

FLORISTIC DIVERSITY AND HALOFORAGE POTENTIAL OF HERBACEOUS-SHRUBBY SPECIES RECORDED IN ANTHROPIZED AREAS OF THE FORQUILHA-CE IRRIGATED PERIMETER

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ORIGINAL ARTICLE

ABSTRACT

Caatinga vegetation is an important food source for livestock in the Brazilian Semi-Arid region, and some species show promise as alternative forage options for animal feeding. However, soil salinization in this region has emerged as a problem, compromising agriculture and biodiversity in this biome, leading to economic and environmental impacts. This study aimed to analyze plant communities in anthropized areas of the irrigated perimeter of Forquilha-CE, identifying forage species tolerant to soil salinity. Four collections were conducted in an area of Lot 77 in Sector III of the irrigated perimeter, at four different times between 2021 and 2023 (dry seasons of 2021 and 2022 and rainy seasons of 2022 and 2023), consisting of plant identification and soil sampling. It was recorded a total of 95 species distributed across 30 families, with Malvaceae being the most representative. Eighteen species were identified as halophytic or halotolerant, among which *Cynodon dactylon* (L.) Pers., *Eleusine indica* (L.) Gaertn., *Dactyloctenium aegyptium* (L.) Willd., *Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L. Jacobs, *Distimake aegyptius* (L.) A.R. Simões & Staples, *Calotropis procera* (Aiton) Dryand., and *Lantana camara* L. show promise for research in halophytic forage cultivation programs. Thus, it was possible to record species tolerant to soil salinity with potential use in ruminant feeding.

Keywords: Livestock; Forage; Phytosociology; Caatinga.

RESUMO

A vegetação da Caatinga é uma importante fonte de alimento para a pecuária no Semiárido brasileiro e algumas espécies são promissoras como alternativas de forragem na alimentação animal. No entanto, a salinização dos solos nessa região tem se apresentado como um problema que vem comprometendo a agropecuária e a biodiversidade desse bioma, determinando impactos econômicos e ambientais. O objetivo desse trabalho foi analisar comunidades vegetais presentes em áreas antropizadas do perímetro irrigado de Forquilha-CE, identificando as espécies forrageiras tolerantes a salinidade do solo. Foram realizadas quatro coletas em uma área do lote 77 do Setor III no perímetro irrigado, em quatro épocas entre 2021 e 2023 (estações secas de 2021 e 2022 e quadras chuvosas de 2022 e 2023), constituídas de identificação de plantas e coletas de solo. Foram registradas 95 espécies distribuídas em 30 famílias, onde Malvaceae foi a mais representativa. Dezoito espécies foram identificadas como halófitas ou halotolerantes das quais *Cynodon dactylon* (L.) Pers., *Eleusine indica* (L.) Gaertn., *Dactyloctenium aegyptium* (L.) Willd., *Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs, *Distimake aegyptius* (L.) A.R. Simões & Staples, *Calotropis procera* (Aiton) Dryand. e *Lantana camara* L. são promissoras para pesquisas em programas de haloforraginocultura. Assim foi possível registrar espécies tolerantes à salinidade do solo com potencial de uso na alimentação de ruminantes.

Palavras-chave: Pecuária; Forragem; Fitossociologia; Caatinga.

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1 INTRODUCTION

In 2023, the world population exceeded 8.019 billion inhabitants (USCENSUS, 2024). Despite the decline in the world population growth, the United Nations estimates a global population of over 9 billion people by 2050, with approximately 95% of this growth occurring in less developed countries, which suffer from water and food scarcity. This scenario, along with the effects of climate change, such as droughts and floods intensified by extreme weather events, has placed significant pressure on the agricultural and livestock sectors, compromising their productivity and ability to meet the growing demand for food (Makate, 2019; Costa et al., 2020; Oliveira-Júnior et al., 2021).

High temperatures resulting from global warming along with rainfall reduction have led to an increasing desertification process in some areas, while underground water reserves are becoming more saline due to the growing use of these aquifers and the salt accumulation in the soil of agricultural areas (Fernandes et al., 2016; Costa et al., 2020). Likewise, Shrivastava and Kumar (2015) had already stated that in the future, water scarcity would become one of the main problems for populations in several countries.

Salinization of agricultural areas in arid and semi-arid regions is primarily caused by human activity, especially the improper use of non-conventional quality water in misguided irrigation projects (Souza et al., 2014; Soares Filho et al., 2016; Castro; Santos, 2020). Thus, the demand for food and forage for animal feed is growing in much of the planet, leading to the need for expanding the agricultural frontier to promote new research that enables the reuse of anthropized areas in agricultural production, as is the case in the Brazilian semi-arid region. (Fernandes et al., 2016; Alves et al., 2022).

The semi-arid region of the Northeast, although it presents irregular rainfall and is seen as a risk area for soils degraded by salinization, stands out in the livestock sector at the national level, particularly in sheep and goat farming. However, access to nutritionally adequate food is a limiting factor for the growth of this sector (Freire; Freire; Souza, 2016; Azevedo et al., 2018; Nogueira; Peixoto, 2019). In this sense, the cultivation of species with forage native potential for animal feed that are native to the Caatinga has emerged as a relevant alternative for nutritional supplementation, as these plants are well adapted to the ecological conditions of this biome, despite their low productivity (Antonio, 2015; Alves et al., 2015; Rogério et al., 2020).

