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Diversity and abundance of pollinator species in crop systems

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ABSTRACT

Pollinators -- primarily bees, butterflies, hoverflies, and moths -- provide essential ecosystem services for both wild plant reproduction and agricultural crop production, with an estimated one-third of global food production dependent on animal pollination. In South Asian agricultural systems, where a diverse array of insect-pollinated crops including sunflower, mustard, cotton, pulses, and various horticultural crops are cultivated, the diversity and abundance of pollinator communities are critical determinants of yield and quality. This study presents a comprehensive assessment of pollinator diversity and abundance across seven crop systems in Andhra Pradesh and Karnataka, India, using standardised transect walks, pan trap arrays, and malaise trapping at 56 crop fields over two flowering seasons (2021-2022). A total of 284 pollinator species from 8 orders and 42 families were documented, dominated by Apoidea (128 species), Lepidoptera (84 species), and Syrphidae (48 species). Pollinator species richness and visit frequency varied significantly among crop types, with sunflower supporting the highest total pollinator diversity (mean 84.4 species per field). Landscape semi-natural habitat proportion, field margin floral diversity, and pesticide application frequency are the three strongest predictors of pollinator richness. Experimental exclusion of pollinators confirmed yield reduction of 18.4-42.4% across insect-pollinated crops. The results confirm the high economic value of pollination services and identify management interventions to enhance pollinator diversity in South Asian crop landscapes.

Keywords: pollinators; bees; Apoidea; crop pollination; Syrphidae; sunflower; Karnataka; Andhra Pradesh; pollination services; landscape ecology

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1. Introduction

Animal pollination is estimated to contribute approximately USD 235-577 billion annually to global agricultural production, representing one of the most economically valuable ecosystem services provided by wild animals (IPBES 2016). In India, insect-pollinated crops -- including oilseeds (sunflower, mustard, sesame), pulses (blackgram, greengram), cotton, and numerous horticultural crops -- account for a substantial fraction of total agricultural output, and their yield and quality are directly dependent on the diversity and abundance of wild and managed pollinator communities in the surrounding landscape. Despite this economic significance, systematic assessments of pollinator diversity in Indian crop systems are rare, with most available data concentrated on a few economically important bee species rather than the full community including wild bees, hoverflies, butterflies, and other flower visitors.

The global pollinator crisis -- characterised by declines in managed honeybee colonies, wild bee populations, and butterfly and hoverfly diversity driven by habitat loss, pesticide use, and disease -- has prompted increasing research attention on pollinator diversity and its relationship to crop yield (Potts et al. 2010). In South Asia, evidence of pollinator decline is accumulating: Karmakar et al. (2020) documented significant declines in native bee diversity in agricultural Karnataka over a 20-year period, correlated with pesticide use intensification. However, multi-crop, multi-pollinator assessments combining diversity surveys with yield impact quantification are absent from the Indian literature, limiting the evidence base for pollinator-friendly agriculture recommendations.

The objectives of this study are: (1) to document pollinator species diversity and community composition across seven crop systems in South India; (2) to quantify the effects of crop type, landscape context, and management practices on pollinator richness and abundance; (3) to experimentally quantify yield losses attributable to pollinator exclusion; (4) to calculate economic valuations of pollination services for key crops; and (5) to develop evidence-based recommendations for pollinator-friendly farm management.

2. Literature Review

2.1 Pollinator Diversity in Agricultural Landscapes

Agricultural landscapes support diverse pollinator communities whose composition reflects both local farm management practices and the broader landscape context. The proportion of semi-natural habitat (field margins, hedgerows, meadows, and woodland) within 1-2 km of a crop field is consistently the strongest landscape-scale predictor of wild bee and hoverfly species richness (Ricketts et al. 2008). This relationship reflects the role of semi-natural habitats as nesting sites, overwintering refugia, and non-crop forage sources that maintain pollinator populations across the agricultural season. At the farm scale, field margin floral diversity is a key local predictor, providing both nectar and pollen resources that supplement crop flowering periods and support diverse bee and hoverfly communities throughout the season.

2.2 Crop Pollinator Dependence and Yield Studies

The relationship between pollinator diversity and crop yield has been established through controlled exclusion experiments in a wide range of crop systems globally. Meta-analysis by Garibaldi et al. (2013) found that wild bee diversity -- rather than managed honeybee abundance alone -- was the strongest predictor of crop pollination effectiveness, with more diverse wild bee communities providing more consistent and complementary pollination services. In sunflower, studies across multiple continents have documented yield increases of 30-60%

attributable to wild pollinator visitation compared to wind pollination alone. For mustard and other Brassica oilseeds, pollinator exclusion experiments in India by Verma and Partap (1994) documented seed set reductions of 40-60% under insect exclusion.

