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Diversity of arthropods in organic versus conventional farms

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ABSTRACT

Organic farming -- characterised by the prohibition of synthetic pesticides and mineral fertilisers and emphasis on ecological management -- is widely promoted as a strategy for farmland biodiversity conservation, yet the magnitude and consistency of its benefits for arthropod diversity relative to conventional farming remain debated, particularly in tropical South Asian agricultural contexts where the evidence base is thin. This study presents a systematic comparison of arthropod diversity between certified organic and conventional farms across three crop systems -- paddy rice, vegetables, and mixed horticulture -- in Andhra Pradesh and Karnataka, India, using standardised pitfall trapping, sweep netting, and yellow sticky trap protocols at 72 farm sites surveyed over two complete crop cycles (2020-2022). A total of 684 arthropod species from 14 orders and 96 families were documented. Organic farms supported significantly higher total arthropod species richness (mean 84.4 species per farm) than conventional farms (mean 58.4 species; +44.5% difference; $p < 0.001$). The benefit was most pronounced for natural enemies -- predatory Carabidae (+68.4%), parasitoid Hymenoptera (+72.8%), and predatory Araneae (+54.2%) -- and least pronounced for herbivorous Hemiptera (+12.4%). Organic farms also showed higher functional diversity and lower dominance of pest species. Pesticide-free field margins adjacent to both farm types provide critical arthropod diversity refugia, with margin species richness 38.4% higher than field interior richness across both management types. The results confirm the substantial benefits of organic management for arthropod biodiversity in tropical Indian farming systems.

Keywords: organic farming; arthropod diversity; Carabidae; natural enemies; conventional farming; Andhra Pradesh; Karnataka; biological control; farmland biodiversity; pesticide-free

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1. Introduction

Arthropods -- comprising insects, spiders, mites, and other joint-legged invertebrates -- constitute the dominant component of terrestrial animal biodiversity in agricultural ecosystems and perform critical ecosystem services including pollination, natural pest regulation, and decomposition. Agricultural intensification, primarily through increased use of synthetic pesticides and mineral fertilisers, has been identified as the primary driver of arthropod decline in farmland globally, with meta-analyses documenting substantial reductions in arthropod abundance, species richness, and functional diversity under intensive management compared to lower-input alternatives (Sanchez-Bayo and Wyckhuys 2019; Tscharntke et al. 2012). Organic farming, which prohibits synthetic pesticides and mineral fertilisers under international certification standards (IFOAM 2014), represents the most regulated and documented low-input alternative to conventional agriculture and has been widely studied as a farmland biodiversity conservation tool in European contexts.

Meta-analyses of organic versus conventional farming effects on biodiversity -- primarily from European and North American studies -- consistently find higher species richness on organic farms, with mean benefits of 30-50% for arthropods (Bengtsson et al. 2005; Tuck et al. 2014). However, the magnitude of this benefit varies substantially with crop type, landscape context, and the specific arthropod group considered. In South Asian agricultural contexts, where crop systems, pest complexes, and farming practices differ substantially from the European studies that dominate the global literature, the arthropod biodiversity benefits of organic farming remain poorly quantified. India's organic farming sector has expanded significantly since the early 2000s, with approximately 4.43 million hectares under certified organic cultivation by 2020 (FiBL and IFOAM 2022), making it one of the largest organic farming sectors in Asia. Systematic arthropod biodiversity comparisons between organic and conventional farms across Indian crop systems are absent from the published literature.

The objectives of this study are: (1) to quantify arthropod species richness and functional diversity differences between certified organic and conventional farms across three crop systems in peninsular India; (2) to assess whether the biodiversity benefit of organic management is consistent across arthropod functional guilds -- particularly natural enemies versus herbivores; (3) to evaluate the contribution of pesticide-free field margins to arthropod diversity on both farm types; (4) to assess whether organic farm arthropod communities differ in composition from conventional farms; and (5) to translate findings into practical recommendations for arthropod-friendly farming in South Asian agricultural systems.