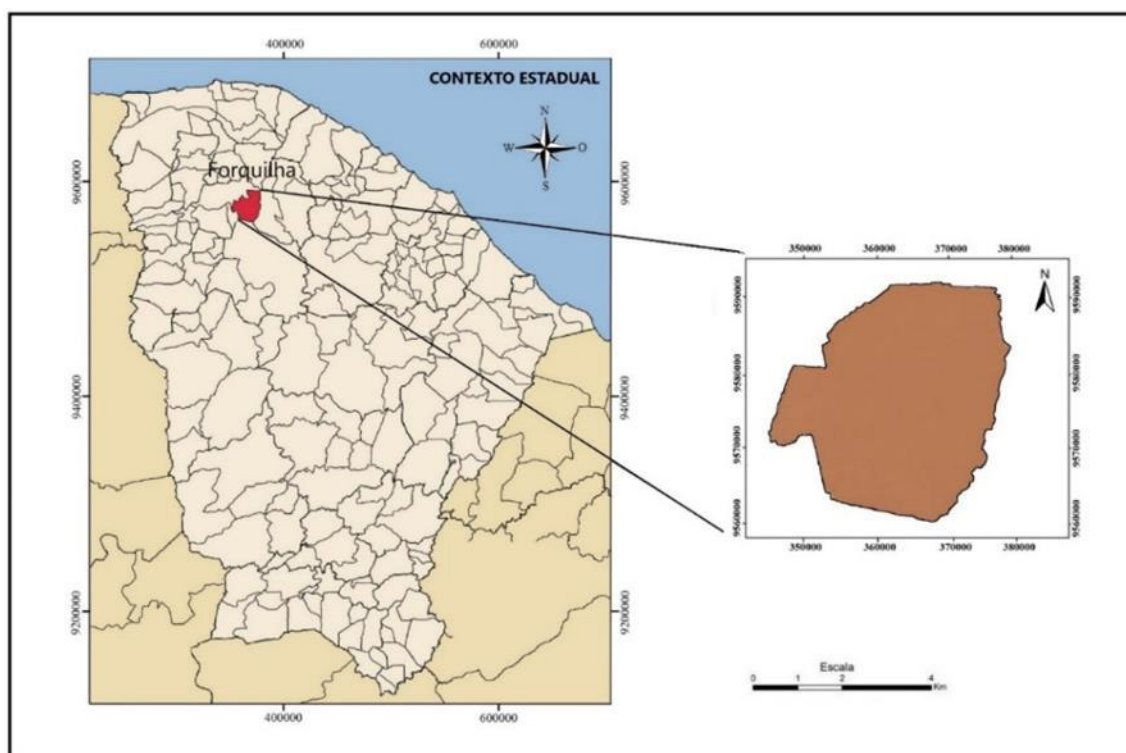
There is a need to implement a new forage culture aimed at increasing the availability of forage from these native Caatinga species, beyond the rainy season when their use is most significant, particularly in feeding small ruminants (Melo et al., 2014; Oliveira et al., 2018). Even though the high biomass productivity of forage species from this biome is known, the limited knowledge of these plants is still a limiting factor for their sustainable management (Souza et al., 2013; Pereira Filho et al., 2013; Rogério et al., 2020).

Thus, the objective of this study was to analyze plant communities present in anthropized areas of the Forquilha-CE irrigation perimeter with forage potential, resistant and/or tolerant to water and salt stress, capable of being used in animal feeding, and that can contribute to future research aimed at improving the sustainable production conditions of these species.

2 METHODOLOGY

The research was conducted in the municipality of Forquilha–CE, which borders Sobral (North, East, and West), Santa Quitéria, and Groaíras (South) (Praciano *et al.*, 2020) (Figure 1), extending to a latitude of 03°48'9"S and longitude of 40°16'7"W, with an altitude of 87 meters (Ipece, 2018). The municipality is part of the Acaraú River watershed in the Northwestern Ceará mesoregion, characterized by its aridity, with few wet areas and a flat or slightly undulating surface occupied by Caatinga areas and agricultural land (SOUZA, 2000). It covers an area of 569 km², with an estimated population of 24,173 inhabitants in 2022, a population density of 42.5 inhabitants/km², and is approximately 208 km from the capital, Fortaleza (IBGE, 2022).

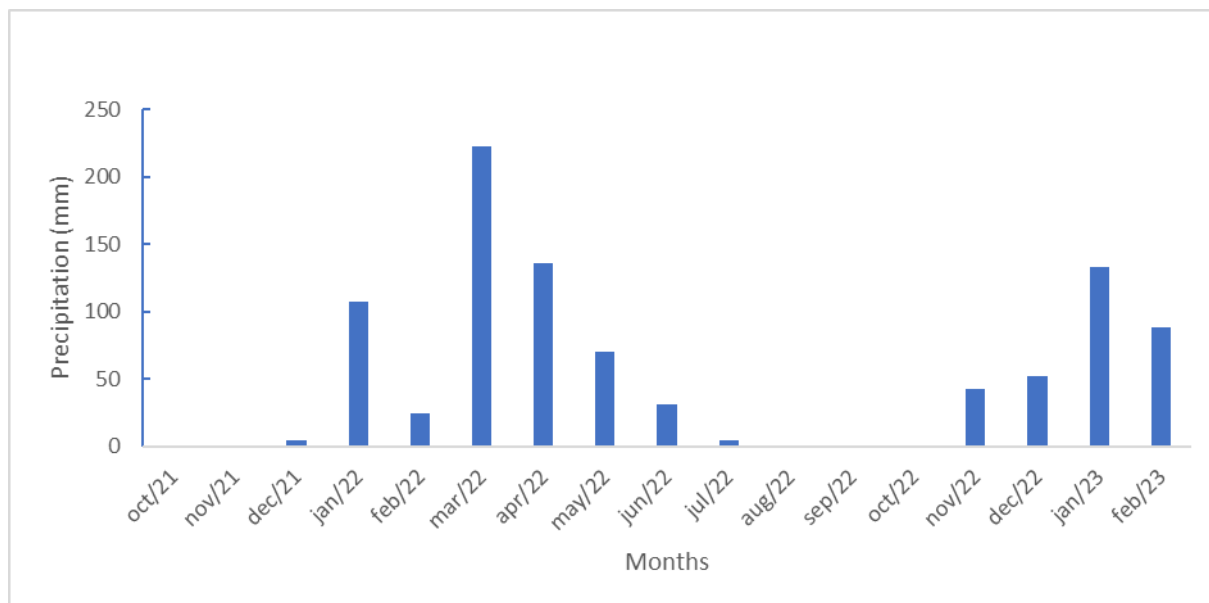
Figure 1 – The study area location, municipality of Forquilha-CE



Source: Modified Cogerh (2017).

The regional climate, according to Köppen's classification, is Bsh type, hot semi-arid, characterized by irregular precipitation concentrated in the rainy season, between March and May, and a well-defined dry period lasting nine months with high evaporation rates, with an average annual rainfall of 826 mm. The annual average temperatures are around 27°C, with the highest averages (36.8°C) observed between October and November, while the lowest averages (21.4°C) are recorded in July (FUNCEME, 2023; IPECE, 2018). The precipitation data for the research period were obtained from FUNCEME (Figure 2).

Figure 2 – Rainfall average in Forquilha-CE (FUNCEME, 2023).

