Moths with relation to plants' pyrrolizidine alkaloids in El Bosque Nuevo, Costa Rica

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What are pyrrolizidine alkaloids?

Pyrrolizidine alkaloids (PAs) are secondary plant compounds, produced by > 560 plant species for protection against herbivores.
Despite and because of a widespread deterrent or repellent effect of PAs against herbivores and carnivores, invertebrates as well as vertebrates, a variety of insects has adapted to sequester PAs from certain plants and use them for protection and communication.

Pharmacophagy

Pharmacophagy is one important way of obtaining PAs. PA-pharmacophagous insects search for and take up PAs independent of nutritional requirements. As PAs are sealed in cell vacuoles in living, undamaged plant tissue, PA-pharmacophages visit exclusively dead or damaged plant material (Fig. 1) from which they extract PAs.

Pharmacophagous moths

Naturalists have already been puzzled by the attractive power of certain dead plants for a variety of Lepidoptera more than 100 years ago. Ca 200 species of Arctiinae (subfamiliy of tiger moths with ca 6,500 species worldwide) have been shown to be PA-pharmacophages so far, but for most no further biological data is available (e.g. Conner & Weller 2004). Tiger moths are known for their often colourful, aposematic appearance – PA-containing species optically warn potential predators. Colour only makes sense in daylight, and many of these moths are indeed active during day.

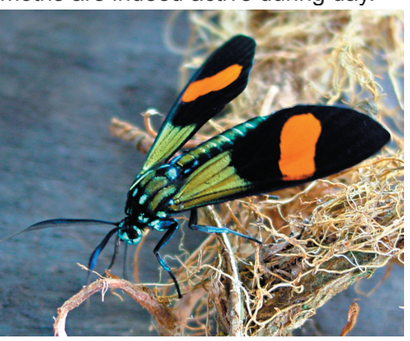

Fig. 1 *Belemnia* sp. at PA-containing roots

Fig. 2 Arctiinae gathering PAs from dry plant material and dishes containing pure PAs

First step: surveying

To overcome the lack of ecological understanding of PA-pharmacophagy in Arctiinae, a pilot study to survey PA-pharmacophages in El Bosque Nuevo was conducted. Using both natural PA-plants and pure crystalline PAs (Fig. 2) as baits, PA-pharmacophagous moths were collected during night and day and characterized due to several traits related to protection (aposematism, mimicry, acoustic signals) and sexual communication (androconial organs, acoustic signals).

Plants containing PAs

Six ruderal PA-plants were found in El Bosque Nuevo and used as baits: *Ageratum conyzoides*, *Emilia* spp., *Chromolaena odorata*, *Heliotropium* cf. *polyphyllum* and *Crotalaria* sp.. As moist forests are the main natural habitats of Arctiinae in general, these plants are most probably not the natural PA-sources. We thus expect to find further (and yet unknown?) PA-plants in future surveys.

Taxonomic diversity (Fig. 3)

Altogether 65 PA-pharmacophagous species (21 genera) were collected from PA-baits, about half of them with only one or two specimens per species. Among the 31 species with more than five individuals each, 16 exhibited pharmacophagous behavior exclusively in the dark, nine exclusively during day and six were found at PA-baits both night and day. A strong male sex-bias, indicating a use of PAs in a sexual context, was detected in 19 species, in eleven species PA-baits were visited by male as well as female individuals.

Fig. 3 Selected species of PA-pharmacophagous Arctiinae in El Bosque Nuevo

Functional diversity

Communication with sound

54 of the 65 species collected in this study possess tymbal organs and are thus capable of sound production. In nocturnal species, ultrasonic sound has been interpreted as defense against bats (acoustic aposematic signal). In some cases it has been shown to also have a significance in intraspecific, particularly in sexual communication.

