Are local crops home to frogs? A case study in the Ibiapaba Plateau, state of Ceará, Northeast Brazil

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Abstract

Studies investigating the impact of agricultural landscapes on amphibian diversity are crucial to understanding their consequences on amphibian population dynamics. Nevertheless, some environments, such as montane ecosystems, are still understudied. Herein, we describe the anuran composition in several agricultural landscapes of the Ibiapaba Plateau, Ceará State, Northeast Brazil. We performed anuran sampling in January and February 2019, with a total sampling effort of 154 hours by 3 researchers in 29 collection days. We found 170 individuals in 20 species and six families, of which

65% were found in the National Park of Ubajara, Ceará, Brazil. The anuran fauna was similar regardless of the crop type, and the Hylidae and Leptodactylidae had the highest species richness and abundance. Overall, we observed that these crops are usually homes for generalist frogs that are more adapted to disturbed environments. This will support awareness of public policies aimed at herpetofaunal preservation and conservation in this mountain due to the increase of anthropogenic disturbances in these areas.

Keywords: Amphibians, Anthropogenic disturbances, rainforest enclaves.

INTRODUCTION

The environmental changes involving the expansion and retraction of the Amazon and Atlantic Rainforests resulted in the emergence of unique mountain ecosystems in the Caatinga biome, recognized as Relictual Forest Mountains (Andrade-Lima, 1982). These areas are characterized by a milder climate, higher precipitation, and higher humidity than the surrounding lowlands (Lupikasza & Szypula, 2019; Lucena et al., 2022). Because of these environmental characteristics, they provide suitable places for human habitation and are attractive for agricultural practices, resulting in consequences such as habitat fragmentation (Bhatta et al., 2019; Resende et al., 2018). Natural landscapes are replaced by avocado, banana, and sugarcane plantations (Charre-Medellín et al., 2021; Said et al., 2021), resulting in the loss of local biodiversity (Spehn et al., 2010) and consequently the imbalance of ecosystem functions.

Among these Relictual Forest Mountains, the Ibiapaba plateau in the state of Ceará is classified as an area of biological importance (Ab'Sáber, 2003; Tabarelli & Silva, 2003) with a high and unique biodiversity of vertebrates such as reptiles and amphibians (Loebmann & Haddad, 2010). However, this biodiversity is threatened because there has been an increase in anthropogenic areas on this mountain (Lima et al., 2022). Agricultural activities are common in this highland region, and pesticide use is prevalent (Silva et al., 2019). Contaminants such as atrazine, simazine, and methyl parathion have been detected in the surface and underground water supplies of the municipality of Tianguá, in the Ibiapaba plateau (Canuto et al., 2010; Gama et al., 2013; Silva et al., 2019). These contaminants represent a high risk to both human and environmental health.

Aside from agricultural activities, the Ibiapaba plateau is considered a hotspot for amphibians and reptiles in the state of Ceará. The herpetofauna of this mountain is composed of 122 species, of which 71 species (58.2 %) are recorded in the National Park of

Ubajara (Loebmann & Haddad, 2010; Castro et al., 2019). Additionally, some endemisms from the Relictual Forest Mountains occur in the Ibiapaba plateau, such as *Adelophryne baturitensis* Hoogmoed, Borges, and Cascon, 1994 (Hoogmoed et al., 1994) and the newly described *Pristimantis relictus* Roberto, Loebmann, Lyra, Haddad, and Ávila, 2022 (Roberto et al., 2022). These studies were conducted in pristine and protected environments; little fieldwork has been done in buffer zones and anthropized areas.

Studies of the impact of agricultural landscapes on amphibian diversity try to understand and assess the patterns and consequences of populations' dynamics from different perspectives. For instance, to assess which habitat characteristics better contribute to amphibian diversity (Silva et al., 2012; Li et al., 2020), to investigate the richness and abundance patterns (Li et al., 2018), species dispersion (Ribeiro et al., 2019), and reproductive dynamics (Boissinot et al., 2019). In addition, agricultural contaminants can have devastating impacts on amphibian survival and development because anurans are one the most sensitive groups to environmental disturbances (Marcogliese et al., 2009, Camacho-Rozo & Camacho-Reyes, 2022, Pérez-Iglesias et al., 2023).