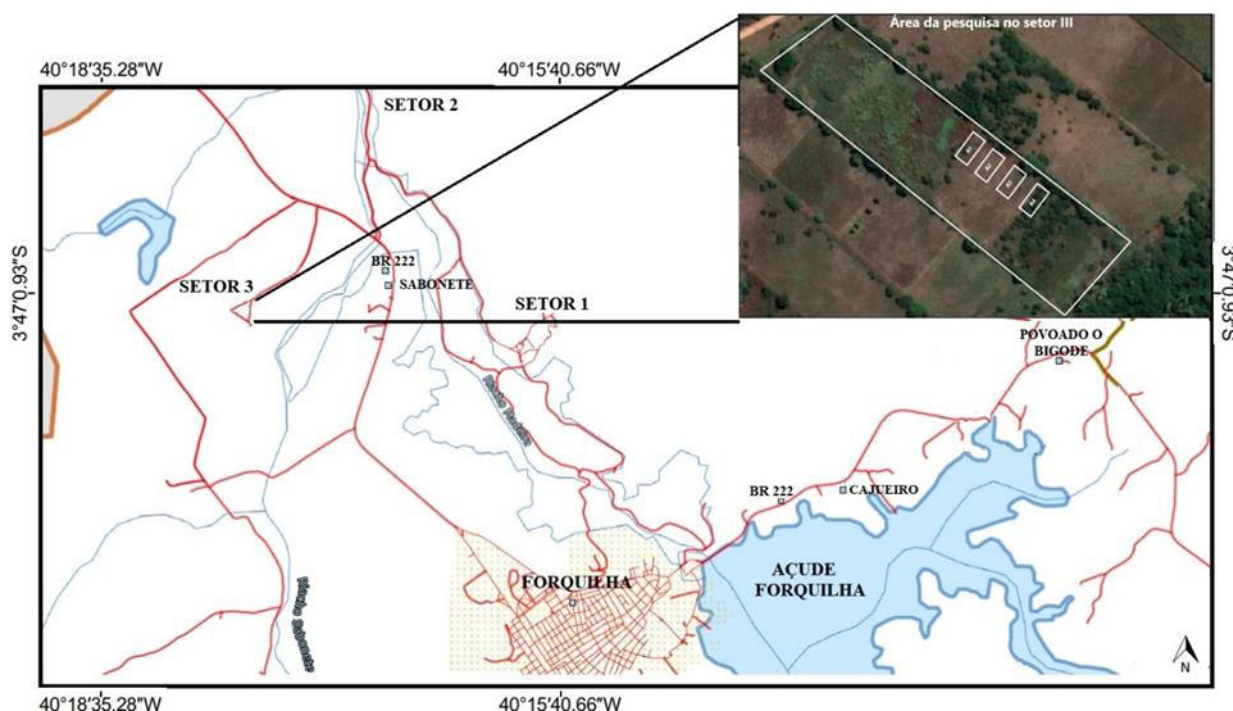


Source: Elaborated by the authors.

The Forquilha irrigation perimeter has its lots divided into three sectors, which are located 300 meters downstream from the Forquilha reservoir basin, with Fluvisols, moderately deep, with textures ranging from very fine to coarse, and poorly developed soils along the banks of the Madeira and Sabonete rivers, which are tributaries of the Acaraú River (FREIRE et al., 2009). The water supply is provided by the Forquilha Public Reservoir, with a storage capacity of 50,132,000 m³ and a regulable flow rate of 0.24 m³/s. The irrigation network in the perimeter is gravity fed through irrigation channels and furrows, with the Madeira River being the main collector (COGERH, 2008).

The lots in the Forquilha-CE irrigation perimeter are divided into three sectors (I, II, and III). Lot 77 (3°46'33.4" S, 40°17'11.1" W), which is located in sector III (Figure 3), was randomly selected for four field collections between October 2021/2022 and April 2022/2023 (dry period of 2021/2022 and rainy period of 2022/2023). Each collection was considered an independent sample.

Figure 3 - The three sectors' location in the Forquilha-CE irrigation perimeter, emphasizing the research areas in sector III.



Source: Adapted from Ibge (2021)

Initially, four areas were selected, distributed along the slope direction of the drain, each measuring 25 m², spaced 10 meters apart, totaling 600 m² for data collection. Each area was divided into six permanent plots of 25 m², totaling twenty-four experimental units.

During the plant community survey in the selected areas, a collection and herbarium preparation of the specimens found in the plots were carried out based on technical literature on collection, preservation, and herbarium preparation of botanical material (Souza; Lorenzi, 2012). The identification of the recorded individuals was performed through comparative morphology, using specialized bibliographies, comparisons with herbarium material, and consultations with experts. The names and classifiers of the species were reviewed through consultations with the lists available at the Missouri Botanical Garden (2024), Rio de Janeiro Botanical Garden (2024), and The International Plant Names Index (IPNI, 2024). The exsiccates were incorporated into the Herbarium Prof. Francisco José de Abreu Matos (HUVA) at the State University of Vale do Acaraú (UVA).

For the floristic survey, a 1 m² PVC pipe quadrat was randomly placed within each of the permanent plots in each area during the four collection periods. All living individuals were collected for later counting and identification by family and species. The following structural attributes were estimated: absolute frequency (AF) and relative frequency (RF) (Oliveira; Amaral, 2004). The phytosociological parameters were calculated using the Fitopac 2.1 program (Shepherd, 2010).

During the floristic survey described above, four soil sample collections were also conducted at each of the PVC, square vertices to a depth of 0-20 cm between October 2021/2022 and April 2022/2023 (dry period of 2021/2022 and rainy period of 2022/2023). Then, the samples were mixed in a bucket, forming a composite soil sample for each plot, totaling six independent samples for each area. A portion of each composite sample was stored in pre-weighed 200 ml, metal containers, which were

hermetically sealed to prevent moisture loss or gain, while the remaining sample was stored in plastic bags previously labeled with the collection period, plot, and area.

The soil samples from the metal containers were weighed on an analytical scale in the laboratory to confirm the wet weight. After that, the lids were removed from the containers, and the samples were placed in an oven at 105°C until a constant weight was reached. After complete drying, the samples were weighed again to obtain the dry weight and subsequently calculate the moisture content on a gravimetric basis (Embrapa, 2017).

