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# FATE OF COCAINE IN THE LYMANTRIID *ELORIA NOYESI*, A PREDATOR OF *ERYTHROXYLUM COCA*

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**Key Word Index**—*Erythroxylum coca*; Erythroxylaceae; *Eloria noyesi*; moth; alkaloid, cocaine; excretion; sequestration; feeding deterrent.

**Abstract**—Larvae of the lymantriid moth *Eloria noyesi*, which are obligate feeders on *Erythroxylum coca*, excrete most of the ingested cocaine as unchanged base. Cocaine, analysed by mass fragmentography, is readily detectable in the blood of larvae and is presumably sequestered during larval feeding, since it is present in the bodies of adult moths that do not feed on *E. coca*. Cocaine is an effective feeding deterrent for the ant *Monomorium pharaonis* when present at a concentration below that found in the leaves of *E. coca*.

## INTRODUCTION

Many species of insects are obligate feeders on plants that contain a variety of natural products which are frequently noted for being either distasteful and/or toxic to other animals [1]. Lepidopterous larvae often have a predilection for feeding on a diversity of plant species rich in alkaloids or cardenolides, and in many cases these compounds are sequestered and retained in the bodies of the adult insects [1, 2]. Larvae of arctiid moths, in particular, feed on plants containing both classes of compounds and their ability selectively to sequester pyrrolizidine alkaloids from the leaves of *Senecio* and *Crotalaria* species has been well documented [3, 4]. On the other hand, several species of moth larvae have been observed rapidly to excrete ingested nicotine but no evidence of sequestration of this alkaloid was obtained [5, 6]. The results of these investigations indicate that a variety of strategies have been evolved by different insects to cope with the alkaloids that fortify the tissues of their food plants.

In the present report we describe the fate of a tropane alkaloid, cocaine, after ingestion by larvae of the lymantriid moth *Eloria noyesi*, an obligate feeder on *Erythroxylum coca*. In addition, we examined the effectiveness of cocaine as a feeding deterrent for Pharaoh's ant, *Monomorium pharaonis*, a very successful tramp species which is characterized by the rapid exploitation of food finds through the utilization of well-developed foraging trails.

## RESULTS AND DISCUSSION

Larvae of *E. noyesi* clearly excrete most of the ingested cocaine (Table 1). However, small amounts of cocaine pass through the intestine, as evidenced by the presence of this alkaloid in blood samples collected from actively feeding larvae. At least some of this absorbed cocaine is apparently sequestered by the larvae and retained in the body during metamorphic development, since it is present in both adult males and females (Table 1). It appears that females are more efficient in sequestering the alkaloid than the males.

Table 1. Cocaine concentrations in larval blood, larval frass, and adult bodies of *E. noyesi*

| Material analysed | Cocaine concentration ± s.d. | (*n*) |
|---|---|---|
| Larval blood | 0.68 ± 0.17 ng/μl | 3 |
| Larval frass | 0.91 ± 0.01 μg/mg | 6 |
| Adult males | 35.2 ± 5.5 ng/g | 6 |
| Adult females | 52.6 ± 5.9 ng/g | 5 |

None of the known metabolites of cocaine were detected in any of the extracts although it is possible that they are present in very low concentrations. It appears that larvae of *E. noyesi* primarily cope with ingested cocaine by excreting it, since the amounts in the blood and in the adult bodies are negligible compared to what is eliminated in the frass (Table 1). The strategy evolved by these lymantriid larvae for dealing with high enteric levels of alkaloids differs considerably from that of arctiid larvae which selectively sequester specific pyrrolizidine alkaloids while producing a frass with a relatively low alkaloidal content [3]. From a metabolic standpoint, larvae of *E. noyesi* do not 'see' cocaine, treating most of this alkaloid as an inert concomitant of ingested nutrients which passes through the intestine and is excreted as an intact moiety. If the failure of the larvae to absorb most of enteric cocaine reflects a negligible metabolic expenditure, it will constitute a major evolutionary adaptation that has enabled this species preferentially to exploit *Erythroxylum* as a food plant.

Cocaine, at concentrations lower than those found in leaves of *E. coca*, is an outstanding feeding deterrent for workers of *M. pharaonis*. Although workers rapidly

discovered the droplets of sucrose solution, those fortified with cocaine were invariably treated with disdain after brief examination. Control droplets, on the other hand, were rapidly encircled by feeding workers and subsequently became the focus of strong recruitment trails. Thus, for *M. pharaonis*, at least, cocaine constitutes an effective gustatory inhibitor.

