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Integrative Insect Taxonomy: From Classical Morphology to DNA Barcoding and Artificial Intelligence

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INTRODUCTION

Insect taxonomy is the scientific discipline concerned with the identification, classification, nomenclature, and evolutionary relationships of insects. Insects represent one of the largest and most diverse groups of organisms on Earth, with millions of species estimated to exist and a substantial proportion still awaiting formal description. Accurate insect identification is fundamental to entomology because knowledge of insect biology, ecology, pest status, biodiversity, conservation, and management depends on correctly recognizing the species involved.

The development of molecular techniques has substantially expanded the taxonomist's toolkit. DNA barcoding, particularly the use of standardized genetic markers such as the mitochondrial cytochrome c oxidase subunit I (COI) gene, has enabled rapid identification of many insect specimens. Molecular approaches can reveal cryptic species, associate immature stages with adults, identify damaged specimens, verify morphological identifications, and support biodiversity surveys.

2. Concept of Integrative Taxonomy

Integrative taxonomy is an approach in which multiple independent lines of evidence are used to delimit, identify, classify, and understand species. Rather than depending exclusively on morphology or DNA sequences, integrative taxonomy combines complementary information from different biological levels. Evidence may include classical morphology, comparative anatomy, genital morphology, larval and immature-stage characteristics, molecular markers, DNA barcoding, genome-level information, behaviour, ecology, host association, geographic distribution, bioacoustic characteristics, chemical profiles, digital imaging, and artificial intelligence.

3. Classical Morphological Taxonomy

The head of an insect provides numerous taxonomically important characters. The shape and size of the head, structure of compound eyes, presence and arrangement of ocelli, shape and segmentation of antennae, and structure of mouthparts can be useful for distinguishing insect groups. The clypeus, labrum, mandibles, maxillae, and labium may also contain important diagnostic characters. Antennae are particularly useful because their structure varies considerably among different insect orders, families, genera, and species. Differences in antennal segmentation, shape, length, surface structures, and sexual dimorphism may contribute significantly to species identification.

The thorax consists of the prothorax, mesothorax, and metathorax, and its structure provides numerous diagnostic features. The shape and sculpture of the pronotum, development of the scutellum, attachment of wings, structure of legs, presence of spines, spurs and claws, and other thoracic characteristics are commonly used in insect classification. Wings are particularly important in many insect groups because wing shape, venation, margins, pigmentation, scales, and patterns can provide reliable taxonomic information. Wing venation has been extensively used in the classification of groups belonging to Lepidoptera, Diptera, Hymenoptera, Hemiptera, Neuroptera, Odonata, and several other insect orders.

The abdomen also provides important taxonomic information. Abdominal segmentation, spiracles, surface structures, terminal appendages, and reproductive organs may differ among closely related taxa. Male and female genital morphology is particularly important in many insect groups because reproductive structures may show relatively stable and species-specific characteristics. Genitalic examination is therefore frequently used to distinguish species that cannot be separated reliably on the basis of general external morphology.

4. Strengths and Limitations of Classical Morphology

Classical morphological taxonomy has several important advantages. It is comparatively inexpensive and can often be conducted without advanced molecular laboratory facilities. Morphological examination can be performed on preserved specimens and remains particularly valuable for museum collections and historical material. It provides directly observable diagnostic characters and is essential for formal species descriptions and the construction of taxonomic keys. Morphological characteristics can also provide information about phenotypic variation, sexual dimorphism, developmental stages, and adaptation.

5. Molecular Taxonomy and DNA Barcoding

Molecular taxonomy uses DNA, RNA, proteins, and genomic information to investigate relationships among organisms and to support species identification. Molecular characters provide an additional source of evidence that can be compared with morphological information. Among molecular techniques, DNA barcoding has become one of the most widely used approaches for species identification. DNA barcoding involves the analysis of a relatively short, standardized DNA sequence that can serve as a molecular identifier or genetic signature for a species.

6. DNA Barcoding Workflow in Insect Taxonomy

The DNA barcoding workflow begins with appropriate specimen collection and documentation. Insects may be collected using sweep nets, light traps, pitfall traps, Malaise traps, sticky traps, pheromone traps, aspirators, or direct host-plant sampling. Detailed collection information such as locality, collection date, habitat, host plant, collector, specimen code, and geographic coordinates should be recorded whenever appropriate. Maintaining a physical voucher specimen is highly desirable because it permits subsequent morphological verification and provides a permanent reference for the molecular result

Table 1: Comparative overview of major approaches used in integrative insect taxonomy.