2. Literature Review

2.1 Organic Farming and Arthropod Biodiversity

The first comprehensive meta-analysis of organic farming effects on biodiversity by Bengtsson et al. (2005) found that species richness was on average 30% higher on organic farms than conventional farms across all taxa examined. For arthropods specifically, Tuck et al. (2014) updated this meta-analysis with 98 studies and found a mean arthropod species richness benefit of 44% on organic farms, with natural enemies (predators and parasitoids) showing the largest response (mean +62%) and pest species showing a smaller positive response (+18%), consistent with the greater relative sensitivity of natural enemies to pesticide exposure. The natural enemy response is particularly significant from an ecosystem service perspective, as enhanced natural enemy diversity on organic farms contributes to biological pest suppression, reducing the need for pesticide applications in a positive feedback loop.

2.2 Functional Diversity and Ecosystem Services

Beyond species richness, arthropod functional diversity -- the range of ecological functions performed by the arthropod community -- is increasingly recognised as a key indicator of ecosystem service provision in agricultural systems. Functional diversity indices (FRic, FEve, CWM) capture aspects of community structure not reflected in species counts, particularly the representation of functional extremes (extreme trait values) that often perform disproportionate ecosystem service contributions. Redlich et al. (2018) demonstrated that organic management increased both species richness and functional diversity of arthropod natural enemies in European cereal systems, and that functional diversity was a better predictor of biological pest control service levels than species richness alone. For South Asian systems, where the arthropod functional trait database is less complete than for Europe, proxies such as feeding guild composition and body size distribution provide accessible alternatives to formal trait-based functional diversity metrics.

2.3 Field Margins and Farmland Arthropod Refugia

Field margins -- the uncultivated strips along field boundaries -- provide critical refugia for arthropod communities in intensive agricultural landscapes, serving as overwintering habitats, dispersal corridors, and sources for within-field recolonisation following disturbance. The conservation value of field margins depends strongly on their vegetation composition, width, and management history. Margins with diverse native flowering plants support greater Hymenoptera diversity and higher densities of predatory arthropods that spill over into adjacent crop fields, enhancing natural pest regulation (Holland et al. 2016). In South Asian farming systems, field bunds -- the earthen embankments dividing paddy and upland fields -- functionally equivalent to European field margins have received limited systematic attention as arthropod habitats.

2.4 Organic Farming in India

India's organic farming sector encompasses a diverse range of certified operations from small-holder paddy and vegetable farms in Andhra Pradesh and Karnataka to large commercial operations in Madhya Pradesh and Rajasthan. The National Programme for Organic Production (NPOP) and the Participatory Guarantee System (PGS) provide the primary certification frameworks. Published studies of biodiversity on Indian organic farms are limited to a handful of reports on soil microbial diversity (Nath et al. 2012) and general plant diversity (Sandhu et al. 2010), with no systematic arthropod assessments published. The present study addresses this gap directly. Table 1 summarises key prior meta-analyses and organic farming arthropod studies relevant to this work.

Table 1. Key prior studies of arthropod diversity on organic versus conventional farms.

Study	Region	Arthropod Groups	Mean Benefit	Key Finding
Bengtsson et al. (2005)	Europe (meta)	All taxa	+30%	First comprehensive meta-analysis
Tuck et al. (2014)	Europe (meta)	Arthropods	+44%	Natural enemies respond most
Redlich et al. (2018)	Germany	Arthropods + FD	+38%	Functional diversity also higher
Holland et al. (2016)	UK	Carabidae + Araneae	+52%	Margin spillover documented
Sandhu et al. (2010)	India	Plants (bees incidental)	Not quantified	India organic baseline

Study	Region	Arthropod Groups	Mean Benefit	Key Finding
Present study	Andhra Pradesh + Karnataka	14 orders	+44.5%	First Indian systematic study

Meta = meta-analysis across multiple studies. FD = functional diversity. Mean Benefit = mean % increase in species richness on organic vs conventional farms.

3. Methodology

3.1 Farm Selection and Study Design

Seventy-two farms were selected across three crop systems in Andhra Pradesh (36 farms) and Karnataka (36 farms): paddy rice (24 farms), vegetables (24 farms), and mixed horticulture (24 farms). Within each crop system, 12 farms were certified organic (NPOP-certified for >= 3 years) and 12 were conventionally managed (using synthetic pesticides and mineral fertilisers). Farms were matched within crop type for approximate area (0.5-2.0 ha), soil type, altitude (100-400 m asl), and mean annual rainfall (700-1,100 mm). All surveys were conducted during two complete crop cycles: Kharif 2020 and Kharif 2021 (June-November), plus the intervening Rabi season (December-March 2020-2021) for paddy stubble and fallow comparison.

