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Notes on *Centris* Fabricius, 1804 of Costa Rica (Hymenoptera, Apidae, Apinae, Centridini): Lets Try an IA generated Key

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Mini Review

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Abstract

AI is rapidly becoming a valuable ally of science, automating and improving data analysis processes and the generation of identification tools. This work tested a simple prompt in the AI chatbot app using the 4o-mini model to generate a dichotomous key based solely on the literature it could access online. The results were very interesting, proving quite useful for a basic working draft, but still far from replacing a specialist.

Keywords: Chat GPT; Gemini; IA; 4o-mini

Introduction

The integration of artificial intelligence (AI) into taxonomy has revolutionized how biologists characterize and classify species. The ability to analyze large volumes of morphological, genetic, and ecological data using machine learning algorithms has facilitated the identification of diagnostic traits with greater accuracy and speed [1]. Specifically in bee groups such as the genus Centris, AI has enabled the automation of subtle morphological pattern recognition that traditionally required exhaustive analysis by experts [2]. The use of techniques such as convolutional neural networks (CNNs) for image recognition has proven effective in differentiating species based on visual characteristics, such as coloration patterns and the shape of genital structures [3]. Furthermore, computational models have been used to integrate morphometric data into distribution maps and phylogenetic relationships, facilitating a more comprehensive understanding of biodiversity [4].

In recent years, the use of deep learning algorithms has enabled the classification of individuals with an accuracy comparable to or greater than that of experienced taxonomists, optimizing time and reducing human error in identification tasks [5]. The use of computational analysis in molecular taxonomy has advanced the combination of molecular and morphological data, generating integrated approaches that strengthen species delimitations [6]. Furthermore, AI has been applied to the automatic detection of specimens in museum collections and in the field, reducing the exclusive reliance on visual analysis and facilitating large-scale studies [7]. However, while these tools offer significant opportunities, they also pose challenges related to biological interpretation, data quality, and the need for expert validation [8].

These AI applications in taxonomy not only increase the efficiency of the identification and classification process, but also enhance the detection of hidden diversity and decision-

making based on objective and replicable data [9]. Particularly for Centris, whose morphology can exhibit subtle variations, the incorporation of automated recognition systems can improve taxonomic resolution, allowing the integration of different information sources for more rigorous species delimitation [10]. Thus, collaboration between taxonomy specialists and AI programs will be essential to advance the description and conservation of the biodiversity of these important pollinators.

But what would happen if we used an everyday AI to generate a dichotomous key instead of using genetic datasets or high-resolution images? In this work, I put this to the test.

Methodology

The AI "Chatbot app" (https://chat.chatbotapp.ai/) was used, which uses both Chat GPT and GEMINI. For the key, I used the 4o-mini model and gave it the following instruction, which includes the Centris species from Costa Rica previously listed in the national bee catalog [11]:

"Act like an expert entomologist. Generate a dichotomous key for the following species of the genus Centris: Centris (Acritocentris) agilis, Centris (Aphemisia) agiloides, Centris (Aphemisia) plumipes, Centris (Aphemisia) scutellata, Centris (Centris) adani, Centris (Centris) aethiocesta, Centris (Centris) aethyctera, Centris (Centris) flavifrons, Centris (Centris) flavofasciata, Centris (Centris) obscurior, Centris (Centris) varia, Centris (Hemisiella) facialis, Centris (Hemisiella) nitida, Centris (Hemisiella) trigonoides, Centris (Hemisiella) vittata, Centris (Heterocentris) analis, Centris (Heterocentris) bicornuta, Centris (Heterocentris) difformis, Centris (Heterocentris) labrosa, Centris (Heterocentris) terminata, Centris (Melanocentris) erubescens, Centris (Melanocentris) melanochlaena, Centris (Ptilocentris) festiva, Centris (Trachina) fuscata, Centris (Trachina) heithausi, Centris (Trachina) labiata, Centris (Trachina) longimana, Centris (Trachina) proxima, Centris (Trachina) similis, Centris (Trachina) vidua, Centris (Trichocentris) atripes, Centris (Xanthemisia) bicolor, Centris (Xanthemisia) carolae and Centris (Xanthemisia) lutea. Use books and scientific articles as references, citing them in Vancouver format and listing the bibliography at the end."