The samples from the plastic bags were crushed, dried in a forced-air oven at 60°C, and sieved through a 2 mm mesh for chemical analyses. During the pH analysis, 10 g of soil was weighed on an analytical balance and then diluted in 25 ml of distilled water (1:2.5), with a settling time of 1 hour, for subsequent reading on a benchtop pH meter (EMBRAPA, 2017). For the electrical conductivity (EC) analysis, 100 g of soil was diluted in a volume of distilled water ranging from 15 to 50 ml to obtain a saturated paste, with a settling time of 12 hours, followed by the EC reading, which was performed using a benchtop conductivity meter (EMBRAPA, 2017). Additionally, the readings of the levels of P, K⁺, Na⁺, H⁺+Al³⁺ Ca⁺, Mg⁺, CTC e V% (Embrapa, 2017).

Thus, this experiment was conducted with four treatments (dry periods of 2021/2022 and rainy periods of 2022/2023), using a randomized block design (RBD) with four replications. The collected data were subjected to analysis of variance using the F-test ($p < 0.05$) and, upon observing a significant effect, the means of the treatments were compared using Tukey's test ($p < 0.05$).

3 RESULTS AND DISCUSSION

Based on the results obtained from all the analyzed samples, the averages of each of these parameters for the dry and rainy periods were calculated (Table 1).

Table 1 – Soil chemical analysis in the experimental area in the Forquilha-CE irrigation perimeter during dry and wet periods.

Periods	pH	P	K ⁺	Na ⁺	H ⁺ +A ³	Ca ⁺	Mg ⁺	CTC	V%	CE	U
		H ₂ O mg/Kg ⁻¹	----- cmolc/ Kg ⁻¹ -----			----- dS/m ⁻¹ %					
dry	6,9	28,1	0,5	1,1	2,2	13,4	7,8	24,8	90,5	0,95	3,5
wet	7,3	24	0,4	0,7	1,2	10,3	7,2	20	93,4	0,42	21,5

P, K, Na: Extractor Mehlich 1; V%: Base saturation; U: moisture; H + Al: Extractor calcium acetate 0,5 M, pH 7,0; CE: Electrical conductivity; Al, Ca, Mg: Extractor KCl 1 M

Regarding the floristic composition and diversity, at the end of the four field collections, 12,482 individuals were sampled, divided into 30 families, 75 genera, and 95 species, of which 17.5% were recorded during both dry and rainy periods, and 57.45% exhibited a herbaceous life form (Table 2). It is worth noting that the species *Mimosa caesalpinifolia* Benth., *Guazuma ulmifolia* Lam., identified as trees, as well as the palm *Copernicia prunifera* (Mill.) H.E. Moore, were recorded as young individuals in the areas of this study.

Table 2 - Family, species, common name, endemism (E), habit (H: Her - herbaceous; Sub - subshrub; Shr - shrub; Tre - tree; Vin - vine; and Pal – Palm), occurrence (dry and wet periods), and voucher number (VN) of the plants found in the research areas of the Forquilha-CE irrigation perimeter.

Families /species	Common name	E	H	Occurrence		NV
				dry	wet	
Acanthaceae						
<i>Elytraria imbricata</i> (Vahl) Pers.	-	Not	Her	X	X	20939
<i>Ruellia asperula</i> (Mart. ex Nees) Linda	Red Melosa	Yes	Shr	-	X	24217
<i>Ruellia paniculata</i> L.	Melosa	Not	Shr	-	X	25807
Amaranthaceae						
<i>Froelichia humboldtiana</i> (Roem. & Schult.) Seub.	Ervanço	Not	Her	-	X	25808
<i>Gomphrena demissa</i> Mart.	Whitehead	Yes	Sub	-	X	34928
Apocynaceae						
<i>Calotropis procera</i> (Aiton) Dryand.	Jealousy	Not	Shr	X	X	24438
<i>Cryptostegia madagascariensis</i> Bojer	Witch's claw	Not	Shr	-	X	24451
<i>Ibatia maritima</i> (Jacq.) Decne.	-	Yes	Her	-	X	26172
<i>Rauvolfia ligustrina</i> Willd.	Toad fruit	Not	Shr	-	X	26136
Arecaceae						
<i>Copernicia prunifera</i> (Mill.) H.E. Moore	Carnauba	Yes	Pal	X	-	26299
Asteraceae						
<i>Bidens riparia</i> Kunth	Picão-do-rio	Not	Her	-	X	26623
<i>Bidens subalternans</i> DC.	-	Not	Her	-	X	22636
<i>Blainvillea acmella</i> (L.) Philipson	Straw herb	Not	Her	-	X	25788
<i>Cyanthilium cinereum</i> (L.) H. Rob.	Ironweed	Not	Her	-	X	25791
<i>Delilia biflora</i> (L.) Kuntze	blasting cap	Not	Her	-	X	25803
<i>Emilia sonchifolia</i> (L.) DC. ex Wight	Serralhinha	Not	Her	-	X	23789
<i>Lagascea mollis</i> Cav.	-	Not	Her	-	X	26617
<i>Melanthera latifolia</i> (Gardner) Cabrera	Watercress	Not	Her	-	X	25789
<i>Tridax procumbens</i> L.	Bullgrass	Not	Her	X	X	26625
Boraginaceae						
<i>Heliotropium angiospermum</i> Murray	Cock's comb	Not	Her	-	X	3329
Cleomaceae						
<i>Tarenaya aculeata</i> (L.) Soares Neto & Roalson	Small muçambê	Not	Her	-	X	26630
Combretaceae						

