TAXONOMIC DIFFERENCES BETWEEN BIRDS AND MAMMALS IN THEIR RESPONSES TO CHEMICAL IRRITANTS

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INTRODUCTION

Ninety-five products are registered with the U.S. Environmental Protection Agency as bird damage control chemicals, but 38 (40%) are non-lethal chemical repellents (Eschen and Schafer, 1986). Of these products, the active ingredients in 27 (71%) are methiocarb (a physiologic repellent that acts through food avoidance learning) or polybutene (a tactile repellent). In general, chemical repellents are effective either because of aversive sensory effects (irritation), or because of post-ingestional malaise (sickness). If the former, then chemicals are usually stimulants of trigeminal pain receptors (i.e., undifferentiated free nerve endings) in the nose, mouth, and eyes (Mason and Otis, 1990). Although many birds possess adequate olfactory and gustatory capabilities (e.g., Berkhoudt, 1985, Kare and Mason, 1986) smell and taste, per se, are rarely of consequence for bird damage control. Here, we address chemosensory repellents only.

Trigeminal chemoreception is a component of the common chemical sense, and its biological function appears to be the initiation and mediation of protective reflexes (Green et al., 1990). While the morphological organization of the peripheral trigeminal system in birds and mammals is similar, there are broad functional discrepancies (Kare and Mason 1986). Thus, the avian trigeminal system is essentially unresponsive to strong mammalian irritants, such as capsaicin (Szolcsanyi et al., 1986).

Explanation of this taxonomic difference is of fundamental interest. For example, it could reflect phylogenetic constraints present at the time of divergence for each group, or an evolutionary response to selective pressures relating to the chemical ecology prevailing at the time of divergence. Explanation of the taxonomic difference also is of practical interest, because it might lead to the systematic identification of new avian repellents. To this end, we are examining derivatives of a basic phenyl ring structure to develop a chemical model of avian repellency. Our presumption is that repellency and irritation are isomorphic (Mason et al., 1989).

CHEMISTRY

Both methyl and dimethyl anthranilate are repellent to birds at concentrations that are accepted by mammals (Glahn, 1989). Avoidance of these ester derivatives of anthranilic acid is based on odor quality and irritation (Mason et al., 1989). To humans, both have a grape-like or fruity odor, and a slightly bitter, pungent taste (Furia and Bellanca, 1975). Methyl anthranilate is a commonly used grape flavoring in human food preparations (Furia and Bellanca, 1975), and is the chemical traditionally blamed for the "foxy" quality of red wines produced from *Vitis lambrusca* grapes (Amerine and Singleton, 1966; Broadbent, 1970). The term "foxy" presumably is derived from the colloquial name of the Concord grape (i.e., fox grape), and there are suggestions that wines from *V. lambrusca* have an "animal-den" odor (Amerine and Singleton, 1966).

There is at least one other chemical responsible for the "foxy" off-flavor of some red wines. Ortho-aminoacetophenone has an odor similar to that of methyl anthranilate, and is structurally similar, differing only in the substitution of a ketone for an ester group (Acree et al., 1990). Coincidentally, ortho-aminoacetophenone is present in the scent glands of a variety of mammalian species (Novotny et al., 1990; Hall, 1990), including mustelids that prey on birds (Acree et al., 1990).

Our attempts at chemical modelling have focused on isomers of aminoacetophenone and anthranilate derivatives, and we have used behavioral tests of European starlings (*Sturnus vulgaris*) to measure aversiveness. This bird is used as the test species for several reasons. First, starlings exhibit good chemical sensing abilities (Mason and Silver, 1983; Clark and Mason, 1987). Also, data on the responsiveness of starlings to irritants is available (e.g., Mason et al., 1989; Glahn et al., 1989). Finally, starlings are considered agricultural pests (Besser et al., 1968).