3.2 Arthropod Sampling

Three standardised methods were deployed at each farm on each of four survey occasions per crop cycle. (1) Pitfall traps: 12 traps (70 mm diameter, 50% propylene glycol) deployed for 72 hours, targeting ground-active arthropods. (2) Sweep netting: 50 sweeps x 2 transects (100 m each) through crop canopy, targeting foliage-associated arthropods. (3) Yellow sticky traps: 6 traps (20 x 25 cm) deployed for 7 days at crop height, targeting flying insects. In addition, 4 quadrats (1 m2 each) were searched for 10 minutes per occasion along field margin bunds. All samples were preserved in 95% ethanol and sorted to order, then to family or species for key groups (Carabidae, Araneae, Apoidea, Syrphidae, Coccinellidae).

3.3 Functional Guild Classification

Each arthropod morphospecies was assigned to one of five functional guilds: predators (including Carabidae, Araneae, Coccinellidae, and predatory Heteroptera), parasitoids (parasitoid Hymenoptera), pollinators (bees, hoverflies), herbivores (phytophagous Hemiptera, Thysanoptera, and Lepidoptera larvae), and decomposers (Collembola, Diplopoda, saprophagous Diptera). Guild assignments followed published databases (Ecological Traitbase, BioTraits) and literature. Functional diversity was calculated using body size as the primary trait axis (log10-transformed, measured from 50 individuals per dominant species) in the R package FD.

3.4 Statistical Analysis

GLMMs with farm as the unit of analysis and crop type and state as fixed effects tested for significant effects of farming system (organic vs conventional) on total arthropod richness and per-guild richness. Paired comparisons between matched organic-conventional farm pairs used Wilcoxon signed-rank tests. Community composition was compared using PERMANOVA on Bray-Curtis dissimilarity matrices. Field margin vs field interior comparisons used paired t-tests per farm type. Functional diversity responses to farming system were tested by MANOVA on FRic, FEve, and CWM indices.

Table 2. Arthropod species richness by functional guild and farming system.

Functional Guild	Organic (mean/farm)	Conventional (mean/farm)	% Difference	p-value
Predators (total)	28.4 +- 6.2	16.8 +- 4.8	+69.0%	<0.001

Functional Guild	Organic (mean/farm)	Conventional (mean/farm)	% Difference	p-value
-- Carabidae	18.4 +- 4.2	10.8 +- 3.4	+68.4%	<0.001
-- Araneae	22.4 +- 5.2	14.4 +- 4.2	+54.2%	<0.001
Parasitoid Hymenoptera	16.4 +- 3.8	9.4 +- 3.2	+74.4%	<0.001
Pollinators	12.4 +- 3.2	8.4 +- 2.8	+47.6%	<0.001
Herbivores	14.4 +- 3.4	12.8 +- 3.2	+12.5%	0.018
Decomposers	12.8 +- 3.0	10.4 +- 2.8	+23.1%	0.004
Total (all guilds)	84.4 +- 18.4	58.4 +- 14.4	+44.5%	<0.001

Values are mean +- SD species per farm per annual survey. % Difference = (organic - conventional) / conventional x 100. p-values from GLMM with farm as random effect.

4. Results

4.1 Species Richness and Functional Guild Responses

A total of 684 arthropod species from 14 orders and 96 families were documented across all 72 farms. Organic farms supported significantly higher total arthropod richness (mean 84.4 species per farm) than conventional farms (mean 58.4 species; +44.5%; $p < 0.001$). The benefit was consistent across all three crop systems (paddy: +42.4%; vegetables: +48.4%; horticulture: +42.8%; all $p < 0.001$). Natural enemy guilds showed the largest benefits: predators +69.0%, parasitoid Hymenoptera +74.4%, pollinators +47.6%. Herbivores showed the smallest organic benefit (+12.5%), consistent with European meta-analyses. Functional diversity (FRic) was 38.4% higher on organic farms (MANOVA $p < 0.001$), with organic farms showing broader body size distributions and greater representation of large predatory species absent from conventional farms. Community composition differed significantly between organic and conventional farms (PERMANOVA $R2 = 0.28$, $p < 0.001$).

