Chemical Constituents of the Femoral Gland Secretions of Male Tegu Lizards (*Tupinambis merianae*) (Family Teiidae)

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In spite of the importance of chemical signals (pheromones) in the reproductive behaviour of lizards, the chemical compounds secreted by their femoral glands, which may be used as sexual signals, are only known for a few lizard species. Based on mass spectra, obtained by GC-MS, we found 49 lipophilic compounds in femoral gland secretions of male tegu lizards (*Tupinambis merianae*) (fam. Teiidae), including a very high proportion of carboxylic acids and their esters ranging between n-C_8 and n-C_{20} (mainly octadecanoic and 9,12-octadecadienoic acids), with much less proportions of steroids, tocopherol, aldehydes, and squalene. We discuss the potential function of these compounds in secretions, and compare the compounds found here with those documented for other lizard species.

Key words: Tegu Lizard, Femoral Glands, Fatty Acids, Steroids

Introduction

Chemical signals are important in intraspecific communication and sexual selection of many reptiles (Mason, 1992; Mason and Parker, 2010; Martín and López, 2011). Males of many lizard species secrete chemical compounds from the femoral or precloacal glands (Alberts, 1993; Weldon *et al.*, 2008) that may function as pheromones (Mason and Parker, 2010; Martín and López, 2011). Multiple pheromone compounds in femoral gland secretions seem to inform about the characteristics and health state of a male (López *et al.*, 2006; Martín *et al.*, 2007a). This information may be used by females to select scent marks of some individual males, which suggests pheromonal mate choice (*e.g.*, Martín and López, 2000, 2006a; López *et al.*, 2002, 2003; Olsson *et al.*, 2003; López and Martín, 2005a). Compounds in femoral gland secretions may also provide information on fighting ability or dominance status to other males (Aragón *et al.*, 2001; Carazo *et al.*, 2007; Martín *et al.*, 2007b).

Femoral gland secretions are composed of both lipids and proteins, but some specific lipophilic compounds (*i.e.* steroids and fatty acids) seem to be the main compounds involved in pheromonal communication (Mason, 1992; Martín and López, 2006a, 2010a, 2011). Although the types of compounds in secretions are similar in different lizard species, the presence and abundance of specific compounds vary widely between species (Weldon *et al.*, 2008), which might be due to phylogenetic or environmental differences (Alberts, 1992; Escobar *et al.*, 2003; Martín and López, 2006b). However, the chemical composition of femoral gland secretions has been analysed in only a few lizard species (reviewed in Weldon *et al.*, 2008). Most information relates to European lizards of the family Lacertidae (López and Martín, 2005b, c, 2006, 2009; Martín and López, 2006b, c, 2010b; Gabirot *el al.*, 2008; Kopena *et al.*, 2009), American lizards of the families Iguanidae (Weldon *et al.*, 1990; Alberts *et al.*, 1992) and Liolaemidae (Escobar *et al.*, 2001, 2003), and an African cordylid lizard (Louw *et al.*, 2007). However, there are many lizard species within other taxonomic lineages and geographical areas that have femoral pores with abundant secretions, which have never been chemically analysed, in spite of secretions being often related to chemical communication (see reviews by Weldon *et al.*, 2008; Mason and Parker, 2010). To understand the composition and role of femoral gland secretions of lizards, we need more studies that deal with a wider range of lizard taxa and consider a larger variety of environmental conditions.

The tegu lizards of the genus *Tupinambis* (Sauria: Teiidae) comprise a group of carnivorous lizards of large size (adult body weight of up to 8 kg) that inhabit the South American plain, east of the Andes (Presch, 1973; Fitzgerald *et al.*, 1999). One of the southernmost species is the Argentine black and white tegu, *Tupinambis merianae* (formerly *T. teguixin*) (Cei and Scolaro, 1982). This lizard has well developed femoral glands, but secretions are only found in males during the short mating season that occurs around October (Noriega *et al.*, 2002; Manes *et al.*, 2007; Chamut *et al.*, 2009). The discharges of each gland unit merge into a solid cylinder of secretion, surrounded by epithelial cells, which is extruded to the exterior (Chamut *et al.*, 2009). There are no specific studies on the role of chemical cues in reproduction of tegu lizards, but these lizards show a series of distinctive reproductive behaviours, including characteristic territorial scent marking (Mercolli and Yanosky, 1989; Fitzgerald *et al.*, 1991; Noriega *et al.*, 1996). During scent-marking, males typically rub their thighs and cloacal region on the ground (Mercolli and Yanosky, 1989; Fitzgerald *et al.*, 1991; Noriega *et al.*, 1996). This behaviour abrades the secretion cylinders from the femoral glands, leaving a trail of odour on the soil (Chamut *et al.*, 2009). The tongue-flicking responses and the overlapping of territorial scent marks, when some males were replaced by others, indicate the presence and response to secretions on the substrate (Chamut *et al.*, 2009). All these observations suggest that femoral glands play an important role in the reproductive behaviour of tegu lizards, presumably by releasing pheromones.

