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Research Article

Documenting Moths (Lepidoptera, Heterocera) across Two Rural Landscapes in Uttar Pradesh, India

R. Kumar, Sweta Singh and Sangeeta Sharma
Department of Agriculture
Mangalayatan University, Aligarh (U.P.), India

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***Correspondence:**
R. Kumar
Department of Agriculture
Mangalayatan University, Aligarh (U.P.), India

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Abstract
This study evaluated macro-moth (Lepidoptera: Heterocera) community structures across two contrasting rural landscapes in Uttar Pradesh, India, to assess the impacts of agricultural intensification on nocturnal insect biodiversity. Bi-monthly light-trap surveys conducted from May 2024 to September 2025 yielded a baseline checklist of 18 distinct genera spanning five families. Community composition diverged sharply between the two sites, with only six species shared.
In Study Area I (Chiraigaon Plains), an intensive monoculture matrix, severe environmental filtering restricted local richness to 10 species, heavily dominated by crop pests within Crambidae (40%) and Noctuidae (30%). Conversely, Study Area II (Chunar Fringe), a complex ecotone of smallholder agroforestry and dry deciduous scrub-forest, functioned as a biodiversity refuge hosting 14 species; here, Erebidae dominated (43%), alongside specialized lichen-feeders and large sphingids.
These findings demonstrate that while standardized monoculture farming simplifies insect communities and selects for resilient economic pests, preserving forest-fringe boundaries and mixed agroforestry matrices maintains critical ecological refugia within the heavily modified Indo-Gangetic Plain.

Keywords: Macro-moths, Environmental Filtering, Agroecosystem, Refugia, Indo-Gangetic Plain.

Introduction
Moths are an integral part of urban food webs, pollination, agricultural pest of urban plantations as well as indicator of biodiversity, ecosystem health and climate change [1-8]. Moths (Lepidoptera: Heterocera) represent a hyper-diverse component of terrestrial ecosystems, acting as nocturnal pollinators, primary herbivores, and crucial prey within multi-trophic food webs. Because of their complex life cycles, specialized larval host requirements, and high sensitivity to microclimatic changes, these insects serve as reliable bioindicators of environmental quality. Monitoring heteroceran communities allows researchers to detect habitat degradation.

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Historically, the closest structured baseline data in the macro-region comes from urban and peri-urban surveys in adjacent territories like Delhi. Early macro-moth records in Delhi were remarkably sparse, with Ghosh and Varshney (1997) [9] initially reporting just 11 species, followed by Baviskar (2016)[10] documenting 15 species. More recent extensive inventories by Paul et al. (2016, 2017)[11,12] expanded the baseline for Delhi to 51 species, identifying 47 new records for the area. While these adjacent studies provide a vital starting point for capturing Northern Indian biodiversity, their focus remains confined to urban forest patches, and they frequently omit the mathematical interpretations and diversity indices needed to assess how community structures shift outside of city spaces.

Early documentation of Indian moth diversity relies on foundational monographs and catalogs [15,22,13] that established the baseline taxonomy for the subcontinent. Modern field guides and open-access digital repositories [29,31] have since updated these records, enabling real-time mapping of species distributions across changing landscapes. Despite their ecological value, global lepidopteran populations are facing severe declines driven by habitat fragmentation, land-use conversion, and chemical pollution. Long-term datasets reveal clear downward trends in macro-moth abundance and occupancy, underscoring systemic biodiversity losses in human-modified landscapes [16]. While urban centers are known to filter for highly mobile, thermophilic generalists capable of navigating artificial light arrays and fragmented urban green spaces [26], the distinct ecological pressures within rural environments remain understudied. Rural landscapes are not uniform; they form a complex gradient ranging from high-input industrial monocultures to low-intensity agroforestry networks and natural forest edges. Each landscape layout imposes unique filters on local insect populations. However, lepidopteran research remains heavily focused on pristine protected reserves or expanding urban zones, leaving rural agricultural matrices largely unsurveyed. This imbalance is highly evident across the Indo-Gangetic Plain of Northern India, a region fundamentally altered by agricultural expansion. Throughout Uttar Pradesh, traditional smallholder farming has largely been replaced by intensive monoculture systems characterized by continuous crop rotations, high synthetic fertilizer inputs, and routine pesticide applications. This landscape simplification has stripped away non-crop vegetation boundaries, replacing diverse plant communities with uniform crop blocks and disrupting native insect food webs [32]. While urbanized pockets like university campuses have received basic checklist documentation [27], and extensive research exists for targeted economic pests within vegetable and field crop systems [28], comparative studies tracking the broader macro-moth community across differing rural matrices are missing.