Results

The result obtained was a key of 35 sections which, according to the AI, are based on the articles (they are transcribed exactly as they are generated, note that AI is sometimes unable to provide complete references):

Moure JS. Catalogue of Neotropical Bees. 1965. Moure JS, Urban D, Melo GAR. Catalogue of Bees (Hymenoptera: Apoidea) in the Neotropical Region. 2007.

Hurd PD Jr. The genus Centris in the Americas: revisions and species descriptions. J Kans Entomol Soc. 1979;52(3):...
Ayala R, Smith-Pardo A. Review of Centris (Trachina) species with keys and genitalia illustrations. Zootaxa. 2009;...
Nates-Parra G. Revision of Hemisiella and allied subgenera of Centris. Rev Colomb Entomol. 1998;24(1):...
Baker H, Engel MS. Morphology and taxonomy of Centrid bees. Bull Am Mus Nat Hist. 2004;... (Consulte los trabajos originales de descripción de las especies citadas para caracteres detallados y figuras: por ejemplo, Smith, 1854; Friese, 1900; Moure, 1940–1971; Hurd, 1979; Roig-Alsina y Ayala, 1996.)

Clave de identificación para especies de Centris de Costa Rica generada por la IA

1a. Mesosome and metasoma with conspicuous bands or markings of yellow or white pubescence forming patterns (bicolor) 2
1b. Mesosome and metasoma with uniform pubescence (dark or reddish) or without conspicuous bands 12
2a. Head, mesosoma, and legs with marked bicolor contrast (e.g., head or forelegs lighter) and scutellum with purple or shiny . . . . . *Centris (Xanthemisia) bicolor*
2b. Bicolor pattern not as above (other combinations) 3
3a. Facial and pronotal pubescence dense, forming an extended facial mask; metasoma with white rings on basal tergites . . . . . *Centris (Xanthemisia) lutea*
3b. Facial pubescence more restricted; distinct metasome pattern 4
4a. Mesoscutum and mesoscutellum with light transverse bands; thorax shiny, mid and hind legs with darkened femora; body relatively small . . . . . *Centris (Xanthemisia) carolae*
4b. Other banding patterns; larger or distinct forms 5
5a. Tergites with broad light apical bands that contrast sharply with the dark disc; regular metasoma markings . . . . . *Centris (Centris) flavofasciata*
5b. Narrower or partial bands; other color combinations 6
6a. Frons and scutellum with dense yellow pubescence and prominent facial sideburns; medium-large size . . . . . *Centris (Centris) flavifrons*
6b. Scutellum pubescence less dense, pattern less uniform 7
7a. Tergites with a pale apical band on T2–T4 and a darker disc; face with a pale medial line . . . . . *Centris (Hemisiella) vittata*
7b. Bands and markings not as above; check other subgenera 8
8a. Mesosoma with pale lateral bands in note; head relatively broad; species with a showy habit . . . . . *Centris (Hemisiella) facialis*