There has been a human population and agricultural area increase in the Ibiapaba plateau in the last decades (ICMBio, 2002; Ipece, 2018a, b), affecting the local fauna (Araújo et al., 2017; Martins-Neto, 2022). However, the anuran fauna is unknown in these areas. We hypothesize that the growing expansion of land use for pasture and fruit and vegetable production with the intensive use of agrochemicals may negatively alter the assemblage of amphibians on the Ibiapaba plateau. In this study, we described the anuran composition in various crop areas in the Ibiapaba plateau, Ceará state, Northeast Brazil, and compare it with the species recorded in protected areas of this mountain.

MATERIAL AND METHODS

Study area

The present study was carried out on seven agricultural landscapes in the municipalities of Tianguá and Ubajara, both contained within a buffer zone of the National Park of Ubajara, state of Ceará, Northeast Brazil (Fig. 1). Rainfall in these areas are concentrated between January and May, and the mean temperature ranges from 22 °C to 26 °C (Ipece, 2018a, b). The main natural vegetation covers are Tropical seasonal deciduous forest and Tropical seasonal evergreen forest (Silveira et al., 2020). The sampling was conducted in areas with four agricultural crops (AG): AG1 (3º43'25.0" S, 40º57'01.5" W, elephant grass), AG2 (3º43'07.7" S, 40º56'42.5" W, banana), AG3 (3º44'07.7" S, 40º58'17.8" W, bean), AG4 (3º47'37.9" S, 40º55'23.9" W, banana), AG5 (3º48'07.3" S, 40º57'03.0" W, elephant grass), AG6 (3º51'43.6" S, 40º53'57.6" W, sugarcane), and AG7 (3º52'20.8" S, 40º56'00.5" W, sugarcane). The locations were in areas of subsistence agriculture where permanent lentic water ponds were scant but remained humid because they contained an irrigation system. Pesticide use is a common practice in these crops (HTSM, personal observation).

Sampling

Anuran sampling occurred during the rainy season at night between 18 h to 01 h in January and February 2019 using visual and auditory searches (Heyer, 1994). We visited the seven sampling points daily for 40 minutes in each location for 11 consecutive days. The locations were sampled at alternating times during the sampling period to avoid biases in anuran activity. Our total sampling effort was approximately 154 hours/3 researchers. One individual of each species was manually collected, euthanized with an injection of lidocaine (2 %), fixed in 10 % formalin, and preserved in 70 % ethanol (collection permit SISBio-ICMBio: 66902-1). We followed the guidelines established by the National Council for the Control of Animal Experimentation in accordance with Law 11.794 of 2008, article 14 § 1º and with Normative Resolution 37, February 15, 2018 (Concea, 2018) and the recommendations of the Brazilian Guide for the Production, Maintenance or Use of Animals in Teaching or Scientific Research Activities (Jared et al., 2023). Voucher specimens were deposited in the Núcleo Regional de Ofiologia of the Universidade Federal do Ceará (NUROF-UFC), Fortaleza, Brazil. Anuran nomenclature follows Frost (2024), and conservation status follows IUCN (2024).

Statistical analyses

We evaluated the sampling effort through a sample-based accumulation curve with 1000 randomizations from an incidence matrix (Gotelli & Colwell, 2001). Each night of observation corresponded to a sample, resulting in 11 samples. The expected richness was obtained through the estimators Chao1 and Jackknife1 with 100 randomizations (Magurran & McGill, 2011), the diversity patterns through Shannon-Wiener diversity index and Equity of Pielou (Krebs, 2000), and the species dominance through the Berger-Parker index (d).

We used the Jaccard Similarity coefficient J' (Magurran & McGill, 2011) and the ANOSIM test with 1000 permutations to investigate the differences in species composition between each agricultural crop type. The anuran distribution in Brazilian biomes was obtained from literature records (Andrade et al., 2017; Araújo et al., 2020; Frost, 2024). Statistical analyses were performed using the packages BiodiversityR (Kindt & Coe, 2005), and Vegan (Oksanen et al., 2016) for R v.5.6.1 software (R Core Team, 2020).

