How does bitter taste guide the utilization of medicinal plants in the semiarid region of Brazil?

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Research

Abstract

Background: In numerous cultures, taste plays a pivotal role in the selection of medicinal plants by humans. We investigated whether the bitter taste of plants, as perceived by people, influenced the selection of medicinal plants for treating specific ailments.

Method: Using the free-listing technique, we documented local knowledge about medicinal plants across five communities within Catimbau National Park, Pernambuco, Brazil. Participants who were older than 18 years and consented to participate in the study shared insights about medicinal plants, therapeutic targets, and taste attributes. The relationship between a plant's taste and the body systems for which it is recommended was analyzed using the chi-square test.

Results: A bitter taste was associated with treating specific diseases; addressing ailments of the digestive, respiratory, gastrointestinal, and urogenital systems; infectious and parasitic diseases; and injuries as well as general symptoms and signs. Among the taste attributes reported, bitterness was the most common trait (42.34%), followed by astringent (26.78%), sweet (8.04%), sour (1.84%), and other/not classified (21.24%).

Conclusion: In our study, we discovered that bitter taste is intricately linked to the selection of medicinal plants for treating certain ailments. Our findings underscore the significance of bitterness as a crucial factor in identifying plants for disease treatment in the region.

Keywords: Bitter Taste, Chemosensory Perception, Local Medical Systems

Background

Ethnobotanical studies have demonstrated that organoleptic properties, such as taste, can influence plant selection for disease treatment (Brett & Heinrich 1998, Medeiros *et al.* 2015, Molares & Ladio 2009). This organoleptic attribute is frequently dictated by bioactive compounds that exhibit pharmacological activities. Hence, taste might be a vital indicator of certain bioactive compounds present in plants. In some societies, taste helps differentiate medicinal plants from nonmedicinal plants (Ankli *et al.* 1999; Leonti *et al.* 2002). Moreover, evidence indicates that taste serves as a criterion for plant selection to treat ailments. For instance, plants perceived as bitter are often used to address digestive system issues (Medeiros *et al.* 2015), while those with a strong taste and smell are used for stomach problems (Molares & Ladio 2009). The taste also offers clues about the optimal preparation and administration method (Schmeda-Hirschmann *et al.* 2005).

The human perception of plant taste is a fusion of biological and cultural processes. Biological aspects pertain to the chemosensory perception of taste, where humans detect chemical taste stimuli (Jeruzal-Świątecka *et al.* 2020, Mennella *et al.* 2013). This approach plays a crucial role, as it aids in preventing potentially toxic substances, which are typically bitter, while promoting the discovery of beneficial compounds (Johns 1996). The cultural dimension relates to the interpretation, evaluation, and local validation of perceived stimuli (Brett & Heinrich 1998). Taken together, these processes can steer humans toward experimenting with and choosing diverse plants for treating various ailments.

Apart from influencing the selection of medicinal plants, taste can also sway affective responses and the consumption of these plants (Geck *et al*. 2017). For instance, food items rich in polyphenols, which manifest bitter and astringent qualities, are not readily accepted by children (Canivenc-Lavier *et al.* 2019), while sweet substances are preferred by humans (Venditti *et al*. 2020, Schaefer *et al.* 2023). These reactions might have evolved as a mechanism to navigate nature-derived chemicals, where bitter and sour flavors denote toxic compounds (Glendinning 1994) and sweet and salty tastes signify energy sources (Hayes & Johnson 2017). The acceptability of a specific taste of medicinal plants might dictate how communities select plants for therapeutic purposes.

Evidence suggests that taste serves as a mnemonic cue, with the association between taste and therapeutic indication helping individuals recall a plant's therapeutic purpose (Casagrande 2000, Heinrich *et al*. 1992). In the semiarid region of Brazil, studies on plant organoleptic properties indicate that bitter taste serves as a guide for human groups in selecting resources for disease treatment (Caetano *et al*. 2020, Medeiros *et al*. 2015, Reinaldo *et al*. 2022) to the detriment of other flavors. In this context, our objective was to investigate the importance of the bitter taste of plants for medicinal use in rural communities in northeastern Brazil. We believe that, proportionally, certain taste attributes will be associated with a specific set of diseases, revealing the significance of this organoleptic property in local therapeutic choices.

