and galwang (*Albizia lucida*). Two strains of lac insect are recognised: the Kusumi strain, which lives only on kusum trees and the Rangeeni strain, which thrives on all the other hosts.

New colonies are established through inoculation, transferring lac-insect brood from an infested tree to a healthy one. This involves spotting the swarming stage (marked by a yellow spot on the insect's body), cutting infested twigs into 15–20 cm brood bundles, tying them onto a new host just before the crawlers emerge, letting the young insects settle onto fresh twigs and removing the empty brood sticks two to three weeks later to prevent pest build-up.

The resin's uses are remarkably wide-ranging: varnishes and paints, toys, bangles and buttons, sealing agents for ships and containers, electrical insulation ornament polishing, mirror silvering, printing inks, wood finishing, food-grade glazing on fruits and sweets, pharmaceutical tablet coatings, leather finishing and shoe polish even nail polish and dyes trace back to the lac industry.

Pollinators

Entomophily pollen transfer by insects has shaped flowering plants for an estimated 60 to 100 million years and its economic footprint today is enormous. Of the roughly 95% of flowers that are cross-pollinated, more than 85% rely on insects to do it. Overall, more than 65% of flowering plants are insect-pollinated and about a third of the world's food supply depends directly or indirectly on insect pollination. In India alone, of the roughly 160 million hectares under cultivation, over 55 million hectares depend on bee pollination for better yield and productivity.

Insects don't all pollinate the same way and entomologists have named each relationship: bees practice melittophily, hawk moths sphingophily, small moths phalaenophily, hoverflies myophily, butterflies psychophily, beetles cantharophily, ants myrmecophily, wasps sphecophily and carrion flies saprophily even bats, snails and birds have their own terms (chiropterophily, malacophily and ornithophily respectively), a reminder of just how many species quietly move pollen around. The importance of honey bee pollination already discussed in the above section.

Other mutual pollinators

Fig wasp mutualism, Yucca moths (genus *Tegeticula*) form an obligate mutualistic relationship with yucca plants (*Yucca* spp.), where they serve as the exclusive pollinators (20-40%). The oil palm pollinating weevil (Elaedobius *kamerunicus*) aids in increasing oil palm bunch weight by 35% and oil content by 20%. Bumble bees and solitary bees play an important role in strawberry, apple and oilseeds, rape seeds. House fly in mango orchards; they contribute alongside blow flies, improving fruit quality without outperforming bees overall. Combinations with other insects often yield better results than house flies alone. Hover flies pollinate carrots, cotton and pulses, Bees on onion- 94%.

Scavengers

A scavenger is an animal that feeds on decaying organic matter and can be either carnivorous or herbivorous. Since insects help to remove dead and decomposing bodies from the earth surface, which would otherwise be a health hazard, they are referred to as scavengers. In addition, these insects help to convert those bodies into simpler substances before recycling them back to soil, where they become easily available as food for growing plants.

The following are the important groups of insects that serve as scavengers in nature:

Coleoptera: Rove beetles, Chafer beetles, Ptilinid beetles, Darkling beetles, Skin beetles, Nitidulids, Carrion beetles, Water scavenger beetles, Powder post beetles

Diptera: Sand flies or moth flies, Hover flies, Root maggot flies, Isoptera (white ants)

Hymenoptera (ants) also live and feed upon dead wood, dead animal or decaying vegetable matter.

Dung Beetles (Scarabaeidae): Bury and decompose animal manure, recycling, nutrients and improving soil aeration. In pastures, they increase grass yields by 10-15%.

Termites: Break down organic matter like wood and leaf litter, enriching soil with nitrogen and phosphorus in tropical agriculture.

Ants: Aerate soil through nest-building and redistribute nutrients, benefiting crops like coffee in agroforestry systems.

Importance of Scavengers in IFS

Efficient Waste Recycling, Nutrient Cycling, Soil Fertility Improvement, Reduction in External Inputs, Disease and Pest Reduction, Energy Flow Enhancement, Environmental Sustainability, Cost-effective Farming.

Biological control

Rather than reaching for a pesticide, an IFS leans on nature's own pest controllers predators, parasitoids, weed-killing insects and disease-causing microbes that target pests specifically.