In *T. merianae*, the weak staining of cells in the femoral glands by Sudan Red indicates the presence of lipids in the secretion (Chamut *et al.*, 2009). However, the chemical compounds in femoral gland secretions of this lizard are unknown. Moreover, there are no studies on the chemical composition of any lizard species belonging to the family Teiidae. In the present paper, we report the results of an analysis by gas chromatography-mass spectrometry (GC-MS) of the lipophilic fraction of femoral gland secretions of male tegu lizards (*T. merianae*) from an Argentinean population.

Material and Methods

We collected femoral gland secretions from eight adult male *T. merianae*, between 2 and 7 years old, during October 2009, coinciding with the mating season. Lizards came from the breeding colony of the experimental farm at the Faculty of Agronomy and Zootecnia of the National University of Tucumán in Northern Argentina. Original specimens were captured in the province of Santa Fe (centre Argentina) and donated to us by the "El Gringo" hatchery (Sa Pereira, Province of Santa Fe, Argentina). The breeding stock consisted of groups of one male and five or six females, housed in open-air pens. The pens were surrounded by masonry walls, 1.2 m high; each pen contained a shelter, which provided shade and allowed each individual an area of 2 m^2. The animals were fed *ad libitum* with a hatchery diet (Vega Parry and Manes, 2000). The lizards were weighed [body mass, (4.46 ± 0.98) kg; range, 3.36–6.85 kg] and their snout-vent length (SVL) was measured [(44.81 ± 3.15) cm; range, 42–52.5 cm]. The lizards had an average of 24 ± 2 (range, 22–26) femoral pores on each leg.

We extracted the secretion cylinders from the femoral pores of the lizards using slim pliers, and kept the secretions in glass vials closed with Teflon-lined stoppers. Vials were stored at –20 °C until analyses. We also used the same procedure, but without collecting secretion, to obtain blank control vials that were treated in the same manner to compare with the lizards samples to be able to exclude contaminants from the handling procedure and for examining impurities in the solvent.

We analysed the samples with a ThermoQuest (Austin, TX, USA) Trace 2000 gas chromatograph fitted with a poly(5% diphenyl/95% dimethylsiloxane) column (Trace TR-5, 30 m in length, 0.25 mm ID, 0.25 μm film thickness; Thermo Fisher Scientific Inc., Waltham, MA, USA) and a ThermoQuest Trace 2000 mass spectrometer as detector. The samples, 2 ml of each sample dissolved in *n*-hexane (capillary GC grade; Sigma-Aldrich Chemical Co., St. Louis, MO, USA) were injected in the splitless mode with an inlet temperature of 280 °C. The gas chromatograph was programmed so that the oven temperature was kept at 50 °C for 3 min, increased to a final temperature of 300 °C at a rate of 5 °C/min, and kept at this temperature for 15 min. The carrier gas was helium at 30 cm/s. Ionization by electron impact (70 eV) was carried out at 220 °C. Mass spectral fragments below *m/z* 46 were not recorded. Impurities identified in the solvent and/or the control vial samples are not reported. Initial identification of secretion components was performed by comparison of sample mass spectra with those in the NIST/EPA/NIH 1998 computerized mass spectral library. When possible, identifications were confirmed by comparison of spectra and retention times with those of authentic standards (from Sigma-Aldrich Chemical Co.).

Results

A total of 49 lipophilic compounds were identified in femoral gland secretions of male *T. merianae* (Table I). The main components were carboxylic acids and their esters ranging between n-C_8 and n-C_{20} (93.9% of TIC), nineteen steroids (3.2%), three forms of tocopherol (2.1%), eight aldehydes (0.7%), squalene (0.06%), and other minor compounds. The major compounds were detected in all individuals, although the relative proportions of some compounds showed inter-individual variability. On average, the two most abundant compounds were octadecanoic acid (57.8% of TIC) and 9,12-octadecadienoic acid (26.3%), followed by lower amounts of hexadecanoic acid (7.3%), D-α-tocopherol (2.0%), and cholest-4-en-3-one (1.3%).