Materials and Methods

Study area

The research was conducted in five rural communities situated within Catimbau National Park (PARNA Catimbau): Sítio Igrejinha, Sítio Muquém, Sítio Breu, Sítio Dor de Dente, and Sítio Açude Velho (see Figure 1). The PARNA Catimbau is an integral protection conservation unit established by a decree on December 13, 2002. Spanning approximately 62,000 hectares, it is located in the municipalities of Ibirimirim, Tupanatinga, and Buíque in the state of Pernambuco, 295 km away from Recife, the state capital. At present, the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) oversees the management of this conservation unit, although a formal management plan has not yet been drafted. The park lies in a transitional zone between the wild areas and hinterlands. The climate in Catimbau National Park is warm, with an average annual temperature reaching 23°C and annual precipitation ranging between 480 and 1100 mm (Rito *et al.* 2017).

The five chosen communities are closely related and rely predominantly on land for their economic activities, primarily focused on subsistence farming and goat breeding (see Figure 2a-c). In previous studies conducted by our research team in these communities, we observed that the informants had low levels of education and were engaged in professional occupations related mainly to subsistence agriculture (Magalhães *et al*. 2021; Sousa *et al*. 2022a,b). Additionally, there is a significant reliance on natural resources for disease treatment since access to the public health system is restricted (Reinaldo *et al*. 2020, Sousa *et al*. 2022a,b). Healthcare facilities are situated in a minor village outside the PARNA Catimbau, known as Vila do Catimbau; these facilities are approximately 15 km away from these communities and accessible via dirt roads. There are also facilities in Buíque's city center, approximately 27 km from these settlements. Given this background, families with limited financial resources cannot frequently travel to access healthcare services. Hence, medicinal plants are vital for treating ailments in these communities. Several previous investigations carried out in this area (Laurentino *et al*. 2022, Reinaldo *et al*. 2020, Silva *et al*. 2021, Sousa *et al*. 2022a,b) have highlighted the relevance of medicinal plants in the health care of this locality.