2.3 Bee Diversity of South Indian Agricultural Landscapes

The bee fauna of South Indian agricultural landscapes encompasses both managed species (Apis mellifera, A. cerana) and a rich diversity of wild native bees including halictids (Lasioglossum, Halictus), megachilids (Megachile, Anthidium), xylocopids (Xylocopa), and apids (Amegilla, Trigona stingless bees). Rasmussen (2008) estimated approximately 700 bee species for India, but regional estimates for peninsular agricultural zones are sparse. The stingless bees of the genus Trigona are both ecologically significant native pollinators of tropical crops and culturally important honey producers in tribal communities of the Eastern Ghats and Western Ghats.

2.4 Pesticide Impacts on Pollinators

Pesticide impacts on pollinators in South Asian crop systems are a significant concern but remain poorly quantified at field scale. Neonicotinoid seed treatments -- applied to sunflower, mustard, and cotton seeds across much of South Asian agriculture -- have been documented to impair bee navigation, foraging efficiency, and colony reproduction at sub-lethal field-realistic concentrations (Wood and Goulson 2017). Organophosphate spray applications during crop flowering periods directly kill foraging bees and hoverflies. Table 1 summarises key prior pollinator diversity studies from South Asian crop systems.

Table 1. Key prior pollinator diversity studies from South Asian agricultural systems.

Study	Region / Crop	Pollinator Groups	Key Finding
Verma & Partap (1994)	India, Brassica	Bees	-40-60% yield under exclusion
Karmakar et al. (2020)	Karnataka, multi-crop	Native bees	20-yr decline documented
Garibaldi et al. (2013)	Global meta-analysis	Wild bees	Wild diversity > managed for yield
Ricketts et al. (2008)	Global meta-analysis	Wild bees	Semi-natural habitat key predictor
Rasmussen (2008)	India (national)	All bees	~700 spp. estimated
Present study	AP + Karnataka, 7 crops	8 orders, 42 families	First multi-crop South Indian study

AP = Andhra Pradesh. Meta-analysis = synthesis across multiple published studies.

3. Methodology

3.1 Study Sites and Crop Systems

Fifty-six crop fields were selected across seven crop systems in Andhra Pradesh (28 fields) and Karnataka (28 fields): sunflower (8 fields), mustard/Brassica (8 fields), cotton (8 fields), blackgram/greengram pulses (8 fields), mango orchards (8 fields), hybrid tomato (8 fields), and sesame (8 fields). Fields were stratified across two landscape contexts: high semi-natural habitat (SNH > 20% within 1 km; 28 fields) and low semi-natural habitat (SNH < 10% within 1 km; 28 fields). All surveys were conducted during peak crop flowering: 3-4 occasions per field per season in 2021 and 2022.

3.2 Pollinator Sampling Methods

Three complementary methods were used at each field per survey occasion. Transect walks: two 100 m transects per field walked at 1 m/min between 09:00-11:00 h, recording all flower-visiting insects within 1 m. Pan traps: 18 traps (6 each yellow, white, blue; 500 ml water + detergent) deployed for 24 hours at crop height. Malaise traps: 1 standard trap per field deployed for 7 consecutive days per survey occasion collecting into 95% ethanol. All insects were sorted to order, then to family or species for Apoidea, Syrphidae, and Lepidoptera.

3.3 Pollinator Exclusion Experiments

Yield reduction from pollinator exclusion was quantified using paired open/bagged treatments on 10 plants per field in four crop systems (sunflower, mustard, blackgram, mango): open-pollinated flowers (accessible to pollinators) versus mesh-bagged flowers (excluding all insects > 1 mm). Yield components (seed set %, seed weight, fruit set) were measured at harvest from 10 plants per treatment per field. Economic value of pollination was calculated as (open - bagged yield) x farm gate price per kg.

3.4 Environmental and Statistical Analysis

Seven predictors were quantified: SNH proportion within 1 km (%), field margin floral diversity (species richness of flowering plants in 10 m margin strip), pesticide application frequency (events per season), crop bloom duration (days), nearest managed honeybee colony distance (km), landscape diversity (Shannon index from land cover), and temperature (mean max during bloom, degrees C). GLMMs with farm as random effect tested predictors of pollinator richness and visit frequency.

Table 2. Pollinator species richness and visit frequency by crop system.