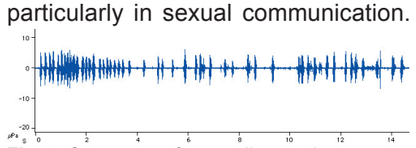

Fig. 4 Sonogram of an arctiine moth

Mimetic relationships

Interesting mimicry relationships have been found. Several (including unrelated) arctiine species resemble each other, all being protected. The wing pattern depicted (Fig. 5) was so far only found in a yet undetermined beetle.

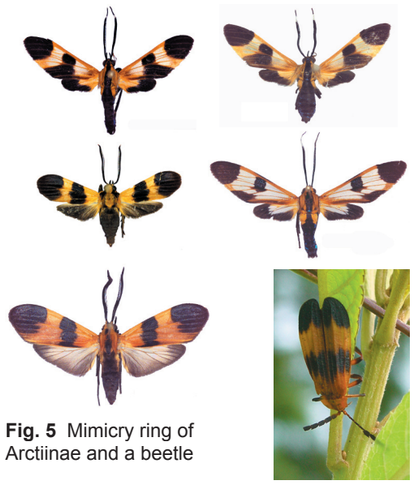

Fig. 5 Mimicry ring of Arctiinae and a beetle

Several arctiines strikingly resemble wasps (Fig. 6). This is a particularly interesting relationship which for long has been interpreted as being a prime example for Batesian mimicry: palatable moths imitate well-defended wasps. As the wasp mimics found in this study are PA-pharmacophages, the relationship might prove to be a Müllerian mimic of two groups with very different but still similarly efficient chemical defenses: stinging wasps and PA-storing and thus 'bitter-tasting' moths.

Fig. 6 A wasp (bottom left) and several wasp-mimicking moths

Androconial organs

Males of 26 out of 28 species which could be checked possessed androconial organs of some kind, inside the abdomen, on the hindwings, or at the thorax (Fig. 7). The striking diversity and complexity of these structures underlines their importance in a sexual context, and PA-related sex-pheromones were identified previously. For the majority of species, however, details on the use of androconia are completely unknown.

Fig. 7 Diversity of androconial organs in Arctiinae

Demands on natural habitats

The occurrence of Lepidoptera in a specific area largely depends on the occurrence of suitable host plants which usually have highly specific habitat demands. In this study, very few caterpillars were detected, and natural host plants are widely unknown. However, due to the relatively easy sampling method with PA-baits and their high diversity, PA-pharmacophagous Arctiinae might prove to be good indicators for habitat quality. This is particularly interesting in a place like El Bosque Nuevo, with pristine forest in direct vicinity to a reforestation project. Regular monitoring might be worthwhile to estimate the quality improvement over time.

Potential commercial value of PA-pharmacophagous tiger moths

Colour sells – the spectacularly coloured tiger moths are promising candidates for commercial breeding in butterfly projects like El Bosque Nuevo. Moreover, these moths tell stories! Firstly, however, their hostplants have to be identified.

Perspectives

The three-months pilot study already revealed a high diversity of PA-utilizing Arctiinae in the direct vicinity of the farm house of El Bosque Nuevo, thus making this area ideal for future comparative investigations on PA-use in this taxon. Here are some topics we would particularly like to study further:

- Detection of reliable patterns: collecting more specimens and species will help to detect patterns in defensive and sexual use of PAs in Arctiinae. Comparison with material obtained by non-PA-related methods (light traps, netting) will help to further evaluate data.
- Use of PAs in sexual communication: chemical analyses of androconial organs will reveal the significance of PA-derived pheromones in sexual communication.
- Selective sequestration and storage of PAs: as PAs always are present as bouquets in plants, it would be interesting to study patterns of selective sequestration in different species. Insects have been shown to even transform plant-PAs to unique "insect-PAs".
- Qualitative and quantitative patterns of PAs within a population; detection of natural food plants; detection of natural PA-sources; …
  … and several others.

Thanks

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Context information is found at
http://www.fzi.uni-freiburg.de

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