Materials and Methods

Study Sites and Environmental Gradients

Field sampling was systematically conducted across two ecologically contrasting rural landscapes situated within the Middle Gangetic Plain of Uttar Pradesh, India, to evaluate the variance in lepidopteran community assemblages across a gradient of anthropogenic pressure and structural habitat complexity. This geographic region experiences a classic humid subtropical climate, categorized under the Köppen climate classification as *Cwa*, which is characterized by three distinct seasonal periods: a hot, dry summer extending from March to June, a humid monsoon wet season spanning July to October, and a sharp winter cooling phase from November to February. The selection of these specific locations allows for a direct comparison between a highly homogenized, structurally simplified agricultural matrix and a heterogeneous, multi-layered forest-fringe ecotone, thereby highlighting how varying landscape architecture shapes local macro-moth populations.

Study Area I, designated as the Rural Chiraigaon Plains, is positioned within the Varanasi District at geographical coordinates of 25.3908° N, 83.0245° E, featuring a flat, low-lying alluvial floodplain terrain that rests at a mean altitude of approximately 76 meters above sea level. This site represents an intensely modified and structurally uniform landscape dominated by high-input crop rotations, where vast fields of *Oryza sativa* (paddy) and *Triticum aestivum* (wheat) are grown alongside dense, commercial multi-crop vegetable patches belonging primarily to the Solanaceae and Fabaceae families. A natural forest canopy is entirely absent from this locality, and the remaining woody vegetation is strictly confined to managed, isolated orchards of *Mangifera indica* (mango) or a few scattered, semi-domesticated tree species like *Azadirachta indica* (neem) and *Dalbergia sissoo* (shisham) acting as boundary markers between private plots. Due to continuous agricultural operations, the area experiences a chronic disturbance regime marked by heavy agrochemical deposition, structural habitat fragmentation, minimal microclimatic buffering against thermal spikes, and elevated levels of artificial light at night (ALAN) emitted from expanding rural infrastructure.

Study Area II, designated as the Rural Chunar Fringe, is located within the Mirzapur District at geographical coordinates of 25.1242° N, 82.8847° E, presenting an undulating, transitional ecotone topography at the northern terminal spurs of the Vindhyan Hill Range with a mean altitude varying from 90 to 145 meters above sea level. The geological substrate here consists of gravelly sandy loam and exposed Vindhyan sandstone, which supports a highly heterogeneous habitat architecture formed by a complex mosaic of low-input smallholder agroforestry systems, traditional home gardens, and natural, unfragmented tropical dry deciduous scrub-forest edges. Unlike the first site, this region preserves a robust, multi-layered botanical stratification and a semi-natural canopy dominated by native structural species such as *Butea monosperma* (dhak/palas), *Madhuca longifolia* (mahua), *Ziziphus mauritiana* (ber), and wild *Anogeissus latifolia* scrub, all of which provide a rich diversity of larval host reservoirs. The ambient environment benefits from significant microclimatic buffering maintained by natural tree shading, while the local anthropogenic disturbance regime remains low-to-moderate, characterized by low-intensity seasonal livestock grazing, minimal agrochemical interference, and pristine, dark-sky baseline conditions.

Sampling Design and Light-Trapping Protocol

To systematically document the macro-moth fauna while accounting for seasonal fluctuations in regional weather, bi-monthly field inventories were carried out over a continuous 17-month timeframe from May 2024 to September 2025. Sampling operations were strictly confined to three consecutive nights centered around the new moon phase each month. This step was essential to eliminate the confounding effects of natural lunar illumination, which can significantly reduce moth phototactic responses and distort capture frequencies.

Nocturnal sampling relied on portable light-trap systems utilizing a 160W mercury vapor (MV) lamp as the primary omnidirectional attractant. The light source was suspended at a fixed height of 1.5 meters above the ground, centered directly in front of a vertical 3 m × 3 m bleached white cotton sheet that served as a highly reflective landing backdrop. To capture distinct crepuscular, early-night, and late-night flight cohorts, the light traps were operated continuously for nine hours per sampling night, starting at sunset (19:00 hours) and concluding at dawn (04:00 hours).