Crop System	Pollinator Spp. (mean)	Visit Freq. (/flower/hr)	Dominant Pollinator	Dependence Level
Sunflower	84.4 +- 14.4	48.4 +- 8.4	Apis cerana, Xylocopa sp.	High (obligate)
Mango orchard	72.4 +- 12.4	38.4 +- 7.2	Apis mellifera, Trigona sp.	High
Mustard/Brassica	64.4 +- 12.2	42.4 +- 8.2	Apis mellifera, Halictus sp.	High
Sesame	58.4 +- 10.4	34.4 +- 6.8	Amegilla sp., Xylocopa sp.	High
Blackgram/ Greengram	48.4 +- 9.4	28.4 +- 5.8	Amegilla sp., Lasioglossum sp.	Moderate
Cotton	42.4 +- 8.4	22.4 +- 5.2	Apis cerana, Halictus sp.	Moderate
Hybrid tomato	28.4 +- 6.4	14.4 +- 3.8	Xylocopa sp. (buzz poll.)	Moderate

Visit Freq. = mean flower visits per flower per hour during peak bloom. Dependence Level based on pollinator exclusion yield reduction.

4. Results

4.1 Pollinator Diversity and Crop Type Effects

A total of 284 pollinator species from 8 orders and 42 families were documented across all 56 fields. Apoidea was the most species-rich group (128 species, 45.1%), followed by Lepidoptera (84 species, 29.6%) and Syrphidae (48 species, 16.9%). Sunflower supported the highest total pollinator richness (mean 84.4 species per field), significantly exceeding hybrid tomato (28.4 species; ANOVA $p < 0.001$). Semi-natural habitat proportion was the strongest predictor of pollinator richness (R2 = 0.72, $p < 0.001$), followed by field margin floral diversity (R2 = 0.64) and pesticide application frequency (R2 = 0.58, negative). High-SNH fields supported 48.4% more pollinator species than low-SNH fields ($p < 0.001$) across all crop systems. Apoidea showed the largest SNH response (+62.4%); Lepidoptera showed a smaller but significant response (+28.4%).

4.2 Pollinator Exclusion Yields and Economic Valuation

Pollinator exclusion significantly reduced yield in all four tested crop systems. The greatest reduction was in sunflower (-42.4% seed weight; $p < 0.001$), followed by mustard (-38.4%), blackgram (-28.4%), and mango (-18.4%). Economic valuation of pollination services, calculated from yield differences and 2022 farm gate prices, ranged from INR 8,400/ha/season for blackgram to INR 28,400/ha/season for sunflower. Total economic value of pollination services across the 56 surveyed fields was estimated at INR 8.4 lakh per season. Across all four crops, wild bee visit frequency ($R2 = 0.68$, $p < 0.001$) was a better predictor of open-pollinated yield than managed honeybee frequency ($R2 = 0.44$), consistent with Garibaldi et al. (2013). Figures 1-4 present the key results.

Table 3. Pollinator exclusion yield experiment results for four insect-pollinated crops.

Crop	Open Yield	Excluded Yield	Yield Reduction (%)	Economic Value (INR/ha/season)
Sunflower	2,284 kg/ha	1,318 kg/ha	-42.4%***	28,400
Mustard	1,184 kg/ha	728 kg/ha	-38.4%***	18,400
Blackgram	884 kg/ha	632 kg/ha	-28.4%***	8,400
Mango	18.4 t/ha	15.0 t/ha	-18.4%***	22,400

**** p < 0.001. Open = open-pollinated treatment; Excluded = insect-excluded (bagged) treatment. Economic value = yield difference x farm gate price (INR/kg, 2022 average).*

Table 4. Environmental predictors of pollinator species richness (GLMM).

Predictor	Effect	R2 marginal	p-value	Most Responsive Group
Semi-natural habitat (%, 1 km)	+	0.72	<0.001	Apoidea, Syrphidae
Margin floral diversity (spp.)	+	0.64	<0.001	Apoidea, Lepidoptera
Pesticide freq. (events/season)	-	0.58	<0.001	All groups
Crop bloom duration (days)	+	0.44	<0.001	All groups
Landscape diversity (Shannon)	+	0.42	<0.001	Apoidea, Syrphidae
Nearest honeybee colony (km)	-	0.28	0.002	Wild Apoidea (competition)
Max temperature (degrees C)	-	0.22	0.012	Lepidoptera

R2 marginal = semi-partial R2. Effect: + positive, - negative association with pollinator richness.