<i>Combretum lanceolatum</i> Pohl ex Eichl.	Jerimataia	Not	Shr	-	X	25806
Commelinaceae						
<i>Commelina benghalensis</i> L.	Dog's beard	Not	Her	-	X	26015
Convolvulaceae						
<i>Ipomoea asarifolia</i> (Desr.) Roem & Schult	Wild parsley	Not	Her	X	X	24923
<i>Distimake aegyptius</i> (L.) A.R. Simões & Samp; Staples.	Hairy Jitirana	Not	Her	X	X	24.213
Cucurbitaceae						
<i>Melothria pendula</i> L.	Rat watermelon	Not	Vin	-	X	26613
<i>Momordica charantia</i> L.	Bitter melon	Not	Vin	X	X	20949
Cyperaceae						
<i>Cyperus haspan</i> L.	Goat's beard	Not	Her	-	X	44211
<i>Cyperus rotundus</i> L.	Nutgrass	Not	Her	-	X	838
Euphorbiaceae						
<i>Acalypha communis</i> Müll. Arg.	Indian nettle	Not	Shr	-	X	26611
<i>Acalypha poiretii</i> Spreng.	Poiret's acalypha	Not	Her	-	X	27936
<i>Astraea surinamensis</i> (Miq.) O.L.M. Silva & Cordeiro	Surinam spurge	Not	Her	-	X	26628
<i>Dalechampia pernambucensis</i> Baill.	-	Yes	Her	-	X	26618
<i>Dalechampia scandens</i> L.	Nettle vine	Not	Her	-	X	25942
<i>Euphorbia hirta</i> L.	Spurge	Not	Her	-	X	21099
<i>Euphorbia hyssopifolia</i> L.	Milkweed	Not	Her	-	X	23965
Fabaceae						
<i>Arachis dardani</i> Krapov. & W. C. Greg.	Caracara peanut	Yes	Her	-	X	8432
<i>Aeschynomene americana</i> L.	American jointvetch	Not	Sub	-	X	25796
<i>Cajanus cajan</i> (L.) Huth	Pigeon pea	Not	Shr	-	X	25809
<i>Centrosema brasilianum</i> (L.) Benth.	Feijão-de-rolinha	Não	Her	X	X	25793
<i>Chamaecrista</i> sp.	-	Not	-	-	X	26612
<i>Clitoria ternatea</i> L.	Butterfly pea	Not	Her	X	X	30178
<i>Crotalaria spectabilis</i> Röth	Rattlebox	Not	Shr		X	5874
<i>Desmanthus virgatus</i> (L.) Willd.	Jureminha	Not	Sub	X	X	25792
<i>Mimosa caesalpiniiifolia</i> Benth.	Silk tree	Yes	Tre	-	X	25794
<i>Mimosa pudica</i> L.	Sensitive plant	Not	Sub	-	X	17054
<i>Mimosa somnians</i> Humb. & Bonpl. ex Willd.	Malícia	Not	Sub	X	X	26100
<i>Senna obtusifolia</i> (L.) H.S. Irwin & Barneby	Sicklepod	Not	Sub	-	X	21623
Loasaceae						
<i>Mentzelia aspera</i> L.	Stickleaf	Not	Her	-	X	26614
Loganiaceae						

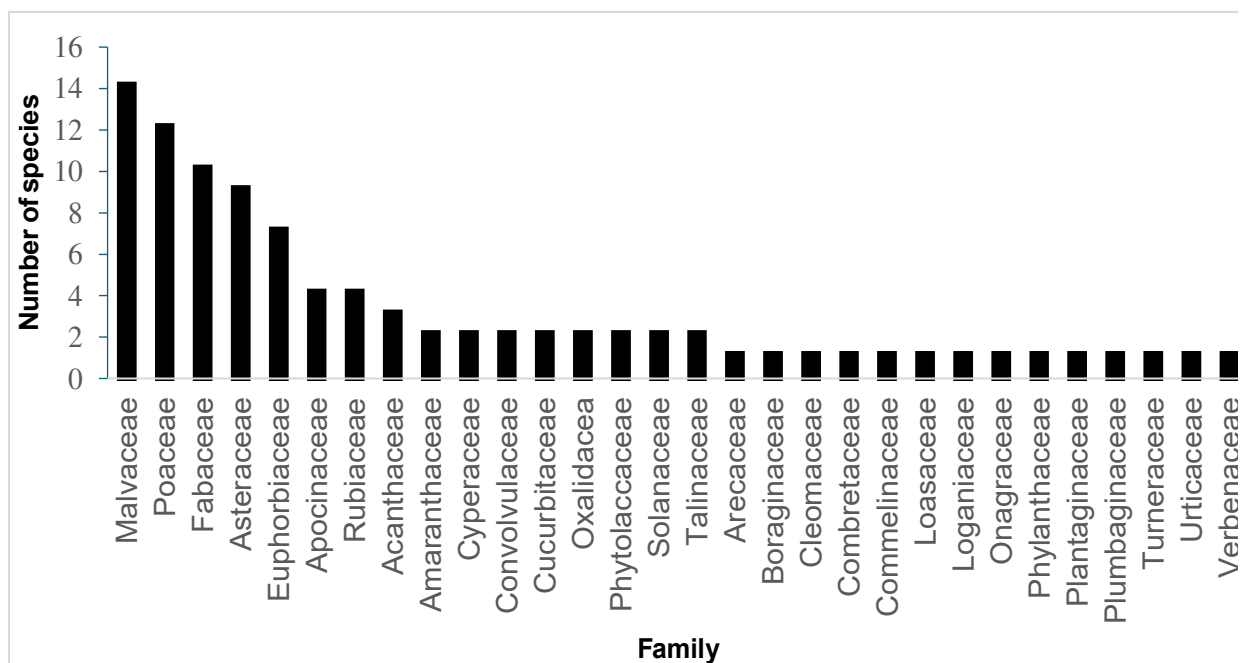
<i>Spigelia anthelmia</i> L.	Worm grass	Not	Her	-	X	15133
Malvaceae						
<i>Corchorus aestuans</i> L.	Jute weed	Not	Sub	X	X	60295
<i>Corchorus hirtus</i> L.	Hairy jute	Not	Sub	-	X	26622
<i>Guazuma ulmifolia</i> Lam.	Musclewood	Not	Tre	X	X	26458
<i>Malachra fasciata</i> Jacq.	-	Not	Sub	-	X	24443
<i>Melochia pyramidata</i> L.	Pyramid mallow	Not	Sub	X	X	26006
<i>Melochia tomentosa</i> L.	Tomentose mallow	Not	Her	X	-	22158
<i>Sida ciliaris</i> L.	-	-	Her	X	X	21758
<i>Sida galheirensis</i> Ulbr.	Malva	Yes	Sub	-	X	20938
<i>Sida spinosa</i> L.	Prickly Sida	Not	Sub	-	X	20670
<i>Sida urens</i> L.	Urticaria Sida	Not	Sub	-	X	15599
<i>Sidastrum micranthum</i> (A.St.-Hil) Fryxell	Small-flowered Sidastrum	Not	Shr	X	X	25802
<i>Waltheria indica</i> L.	Indian walnut	Not	Her	X	X	25921
<i>Wissadula periplocifolia</i> (L.) C.Presl. ex Thwaites	Pink mallow	Not	Shr	-	X	2811
Onagraceae						
<i>Ludwigia octovalvis</i> (Jacq.) P. H. Raven	Malta cross	Not	Sub	-	X	26629
Oxalidaceae						
<i>Oxalis cratensis</i> Oliv. ex Hook	Imbu herb	Not	Her	-	X	25797
<i>Oxalis cytisoides</i> Mart. ex Zucc.	Wood sorrel	Not	Her	-	X	25811
Phyllanthaceae						
<i>Phyllanthus niruri</i> L.	Stonebreaker	Not	Her	X	X	1579
Phytolaccaceae						
<i>Phytolaccaceae</i> sp.	-	-	-	-	X	-
<i>Rivina humilis</i> L.	Bloodberry	Not	Shr	-	X	26627
Plantaginaceae						
<i>Scoparia dulcis</i> L.	Broomweed	Not	Her	-	X	21106
Plumbaginaceae						
<i>Plumbago scandens</i> L.	-	Not	Shr	-	X	19179
Poaceae						
<i>Cynodon dactylon</i> (L.) Pers.	Bermuda grass	Not	Her	-	X	23242
<i>Dactyloctenium aegyptium</i> (L.) Willd.	Goatgrass	Not	Her	-	X	21761
<i>Digitaria sanguinalis</i> (L.) Scop.	Crabgrass	Not	Her	-	X	26620
<i>Dinebra scabra</i> (Nees) P.M. Peterson & N. Snow	-	Not	Her	-	X	26619
<i>Eleusine indica</i> (L.) Gaertn.	Goosegrass	Not	Her	-	X	24565
<i>Eriochloa polystachya</i> (Kunth) Hitchc.	Caribbean grass	Not	Her	-	X	26610
<i>Hyparrhenia rufa</i> (Nees) Stapf	Jaragua grass	Not	Her	X	-	25804
<i>Megathyrsus maximus</i> (Jacq.) B.K.Simon & S.W.L.Jacobs	Guinea grass	Not	Her	-	X	25814
<i>Oplismenus hirtellus</i> (L.) P.	-	Not	Her	-	X	26631