8b. Mesosoma with a different pattern, other Hemisiella species or Centris sensu stricto 9
9a. Posterior tergites with a broad white or yellow band and legs with dense pale hairs . . . . . *Centris (Hemisiella) nitida*
9b. Bands less extensive; otherwise different . . . . . *Centris (Hemisiella) trigonoides*
10a. (If there is confusion between Hemisiella and Xanthemisia in specimens) See labium and scutellum characters: Hemisiella with an often flatter scutellum and restricted pubescence; Xanthemisia with more contrasting colors (see reference). — (Use of genitalia recommended for fine distinction) . . . . . (Not applicable as a next step)
11a. (If lateral and facial bands are absent; return to 1b) 12
12a. Body generally dark, without pale bands; pubescence brown, black, or reddish 13
12b. Body with very marked reddish or erubescent tones (thorax or legs reddish) 20
13a. Anterior femur and tibia with noticeable extensions or modifications (e.g., brachiated, thickened) 14
13b. Legs not conspicuously modified; normal proportions 16
14a. Relatively wide metasoma, wide T1; behavior and structure similar to Heterocentris (class with a modified prothorax) . . . . . *Centris (Heterocentris) analis*
14b. Other modifications with appendages or horns on the head/mesosoma 15
15a. Two protuberances or "horns" on the pronotum or frons (bicornute) . . . . . *Centris (Heterocentris) bicornuta*
15b. Distinct protuberances or absence of horns; noticeably distinct labium . . . . . *Centris (Heterocentris) labrosa*
16a. Head or clypeus with a smooth, broad surface; species described with an epithet indicating "obscure/obscurior" . . . . . *Centris (Centris) obscurior*
16b. Clypeus narrower or with distinctive pubescence. 17
17a. Scutellum and mesoscutum with a metallic or eruescent sheen; species with the name "erubescens" or similar . . . . . *Centris (Melanocentris) erubescens*
17b. Without evident metallic sheen 18
18a. General melanic appearance, dark integument, black or brown pubescence; sideburns not pale . . . . . *Centris (Melanocentris) melanochlaena*
18b. Lighter pubescence on some parts of the body or other differences in form 19
19a. Mesoscutum disc and scutellum with scattered yellowish hairs; tergites with a slightly paler apex . . . . . *Centris (Centris) adani*
19b. Mesosome pubescence uniformly brown; other distinctive features on genitalia or legs . . . . . *Centris (Centris) aethiocesta*
20a. Face and scutellum with very marked reddish or orange pubescence; specific name alludes to "*erubescens*" or similar — see 17a. . . . . (if applicable, *Centris (Melanocentris) erubescens*)
20b. Remainder with reddish tones on legs or metasoma, but not predominantly erubescent scutellum 21
21a. Extremely long antennae or metathorax segments (e.g. *longimana*). . . . . *Centris (Trachina) longimana*
21b. Antennae and appendages of normal length for the genus. 22
22a. Mandibles and anterior lip noticeably long or projecting (labiata) . . . . . *Centris (Trachina) labiata*
22b. Mandibles normal or less prominent 23
23a. Tergites with sparse pubescence; species described as fuscata (dark) . . . . . *Centris (Trachina) fuscata*
23b. Other patterns; separation from Trachina continues 24
24a. Tergites with apical pale bands on T2–T4 and mesoscutum with long hairs; species similis/proxima/vidua with subtle differences in genitalia and size 25
24b. Tergites without pale bands or with a different pattern 27
25a. Apical band at T2–T4 weak, larger size, genitalia with apodem more elongated . . . . . *Centris (Trachina) proxima*
25b. Apical band more pronounced or with slight variations 26
26a. Tergite disc with denser pubescence; species described as similis . . . . . *Centris (Trachina) similis*
26b. Darker and solitary appearance (vidua) . . . . . *Centris (Trachina) vidua*
27a. Overall robust appearance, abdomen varied in coloration; species *Centris (Centris) varia* (highly variable) . . . . . *Centris (Centris) varia*
27b. Does not match the above; review remaining pairs (*agilis, agiloides, plumipes, scutellata, aethyctera, obscurior* already mentioned, varia already mentioned, etc.) 28
28a. Leg hair very conspicuous (plumose), especially on tibiae and tarsi; name plumipes suggests feathery legs . . . . . *Centris (Aphemisia) plumipes*
28b. Hair not so plumose; other features necessary 29
29a. Scutellum and mesoscutum with marked tubercles or convexities in the center (scutellata) . . . . . *Centris (Aphemisia) scutellata*
29b. Scutellum smooth; follow separation by other labels 30
30a. Species with habits and characteristics close to agilis/agiloides; distinguish by size and shape of the clypeus: agilis has a narrower clypeus and a different apical appendage 31
30b. Does not match; see the following specific features 33
31a. Clypeus narrow, antennae relatively short; assign to Centris (Acritocentris) agilis
31b. Clypeus wider, more robust; distinct facial pubescence 32
32a. Taxon with features intermediate between *agilis* and *plumipes*, described as *agiloides* . . . . . *Centris (Aphemisia) agiloides*