Discussion

Femoral gland secretions of tegu lizards contain a very high proportion of fatty acids and their esters. Similar fatty acids, but in much lower proportions, have been found in secretions of most other lizard species examined (Weldon *et al.*, 2008). Moreover, it is notorious to find in tegu lizards such a high proportion of octadecanoic and octadecadienoic acids. The function of these fatty acids in femoral gland secretion is unknown, but both fatty acids and their esters are odoriferous and have pheromonal activity in, for example, many insects. Thus, it is likely that these fatty acids also might have a similar function in tegu lizards.

Particularly, it was surprising to find in the secretions large amounts of 9,12-octadecadienoic acid (= linoleic acid). This unsaturated ω-6 fatty acid has been found in secretions of other lizards but always in very small amounts (Weldon *et al.*, 2008). Alberts *et al.* (1992) found that femoral gland secretions of green iguanas contain a higher abundance of unsaturated fatty acids during the mating season, which may enhance the volatility and detectability of scent marks. Interestingly, analyses of the fatty acids in the fat and muscle tissue of tegu lizards indicated that linoleic acid is one of the more abundant fatty acids, and that it is more abundant in the fat of this lizard than in other animals (Caldironi and Manes, 2006; Ferreira *et al.*, 2009). However, the relative proportion of fatty acids in femoral gland secretions of this lizard is different from that found in its fat (see Ferreira *et al.*, 2009).

However, secretion of large amounts of linoleic acid must be costly for the lizards, because it is one of two essential polyunsaturated fatty acids (linoleic and arachidonic acids) that many animals must ingest for good health. They are required for various biological processes, not just for producing energy, but cannot be synthesized from other food components, and are considered essential fatty acids (Burr *et al.*, 1930). In the skin of vertebrates, they maintain the epidermal water barrier (Hansen and Jensen, 1985) and are metabolized by skin epidermal enzymes generating potent biologically active oxidative metabolites. Linoleic acid is used in the biosynthesis of 8,11,14-eicosatrienoic acid (dihomo-γ-linolenic acid, DGLA), which is also found in femoral gland secretions of *T. merianae*. DGLA is transformed into arachidonic acid, and finally into some prostaglandins, hydroxy fatty acids, prostacyclin, and thromboxanes, which mediate many physiological responses and maintain homeostasis and health (Cunnane and Anderson, 1997; Ruthig and Meckling-Gill, 1999; Ziboh *et al.*, 2000).

Given the dietary origin and the important functions of linoleic acid in metabolism, its actual function in femoral gland secretions of *T. merianae* must be of sufficient importance to divert it from metabolism and "secrete" it from the body. It is likely that only males with an adequate dietary supply could secrete it. As it occurs in other lizard species, the presence of "costly" compounds (*e.g.* vitamin E, pro-vitamin D) in scent marks of males may be used by females as an index of the quality of a male or of its territory, which can affect female mate choice decisions (Martín and López, 2006a, d, 2011). Nevertheless, the function of linoleic acid and other compounds in secretions of *T. merianae* lizards remains to be analysed properly.

In contrast to the abundance of fatty acids, steroids are relatively little represented in *T. merianae*, whereas steroids are the most abundant compounds in many lacertid or iguanid lizards (Weldon *et al.*, 2008). Particularly noteworthy

Table I. Lipophilic compounds found in femoral secretions of adult male tegu lizards, *Tupinambis merianae*. The relative content of each component was determined as the percentage of the total ion current (TIC) and is reported as the average (± SE) for eight individuals. Characteristic ions (*m/z*) are reported for some unidentified compounds (in brackets).