Initially, we found that the strength of repellency was related to resonance of lone electron pairs and intramolecular hydrogen bonding (Mason et al., 1991). Subsequent studies showed that hydrogen bonding is not required for repellency, though it may play an ancillary role (Clark and Shah, 1991). Also, we verified that increased electron donation and/or decreased electron withdrawal to the phenyl ring enhances repellency (Shah et al., 1991). At present, our investigations are designed to more precisely determine the influence of basicity, pi cloud planarity, and electron donating and withdrawing groups on avian repellency. A detailed discussion of on-going attempts to relate chemical structure with behavioral activity is provided by Shah et al. in the present volume.

APPLICATIONS

Agriculture

Birds damage ripening grain (Dolbeer, et al., 1982; Bullard et al., 1981; Dolbeer et al. 1978; Henne et al., 1979) and fruit crops (Hothem et al., 1981; Tobin et al., 1989a,b; Avery et al., 1991; Hobbs and Leon, 1988). Although bird depredation on vegetables, nut crops, and legumes is less publicized, it is a common complaint among growers (Mott et al., 1972). In addition to depredation losses, *per se*, damage results in higher levels of insect damage and spoilage (Woronecki et al., 1980). The economics of damage varies greatly. For example, a 1972 survey of sunflower fields in North Dakota and Minnesota showed that the mean loss to birds was only 13 kg/ha (Besser, 1978). Because 174,500 ha were planted in sunflower during that year, we estimate that the national loss was 2,270 metric tons (Woronecki et al., 1980). At an average value of $230 per metric ton (Cobia, 1978), bird damage cost growers $522,100. On the other hand, Avery et al. (1991) estimate that birds destroyed nearly 11% of the national blueberry crop in 1989. Because total blueberry production in 1989 was 158 million pounds, and the average price was $0.50/pound, bird damage may have cost growers as much as $8.5 million from a total market size of $77.3 million.

Non-food crops also are damaged. Turf (Laycock, 1982), flowers [e.g., orchids and anthurium (Cummings et al., 1990)], and cover crops are lost. Because some non-food crops remain in the field for years, damage can be cumulative and costly. Estimates of annual bird damage to orchids grown in the Hawaiian Islands are as high as 75% of the total crop; the 1985 market value of Hawaiian orchids exceeded $12 million (Kefford et al. 1987), representing a potential loss of $9 million.

Apart from field crops, bird damage has been documented in feedlots and at grain storage operations (Twedt and Glahn, 1982). Birds are a vector for transmissible gastroenteritis (Pilchard, 1965), tuberculosis (Bickford et al., 1966), and avian influenza. As predators, birds prey on livestock (Phillips and Blom, 1988), and take fish from pound nets (Craven and Lev, 1988) and fish-culture ponds (Parkhurst and Brooks, 1988). Estimates of bird damage to catfish operations in the Mississippi delta exceed $5 million annually (Stickley and Andrews, 1989).

A potentially more important problem than agricultural loss is the hazard that modern agricultural practices present to birds. Pelleted chemicals and chemically treated seeds are essential to no-till conservation farming, a practice that will be used on 60% of the nation's cropland by the year 2010 (Crosson, 1982). This technique generally benefits wildlife by providing cover and food (Castrale, 1987), and is environmentally safe (Greig-Smith, 1987). However, pelleted chemicals and treated seeds present dangers to birds that accidentally ingest them (Best and Gionfriddo, 1991); most granular insecticides are highly toxic to birds (Schafer et al., 1983).

Chemosensory repellents might be used to resolve many of the problems above. For example, methyl anthranilate or a similar substance (e.g., orthoaminoacetophenone) could be added to livestock feeds to repel birds without affecting consumption by livestock (Glahn et al., 1989). Not only is bird consumption of feed essentially eliminated, but bird numbers at treated sites are significantly reduced (Figure 1). Similarly, chemosensory repellents are effective when applied to nonfood crops like orchids.