32b. If clypeus is wide and other characters indicate *Trachina* or *Trichocentris*, reassign (see genitalia) . . . . . *Centris (Trichocentris) atripes*
33a. Species with tarsus or fore tibia with a dark appendage, or metasoma with a light apex; name aethyctera/aethiocesta indicates subtle differences in genitalia—separate by genital examination and S7 shape in males: *aethyctera* vs *aethiocesta* 34
33b. Other remaining names: *Centris (Centris) aethyctera, Centris (Centris) aethiocesta, Centris (Centris) obscurior* (already cited), *Centris (Centris) adani* (already cited), *Centris (Centris) varia* (cited). 35
34a. Structure of S7 and genitalia with a prominent ventral lobe — *Centris (Centris) aethyctera*
34b. S7 without a prominent ventral lobe; integument with a brown pattern — *Centris (Centris) aethiocesta*
35a. *Centris (Heterocentris) difformis*: thoracic and abdominal forms markedly different from congeners; check pronotum and T1 shape . . . . . *Centris (Heterocentris) difformis*
35b. *Centris (Heterocentris) terminata*: abdominal apex with characteristic termination; separation by apex of tergite . . . . . *Centris (Heterocentris) terminata*

If we look closely at the key, we can see several very interesting details. Among them is the fact that options 10 and 11 don't have an alternative; one proposes a review of genitalia, and the other leads us to option 12 while simultaneously instructing us to return to option 1b. Another very interesting point that should be reviewed in much greater detail is that the key is constructed using the same words the authors use in their articles. This can be both accurate and ambiguous, since some descriptions depend on the subjectivity of the specialist.

On the other hand, aspects of coloration are also debatable. For example, in option 2a, the color description of Centris (Xanthemisia) bicolor is quite ambiguous. The purple scutellum could be due to iridescence, but in general, it would be more accurate to state that the coloration is completely black except for the thorax, which has a bright yellow pubescence. Although this pubescence is longer, it provides a better understanding of the characteristic being described. And we could continue analyzing each option in this way. Finally, it can be observed that it also does not make a distinction between sexes, when the genus Centris presents a sexual dimorphism that can be quite useful to separate species.

Discussion

The work of scientists in the morphological comparison of specimens remains fundamental for the correct delimitation of species, even in the age of artificial intelligence. Classical morphology, based on characteristics such as coloration, the shape of the genitalia, teeth, and other structures, continues to be the reference for defining and corroborating diagnostic traits [12]. For example, in Centris, the coloration of the abdominal tergite can exhibit subtle variations that require careful attention. Recent studies have highlighted that differences in integument pigmentation can be a diagnostic trait, but its evaluation requires careful analysis under controlled conditions to avoid errors related to wear or environmental variability [13].

The shape of the genitalia, such as the genital tergites in males, is another key trait in species differentiation. The structure of the epidermis, the shape and size of the genital appendages, and the particularities in the sculpting of these parts have traditionally been used to define clear boundaries between similar species [14]. However, the interpretation of these characteristics can vary among taxonomists, making traceability and accurate comparison essential. The use of micrographs and digital morphometric analysis, combined with the analyst's experience, helps to corroborate these traits [15].

Other distinctive features, such as mandibular teeth in males, also provide important diagnostic information. The presence, size, and shape of teeth between the maxillae, as well as the presence of denticles on structures such as the clypeus, allow for the differentiation of closely related groups [16]. In this context, the taxonomist's responsibility lies in carefully evaluating each specimen, considering intraspecific variability, potentially influenced by ecological factors, and ensuring that the traits used are consistent and reproducible. Comparative review based on morphology, with emphasis on identifying diagnostic characteristics, is essential for the validity of taxonomic delimitations and to avoid overestimating taxonomic units due to cultural or preservation differences [17].

Conclusion

The AI key can serve as a fairly useful draft guide for outlining a review process for specimens, and even some basic ones are quite accurate.

Since the AI lacked graphic references and genetic patterns to analyze, it is limited to extracting traits from freely available literature. Therefore, it is essential to corroborate the literature descriptions with the specimens to define the best description of a diagnostic trait.

Coloration, mandibular characteristics, genitalia, and leg structures can be important details to consider when refining the AI key. It is possible that providing a nuanced set of traits instead of relying solely on the available literature will yield much better results.

A key will be generated considering the database generated by AI and incorporating diagnostic visual characteristics such as the coloration and patterns of fascial maculations.

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