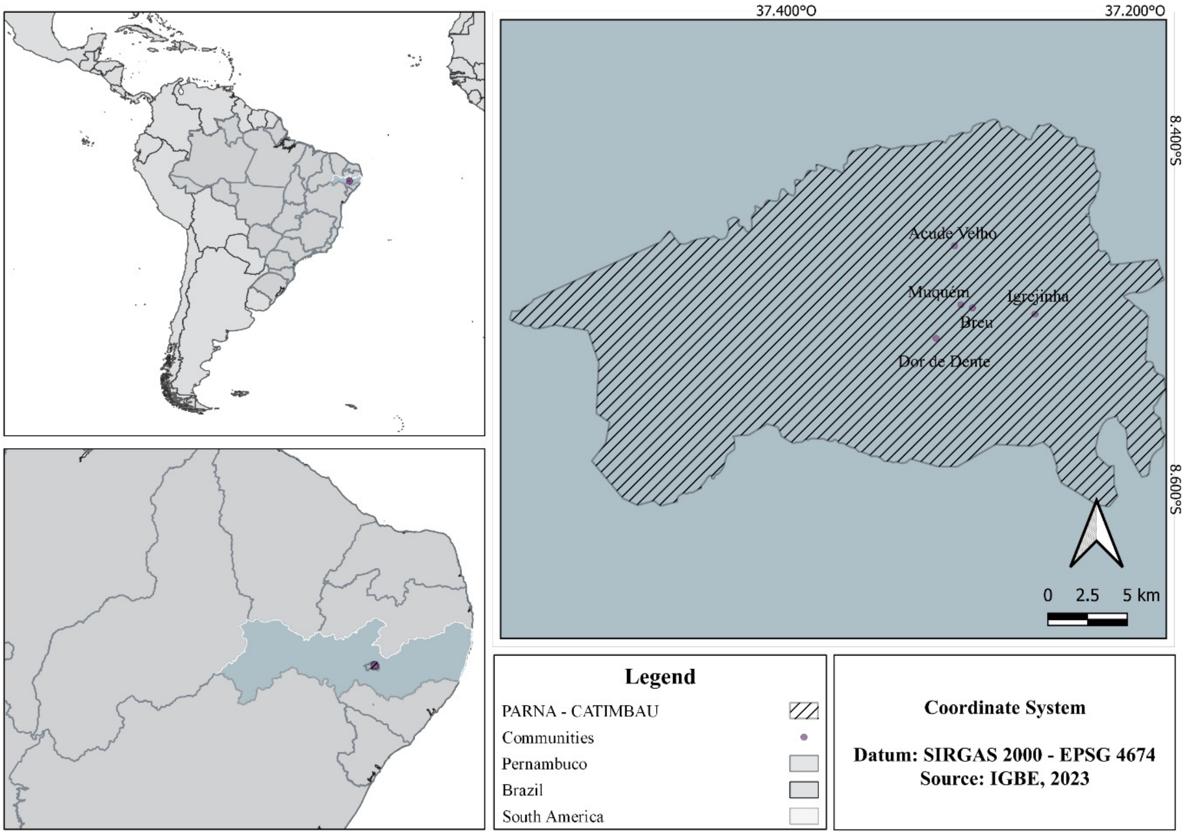

Figure 1. Locations of the five communities spread across Catimbau National Park, NE Brazil.

Data collection

This study was assessed and approved by the Research Ethics Committee of the University of Pernambuco (CAAE: 89890917.1.0000.5207). Our research also obtained authorization from the Biodiversity Authorization and Information System (SISBio) to conduct studies in the PARNA Catimbau (No. 55107) and from registration in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SISGEN) (AD9E2D8).

After obtaining the consent of the participants, all informants older than 18 years who were present at the time of the visit and who agreed to participate were interviewed. We interviewed 129 individuals (Igrejinha = 88, Muquém = 22, Açude Velho = 5, Dor de Dente = 7, Breu = 7). Using the free listing technique (Albuquerque *et al*. 2014), we posed the following question: "Which medicinal plants do you know?" Subsequently, for every plant mentioned, we took note of the ailments they treated, the ways they were utilized, and which parts were used. To evaluate the perception of the bitter taste, the following question was asked: "Does this plant have a taste?" Thus, details were recorded according to the attributes mentioned by the participants. In this context, the taste perceived by the participants for each plant was duly recorded, and subsequently, words indicating similarities in taste were grouped. For example, plants mentioned as having the taste "travoso" or "travoso leve" were grouped as astringent. Just as plants mentioned as "amargas suave," "meio amargas," and "amargas fortes" were classified simply as bitter. We retained the local terms for defining the bitter taste and its variations (see Heinrich *et al*. 2009).

The interviews took place between January and December 2017 at the informants' residences. During interviews, when informants mentioned plants that we could not identify, guided visits were arranged for them to display the plants they had cited, ensuring correct species identification (Albuquerque *et al.* 2014). A specialist from the Agronomic Institute of Pernambuco identified these species. Specimens were subsequently added to the Herbarium Dárdaro de Andrade Lima (IPA) collection at the same institution and at Herbário Sérgio Tavares (HST) of the Federal Rural University of Pernambuco

(UFRPE). On the other hand, some cultivated or common plants were determined through their popular names, consulting the website (Missouri Botanical Garden, 2023).

The Angiosperm Phylogeny Group (APG IV) system was used for the taxonomic classification of families and genera. To ensure consistent spelling, avoid synonyms, and maintain nomenclature uniformity, all binomials were checked using the Taxonomic Name Resolution Service (Taxonomic Name Resolution Service, 2023).