RESULTS

We found 170 anurans in 20 species (Fig. 2) from the following families: Bufonidae (two species), Hylidae (nine species), Leptodactylidae (six species), Odontophrynidae (one species), Phyllomedusidae (one species), and Strabomantidae (one species). The most abundant species belonged to the families Leptodactylidae and Hylidae, in which *Scinax x-signatus* (Spix, 1824) and *Leptodactylus mystaceus* (Spix, 1824) were dominant. Except for *Pristimantis relictus* (endemic to the Relictual Forest Mountains of Ceará State), all frogs observed are widespread species in Brazil. The conservation status of *Pristimantis. relictus* is unknown because it was recently described, but it is abundant in these mountains. All other frogs observed were classified as 'Least Concern' (LC) according to IUCN Red List Categories and Criteria (IUCN, 2023, see. Table 1).

The species accumulation curve did not reach asymptote (Fig. 3), and the richness estimators Chao 1 (22.4, *sd* = 3.20) and Jackknife 1 (23.6, *sd* = 1.81) suggest at least three more species may occur in the studied areas. Among the seven agricultural landscapes of the Ibiapaba plateau sampled, we observed that the crops AG5 and AG6 were the most similar (j' = 0.55), followed by AG1 and AG4 (j' = 0.53) and AG5 and AG7 (j= 0.44), whereas AG1 and AG6 (J' = 0.13) were the most dissimilar concerning species composition. In addition, there is no significant influence of the agricultural type on anuran composition (R = -0.27, p = 0.76), meaning that regardless of the crop type, these environments usually harbor similar species that are common to anthropized landscapes (Fig. 4).

DISCUSSION

In general, we observed that these agricultural areas harbor more than 50% of the anuran species registered in the Ubajara National Park (Botero et al., 2014; Castro et al., 2019). Herpetofaunal studies carried out in a short period may not always represent the total local richness (e.g., Cavalcanti et al., 2014; Pedrosa et al., 2014), because anurans have different periods and reproductive strategies during the rainy season (Wells, 1977; Crump, 2015), and as a result, some species may reproduce at the beginning, middle, or end of the rainy season. The richness estimators suggest at least three more species may occur in the area; thus, it is likely that some explosive breeding amphibians were not sampled in this study.

Hylidae and Leptodactylidae were the most diverse and abundant families, which is the common pattern for Neotropical regions (Duellman & Trueb, 1994). Similar results were found in other Relictual Forest Mountains where there was a predominance of hylids and leptodactylids (Castro et al., 2019; Freitas et al., 2023; Marques et al., 2023). It is common for habitat-generalist species to be abundant in anurofauna checklists (e.g., Oliveira et al., 2021; Azevedo et al., 2021), including in anthropized environments (Santana et al., 2012; Amorim et al., 2019; Garcia-Neto et al., 2020). Therefore, it is likely that the replacement of forested areas by crops is resulting in local fauna homogenization.

Leptodactylids usually breed near temporary ponds in shaded areas and eggs are laid in underground chambers, shallow flooded areas covered or bare of vegetation, and in foam nests floating in shallow waters (Prado et al., 2000; Hartmann et al., 2010; Kokubum et al., 2009). Likewise, some generalist treefrogs as *Dendropsophus* species, *Scinax x-signatus*, and *Boana raniceps* (Cope, 1862) have deposition of eggs and exotrophic tadpoles in natural or artificial lentic water (Vieira et al., 2009; Crump, 2015). Therefore, these species do not need specialized and complex environments for reproduction, which enable them to inhabit anthropized environments too.

Our results were similar to what other studies found in agricultural landscapes, in which the highest richness and abundance of anurans were composed of generalist species (e.g., Moreira et al., 2014; Guerra & Aráoz 2015; Oda et al., 2016). These studies reinforce findings that some hylids and leptodactylids tend to be abundant in agricultural environments (Prado & Rossa-Feres, 2014; Oda et al., 2016; Diaz-Ricuarte et al., 2022). Thus, the increase of anthropogenic disturbances in different environments might change the local species composition, prevailing habitat generalist species (Ferrante et al., 2017). Nonetheless, more studies are still needed to understand how local crops impact biodiversity as a role.

The studied agricultural areas are home to considerable anuran richness despite being mostly composed of generalist frogs. It is known that anthropized environments influence the community structure and species diversity (Shea et al., 2004). Additionally, the intermediate disturbance hypothesis suggests that local species diversity is influenced by the ecological disturbance frequency (Grime, 1973). This hypothesis was also tested for some anuran communities (e.g., Souza et al., 2008; Westgate et al., 2012), however, further studies are still necessary to understand the main drivers and how the ecological disturbance frequency affects the richness patterns in the study area.

