Trends in Arthropod Defensive Secretions, an Aquatic Predator Assay

Departments of Physiology* and Applied Mathematics**,
University of the Witwatersrand, Johannesburg, Republic of South Africa

Received March 13, 1973

Summary. Twenty-five arthropod defensive chemicals were tested on a potential fish predator to assay basic repellency, interniche effectiveness and mimetic interactions among repellents, and predator tolerance to repellents.

The defensive secretions of aquatic arthropods are more effective repellents than those of terrestrial or cryptozoic arthropods. Phenolic compounds are more effective than carboxylic or acidic compounds. Repellency is most effective in compounds of reduced water solubility. Repeated exposure to gradually increasing molar concentrations of benzoic acid resulted in a greater acceptability of this compound to fish predators. It is suggested that Mullerian mimicry systems based on large numbers of species may be susceptible to dilution effects in terms of effectiveness.

Introduction

The techniques by which arthropods actively defend themselves against predation include the use of repellent secretions, spines and stings; these devices are often reinforced by aposematic colours and sounds. Such defenses may occur singly or in combination and may be effective against a broad spectrum of predators or against just a few (Eisner, 1970). Since different arthropods and their potential predators share varying degrees of niche overlap, defensive techniques often occur in highly specific contexts and are more effective against one group of predators than another (Schildknecht et al., 1966; Rothschild and Kellett, 1972). By contrast, the repeated occurrence in very different habitats of certain defensive secretions (Table 1) may suggest that arthropods produce substances which are general repellents to a wide variety of predators.

The complexity of predator-prey relationships makes it unlikely that the effectiveness of any single arthropod defensive technique can be accurately assessed in whole animal interactions. For this reason, we have tested a series of defense chemicals, each of which is known to be secreted by various arthropods, on a potential fish predator in order to assess the following: a) the basic and relative repellency of each compound; b) trans-habitat effectiveness of the repellents; c) mimetic inter-
actions among repellents; d) whether continuously repeated exposure to a repellent can lead to tolerance on the part of a predator; e) whether there are any factors unique to arthropod chemical defense in an aquatic context.

Materials and Methods

Chemicals. Twenty-five known arthropod defensive secretions were selected for testing (Table 1) and obtained commercially (Schuchardt, Munich; Merck, Darmstadt). All compounds were of gas chromatographically pure grade. The compounds were classified as representative of open-field terrestrial, cryptozoic, or aquatic habitats depending on the general occurrence of the arthropods producing the compounds. The amount of secretion emitted by an arthropod at any one time is extremely variable, ranging from $10^{-10}$ to $10^{-5}$ moles (Waterhouse and Gilby, 1964; Eisner et al., 1967). Therefore an intermediate standard of $6 \times 10^{-7}$ moles was selected to estimate the basic repellency of each compound (Table 2). Watersoluble compounds were dissolved in distilled water; waterinsoluble compounds were all liquids. For the data in Table 4, all of the compounds were prepared in pure ethanol.

Animals. An omnivorous fish, *Tilapia sparmanni* (Perciformes, Cichlidae), was chosen as the test predator. The fish were obtained from a local dam by hook and were kept in a large tank until their wounds healed and their feeding behaviour returned to normal (one month). They were then divided into 4 groups of 15-16 fish and transferred to four aerated tanks of 50 litre capacity. The sides of the tanks were made opaque. The fish were fed bread pellets (40 mg) daily until adjusted to the new tanks.

Experimental Procedures. Twenty-five compounds were tested for the experiments summarized in Tables 2 and 3, the testing regimen for each tank consisted of 20 bread pellets (“surrogate arthropods”) each day of which 15 were controls (untreated) and 5 were topically treated with a compound identified in arthropod defensive secretions. The order of presentation of the control and the treated pellets and the choice of chemical used were determined by sets of assigned random numbers. On the first day 5 chemicals were chosen for each tank. On the second day the remaining twenty compounds were reassigned random numbers, and five of these compounds were tested in the same manner as those tested on the first day. The sequence was repeated on subsequent days until each chemical had been assayed 4 times per tank, or a total of about 16 times. The pellets were of uniform size and were handed to the observer through a screen. The observer therefore was ignorant of the chemical used and of their order of presentation. Testing was conducted at the same time each day.

In another series of experiments the concentration threshold data were obtained from 2 new groups of 15 fish each tested in the same way (Table 4). In the last series of experiments another four groups of fish were used to obtain the concentration-response curve for benzoic acid shown in Fig. 1.

Preliminary observations established that a response interval of 30 seconds was sufficient to measure fish reaction to a given pellet and this interval was applied in all tests. The air supply to each tank was cut off prior to testing in order to minimize bulk movement of the fluids. The water in each tank was replaced each day after testing.

Bioassays. Fish reaction to each pellet was initially recorded in terms of the following behavioural descriptors: 1. in = taking the pellet into the mouth, closing the mouth, then releasing the pellet making it further available to the same or other