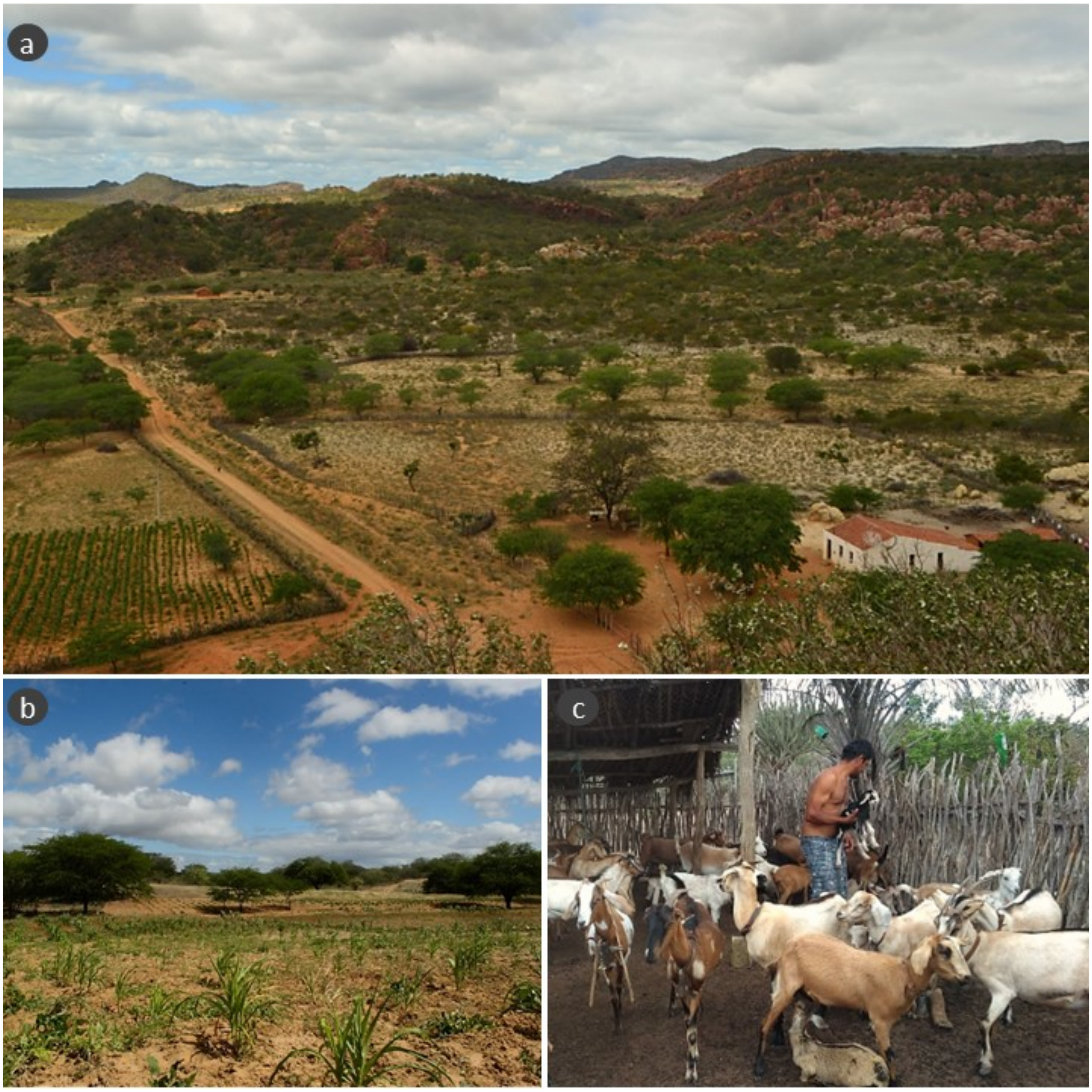

Figure 2**.** Catimbau National Park, Pernambuco, Brazil. a. View from the top of the Túnel community, en route to the Açude Velho site. b. Subsistence agriculture of the region near the Açude Velho site, highlighting the cassava plantation. c. Details of the goat farming practiced by the local populations residing in the PARNA Catimbau. Photos: Daniel Carvalho Pires Sousa.

Data analysis

We applied the chi-square test to examine whether different disease sets were treated using medicinal plants with specific bitter taste properties. Therefore, diseases were categorized according to the International Classification of Diseases by the World Health Organization (WHO) ICD-11 2019. Our choice of WHO's classification aimed to standardize the categorization employed in ethnopharmacological research (Heinrich *et al.* 2009). In addition to these categories, we integrated three additional categories to encompass the variety of diseases mentioned: cultural syndromes and others. Cultural or spiritual illnesses, such as an open chest, body cleansing, and evil eyes, were classified as cultural syndromes. The 'others' category covered ailments that were neither specific nor fit into the remaining categories (e.g., body weakness, warmth in the body, and aesthetic conditions).

Similar taste attributes were aggregated into more extensive taste categories to avoid underestimating taste perception categories. For instance, sweet and sweetie belonged to the sweet category; bitter fine, mildly bitter, and bitter were classified as bitter; and astringent, lock, and mild astringent were classified in the astringent category. Finally, the number of taste mentions was tallied for each body system and subsequently contrasted using the chi-square test on a contingency table. The p value was adjusted through simulations (2,000 simulations), as some figures in the contingency table were <5. All tests in this study were conducted using R software, version 3.2.4 (R Core Team 2023).