Beauv.							
<i>Panicum campestre</i> Nees ex Trin.	-	Not	Her	-	X	25812	
<i>Panicum trichoides</i> Sw.	-	Not	Her	-	X	25800	
<i>Urochloa plantaginea</i> (Link) R. D. Webster	-	Not	Her	-	X	25813	
Rubiaceae							
<i>Borreria scabiosoides</i> Cham. & Schltldl.	Whitehead	Not	Sub	-	X	25801	
<i>Borreria verticillata</i> (L.) G. Mey.	Button broom	Not	Sub	-	X	18745	
<i>Spermacoce confusa</i> Rendle	-	Yes	Her	-	X	26026	
Solanaceae							
<i>Physalis angulata</i> L.	Canapum	Not	Her	-	X	26615	
<i>Solanum crinitum</i> Lam.	Jurubeba	Not	Shr	-	X	22404	
Talinaceae							
<i>Talinum fruticosum</i> (L.) Juss.	Waterleaf	Not	Her	-	X	25810	
<i>Talinum paniculatum</i> (Jacq.) Gaertn.	Jewels of Opar	Not	Her	-	X	23011	
Turneraceae							
<i>Turnera subulata</i> Sm.	Chanana	Not	Sub	X	X	26.031	
Urticaceae							
<i>Urera caracasana</i> (Jacq.) Griseb	-	Not	Her	-	X	-	
Verbenaceae							
<i>Lantana camara</i> L.	Lantana	Not	Shr	-	X	26.626	

Source: elaborated by the authors

Malvaceae was the family with the greatest species diversity, with fourteen identified species. It was followed by Poaceae, Fabaceae, Asteraceae, and Euphorbiaceae, with eleven, ten, nine, and seven species, respectively. It is worth noting that 23.8% of the identified families were represented by two species, while 46.7% recorded only one species throughout the entire study (Figure 4). According to Moro et al. (2014), these families are among the ten most cited in terms of species richness in the Phytogeographic Domain of the Caatinga, according to the survey of the collection in the floristic and phytosociological literature on the plant diversity of this biome.

Figure 4 - Species identified by family in Forquilha-CE irrigation perimeter.



Source: Elaborated by the authors

In a survey run in the northern Piauí semi-arid region focusing on herbaceous vegetation, Araújo et al. (2023) found results similar to this study, with the record of 96 species distributed across 38 families and 73 genera, between August 2020 and May 2022. In another study, Bonilla et al. (2019), in a collection carried out during the rainy and dry periods in the irrigated perimeter of the municipality of Pentecoste-CE, recorded about half the number of individuals (6,573), families (14), and 40.3% of the total species identified in that survey. These results may be related to the soil salinity levels in Pentecoste-CE, where the highest records for electrical conductivity (EC) reached 16.22 and 17.59 dS/m-1 for the rainy and dry periods, respectively, well above the EC values observed for these same periods in this study (0.42 and 0.95 dS/m-1). According to Pedrotti et al. (2015), salinization represents a higher concentration of salts in the soil or certain water bodies and acts as a limiting factor for the development of most plant species.

Among the plants identified as tolerant to increased soil salinity, higher relative frequencies were observed during the dry period for the species *Melochia pyramidata* L. (20.69%), *Ipomoea asarifolia* (Desr.) Roem & Schult (18.02%), *Desmanthus virgatus* (L.) Willd. (13.51%), and *Waltheria indica* L. (3.45%), whereas during the rainy period, the species *Melochia pyramidata* (5.43%), *Senna obtusifolia* (L.) H.S. Irwin & Barneby (4.2%), *Distimake aegyptius* (L.) A.R. Simões & Samp; Staples. (3.54%), *Ipomoea asarifolia* (2.96%), and *Megathyrsus maximus* (2.47%) showed the highest values for relative frequencies (Table 3). Among the cited species, *Melochia pyramidata* L. had the highest relative frequency in both the dry and rainy periods in this study. According to García et al. (2008), some species of the Malvaceae family have adaptations, such as the presence of hairs and trichomes on the leaf surface, which repel light and reduce water loss through transpiration. This could explain the high relative frequency of this species during the dry period.