Taxonomic Approach	Major Features	Key Data Used	Advantages	Major Limitations	Applications in Entomology
Classical Morphological Taxonomy	Identification based on external and internal morphological characters	Body shape, colour, wings, antennae, legs, genitalia, wing venation	Cost-effective, widely established, useful for describing new species	Requires expert taxonomists; affected by sexual dimorphism, phenotypic variation and cryptic species	Routine insect identification, taxonomic keys, museum specimens
Molecular Taxonomy	Species identification using genetic markers	DNA sequences, mitochondrial and nuclear genes	Can distinguish morphologically similar species	Requires laboratory facilities and suitable reference sequences	Species confirmation, cryptic species detection, quarantine
DNA Barcoding	Standardized short DNA sequence used for species identification	Mainly mitochondrial **COI** gene in animals	Rapid identification; useful for immature stages and damaged specimens	Incomplete reference databases, hybridization and low genetic divergence can cause problems	Pest identification, biodiversity assessment, biosecurity
Genomic Taxonomy	Uses large-scale genomic information for species delimitation and relationships	SNPs, whole genomes, RAD-seq, UCEs, transcriptomes	Provides high-resolution evolutionary information	Expensive, computationally demanding and data-intensive	Phylogenomics, species complexes, evolutionary studies
Artificial Intelligence (AI)	Automated identification using machine learning and image recognition	Digital insect images, morphological features and trained models	Rapid, scalable and suitable for automated monitoring	Requires large, high-quality datasets; model accuracy may decline with poor images or uncommon species	Automated pest detection, smart traps, biodiversity monitoring
Integrative Taxonomy	Combines multiple independent lines of evidence	Morphology, DNA, genomics, ecology, behaviour, geography and AI	More reliable and comprehensive species identification	Requires multidisciplinary expertise and integration of diverse datasets	Accurate pest diagnosis, species delimitation, biodiversity conservation and precision pest management

7. Applications of DNA Barcoding in Entomology

DNA barcoding is also useful for detecting cryptic species. Genetically distinct lineages may be identified even when morphological differences are subtle or absent. In agricultural entomology, molecular identification can assist in distinguishing closely related pest species, including groups of aphids, fruit flies, whiteflies, thrips, moths, and beetles. Accurate pest identification can improve pest surveillance and support appropriate management strategies.

8. Limitations of DNA Barcoding

Biological processes can also complicate DNA-based species identification. Hybridization and introgression may allow mitochondrial DNA to move between species, resulting in shared haplotypes. Incomplete lineage sorting can cause closely related species to retain ancestral genetic variation. Some species may show low interspecific divergence despite being biologically distinct, whereas geographically separated populations of the same species may show relatively high genetic divergence. Nuclear mitochondrial pseudogenes, commonly called NUMTs, can also interfere with mitochondrial sequence analysis. Therefore, DNA barcoding is most powerful when used alongside morphological, ecological, geographical, and other molecular evidence.

9. From DNA Barcoding to Genomic Taxonomy

The development of high-throughput sequencing has expanded molecular taxonomy beyond relatively short barcode regions. Modern genomic approaches include whole-genome sequencing, transcriptomics, RAD sequencing, genome skimming, ultraconserved elements, target enrichment, single nucleotide polymorphism analysis, and phylogenomics. These techniques can provide thousands or even millions of informative genetic characters and may resolve relationships that cannot be reliably established using a single DNA barcode.

10. Artificial Intelligence in Insect Taxonomy

Artificial intelligence has emerged as a complementary technology for insect identification. AI systems can analyse large volumes of digital images and identify patterns that may be difficult to recognize consistently through manual inspection. Modern insect recognition systems commonly use computer vision, machine learning, deep learning, convolutional neural networks, object detection, image classification, and automated feature extraction.

13. AI Applications in Agricultural Entomology

AI-assisted insect identification has considerable potential in crop protection. Conventional pest monitoring often requires insects to be collected from traps and subsequently examined by trained personnel. When pest populations are high or monitoring covers large geographic areas, manual identification can become labour-intensive. AI-based image recognition can potentially automate portions of this process.

Smart insect traps can combine cameras, lighting, image-processing systems, machine-learning algorithms, and wireless communication. Such systems may capture images of insects and automatically classify them, potentially providing near-real-time information on pest occurrence. AI-based monitoring can also contribute to early warning systems by detecting increases in pest populations. When insect identification is combined with pest-density estimation, crop information, weather data, and other environmental variables, it can contribute to more targeted pest management decisions.

Future Prospects

Integrated pest surveillance systems may combine AI-based insect identification with geographic information systems, weather information, crop data, and pest forecasting models. Whole-genome datasets may become increasingly important for resolving difficult species complexes and evolutionary

relationships. High-resolution digital images, three-dimensional specimen models, DNA sequences, and metadata may create comprehensive digital representations of insect specimens. Citizen-science platforms may also allow farmers, students, naturalists, and other users to photograph insects and obtain preliminary identification, although scientifically important observations should undergo expert validation.

CONCLUSION

DNA barcoding, particularly the COI marker in insects, has become an important tool for rapid species identification, biodiversity assessment, pest detection, and linking different life stages. Nevertheless, molecular identification also has limitations, and DNA sequences should be interpreted within an appropriate taxonomic framework. Genomic approaches further extend molecular taxonomy by providing large numbers of genetic characters for resolving complex evolutionary relationships.

REFERENCES

Chakrabarty, S., Deb, C. K., Marwaha, S., Kamil, D., Bheemanahalli, R., & Shashank, P. R. (2026). Application of artificial intelligence in insect pest identification—A review. *Artificial Intelligence in Agriculture, 16*, 44–61. https://doi.org/10.1016/j.aiia.2025.06.005

Hebert, P. D. N., Cywinska, A., Ball, S. L., & deWaard, J. R. (2003). Biological identifications through DNA barcodes. *Proceedings of the Royal Society B: Biological Sciences, 270*(1512), 313–321. https://doi.org/10.1098/rspb.2002.2218

Tyagi, K., Kumar, V., Singha, D., Chand, D., & others. (2022). DNA barcoding of insects from India: Current status and future perspectives. *Molecular Biology Reports*. https://doi.org/10.1007/s11033-022-07628-2