Predators

Predators are free-living insects that spend their whole lives actively hunting and consuming large numbers of prey. Ladybird beetles are the textbook example; their larvae, active mainly between May and July, are voracious predators of aphids, mites and scale insects. Species like *Coccinella septempunctata* and *Cryptolaemus montrouzieri* target aphids, mealybugs and scale insects specifically. Green lacewings (Chrysoperla spp.) have larvae that feed on aphids, whiteflies and thrips; hoverfly larvae consume aphids in vegetable and fruit crops; predatory mites like *Phytoseiulus persimilis* control spider mites in horticulture; and anthocorid bugs (*Orius insidiosus*) feed on thrips, aphids and whiteflies.

Parasitoids

Parasitoids take a different approach: they lay eggs on or inside a host insect and the developing larvae consume the host from within, eventually killing it. Most insect parasitoids are wasps. Ichneumonid wasps mainly target butterfly and moth caterpillars; braconid wasps attack caterpillars and a wide range of other pests including aphids (green fly); and chalcid wasps parasitise the eggs and larvae of aphids, whiteflies, cabbage caterpillars and scale insects.

Weed Killers

Some insects control weeds rather than pests, feeding on unwanted plants and suppressing them biologically. Successful weed-controlling groups span several orders moths and their relatives (Phycitidae, Tortricidae), scale insects (Coccidae), true bugs (Coreidae, Tingidae), beetles (Cerambycidae, Chrysomelidae, Buprestidae, Curculionidae, Galerucidae) and flies (Agromyzidae, Trypetidae). Within an IFS, these insects help control weeds competing with crops, reduce dependence on herbicides and insecticides, improve farm biodiversity, lower cultivation costs and support long-term productivity.

Microbial bioagents

The final line of biological defence comes from microorganisms; bacteria, fungi, viruses and nematodes that infect and kill pests without harming humans, livestock or beneficial insects.

- **Bacteria:** *Bacillus thuringiensis* (Bt) produces Cry toxins that are highly effective against lepidopteran caterpillar pests such as borers and leaf-eaters and is widely used in field crops, vegetables and orchards. Bacillus sphaericus is commonly used in rice and rice-fish farming systems, since it doesn't harm fish or other aquatic life and also has a role in public-health pest management.
- **Fungi:** *Beauveria bassiana* is mass-produced against whiteflies, thrips, aphids and weevils; *Metarhizium anisopliae* produces toxic compounds called destruxins used against beetles, locusts and grasshoppers; and *Verticillium lecanii* controls aphids and whiteflies.
- **Viruses:** Highly host-specific pathogens such as HaNPV, SlNPV and RHCGV infect and kill particular pest species by replicating inside their bodies.
- **Nematodes:** Steinernema and Heterorhabditis species enter the insect body and release symbiotic bacteria that kill the host especially effective against soil-dwelling pests like grubs and borers.

Microbial bioagents offer a stack of advantages: they cut pesticide use and pollution, protect pollinators and natural predators, act with enough precision to spare non-target species, delay the development of pesticide resistance and in the case of organisms like *Bacillus subtilis* and *Trichoderma* spp. even promote plant growth and improve soil microbial health. Being compatible with broader Integrated Pest Management practices and relatively cheap to mass-produce, they've become a cornerstone of sustainable, cost-effective pest control.

The use of microbial bioagents in Integrated Farming Systems offers several ecological and economic advantages. They reduce the dependence on synthetic pesticides, minimise environmental pollution, protect pollinators and natural enemies and maintain biodiversity within the farming ecosystem. Their target-specific action protects non-target organisms and helps delay the development of pesticide resistance. In addition, many microbial bioagents improve soil microbial diversity, enhance nutrient cycling, promote plant growth and integrate effectively with Integrated Pest Management (IPM) programs. Their ease of mass production, cost-effectiveness and long-term sustainability make them indispensable components of modern ecological farming systems. Thus, biological control agents serve as essential pillars of sustainable pest management in Integrated Farming Systems, contributing significantly to agricultural productivity, environmental conservation and economic profitability.

The New Frontier: Black Soldier Fly and Mealworm Farming

If sericulture and apiculture are agriculture's old guard, the black soldier fly (*Hermetia illucens*) and the yellow mealworm (*Tenebrio molitor*) are its fast-rising newcomer insects being deliberately farmed not for silk or honey, but to solve two problems at once: mounting organic waste and a global shortage of affordable protein for animal feed.