Table 3 - Alphabetical list of halophytic and halotolerant species recorded during the four sampling periods (Dry 1: October/2021; Dry 2: October/2022; Rainy 1: April/2022; Rainy 2: April/2023) in the Irrigated Perimeter of Forquilha-CE. Endemism (E), FA - Absolute Frequency; FR - Relative Frequency.

Species	E	Dry 1		Dry 2		Rainy 1		Rainy 2	
		FA	FR	FA	FR	FA	FR	FA	FR
<i>Calotropis procera</i>	Not	4,55	1,15	0	0	8,33	0,49	0	0
<i>Cynodon dactylon</i>	Not	0	0	0	0	25	1,48	37,5	1,72
<i>Dactyloctenium aegyptium</i>	Not	0	0	0	0	0	0	41,67	1,91
<i>Dalechampia scandens</i>	Not	0	0	0	0	25	1,48	16,67	0,76
<i>Desmanthus virgatus</i>	Not	9,09	2,3	62,5	13,51	8,33	0,49	62,5	2,88
<i>Distimake aegyptius</i>	Not	0	0	3,17	0,7	37,84	2,6	55,56	3,54
<i>Eleusine indica</i>	Not	0	0	0	0	13,89	0,88	22,22	1,42
<i>Heliotropium angiospermum</i>	Not	0	0	0	0	12,5	0,74	0	0
<i>Ipomoea asarifolia</i>	Not	59,09	14,94	66,67	14,41	50	2,96	54,17	2,48
<i>Lantana camara</i>	Not	0	0	0	0	0	0	8,33	0,38
<i>Melochia pyramidata</i>	Not	81,82	20,69	83,33	18,02	91,67	5,43	100	4,58
<i>Melochia tomentosa</i>	Not	0	0	8,33	1,8	0	0	0	0
<i>Megathyrsus maximus</i>	Not	0	0	0	0	41,67	2,47	20,83	0,99
<i>Physalis angulata</i>	Not	0	0	0	0	0	0	12,05	0,57
<i>Senna obtusifolia</i>	Not	0	0	0	0	70,83	4,2	91,67	4,2
<i>Sida galheirensis</i>	Yes	0	0	0	0	16,67	0,99	37,5	1,72
<i>Sidastrum micranthum</i>	Not	0	0	4,17	0,9	33,33	1,98	16,67	0,76
<i>Waltheria indica</i>	Not	13,64	3,45	8,33	1,8	29,17	1,73	4,17	0,19

Source: elaborated by the authors

Several species identified in this survey (Table 3) are described as important native forages, serving as a food source for herbivores in semi-arid regions. Due to the long drought periods in these regions, only part of this biomass remains available for grazing animals for most of the year (Pereira Filho et al., 2013; Carvalho et al., 2017).

Many studies indicate that the families Poaceae, Fabaceae, Convolvulaceae, and Apocynaceae have proven to be good alternatives for the use of native forages adapted to semi-arid conditions as a viable strategy both quantitatively and qualitatively (Leão et al., 2017; Silva et al., 2017; Moreira et al., 2018; Dantas et al.,

2021; Machado et al., 2021; Mahecha et al., 2022; Dantas et al., 2023; Ponte Filho et al., 2023; Silva Neto et al., 2024; Righi et al., 2024).

According to Souza et al. (2014) and Holanda et al. (2016), soil salinization in the semi-arid region of Northeast Brazil is a recurring issue, and it is mainly related to natural pedogenic processes and the lack of proper irrigation management for agricultural production. In this context, the identification of halotolerant species with forage potential in this region can meet the growing demand of livestock farming for alternative pastures.

Among the representatives of the Poaceae family identified in this study, *Cynodon dactylon*, *Eleusine indica*, and *Dactyloctenium aegyptium* are recognized as non-restricted halophyte species that eliminate excess salts from their cells through salt glands. These glands communicate with the cuticle through small openings in their leaves, allowing the secretion of a saline solution (Flores-Oliveira et al., 2016; Fernandes et al., 2016; Bonilla; Lucena, 2021).

The grass *Cynodon dactylon*, commonly known as Bermuda grass, is a perennial species recognized for its high tolerance to soil salinity and its ability to adapt to different climatic conditions worldwide, with records in salinized areas of the Caatinga (Hu et al., 2012; Costa; Bonilla, 2016). Recent research has intensified the search for forage plants of the *Cynodon* genus as alternatives to increasing productivity in the animal production system. (Aguar et al., 2014; Baseggio et al., 2015; Costa et al., 2015; Yarborough et al., 2017; Souza et al., 2020; Carvalho et al., 2021; Mahecha et al., 2022).

Goosegrass (*Eleusine indica*) is an annual grass that produces many small seeds, facilitating its spatial distribution, mainly through animal activity, which justifies its classification as a spontaneous weed occurring in various regions of the country (Moreira; Bragança, 2010; Lessa et al., 2021). This species is considered a forage alternative in arid and semi-arid regions, as it exhibits good digestibility and high dry matter content observed during the dry season (Carvalho et al., 2021).

Dactyloctenium aegyptium is an annual grass characterized by good density and soil cover (Oliveira et al., 2018; Carvalho et al., 2022), recorded during the rainy season in this study. This Poaceae species thrives in saline and salinized environments of the semi-arid region of northeastern Brazil, where it serves as an alternative for grazing cattle and small ruminants in fallow lands. Additionally, it can emerge as a difficult-to-control weed in agricultural areas (Bonilla; Lucena, 2021; Riaz et al., 2022).

Another species of the Poaceae family with forage potential, also collected only during the rainy season of this study, was Massai grass (*Megathyrsus maximus*). It is known as the most productive tropical forage propagated by seeds, mainly due to its high foliage accumulation and dry biomass production, whether in intercropping with annual forages or in monoculture, with good adaptation to the conditions of the Brazilian semi-arid region (Lima et al., 2018; Conrado et al., 2019a; Conrado et al., 2019b; Coêlho et al., 2021; Ponte Filho et al., 2023; Simeão et al., 2023; Righi et al., 2024). Research conducted with different cultivars of this grass under salt stress classified it as moderately sensitive to irrigation water salinity (Praxedes et al., 2019), leading to a decrease in germination speed and plant growth (Salomón; Samudio, 2015), reduction in crude protein content (Silva et al., 2020a), and seedling emergence percentage (Lima et al., 2024) with increased salinity in the water.