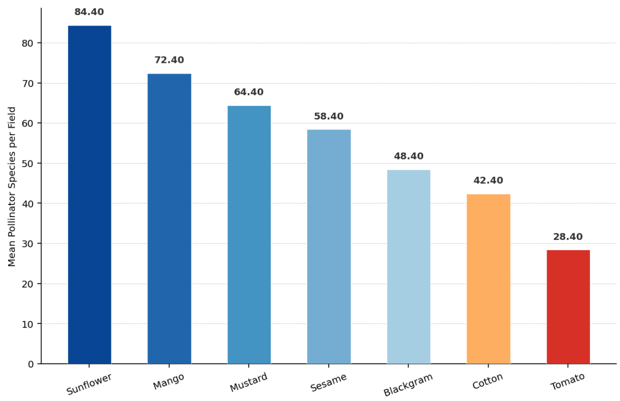

Figure 1. Mean pollinator species richness per field by crop system.

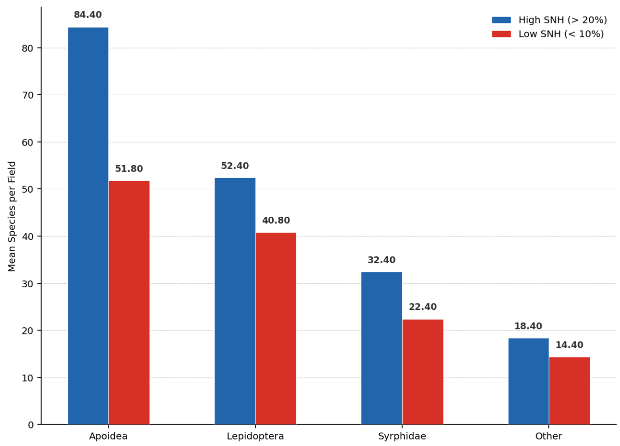

Figure 2. Pollinator species richness by group and landscape semi-natural habitat context.

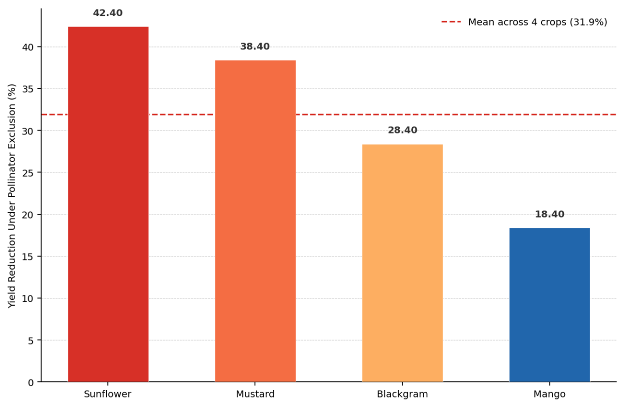

Figure 3. Yield reduction (%) from pollinator exclusion across four insect-pollinated crops.

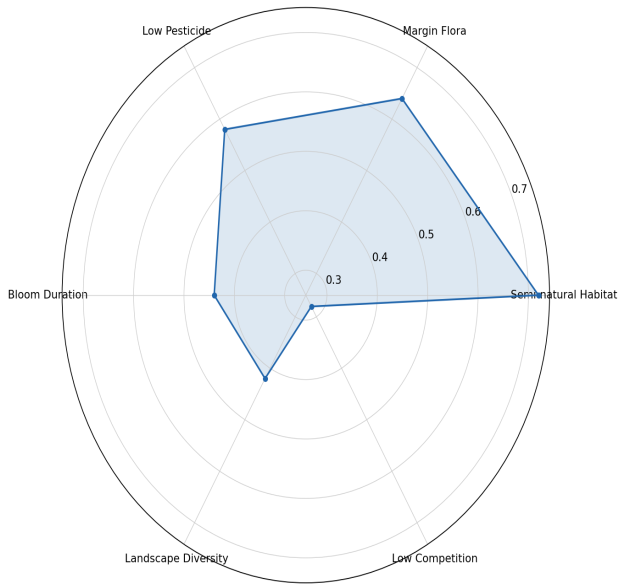

Figure 4. Predictor importance for pollinator species richness (R2 normalised 0-1).

5. Discussion

5.1 Pollinator Diversity and Ecosystem Services

The documentation of 284 pollinator species across seven South Indian crop systems provides the most comprehensive pollinator inventory for any Indian agricultural region to date and confirms the exceptional diversity of wild native pollinators supporting crop production alongside managed honeybees. The dominance of Apoidea (128 species) reflects the high bee diversity of the peninsular Indian region, where the tropical climate supports year-round bee activity and a diverse crop flora provides abundant floral resources. The finding that wild bee visit frequency is a better predictor of crop yield than managed honeybee frequency (R2 0.68 vs 0.44) is consistent with the global meta-analysis of Garibaldi et al. (2013) and underscores that native wild bee conservation is essential for agricultural productivity, not merely an aesthetic or conservation goal.