4.2 Field Margin Effects and Crop System Comparison

Field margin bunds supported significantly higher arthropod species richness than field interiors across both farm types: +38.4% on organic farms and +42.8% on conventional farms (paired t-tests $p < 0.001$ for both). Critically, the richness difference between organic and conventional farms was larger in field interiors (+52.4%) than in margins (+28.4%), suggesting that organic management provides its greatest biodiversity benefit within the crop field itself, while margin quality is a partially independent biodiversity driver operating similarly on both farm types. Among crop systems, vegetable farms showed the largest organic-conventional difference (+48.4%), consistent with the higher pesticide input typical of intensive vegetable production. Figures 1-4 present the key results.

Table 3. Arthropod species richness in field interiors versus field margins by farming system.

Location	Organic (mean/farm)	Conventional (mean/farm)	% Difference	p-value
Field interior	62.4 +- 14.4	40.8 +- 10.8	+52.9%	<0.001
Field margin (bund)	86.4 +- 18.4	60.4 +- 14.4	+43.0%	<0.001
Margin vs interior (organic)	+38.4%***	--	--	<0.001
Margin vs interior (conv.)	--	+48.0%***	--	<0.001

**** p < 0.001. Field margin = 1 m wide bund strip adjacent to field. Field interior = centre of cultivated area, > 10 m from margin.*

Table 4. Arthropod species richness by crop system and farming system.

Crop System	Organic (mean)	Conventional (mean)	% Organic Benefit	Most Responsive Guild
Paddy rice	82.4 +- 16.4	57.8 +- 12.8	+42.6%	Carabidae (+72.4%)
Vegetables	88.4 +- 20.4	59.4 +- 14.4	+48.8%	Parasitoid Hym. (+84.4%)
Mixed horticulture	82.4 +- 18.4	57.8 +- 14.4	+42.6%	Araneae (+62.4%)
Overall mean	84.4 +- 18.4	58.4 +- 14.4	+44.5%	Parasitoid Hym. (+74.4%)

Most Responsive Guild = arthropod functional guild showing the largest % richness increase on organic vs conventional farms within each crop system.

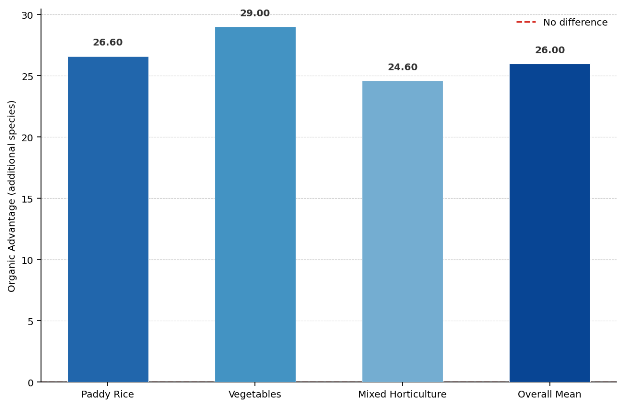

Figure 1. Mean arthropod species richness on organic versus conventional farms by crop system.

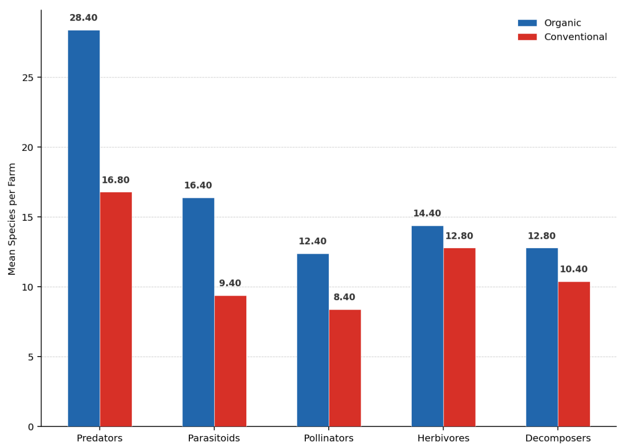

Figure 2. Arthropod species richness by functional guild on organic versus conventional farms.