Specimen Collection and Field Preservation

Moths actively settling on the reflective cotton sheet or resting within an immediate 1-meter ground radius were collected individually. This selective approach minimized the frantic fluttering and mechanical friction typically caused by automated insect trap funnels, thereby protecting delicate wing scales and diagnostic markings.

Larger macro-moths were carefully transferred into wide-mouthed glass killing jars charged with specialized ethyl acetate vapor to ensure rapid, painless euthanasia. Conversely, smaller, fragile specimens were isolated directly into aerated 2 mL micro-centrifuge tubes and placed inside an insulated thermal cooler box maintained at approximately 4°C. This cold-storage method induced immediate metabolic torpor, preventing physical damage or frantic movement during transport back to the laboratory facility.

Taxonomic Processing and Identification

In the laboratory, cold-stunned and euthanized specimens were placed inside high-humidity relaxing chambers for 4 to 6 hours to restore flexibility to the thoracic muscles and wing bases before pinning. Once relaxed, the specimens were pinned dorsally through the center of the mesothorax using corrosion-resistant entomological pins (sizes 1 to 3, depending on individual body mass) on adjustable wooden setting blocks. The forewings and hindwings were carefully extended using fine forceps to expose the complete venation systems, diagnostic forewing maculation patterns, and hindwing margins, then secured in place with transparent glassine paper strips.

The pinned assemblies were placed in a temperature-controlled hot-air oven at a constant temperature of 60°C for exactly 1 hour. This targeted thermal dehydration process removed internal tissue moisture, hardening the structural specimens while preventing dermestid beetle infestations or fungal mold development. The fully cured specimens were then organized into airtight wooden storage cases lined with plastazote sheets and protected with para-dichlorobenzene crystals.

Morphological identification was carried out by cross-referencing clear physical features with classic identification keys [22,13] and updated digital records from the 'Moths of India' open-access portal [31]. Taxonomic classifications, generic assignments, and species names were checked and updated against current systematic revisions.

Data Analysis

The community structures of both rural locations were evaluated by compiling a master presence-absence matrix. Spatial variation and species turnover between the open agricultural matrix of Chiraigaon and the forest-fringe ecotone of Chunar were analyzed by tracking generic distribution across the 18 identified moth genera. Additionally, family-level representations were calculated using percentage contribution metrics to determine how structural landscape complexity influences specific lepidopteran lineages.

Results and Discussion

Taxonomic Inventory and Structural Composition

The field inventory across the two rural study locations in Uttar Pradesh yielded a total of 18 distinct macro-moth genera distributed across five families: Erebidae, Crambidae, Noctuidae, Geometridae, and Sphingidae. Collectively, 18 distinct species were confirmed, revealing a clear taxonomic sorting pattern between the highly managed agricultural matrix of Chiraigaon (Study Area I) and the forest-fringe ecotone of Chunar (Study Area II).

Study Area I exhibited lower overall richness, supporting 10 species from 10 genera, whereas Study Area II supported 14 species from 14 genera. The distribution of these assemblages points to a sharp divide in family dominance. Members of the families Crambidae, Erebidae, and Noctuidae made up the vast majority of the documented fauna, reflecting patterns observed in similar agricultural and semi-urban baseline surveys conducted across the Indian subcontinent.

Table 1. Taxonomic Distribution and Spatial Occurrence of Moth Genera Across the Two Rural Sites.