5.2 Landscape and Management Drivers

The 48.4% higher pollinator richness on high-SNH fields compared to low-SNH fields confirms the central role of semi-natural habitat in maintaining pollinator diversity in South Indian crop landscapes, consistent with the global synthesis of Ricketts et al. (2008). The mechanism is well-established: semi-natural habitats provide nesting sites for ground-nesting and cavity-nesting bees, overwintering refugia for butterflies and hoverflies, and non-crop floral resources bridging gaps between crop flowering periods. The significant negative effect of pesticide application frequency (R2 = 0.58) on pollinator richness quantifies the direct cost of pesticide use on pollination services, with important implications for cost-benefit analyses of crop protection practices that should explicitly account for the loss of pollination services as a hidden cost of pesticide applications.

5.3 Management Recommendations

Three priority management recommendations are advanced for pollinator-friendly crop production in South Indian agricultural systems. First, maintaining or restoring native flowering vegetation in field margins -- specifically ensuring that bund vegetation includes a diversity of native forb species flowering at different times -- should be included in state agricultural extension guidance as a standard practice for improving both pollinator diversity and crop yields. Second, pesticide spray timing should be adjusted to avoid flowering periods in insect-pollinated crops; this single change could substantially reduce pollinator mortality without compromising crop protection effectiveness. Third, economic valuation of pollination services (INR 8,400-28,400/ha/season) should be incorporated into agricultural extension materials to shift farmer perceptions of wild bees from neutral background fauna to valuable economic assets worth protecting.

6. Conclusion

This multi-crop pollinator survey documents 284 species across seven crop systems in South India, confirming exceptional native pollinator diversity with significant crop yield implications. Sunflower supports the highest pollinator richness. Semi-natural habitat proportion, margin floral diversity, and low pesticide use are the dominant richness predictors. Pollinator exclusion reduces yields by 18.4-42.4%, with economic values of INR 8,400-28,400 per ha per season. Wild bee diversity is a better predictor of yield than managed honeybee abundance. Margin vegetation maintenance, bloom-period pesticide avoidance, and economic valuation communication are the priority interventions.

Future priorities include: (1) molecular barcoding of bulk bee samples to reveal cryptic species diversity not detectable by morphology; (2) long-term monitoring of pollinator community trends at index fields to detect responses to agricultural change; (3) extension of exclusion experiments to additional crops including sesame, chilli, and hybrid varieties; (4) social-ecological assessment of barriers to pollinator-friendly management adoption among farmers; and (5) modelling of landscape-scale pollination service provision as a function of SNH network connectivity to identify spatial priorities for habitat restoration.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All pollinator occurrence data are deposited in the GBIF India network (dataset doi:10.15468/southindiapollinators2023) and the India Biodiversity Portal. Yield and exclusion experiment data are available at https://doi.org/10.5061/dryad.croppollinators2023.

Ethical Approval

Insect collections for identification (pan traps, malaise traps) are standard invertebrate survey methods requiring no permits in India. No honeybee colonies were disturbed. Mesh bagging of flowers for exclusion experiments was conducted with full farmer consent and supervision. All procedures followed IUCN/SSC pollinator survey best practice guidelines.

Appendix A

Key Wild Bee Species and Their Crop Associations

The following records the 20 most frequently recorded wild bee species from South Indian crop fields, with family, crop system associations, and approximate contribution to pollination services.

Family Apidae -- selected dominant species

Apis cerana Fabricius, 1793 (Eastern honeybee) -- Managed + wild. All crops. Most abundant visitor overall; dominant on sunflower and mustard.

Amegilla cingulata (Fabricius, 1775) (Banded bee) -- Wild. Tomato (buzz pollinator), sesame, blackgram. Critical for buzz-pollinated crops.

Xylocopa latipes (Drury, 1773) (Large carpenter bee) -- Wild. Sunflower, mango, sesame. High pollen transfer efficiency.

Trigona iridipennis Smith, 1854 (Stingless bee) -- Wild (tribal managed). Mango, cotton, sesame. Native; important in low-disturbance fields.

Family Halictidae -- selected species

Lasioglossum (Evylaeus) sp. complex -- Wild, small. All crops. Most species-rich genus in survey (28 spp.); early morning forager.

Halictus rubicundus (Christ, 1791) -- Wild. Mustard, sunflower. Semi-social; ground-nesting in field bunds.

Nomia strigata (Fabricius, 1787) -- Wild. Blackgram, sesame. Specialist ground-nester; bund vegetation essential.

Patellapis calceata (Smith, 1875) -- Wild. Sunflower, mango. New Karnataka record in present study.