Results

Medicinal species and their taste attributes

We registered 139 medicinal plants that were associated with 40 different taste attributes and were recommended for the treatment of 21 different diseases. The most important plants in terms of citations were *Ximenia americana* L., *Dysphania ambrosioides* (L.) Mosyakin & Clemants, *Myracrodruon urundeuva* Allemão, *Sideroxylon obtusifolium* (Roem. & Schult.) T.D. Penn., *Hymenaea courbaril* L., *Aloe vera* L., *Myroxylon peruiferum* L.f., *Sarcomphalus joazeiro* (Mart.) Hauenschild (Table 1).

Among the tastes reported, bitter was the most frequently cited, constituting 42.1% of the mentions. This was followed by astringent (26.78%), sweet (8.14%), sour (labeled "acid" - 1.84%), and other/not classified (21.24%). Given that we prioritized the local or emic classification of the respondents, many of the mentioned taste attributes had localized significance and could not be universally categorized under the five scientifically recognized basic tastes: bitter, sweet, sour, salty, and umami. Remarkably, 42.5% of the mentioned tastes were unique to a single respondent. This reflects the idea that while certain tastes are well defined and common among a population, others are more individualistic.

A certain group of mentioned tastes indicates that while people can discern that a particular species has a flavor, they cannot precisely identify it. Examples of these descriptions include phrases such as "yes/have taste," "taste of itself," and "a different taste." Another subset of the tastes cited was comparative in nature (constituting 1.46% of all citations), where participants related the taste to other familiar flavors such as acerola, ginger, wet clay, sugarcane, or mint. However, another group of cited tastes was evaluative, using words such as "tasty," "neutral," "normal," "light," "smooth," and "strong." Some respondents (10.44%) mentioned at least one plant whose taste they were not sure about, while approximately 11.74% said that at least one plant they mentioned was tasteless.

Our findings revealed that certain disease categories predominantly involve plants perceived as having a bitter taste. This observation was particularly evident for ailments related to the gastrointestinal system (chi-square = 17.61; $p < 0.05$), namely, injuries (chi-square = 19.636; $p < 0.05$); infectious diseases (chi-square = 40.5; $p < 0.05$); the respiratory system (chi-square = 36.962; $p < 0.05$); and general symptoms and signs (chi-square = 18.307; $p < 0.05$).

On the other hand, other disease categories, such as endocrine problems (chi-square = 0.4; $p = 0.75$), neoplasia (chi-square = 1.3333; $p = 0.3763$), circulatory issues (chi-square = 2.631; $p = 0.1389$), the urogenital system (chi-square = 3.9302; $p = 0.06797$), circulatory issues, endocrine problems, cultural syndromes, neoplasias, and veterinary issues, demonstrated no correlation with the taste characteristics of the utilized plants. Intriguingly, across all disease categories, plants with a bitter taste were the most common ones, as shown in Table 2.

Table 1. List of medicinal plant species of greater importance from the five communities studied in PARNA Catimbau (Northeast Brazil) and their respective common names, therapeutic indications, and taste attributes.