Family	Genus	Identified Species Profile	Study Area I (Chiraigaon)	Study Area II (Chunar)	Primary Larval Host Association
Noctuidae	*Spodoptera*	*Spodoptera litura* (Fabricius, 1775) [18]	✓	✓	Polyphagous / Field Crops
	Chrysodeixis	*Chrysodeixis eriosoma* (Doubleday, 1843) [17]	✓	X	Solanaceous Vegetables
	Helicoverpa	*Helicoverpa armigera* (Hübner, 1808) [23]	✓	✓	Pulses and Solanaceous crops
Crambidae	*Maruca*	*Maruca vitrata* (Fabricius, 1787) [20]	✓	✓	Leguminous crops / Pulses
	Spoladea	*Spoladea recurvalis* (Fabricius, 1775) [18]	✓	✓	Amaranthaceous weeds & crops
	Cnaphalocrocis	*Cnaphalocrocis medinalis* (Guenée, 1854) [21]	✓	X	Poaceae / *Oryza sativa*
	Chilo	*Chilo infuscatellus* Snellen, 1890 [30]	✓	✓	*Saccharum officinarum*
	Conogethes	*Conogethes punctiferalis* (Guenée, 1854)	X	✓	Fruits / Wild & Domestic Orchards
Erebidae	*Achaea*	*Achaea janata* (Linnaeus, 1758) [24]	✓	✓	*Ricinus communis* / Euphorbiaceae
	Eudocima	*Eudocima phalonia* (Linnaeus, 1763) [25]	X	✓	Citrus / Wild Menispermaceae vines
	Amata	*Amata passalis* (Fabricius, 1781) [19]	X	✓	Low-growing herbs & shrubs
	Olepa	*Olepa ricini* (Fabricius, 1775) [18]	✓	✓	Polyphagous / Solanaceae & Castor
	Creatonotos	*Creatonotos gangis* (Linnaeus, 1763) [25]	X	✓	Grasses and deciduous weeds
	Cyana	*Cyana peregrina* (Walker, 1854) [33]	X	✓	Lichens / Corticolous growths
Geometridae	*Chiasmia*	*Chiasmia emersaria* (Walker, 1861) [34]	✓	✓	Leguminous woody trees
	Hyposidra	*Hyposidra talaca* (Walker, 1860) [34]	X	✓	Polyphagous / Deciduous shrubs
Sphingidae	*Daphnis*	*Daphnis nerii* (Linnaeus, 1758) [24]	X	✓	Apocynaceae / *Nerium* spp.
	Agrius	*Agrius convolvuli* (Linnaeus, 1758) [24]	X	✓	Convolvulaceae vines

(Key: ✓ = Present; X = Absent)

Community Divergence and Habitat Filtering

The structural composition of the moth assemblages highlights the stark differences in habitat complexity between the two rural landscape types. In Study Area I (Chiraigaon), the community is heavily skewed toward families with short life cycles and a strong affinity for agricultural crops, particularly the Crambidae (40% of local species richness) and Noctuidae (30%).

The open, uniform layout of the Chiraigaon plains acts as an environmental filter. It excludes species that require multi-tiered forest canopies while favoring highly mobile generalists or specialized crop pests. For example, *Cnaphalocrocis medinalis* and *Chilo infuscatellus* are directly supported by the extensive, continuous cultivation of rice and sugarcane in the area.

Conversely, Study Area II (Chunar) displays a more balanced, diverse family structure, dominated by the Erebidae (representing 43% of the local species). The complex landscape at the Chunar forest-fringe provides a wider variety of ecological niches, supporting species that cannot survive in pure monocultures.

The presence of the lithophytic and corticolous lichen-feeding moth *Cyana peregrina* at this site indicates a stable, mature tree canopy and lower ambient chemical pollution, which allows sensitive primitive lichen flora to establish on tree bark and rocks. Similarly, the occurrence of large hawkmoths like *Daphnis nerii* and *Agrius convolvuli* depends entirely on the undisturbed patches of wild Apocynaceae and Convolvulaceae vines found along the scrub-forest margins of the Vindhyan foothills.

Agroforestry Systems vs. Monoculture Intensification

Many of the moths documented across both sites are recognized economic pests within regional agricultural and horticultural networks. However, their distribution across the two sites reveals how the structural design of the landscape influences pest dynamics. Species such as *Spodoptera litura*, *Maruca vitrata*, and *Achaea janata* occurred across both locations, demonstrating their high ecological tolerance and broad larval diets.

In the open plains of Chiraigaon, these species face few ecological barriers. The lack of non-crop vegetation and the removal of natural hedgerows disrupt populations of predatory birds, bats, and parasitoid wasps, leading to frequent pest outbreaks that farmers counter with heavy pesticide applications.

In contrast, the diverse smallholder agroforestry plots and native *Butea-Madhuca* scrub frames in Chunar alter these pest dynamics. While fruit-damaging moths like *Eudocima phalonia* and orchard generalists like *Conogethes punctiferalis* are present, they exist alongside a diverse community of non-pest macro-moths, including *Hyposidra talaca* and *Amata passalis*.