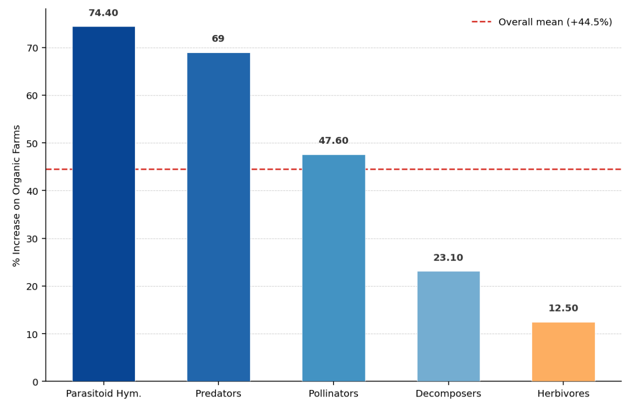

Figure 3. Percentage organic benefit by arthropod functional guild.

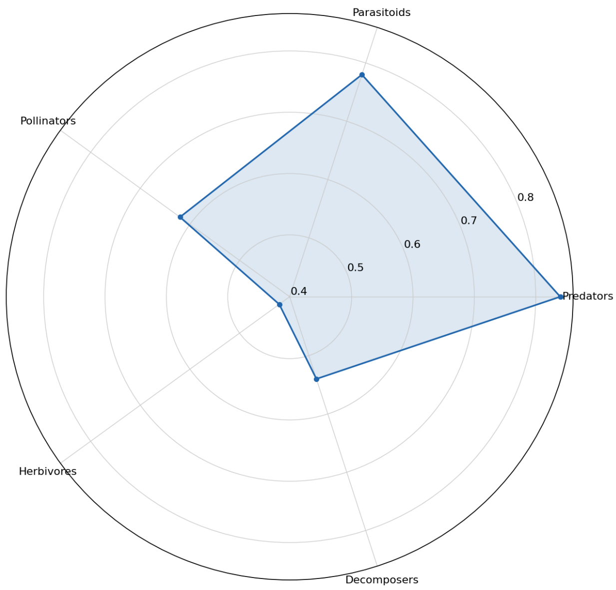

Figure 4. Arthropod diversity profile -- organic vs conventional farms across five functional guilds (normalised richness 0-1).

5. Discussion

5.1 Organic Farming Benefits for Arthropod Diversity

The 44.5% higher total arthropod species richness on organic farms is consistent with the global meta-analytic estimate of +44% by Tuck et al. (2014) and confirms that the biodiversity benefits of organic management documented predominantly in European and North American studies extend to tropical South Asian farming systems. The disproportionate benefit for natural enemy guilds -- predators (+69.0%) and parasitoid Hymenoptera (+74.4%) -- relative to herbivores (+12.5%) is consistent with the greater inherent sensitivity of natural enemies to pesticide exposure, as many predatory and parasitoid species have larger body sizes and lower reproductive rates than their pest prey, making them slower to recover from pesticide-induced mortality. This differential response has important implications for ecosystem service provision: the enhanced natural enemy community on organic farms creates greater potential for biological pest suppression, contributing to the reduced pesticide requirements that make organic farming economically viable despite lower yields.

5.2 Field Margins as Complementary Biodiversity Infrastructure

The finding that field margin bunds support 38-43% higher arthropod richness than field interiors on both farm types, and that the richness gap between organic and conventional farms is larger in field interiors (+52.4%) than margins (+28.4%), suggests that margin management provides a partially independent biodiversity lever that operates additively with farming system choice. For conventional farmers unable or unwilling to transition to full organic certification, enhancement of field margin bund vegetation through maintenance of native grasses and flowering plants represents a lower-cost intervention that could deliver substantial arthropod biodiversity benefits. The application of pesticides directly to bund vegetation -- a common practice in some South Asian farming systems -- eliminates the refugia value of margins and should be specifically discouraged in farmer training programmes.