Scientific name	**Local name**	**Family**	**Herbarium voucher number**	**Number of citations**	**Disease categories**
Acanthospermum hispidum L.	Federação	Asteraceae	**IPA-91682**	27	inf, gas, inj, sym, res, oth
Algrizea minor Sobral, Faria & Proença	Araçá	Myrtaceae	**IPA-93451**	1	res, uro
Allium cepa L.	Cebola branca	Amaryllidaceae	**	1	inf, inj, sym, res, uro, oth
Allium fistulosum L.	Cebolinha	Amaryllidaceae	**	1	sym
Allium sativum L.	Alho	Amaryllidaceae	**	1	gas
Aloe vera (L.)	Babosa	Asphodelaceae	*	54	sym
Anacardium occidentale L.	Cajueiro vermelho	Anacardiaceae	**IPA-93683**	34	cul, inf, inj, sym, cir, res, gas, neo, uro, oth
Anadenanthera colubrina var.*cebil* (Griseb.) Altschul	Ângico	Fabaceae	**IPA-91698**	20	gas
Anethum graveolens L.	Endro	Apiaceae	*	5	inj
Annona squamosa L	pinha	Annonaceae	**	1	uro
Bauhinia acuruana Moric.	Mororó	Fabaceae	**IPA-93434**	31	cul, gas, sym, uro
Bidens sp.	Carrapicho de agulha	Asteraceae	**IPA-91622**	1	gas, cir
Boerhavia diffusa L.	Pega pinto	Nyctaginaceae	**IPA-91679**	13	end, gas, uro
Calliandra aeschyno menoites Benth.	Jiquiri	Fabaceae	**IPA-91664**	3	end, inf, gas, inj, sym, cir, res, oth
Cereus jamacaru DC.	Mandacaru	Cactaceae	**	18	inj, gen
Citrus × limon (L.) Osbeck	Limão	Rutaceae	**	2	gas, sym, cir, res, oth
Cnidoscolus pubescens Pohl	Favela	Euphorbiaceae	**IPA-93460**	2	inf, gas, sym, res, uro, oth
Cnidoscolus urens (L.) Arthur	Urtiga	Euphorbiaceae	**IPA-91704**	3	inf, inj
Cocos nucifera L.	Coqueiro	Arecaceae	**	1	vet, sym, inj
Commiphora leptophloeos (Mart.) J.B.Gillett	Imburana de cambão	Burseracea	**IPA-93685**	32	inf, inj, sym, cir, res, uro, oth
Croton conduplicatus Kunth	Quebra faca do sertão	Euphorbiaceae	*	37	neo
Croton grewioides Baill.	canelinha	Euphorbiaceae	**IPA-91623**	4	gas, sym, cir
Croton heliotropiifolius Kunth.	Velame	Euphorbiaceae	**IPA-91675**	28	neo
Croton micans Sw.	Marmeleiro	Euphorbiaceae	**IPA-91685**	15	inf, gas, res
Croton pulegiodorus Baill.	Alfavaca	Euphorbiaceae	**IPA-91683**	3	oth
Cymbopogon citratus (DC.) Stapf	Capim santo	Poaceae	**	21	inj
Capparis flexuosa (L.) L.	Feijão brabo	Capparaceae	**IPA-93438**	9	gas, uro

Dalbergia cearensis Ducke	Amora	Fabaceae	**IPA-93689**	1	end, inf, gas, inj, sym, res, gen
Dioclea grandiflora Mart. ex Benth.	Mucunã	Fabaceae	**IPA-93476**	1	inf, gas, neo, sym, cir, uro, oth
Dysphania ambrosioides (L.) Mosyakin & Clemants	Mastruz	Amaranthaceae	**IPA-91613**	67	res
Erythrina velutina Willd.	Mulungu	Fabaceae	*	2	end, inf, cir
Euphorbia tirucalli L.	Aveloz	Euphorbiaceae	*	1	inj
Gossypium sp.	Algodão	Malvaceae	**	1	sym, res
Guapira laxa (Netto) Furlan	Piranha	Nyctaginaceae	*	3	gas
Handroanthus impetiginosus (Mart.ex DC.) Mattos	Pau d'árco roxo	Bignoniaceae	*	14	sym
Harrisia adscendens (Gurke) Britto et Rose	Rabo de raposa	Cactaceae	*	10	uro
Hymenaea courbaril L.	Jatobá	Fabaceae	**IPA-93442**	59	sym, res
Jatropha gossypiifolia L.	Pinhão roxo	Euphorbiaceae	**IPA-91702**	2	edn, gas, inj, cir, res
Jatropha mollissima (Pohl) Baill.	Pinhão	Euphorbiaceae	**IPA-91703**	4	sym, res, oth
Jatropha mutabilis (Pohl.) Baill.	Pinhão brabo	Euphorbiaceae	**IPA-93472**	1	gas
Libidibia ferrea (Mart. ex Tul.) L.P.Queiroz	Pau ferro	Fabaceae	**IPA-93448**	3	inf, gas, inj, sym, cir, res, uro, oth
Lippia gracilis Shauer.	Erva cidreira	Verbenaceae	**IPA-91612**	32	gas
Lippia origanoides Kunth	Alecrim	Verbenaceae	**IPA-93457**	27	inf, gas, inj, neo, sym, cir, res, uro, oth
Malpighia emarginata DC.	Acerola	Malpighiaceae	**	1	sym
Mangifera indica L	Manga	Anacardiaceae	**	2	end, inf, res, oth
Maytenus cf.opaca Reissek	Bom nome	Celastraceae	**IPA-91689**	31	cul, inf, gas, inj, sym, cir, res, uro, oth
Mimosa tenuiflora (Willd.) Poir.	Jurema preta	Fabaceae	*	15	inf, res
Musa × paradisiaca L.	Banana	Musaceae	**	2	inf, gas, sym
Myracrodruon urundeuva Allemão	Aroeira	Anacardiaceae	*	61	end, inf, gas, sym, cir, res, oth
Myroxylon peruiferum L.f.	Bálsamo	Fabaceae	*	54	res
Neoglaziovia variegata (Arruda) Mez	Crauá	Bromeliaceae	**IPA-91701**	1	cir
Ocimum basilicum L	Manjericão	-	**	4	inf, inj
Passiflora cincinnata Mast.	Maracujá do mato	Passifloraceae	**IPA-91635**	5	gas, sym
Passiflora edulis Sims	Maracujá	Passifloraceae	**	1	inj, sym, uro
Passiflora foetida L.	Maracujá de estralo	Passifloraceae	**IPA-91677**	1	Res
Periandra mediterranea (Vell.) Taub.	Alcançuz	Fabaceae	**IPA-91648**	46	cir
Persea americana Mill	Abacate	Lauraceae	**	6	sym
Peumus boldus Molina	Boldo	Monimiaceae	**	3	gas
Phyllantus niruri L.	Quebra pedra	Phytollacaceae	**HST-2216**	6	inj
Piptadenia viridiflora (Kunth) Benth.	Espinheiro	Fabaceae	**IPA-93486**	2	sym