The complex mix of crops and forest trees in Chunar breaks up uniform food sources for pests, helping to limit outbreak cycles. This spatial variation demonstrates that while uniform agricultural plains simplify insect communities and select for resilient economic pests, maintaining semi-natural forest borders and traditional agroforestry systems preserves essential biodiversity refuges that support a broader, more balanced insect fauna across the modified rural landscapes of Northern India.

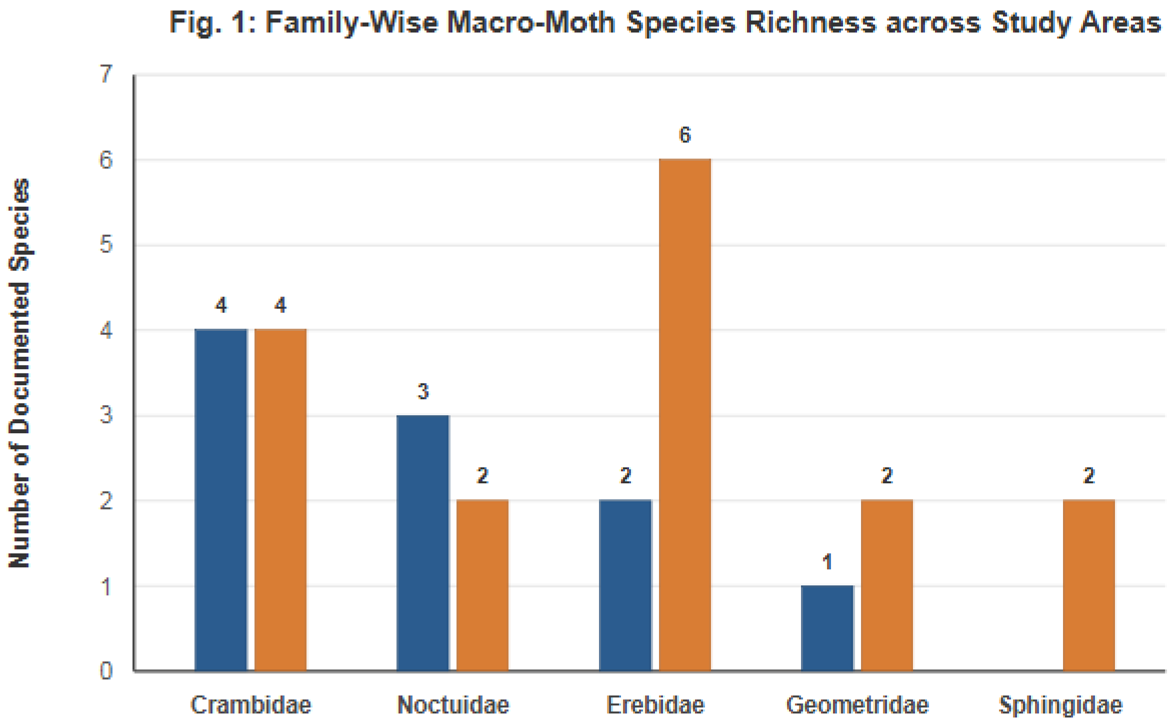

Fig. 1. Family-wise distribution of macro-moth species richness across two contrasting rural landscapes in Uttar Pradesh.

The chart illustrates the shifting ecological dominance between the sites: Study Area I (Chiraigaon) displays a simplified community structural profile heavily dominated by crop-associated pest families (Crambidae and Noctuidae), whereas Study Area II (Chunar) exhibits higher species diversification, particularly within the Erebidae, Geometridae, and Sphingidae, driven by the structural complexity and alternative larval host availability of the forest-fringe matrix.

The structural analysis of the macro-moth assemblages collected across the two rural study locations in Uttar Pradesh reveals a clear divergence in community architecture. A total of 18 distinct species representing 18 unique genera were documented across five core families: Erebidae, Crambidae, Noctuidae, Geometridae, and Sphingidae.