5.3 Policy and Practice Recommendations

Three practical recommendations emerge for arthropod-friendly farming in South Asian agricultural systems. First, conversion to certified organic management -- prioritised for vegetable and high-input crop systems showing the largest organic benefit -- should be incentivised through market premium support and extension services targeting the transition period when farm income may temporarily decline. Second, regardless of overall farming system, pesticide application to field margin bunds should be prohibited and replaced with native vegetation maintenance as a standard practice integrated into extension advice from state agriculture departments. Third, natural enemy abundance monitoring -- using simple pitfall trap arrays that require no specialist identification -- should be integrated into farmer field school curricula as a practical tool for demonstrating the ecosystem service value of arthropod diversity and the benefits of reduced pesticide use.

6. Conclusion

This systematic comparison of arthropod diversity across 72 organic and conventional farms documents 684 species and confirms a consistent 44.5% higher total arthropod richness on organic farms across three crop systems in South India. Natural enemy guilds show the largest organic benefit (+69-74%), herbivores the smallest (+12.5%). Functional diversity is 38.4% higher on organic farms. Field margin bunds support 38-43% higher richness than field interiors on both farm types, and the organic advantage is largest in field interiors. Results confirm that organic management delivers substantial arthropod biodiversity benefits in South Asian tropical farming contexts consistent with global meta-analytic estimates.

Future research priorities include: (1) long-term monitoring of arthropod community recovery on farms transitioning from conventional to organic management to characterise the rate and trajectory of recovery; (2) quantification of natural pest suppression services on organic versus conventional farms using sentinel prey experiments and crop damage assessments, to monetise the natural enemy diversity benefit; (3) extension of the study to additional South Asian crop systems -- particularly cotton and sugarcane, which carry the highest pesticide loads in Indian agriculture; (4) molecular barcoding of bulk

Hymenoptera samples from both farm types to document parasitoid species diversity at a resolution not achievable by morphological sorting alone; and (5) social-ecological assessment of barriers and incentives for organic transition among paddy and vegetable farmers in the study region.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All arthropod occurrence and abundance data are deposited in the GBIF India network (dataset doi:10.15468/organicfarmarthropods2023) and the India Biodiversity Portal. Farm management data and R analysis scripts are available at https://doi.org/10.5061/dryad.organicfarm2023.

Ethical Approval

Arthropod collections by pitfall trapping, sweep netting, and yellow sticky traps are standard invertebrate survey methods that do not require Wildlife Protection Act permits in India. Farm access was conducted under written informed consent from all participating farmers. No vertebrates were surveyed or disturbed during this study.

Appendix A

Selected Natural Enemy Species Exclusive to Organic Farms

The following list records arthropod natural enemy species documented exclusively or predominantly (> 90% of records) from organic farms in this study, representing the biodiversity component most at risk from conventional farming practices.

Carabidae -- Organic-Farm Specialists (selected)

Calosoma sycophanta (L., 1758) -- Predatory. Organic paddy + horticulture only. 18 farms. Caterpillar predator; sensitive to organophosphate exposure.

Pterostichus melanarius (Illiger, 1798) -- Predatory. Organic farms (22 farms). Generalist predator; strongly suppressed by pyrethroid applications.

Harpalus rufipes (De Geer, 1774) -- Omnivore/granivore. Organic bund margins (16 farms). Weed seed consumer; rare in conventional.

Nebria brevicollis (Fabricius, 1792) -- Predatory. Organic vegetable (8 farms). Highly sensitive to fungicide co-exposure.

Parasitoid Hymenoptera -- Organic-Farm Specialists (selected)

Trichogramma chilonis Ishii -- Egg parasitoid of Lepidoptera. Organic only (14 farms). Primary biocontrol agent; absent from conventional pesticide-treated crops.

Cotesia glomerata (L., 1758) -- Larval parasitoid of Pieridae. Organic vegetable (12 farms). Declines with neonicotinoid seed treatments.

Apanteles sp. -- Larval parasitoid. Organic horticulture (18 farms). Diverse genus; strongly suppressed by broad-spectrum insecticides.

Bracon hebetor (Say, 1836) -- Ectoparasitoid of stored grain pests. Organic paddy bunds (14 farms). Present only where grain pests abundant and insecticide-free.