Different factors driven by anthropogenic actions such as hunting, mining, urban expansion, tourism, and energy production affect the Caatinga biodiversity (ICMBio, 2018). The increasing of agricultural lands in mountains, the cities' growth and untenable tourism in the Ibiapaba plateau (Freire-Filho et al., 2018) lead us to raise awareness of public policies that support herpetofaunal preservation and conservation in this "Brejo de altitude", given its high herpetofaunal diversity (Roberto & Loebmann 2016), and biological importance.

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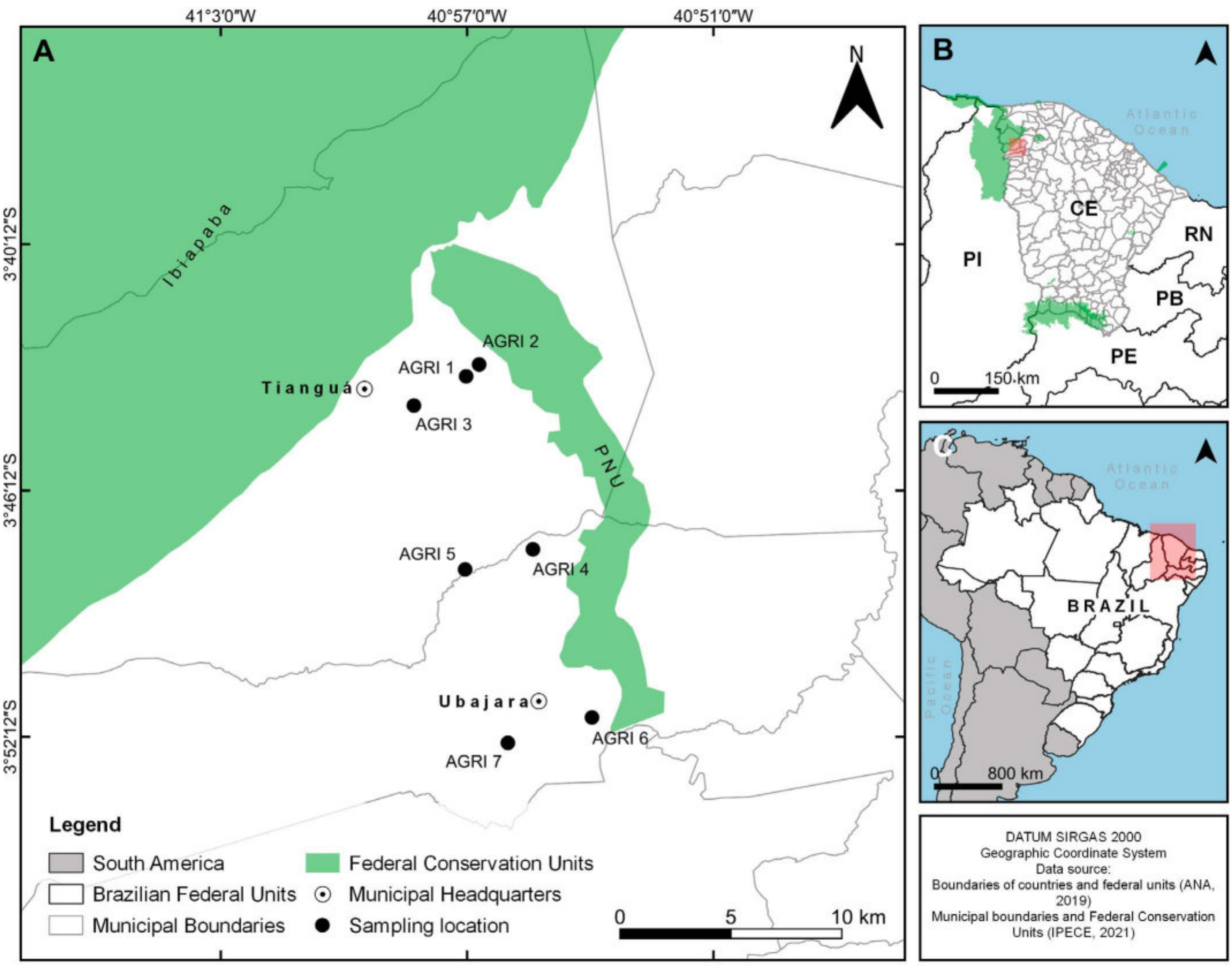

Figure 1. Geographical location of the study area in Ibiapaba plateau, Ceará state, Northeastern Brazil. Agriculture (AG), National Park (PARNA).