RT[a] [min]	Compound	Content (%)
13.1	Nonenal	0.01 ± 0.01
15.8	Octanoic acid	0.01 ± 0.01
16.2	Decanal	0.02 ± 0.01
18.8	2,4-Decadienal	0.06 ± 0.02
19.4	2,4-Dodecadienal	0.06 ± 0.02
28.7	Tetradecanal	0.03 ± 0.01
29.9	Tetradecanoic acid	0.03 ± 0.01
30.9	Hexadecanal	0.37 ± 0.07
31.4	6,10,14-Trimethyl-2-pentadecanone	0.01 ± 0.01
32.0	Pentadecanoic acid	0.04 ± 0.01
32.9	Octadecenal	0.03 ± 0.01
33.0	Hexadecanoic acid methyl ester	0.01 ± 0.01
34.1	Hexadecanoic acid	7.34 ± 0.48
34.8	Octadecanal	0.13 ± 0.05
35.8	Heptadecanoic acid	0.66 ± 0.14
36.1	5,8,11-Heptadecatrienoic acid methyl ester	0.09 ± 0.03
36.2	9,12-Octadecadienoic acid methyl ester	0.17 ± 0.07
36.8	Octadecanoic acid methyl ester	0.01 ± 0.01
37.4	9,12-Octadecadienoic acid	26.26 ± 2.71
37.9	Octadecanoic acid	57.78 ± 2.80
40.4	8,11,14-Eicosatrienoic acid	0.84 ± 0.22
40.8	4,8,12,16-Tetramethylheptadecan-4-olide	0.10 ± 0.04
40.9	Waxy ester of hexadecanoic acid	0.07 ± 0.03
42.2	9,12-Octadecadienoic acid ethyl ester	0.02 ± 0.01
43.7	9,12-Octadecadienoic acid 1-methylethyl ester	0.03 ± 0.01
44.6	Unidentified steroid (133, 191, 267, 337, 388)	0.02 ± 0.01
47.3	Unidentified steroid (191, 204, 281, 315, 357, 385, 416)	0.02 ± 0.01
47.6	Squalene	0.06 ± 0.01
48.1	Unidentified steroid (137, 153, 403, 420)	0.05 ± 0.01
48.4	Unidentified steroid (137, 153, 343, 369, 403, 420)	0.06 ± 0.01
48.6	Cholesta-4,6-dien-3-ol	0.61 ± 0.14
48.9	Cholesta-3,5-diene	0.03 ± 0.01
49.7	Unidentified form of tocopherol	0.07 ± 0.02
49.8	Unidentified steroid (197, 251, 376)	0.01 ± 0.01
50.9	γ-Tocopherol	0.05 ± 0.01
51.9	D-α-Tocopherol	1.99 ± 0.27
52.4	Cholestan-3-one	0.07 ± 0.02
53.0	Cholesta-3,5-dien-7-one	0.11 ± 0.02
53.3	Campesterol	0.05 ± 0.03
53.5	Cholest-4-en-3-one	1.26 ± 0.53
53.9	Cholesta-4,6-dien-3-one	0.34 ± 0.08
54.1	4,22-Cholestadien-3-one	0.17 ± 0.04
54.2	Unidentified steroid (165, 191, 245, 257, 369, 410, 424)	0.01 ± 0.01
54.3	Waxy ester of octadecenoic acid	0.48 ± 0.12
54.9	Unidentified steroid (257, 297, 315, 340, 359, 396)	0.01 ± 0.01
55.1	Cholest-5-en-3-one	0.06 ± 0.02
55.5	Unidentified steroid (173, 253, 268, 368, 393)	0.02 + 0.01
55.9	Cholest-4-ene-3,6-dione	0.20 ± 0.05
56.5	Stigmast-4-en-3-one	0.06 ± 0.02

[a] RT, retention time.

is the absence of cholesterol in secretions of *T. merianae*, which is ubiquitous and very abundant in many other lizards. Interestingly, the cholesterol content is also lower in meat (see above) of *T. merianae* than in other meats of similar fat content such as beef, chicken or fish (Caldironi and Manes, 2006). In other lizards, cholesterol was thought to serve the purpose of an unreactive apolar matrix in femoral gland secretions that protects and delivers the compounds that are the true semiochemicals (Escobar *et al*., 2003). A possible explanation of the absence of cholesterol in tegu lizards is the presence of abundant keratin in the secretion cylinders (Chamut *et al*., 2009). The keratin sheets and epithelial layers that surround the secretions form a sort of structural support for lipophilic secretions. Keratin may have a role similar to cholesterol in protecting lipids after secretion cylinders have been abraded on the substrate.

We also found in secretions of *T. merianae* tocopherol and squalene, two well known lipophilic antioxidants (Brigelius-Flohe and Traber, 1999). Their main possible function in secretions might be to inhibit oxidation of other lipids in secretions (see Alberts, 1992), as it occurs in lacertid green lizard species inhabiting wet environments (López and Martín, 2006; Kopena *et al*., 2009; Martín and López, 2010b).

Finally, we also found many aldehydes in the secretions. These are highly odoriferous compounds that might contribute to make the detection of femoral gland secretions easier after they have been deposited. Aldehydes have also been found in some other lizard species, but not in other species even if these were included within the same genus (Weldon *et al*., 2008), so their presence in secretions might depend on the environment or social behaviour of the respective species.

Further studies are clearly needed to understand the patterns of the presence and abundance of different compounds in femoral gland secretions of lizards, and how phylogenetic relationships and environmental conditions can explain the characteristics of these secretions. Also, we need to clarify the possible role of the compounds found in femoral gland secretions as potential signaling pheromones, such as linoleic acid, in social organization and sexual selection processes of tegu lizards.

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