The spatial distribution data indicates that the two sites share only six species (*Spodoptera litura*, *Helicoverpa armigera*, *Maruca vitrata*, *Spoladea recurvalis*, *Chilo infuscatellus*, and *Chiasmia emersaria*). This limited overlap highlights a profound ecological differentiation between the open agricultural plains of Chiraigaon (Study Area I) and the forest-fringe ecotone of Chunar (Study Area II).

In Study Area I (Chiraigaon), cumulative species richness was restricted to 10 species. The taxonomic distribution within this site shows a steep structural curve, with two families—Crambidae (40%) and Noctuidae (30%)—comprising 70% of the entire local fauna. Erebidae contributed a modest 20%, Geometridae was represented by a single species (10%), and Sphingidae was completely absent from the light-trap samples throughout the 17-month monitoring period.

In contrast, Study Area II (Chunar) exhibited both a higher species richness (14 species) and a more equitable distribution across taxonomic lineages. Erebidae emerged as the dominant family, contributing six species (43%), followed by Crambidae with four species (29%). Noctuidae, Geometridae, and Sphingidae displayed equal representation, each contributing two species (14% per family) to the local census.

Study Area II (Chunar) presents a stark contrast, showing how preserving small-scale forest fringes and traditional, low-input agroforestry systems can maintain high insect diversity within heavily modified regions. The transitional zone between the open fields and the dry deciduous scrub-forests of the Vindhyan hills creates a complex grid of microclimats and diverse plant life that supports multiple ecological niches.

The high diversity of Erebidae in Chunar (six species) highlights the ecological value of this multi-layered habitat. A notable find was *Cyana peregrina*, a specialized moth whose larvae feed exclusively on lichens. The presence of *Cyana* indicates that the Chunar fringe maintains a clean, stable environment with low chemical inputs and mature tree bark, allowing sensitive epiphytic lichens to grow. Similarly, the occurrence of large hawkmoths like *Daphnis nerii* and *Agrius convolvuli* is directly linked to the presence of native wild climbers and perennial shrubs, such as *Nerium* species and wild Convolvulaceae vines, which grow undisturbed along the forest margins.

The mixed canopy of native trees like *Butea monosperma*, *Madhuca longifolia*, and *Ziziphus mauritiana* also buffers the local climate. By reducing wind speeds and temperature spikes while maintaining higher humidity levels during hot dry spells, these trees provide vital shelter for weak-flying or fragile species like *Amata passalis* and *Chiasmia emersaria*, which would struggle to survive in the exposed, open fields of Chiraigaon.

Dividing the documented moth species into functional groups reveals a clear shift in ecological roles between the two study areas. In the intensive farming zone of Chiraigaon, the community is dominated by herbivores that feed on commercial crops. Species like *Cnaphalocrocis medinalis* (rice leaf folder) and *Chilo infuscatellus* (sugarcane shoot borer) find an ideal habitat in these uniform fields, leading to high population densities.

However, because these fields lack diverse plant boundaries, natural predators like insectivorous birds, bats, and parasitic wasps lack the nesting sites and alternative prey they need to establish permanent populations. As a result, the natural biological controls break down, leaving the fields vulnerable to sudden pest surges that farmers manage with heavy applications of synthetic pesticides.

In the Chunar fringe, this herbivorous pest group is balanced by a diverse assembly of non-pest generalists, wood-borers, and lichen-feeders. While crop pests like *Maruca vitrata* and *Helicoverpa armigera* are still present, their populations remain stable and rarely spike into major outbreaks. The complex mix of wild and cultivated plants disrupts the egg-laying patterns of crop pests, making it harder for them to locate host plants.

At the same time, the forest edge provides permanent habitats for a wide range of natural predators. These findings demonstrate that uniform farming landscapes simplify insect communities and select for resilient economic pests. In contrast, maintaining natural forest borders, mixed vegetation buffers, and traditional agroforestry systems preserves essential biodiversity refuges. These complex habitats help sustain a broader, more ecologically balanced insect fauna across the modified rural landscapes of Northern India.

Author statement

We declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Data Availability

The dataset and primary evidence supporting the conclusions of this investigation will be available from the corresponding author upon reasonable request.

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Declaration on the Use of Artificial Intelligence

The authors declare that artificial intelligence based tools were used solely for grammatical correction and language refinement of the manuscript. No AI tools were employed in the study design, data collection, data analysis, interpretation of results, or in drawing scientific conclusions.

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