Pityrocarpa moniliformis (Benth.) Luckow & R.W.Jobson	Canzenzo	Fabaceae	**IPA-93459**	6	inf, gas, sym, res, cir, uro
Plinia cauliflora (DC.) Kausel	Jabuticaba	Myrtaceae	**	1	gas, sym, res, oth
Plumbago scandens L.	Louco	Plumbaginaceae	**HST-22163**	1	inf, gas, inj, neo, sym, cir, uro
Poincianella microphylla (Mart. ex G.Don) L.P.Queiroz	Catingueira	Fabaceae	**IPA-93473**	8	inf, inj, cir, res, uro
Pombalia calceolaria (L.) Paula-Souza	Papaconha	Violaceae	**IPA-91687**	48	sym, oth
Prosopis juliflora (Sw.) DC.	Algaroba	Fabaceae	**IPA-93440**	23	gas, sym
Psidium guajava L	Goiaba branca	Myrtaceae	**	4	sym, res
Punica granatum L.	Romã	Lythraceae	**	14	inf, gas,
Ricinus communis L.	Mamona	Euphorbiaceae	**	1	uro
Ruta graveolens L.	Arruda	Rutaceae	**	21	gen
Sapium argutum (Müll.Arg.) Huber	Pau de leite	Euphorbiaceae	**IPA-93499**	18	gas
Senegalia bahiensis (Benth.) Seigler & Ebinger	Carcará	Fabaceae	**IPA-93428**	2	sym, res
Senna spectabilis var. excelsa (Schrad.) H.S.Irwin & Barneby	Canafístula	Fabaceae	**HST-22166**	2	inf, gas, inj, cir
Sideroxylon obtusifolium (Roem. & Schult.) T.D. Penn.	Quixabeira	Sapotaceae	*	60	cul, inf, inj, sym, cir, res, oth
Solanum agrarium Sendtn.	Gogóia	Solanaceae	**IPA-91688**	1	vet
Solanum paniculatum L.	Jurubeba	Solanaceae	**IPA-91633**	22	inf, gas, sym, res
Solanum stipulaceum Willd. ex Roem. & Schult.	Sacatinga	Solanaceae	**IPA-93429**	2	inf
Spondias purpurea L.	Seriguela	Anacardiaceae	**	1	end, inf, gas, inj, cir, res, uro, oth
Spondias tuberosa Arruda	Umbuzeiro	Anacardiaceae	*	7	sym, res
Syagrus sp.	Ouricuri	Arecaceae	**	2	gas
Terminalia fagifolia Mart.	Muçambê	Combretaceae	**IPA-91638**	2	res
Tocoyena formosa (Cham. & Schltdl.) K.Schum.	Jenipapo	Rubiaceae	**IPA-91681**	8	inf, gas, inj, sym, uro
Trischidium molle (Benth.) H.E.Ireland	Quina quina	Fabaceae	**IPA-91699**	7	gas, sym
Varronia curassavica Jacq.	Moleque duro	Boraginaceae	**IPA-93444**	5	inf, gas, inj, sym, res, uro, oth
Ximenia americana L.	Ameixa	Olacaceae	*	97	le, gen
Zingiber officinale Roscoe	Gengibre	Zingiberaceae	**	4	inj, sym
Sarcomphalus joazeiro (Mart.) Hauenschild	Juazeiro	Rhamnaceae	**IPA-91676**	51	inf, inj, sym, uro
	Batata de onça	-	-	7	sym
	Imburana de cheiro	-	-	47	inf, inj, gas, neo, oth
	Hortelã	-	-	37	inf
	Sassafrás	-	-	32	gas