Black Soldier Fly: The Waste-to-Protein Machine

The black soldier fly itself is harmless it doesn't bite, sting or spread disease and adults barely even eat. All the action happens at the larval stage. Black soldier fly larvae (BSFL) are voracious, unfussy eaters that will happily devour kitchen scraps, fruit and vegetable waste, spent brewer's grain, restaurant leftovers and even manure, converting it into body mass at remarkable speed.

A few numbers explain why farmers and start-ups everywhere are taking notice:

- **Protein powerhouse:** Dried BSF larvae typically run 40–60% crude protein, depending on their diet, alongside a healthy fat content that gives them an energy-dense feed profile comparable in places to fishmeal.
- **Fast turnaround:** A full life cycle from egg to harvestable larva takes just 15-18 days, dramatically faster than raising fish, poultry or livestock for protein.
- **Efficient conversion:** Larvae can process organic waste at roughly a 10:1 ratio, meaning a large volume of food scraps or agricultural residue collapses into a much smaller amount of larval biomass and residue.
- **Less landfill, less methane:** Diverting food waste to BSF larvae keeps it out of landfills, where it would otherwise rot and release methane one reason researchers describe BSF farming as a genuine circular-economy tool.
- **A useful by-product:** What the larvae don't turn into body mass comes out the other end as "frass" a nutrient-rich, chitin-containing organic fertiliser that also shows promise for suppressing soil pests and improving plant health.

Harvested larvae (usually processed into meal or oil) are increasingly used in poultry, fish and pet feed and some studies suggest they can improve feed-conversion efficiency in livestock while their natural antimicrobial compounds support animal immunity. Researchers are also exploring whether BSF larvae reared on high-quality food waste could one day be safe for human consumption, though that pathway needs separate, higher food-safety standards than feed-grade production and is still in early research stages.

For an IFS, the fit is obvious: a small BSF unit can sit beside a poultry shed or fish pond, absorb kitchen and crop waste from across the farm and feed straight back into the livestock or aquaculture component closing yet another loop in the system.

Mealworms

The mealworm actually the larval stage of the darkling beetle, Tenebrio molitor, is BSF's quieter cousin and in many ways a complementary one. Where BSF larvae are bred for speed and waste disposal, mealworms are prized for their consistency, storability and remarkably high protein content, which can reach up to 61% crude protein along with a balanced amino acid profile and beneficial fats.

Mealworms are typically reared on grain by-products like wheat bran, along with fruit or vegetable scraps for moisture, in simple stacked trays that need very little space, water or labour compared with conventional livestock. That makes them well suited to smallholder integration a farmer can run a mealworm unit in a spare shed and feed the output straight to backyard poultry, fish or even reptiles and pet birds. Farmed mealworms and their frass (often called "mealworm castings") are also gaining traction as a soil conditioner, much like BSF frass.

Compared with cattle or poultry, both BSF larvae and mealworms need only a fraction of the land, water and feed to produce a kilogram of protein and their farming produces far lower greenhouse gas emissions one of the reasons insect proteins is increasingly discussed as a climate-smart complement to conventional livestock, rather than a replacement for it (Table 2).

Table 2. Comparison of black soldier fly larvae and mealworms as alternative insect-based feed resources

Feature	Black Soldier Fly Larvae	Mealworms
Crude protein	≈40–60%	Up to ≈61%
Best known for	Rapid waste conversion	Consistency & easy storage
Typical diet	Food waste, manure, crop residue	Grain bran + fruit/veg scraps
Life cycle to harvest	≈15–18 days	Several weeks to a few months
Key farm output	Larvae/oil for feed + frass fertiliser	Larvae for feed + castings

Conclusion

Beneficial insects are indispensable components of Integrated Farming Systems. They contribute significantly to agricultural productivity, income diversification, ecological stability, nutrient recycling, pollination and biological pest regulation. Productive insects such as silkworms, honey bees and lac insects generate direct economic returns, while helpful insects such as pollinators, scavengers, predators, parasitoids and decomposers provide essential ecosystem services. Their effective integration into farming systems reduces dependence on chemical inputs, enhances biodiversity, promotes zero-waste agriculture and ensures long-term sustainability and profitability. Thus, conservation and scientific utilization of beneficial insects should be considered a fundamental pillar of sustainable agriculture and climate-resilient farming systems.