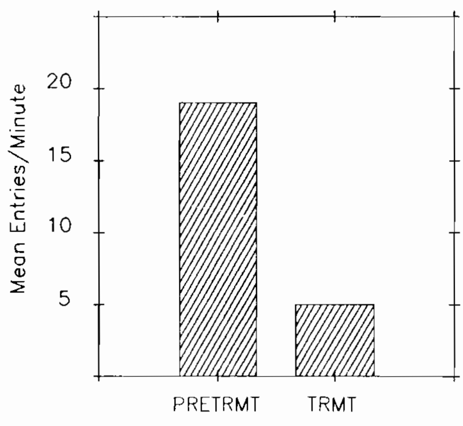

Fig. 1. Mean bird entries per minute of undisturbed pretreatment and treatment (1.0% dimethyl anthranilate) observation at test sites in Kentucky, 1988

Finally, formulated agricultural chemicals can be treated with a chemosensory repellent to reduce nontarget hazards to birds (T. Miller, pers. commun.). For any application, an especially promising strategy may be to combine chemosensory repellents with other cue sources. Ecologically, the superiority of redundant cues is predictable from studies of predator-prey interactions. Toxic prey often use multiple aposematic signals to advertise unpalatability to predators (Wickler, 1968). Redundancy may decrease ambiguity, or might affect different types of predators (Mason, 1989).

Conservation

Industrial by-products and mine effluvia often are stored in open outdoor impoundments. Although the impoundments meet federal and state regulations for the protection of ground water, they pose serious risks to wildlife (Allen, 1990). Waterfowl, shorebirds, and other species are attracted to the freestanding water and risk both acute and chronic poisoning (Ohlendorf et al., 1989).

Birds also are a problem at airport (Blokpoel, 1976). In 1989, the economic loss to U.S. Military operations caused by bird strikes was about $80 million, while civilian losses were about $100 million (R.A. Dolbeer, pers. commun.). In many instances, birds are attracted to airports because of free-standing water that accumulates on paved surfaces. As for mining operations, traditional hazing methods, are ineffective because birds habituate to the harassment or simply move from one location to another.

Chemosensory repellents can be used to reduce consumption and use of free-standing water (Figure 2) (Clark et al. 1991). It is possible that these substances could be used as aversive additives to waste water or fresh water puddles at airports. At presant, the greatest obstacle to use is the lack of delivery technologies that insure an even distribution of repellent over the pond surface.

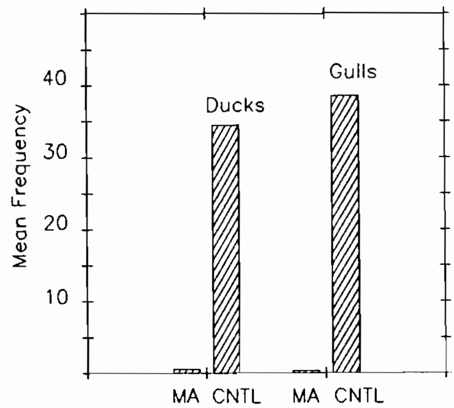

Fig. 2. Mean numbers of swimming bouts by mallards (Anas platyrhynchos) and ring-billed gulls (Larus delawarensis) in treated (0.5% methyl anthranilate, MA) or control (CNTL) pools; Ohio, 1990.

CONCLUSIONS

There is a clear taxonomic difference between birds and mammals in their responsiveness to chemosensory irritants. To date, we have not identified a single mammalian substance also avoided by birds. This observation has diverse practical implications. There are basic implications as well. Perhaps, avian insensitivity to mammalian irritants reflects phylogenetic constraints or an evolutionary response to some unknown selective pressure. One possible explanation might lie with the plants that produce many chemical irritants. Capsaicin illustrates this possibility. Although there is information about the repellency of this material to mammals, its gastronomic significance, and its importance as a neurotoxin, there is little if anything published concerning the biological role of this material. Maybe capsaicin was selected to act as a deterrent to seed predators (i.e., mammals), without influence on seed dispersal agents (i.e., birds). This explanation is especially interesting to us, because many plant manufactured compounds, including piperine, zingerone, gingerol, and mustard oil are repellent to mammals but not birds. Striking though it seems, there are to our knowledge no experimental tests of this proposition.

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