Lack of absorption or metabolism of cocaine by larvae of *E. noyesi* may be highly adaptive *vis-à-vis* potential predators. When molested, these larvae invariably regurgitate enteric fluid, which, because of the presence of high levels of cocaine, may function as an effective repellent, as it does for workers of *M. pharaonis*. On the other hand, the significance of low levels of cocaine in the bodies of adult moths is difficult to ascertain, since it does not seem likely that the alkaloid would function as a repellent at these concentrations. This was certainly the case with dermestid larvae that ravaged the bodies of dead adult moths. Adults of *E. noyesi*, which are poor flyers, spend most of their time resting inconspicuously on vegetation [7] and these insects, while they are not cryptic, can hardly be considered flagrantly aposematic. Whereas cryptic adults derived from immatures that had developed on plants containing toxic natural products invariably do not store these compounds, aposematic adults reared on the same plants almost always sequester them. Although we do not know whether larvae of *E. noyesi* store high concentrations of cocaine, our results indicate that adults of this species contain relatively low levels of this alkaloid in their bodies. Although these lymantriid moths would appear to be poor sequestrators of cocaine, the adaptive significance of retaining low concentrations of this nitrogen heterocycle may nevertheless be considerable.

## EXPERIMENTAL

*Material.* Medium- and late-instar larvae of the Amazonian variety of *E. noyesi* were collected from leaves of Amazonian coca, *E. coca* var. *ipadu*, cultivated in small plots near Pebas, Peru. Larvae were maintained in the laboratory on daily fresh cuttings of *E. coca* var. *ipadu* for a maximum of 48 hr.

Blood was obtained from cold-immobilized larvae by cutting the prolegs with fine scissors and collecting the exuding fluid in calibrated microcapillaries which were immediately placed in EtOH. Adult moths were collected and immediately frozen after which they were weighed and macerated in EtOH for chemical analyses. Frass was collected daily, weighed and extracted in EtOH.

The feeding deterrency of cocaine was evaluated by preparing solns ($5 \times 10^{-3}$ M) of the alkaloid in 1% sucrose. A 0.1-ml droplet of cocaine-fortified sucrose soln was placed on a microscope slide 3 cm from a control droplet of sucrose soln. Slides containing the pairs of sucrose droplets were placed 1 cm from strong foraging trails of workers of *M. pharaonis* and the reactions of workers to the droplets were observed for 30 min.

*Analytical.* The MS analyses were carried out on an LKB 2019 gas chromatograph-mass spectrometer (GC/MS) equipped with a multiple ion detector. The glass column (150 cm × 2 mm i.d.) was packed with 3% SE-30 Ultraphase on GasChrom Q (100–120 mesh) and maintained at a temp. of 200°. Helium was used as carrier gas at flow rate of 30 ml/min. The temp. of the injection port was 240° and the ion source was kept at 250°. The ionizing energy and trap current were 50 eV and 50 μA, respectively.

During the mass fragmentographic analyses, the instrument was adjusted to record ions *m/z* 303 and 306 ($M^+$) for cocaine and cocaine-$d_3$. Standard curves for the determination of cocaine in biological samples were obtained by treating, in the same way as described below, a series of blank samples to which known amounts of cocaine (0.2–10 ng) has been added. The ratio of the peak heights of cocaine and cocaine-$d_3$ was calculated and plotted against the known concns of cocaine in the standard samples.

The cocaine content in the *Eloria* samples was determined following a standard procedure [8], with slight modifications. The biological materials were macerated in EtOH (0.5–1 ml) containing 2 ng of deuterium-labelled cocaine as an int. standard and 0.05 mg $NaHCO_3$. The mixture was heated for 2 min at 75° and allowed to stand at room temp. for over 5 hr. The sample was centrifuged (2000 g, 1 min) and the EtOH was transferred to a 3 ml MeOH-washed glass tube and evaporated to dryness at room temp. under a stream of $N_2$. The residue was dissolved in 30 μl of toluene and 2–4 μl of this soln was analysed by mass fragmentography.

Qualitative analyses of possible cocaine metabolites were performed on frass extracts using TMSi derivatives following a previously described GC/MS procedure [9].

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## REFERENCES

1. Rothschild, M. (1972) in *Insect/Plant Relationships* (van Enden, H. F., ed.) pp. 59–83. *Symp. Roy. Ent. Soc. Lond.* 6. Blackwell, London.
2. Rothschild, M. and Reichstein, T. (1976) *Nova Acta Leopoldina Suppl.* **7**, 507.
3. Aplin, R. T. and Rothschild, M. (1972) in *Toxins of Animal and Plant Origin* (de Vries, A. and Kochva, K., eds.) pp. 579–595. Gordon & Breach, London.
4. Rothschild, M. and Aplin, R. T. (1971) in *Chemical Releasers in Insects* (Tahori, A. S., ed.) Vol. 3, pp. 177–182. Gordon & Breach, London.
5. Self, L. S., Guthrie, F. E. and Hodgson, E. (1964) *Nature* **204**, 300.
6. Self, L. S., Guthrie, F. E. and Hodgson, E. (1964) *J. Insect Physiol.* **10**, 907.
7. Wille, J. E. (1932) *Tropenpflanzer* **35**, 9.
8. Holmstedt, B., Jäätmaa, E., Leander, K. and Plowman, T. (1979) *Phytochemistry* **16**, 1753.
9. Rivier, L. (1981) *J. Ethnopharmacol.* **3**, (in press).