Figure 2. Anuran species found in the agricultural landscapes of Ibiapaba plateau, Ceará state, Northeastern Brazil. A = *Rhinella granulosa*; B = *Rhinella diptycha*; C = *Pristimantis relictus*; D = *Boana raniceps*; E = *Boana multifasciata*; F = *Corythomantis greeningi*; G = *Dendropsophus minutus*; H = *Dendropsophus nanus*; I = *Dendropsophus soaresi*, J = *Scinax nebulosus*; K = *Scinax x-signatus*; L = *Trachycephalus typhonius*; M = *Leptodactylus fuscus*, N = *Leptodactylus macrosternum*; O = *Leptodactylus mystaceus*; P = *Leptodactylus troglodytes*; Q = *Leptodactylus vastus*; R = *Physalaemus cuvieri*; S = *Pithecopus gonzagai*; and T = *Proceratophrys cristiceps*.

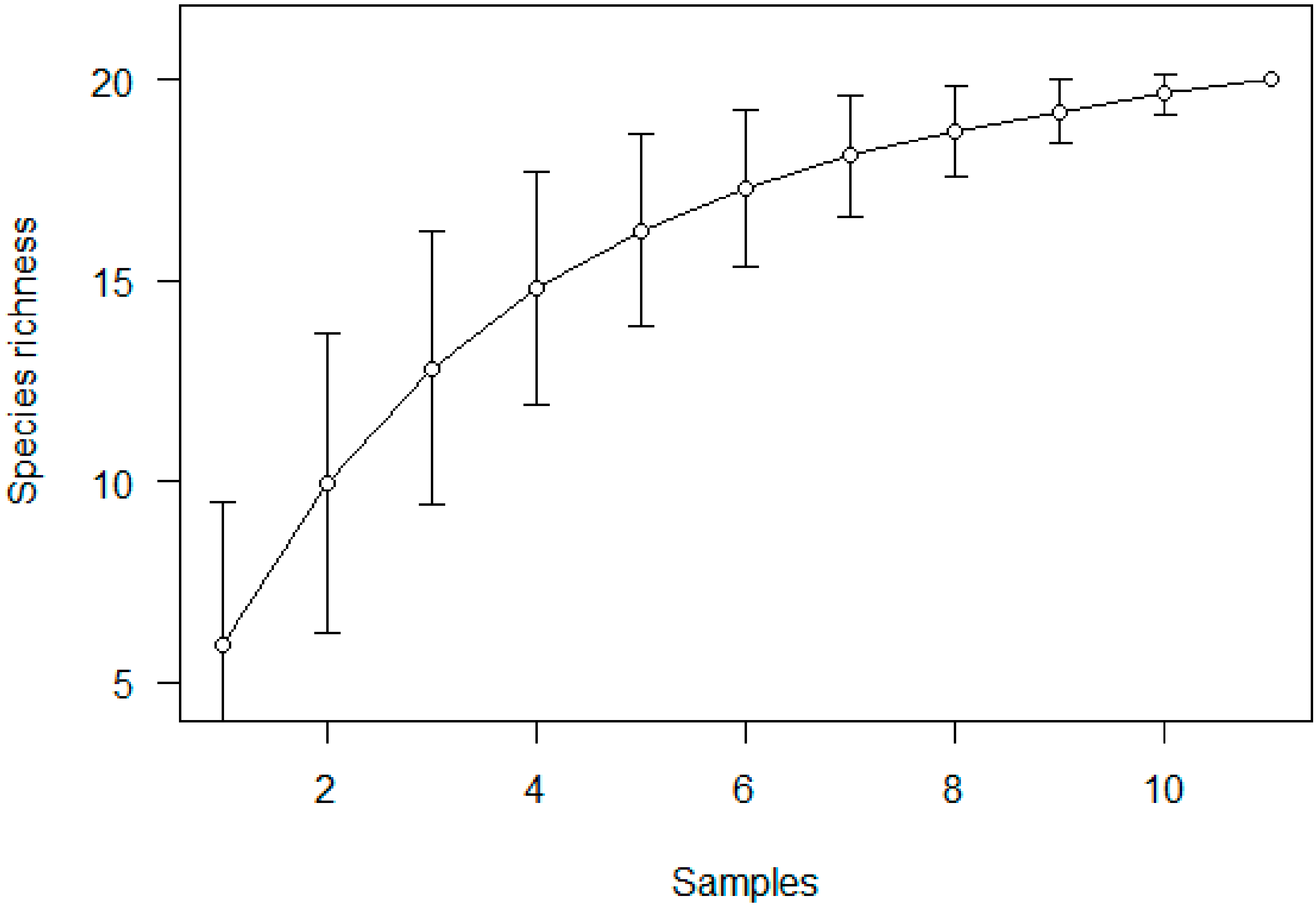

Figure 3. Accumulation curves for anurans sampled in the agricultural landscapes of Ibiapaba plateau, based on the number of samples, constructed from 1000 randomizations.

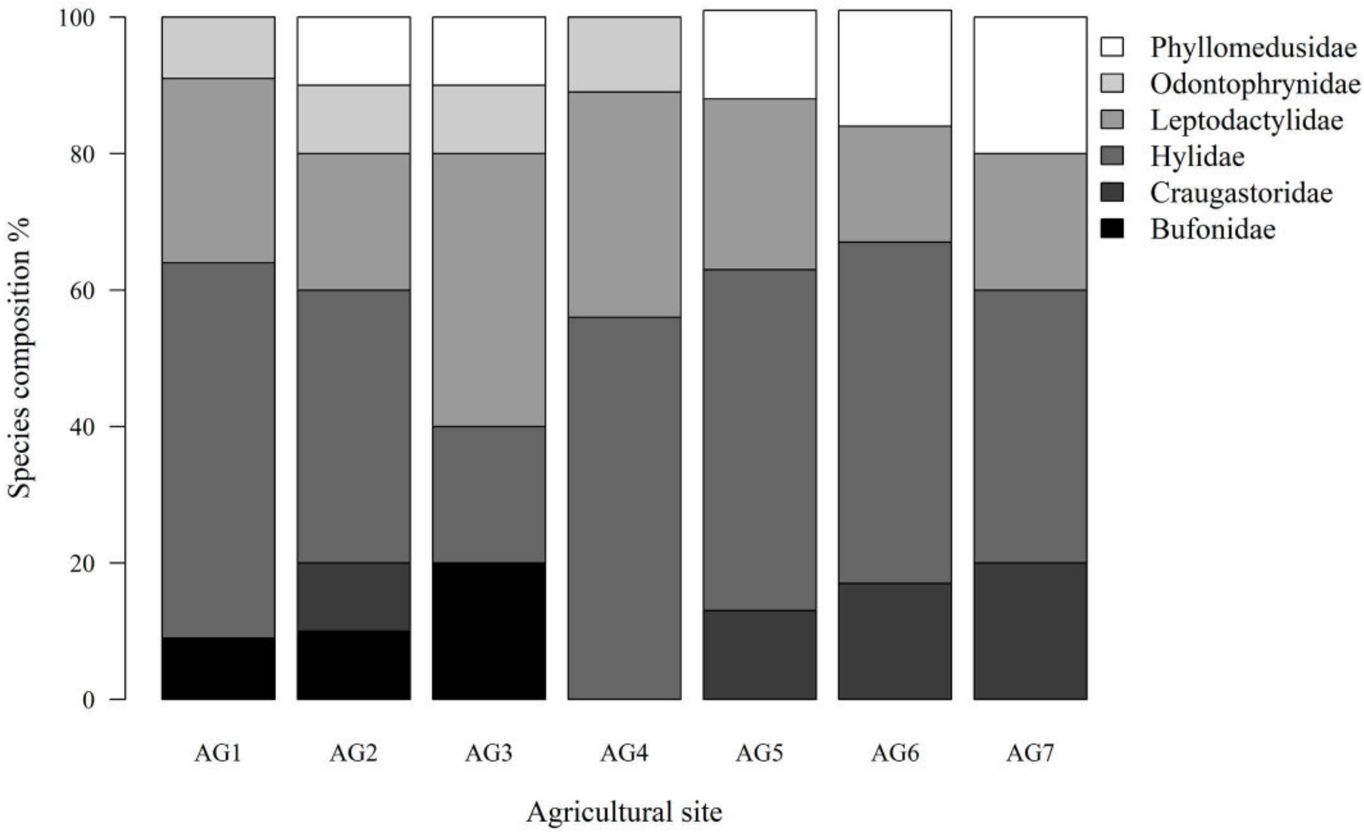

Figure 4. Species composition (%) of the six families found in each local crop in the Ibiapaba plateau, Ceará state, Northeast Brazil