According to Andrade et al. (2014) and Taiz et al. (2017), the impairment in the development of plants exposed to gradual increases in salinity can be related to the

toxic effects caused by the excess of Na^+ and Cl^- absorbed, leading to compromised uptake of essential nutrients for their development.

The species *Eriochloa polystachya*, *Urochloa plantaginea*, *Digitaria sanguinalis*, and *Hyparrhenia rufa* are examples of Poaceae observed in this survey. It is worth noting that only the last species was recorded in the dry period, while the others were collected in the rainy period. Despite the lack of records of the development of these species under saline conditions, they are also recognized for their forage potential (Santos et al., 2010; Oliveira Neto et al., 2013; Moran et al., 2020; Silva et al., 2020b; Torres et al., 2020; Villalva et al., 2020; Gómez et al., 2020; Mahecha et al., 2022; Menezes et al., 2022).

The Poaceae family is characterized in Botany by its great importance, whether through its morphological variety, ecological role, or the economic significance of the species associated with it (Soares Filho et al., 2016), ranking among the ten families with the highest species richness in the Phytogeographic Domain of the Caatinga (Moro et al., 2014; Queiroz et al., 2017). According to Almeida et al. (2015), forage grasses represent a quarter of the exotic invasive species recorded in the Caatinga, many of which may have potential in animal feed that is still little studied (Oliveira et al., 2019).

The Convolvulaceae *Distimake aegyptius*, identified in both seasons of this study, is cited as a native forage species of the semi-arid region, tolerant to salinity and well accepted by sheep, goats, and cattle due to its succulence and fragrance (MARACAJÁ et al., 2008; BEM, 2016). Some studies confirm that this forage can also be used directly in silage and hay production or incorporated into the protein and bromatological enrichment of corn silage, as this species is abundant during the rainy season of the year. (Linhares et al., 2005; Silva et al., 2017; Leão et al., 2017).

Calotropis procera is a perennial Asian shrub from the Apocynaceae family, recorded in both dry and rainy seasons in this study. This species exhibits a set of adaptive characteristics, both structural and functional, that enable its survival in arid and semi-arid areas under water and salt stress (Rivas et al., 2017; Iqbal et al., 2023). According to Frosi et al. (2013) and Rivas et al. (2017), the dry season is the most significant period for this species in the Caatinga. Even under high temperatures and water and salt stress conditions, *C. procera* can maintain its biomass with a high protein content, providing highly digestible dry matter, which justifies its forage potential for this region. (Moreira et al., 2018; Freire et al., 2021).

The Apocynaceae *C. procera* is an invasive species that can easily develop along roadsides, lagoon margins, and native pastures, where it establishes itself as a weed. According to these same authors, it is important to understand the characteristics and adaptation mechanisms of this invader in order to reduce its impacts on ecosystems (Iqbal et al., 2023).

The Verbenaceae *Lantana camara*, a non-restricted halophyte species observed in coastal dune areas and mangroves (Flores-Olvera et al., 2016), was recorded only during the rainy season in this survey. Despite several studies reporting the toxicity of its secondary metabolites in animal feed, causing losses to cattle herds in various regions (Caspe et al., 2008; Pessoa et al., 2013; Priyanka; Joshi, 2013; D'Oliveira et al., 2018; Lakshmi; Sekhar et al., 2018), the leaves of this shrub are voluntarily consumed in the diet of goats in Africa, where they have shown resistance to its harmful effects (Basha et al. 2012; Getachew; Zeleke, 2019; Ntalo et al., 2022). With high crude protein

concentrations, *L. camara* presents itself as an alternative for animal supplementation in semi-arid regions where it is recurrent (Mtui et al., 2008; Osuga et al., 2006; Gusha et al., 2016).

In addition to the water- and salt-stress-tolerant species with forage potential previously mentioned, this survey also recorded plants recognized as halophytic or halotolerant, such as *Ipomoea asarifolia*, *Heliotropium angiospermum*, *Dalechampia scandens*, and *Waltheria indica*. (Flores-Olvera et al., 2016; Bonilla; Lucena, 2021). The vine *Ipomoea asarifolia* (Convolvulaceae) is known for its food toxicity in cattle and sheep and its applications in traditional medicine (CARVALHO et al., 2014; FURTADO et al., 2016; ALENCAR et al., 2020). *Heliotropium angiospermum* is a plant from the Boraginaceae family used in folk medicine for its anti-inflammatory and wound-healing properties (HERNÁNDEZ-BOLIO et al., 2019; SANTOS et al., 2022). Meanwhile, *Dalechampia scandens* (Euphorbiaceae) is a species with antioxidant properties (SRIVASTAVA et al., 2022), and *Waltheria indica* (Malvaceae) is cited for its anti-inflammatory and antimicrobial activity (LACZKO et al., 2020; YIN et al., 2021).

Although the salinity observed in many irrigated areas of the semi-arid region is a limiting factor for the development and productivity of legumes (ARAÚJO et al., 2015), some species of this family with forage potential were recorded in this survey. Among them, we highlight *Desmanthus virgatus*, *Clitoria ternatea*, *Centrosema brasilianum*, *Cajanus cajan*, *Arachis dardani*, *Aeschynomene americana*, *Crotalaria spectabilis*, *Mimosa caesalpiniiifolia*, and *Senna obtusifolia*. However, it should be noted that only the first three species were recorded in both seasons.

4 CONCLUSION

The Caatinga area vegetation analyzed in this study exhibits great floral diversity, with 12,482 individuals sampled across four collections, classified into 95 species, 75 genera, and 30 families. Notably, Malvaceae is the most representative family, followed by Fabaceae and Poaceae.

No soil salinity gradients were evidenced in the areas of this study, as the average EC values ranged between 0.42 and 0.95 dS/m⁻¹ during the dry and rainy periods, respectively. The interruption of the irrigation process in the Forquilha-CE irrigated perimeter, combined with the soil leaching process, may explain these ECes values.

A total of 95 species were identified in this study, of which 86.31% are exotic and 9.47% are native. Additionally, 57.45% exhibited a herbaceous growth form, and 19% showed forage potential and tolerance to water and soil salinity stress, with good adaptation to the semi-arid region of northeastern Brazil. This suggests an alternative for sustainable forage production systems in this region.

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