Table 1. Anurans recorded in agricultural landscapes of Ibiapaba plateau, Ceará state, Northeast Brazil. Voucher species, biome of occurrence: Caatinga (CA), Cerrado (CE), Atlantic Rainforest (AT), Amazon Rainforest (AM), and wide distribution (WD). The localities in agricultural landscapes of Ibiapaba plateau where the species were recorded: AG1, AG2, AG3, AG4, AG5, AG6, AG7.

Taxa (author)	Voucher	Biome	Sampled sites
BUFONIDAE			
Rhinella diptycha (Cope, 1862)	CHUFC 15763	WD	1,2,4
Rhinella granulosa (Spix, 1824)	CHUFC 15772	CA, CE, AT	3
HYLIDAE			
Boana raniceps (Cope, 1862)	CHUFC 15774	WD	1,2,4,6
Boana multifasciata (Günther, 1859)	CHUFC 14617	CA, CE, AM	1,2
Corythomantis greeningi Boulenger, 1896	CHUFC 14619	CA, CE, AT	2
Dendropsophus minutus (Peters, 1872)	CHUFC 15994	WD	1,4,5,7
Dendropsophus nanus (Boulenger, 1889)	CHUFC 14609	WD	1,2,3,4,7
Dendropsophus soaresi (Caramaschi and Jim, 1983)	CHUFC 15970	CA, CE, AT	5
Scinax nebulosus (Spix, 1824)	CHUFC 15993	WD	1
Scinax x-signatus (Spix, 1824)	CHUFC 14615	WD	1,3,4,5,6
Trachycephalus typhonius (Linnaeus, 1758)	CHUFC 15861	WD	4,5,6
LEPTODACTYLIDAE			
Leptodactylus fuscus (Schneider, 1799)	CHUFC 15873	WD	3
Leptodactylus macrosternum Miranda-Ribeiro, 1926	CHUFC 15958	WD	1,4
Leptodactylus mystaceus (Spix, 1824)	CHUFC 14611	WD	1,2,3,4,5,7
Leptodactylus troglodytes Lutz, 1926	CHUFC 15835	WD	3,5,6
Leptodactylus vastus Lutz, 1930	CHUFC 14623	WD	2,4
Physalaemus cuvieri Fitzinger, 1826	CHUFC 15887	WD	1,3,4
ODONTOPHRYNIDAE			
Proceratophrys cristiceps (Müller, 1883)	CHUFC 14608	CA, AT	1,2,3,4
PHYLLOMEDUSIDAE			
Pithecopus gonzagai (Andrade *et al.* 2020)	CHUFC 14614	CA, CE, AT	2,3,5,6,7
STRABOMANTIDAE			
Pristimantis relictus (Roberto *et al.* 2022)	CHUFC 14606	CA	2,5,6,7

Table 2. Anuran diversity in the agricultural landscapes studied with data on species abundance, species richness (Jacknife 1 species richness estimator), dominant species (according to the Berger-Parker index), and evenness (Pielou's index).

Sampled sites	Individuals observed	Richness (observed)	Richness (estimated)	Dominant species	Shannon-Wiener	Pielou's index
AG1	25	11	14.3	*Dendropsophus nanus*	2.21	0.92
AG2	28	10	12	*Leptodactylus mystaceus*	2.08	0.90
AG3	54	10	10	*Scinax x-signatus*	2.12	0.92
AG4	19	9	12.3	*Dendropsophus nanus*	1.94	0.88
AG5	15	8	11	*Leptodactylus mystaceus*	1.95	0.94
AG6	17	6	6	*Boana raniceps*	1.69	0.94
AG7	12	5	5	*Leptodactylus mystaceus*	1.51	0.94
Total	170	20	23	*Scinax x-signatus*	2.68	0.89