Baraúna	-	-	23	gas, sym, res, oth
Eucalipto	-	-	15	cul, inf, gas, inj, neo, sym, uro
Carrapicho de boi	-	-	13	gas
Mangerioba	-	-	12	gas
Coroa de frade	-	-	10	end, inf, sym, oth
Cidreira	-	-	9	gas, sym
Hortelã grande	-	-	9	gas, inj, sym, cir, res
Samba caité	-	-	9	inj, gen
Alento	-	-	8	inf
Erva doce	-	-	7	res
Cabeça de nego	-	-	5	cir, oth
Jucá	-	-	4	cul, sym, res, uro
Melancia	-	-	4	inf, sym
Alecrim de cabloco	-	-	3	vet, sym, res
Beladona	-	-	3	gas
Biratanha	-	-	3	inf, sym, res
Cabacinha	-	-	3	gas
Cana de macaco	-	-	3	uro
Cravo	-	-	3	cul, end, inf, gas, sym, res, oth
Espinho de cigano	-	-	3	sym, res
Fedegoso	-	-	3	inf, sym, res
Hortelã pimenta	-	-	3	res
Sabugueira	-	-	3	end, inf, gas, inj, sym, cir, res, uro
Vassourinha	-	-	3	inj
Alecrim do mato	-	-	2	inf, gas, sym, res, oth
Capeba	-	-	2	inf, inj, sym, cir, res
Cipó de vaqueiro	-	-	2	uro
Folha miúda	-	-	2	sym, cir
Marcela	-	-	2	inf
Ubaia	-	-	2	end, inf, gas, inj, sym, cir, res, oth
Alecrim de serrote	-	-	1	gas
Amargoso	-	-	1	gas, inj, oth
Batata de purga	-	-	1	oth
Batata de raposa	-	-	1	inj, oth
Caiubinha	-	-	1	inf, gas, sym, res, uro, oth

Camboim	-	-	1	end, inf, gas, neo, sym, cir, res, uro
Cansanção	-	-	1	cul, inf, gas, inj, sym, cir, oth
Embaúba	-	-	1	inf, inj
Feijão de corda	-	-	1	inf
Guardião	-	-	1	inf, gas, inj, sym, res, uro, oth
Hortelã roxo	-	-	1	uro
Marva de botão	-	-	1	inf, gas, inj, neo, res, uro, oth
Mata pasto	-	-	1	sym, res
Mato verde	-	-	1	gas, res
Moita de mulher	-	-	1	inf, gas, neo
Plenito	-	-	1	end, inf, gas, inj, oth
Rabo de cavalo	-	-	1	gas
Rajinha	-	-	1	gas, cir

References: inf= infectious and parasitic; gas= gastrointestinal, injury= injuries; sym= general symptoms and signs; res = respiratory; cir = circulatory; uro= urogenital; end = endocrine; neo= neoplasm; cul= cultural syndromes; veterinarian = veterinarian; other = others; * = infertile material; - = specimen not collected, **=determined by popular name.

Tabela 2. Disease categories mentioned by the PARNA Catimbau communities in northeastern Brazil, including the respective counts of diseases, plant species, and species of bitter plants cited.

Category of disease	Number of diseases	Number of plant species	Number of bitter taste species
Gastrointestinal	42	65	31
Urogenital	33	39	15
Injuries	28	45	15
Infectious and parasitic	24	54	28
Respiratory	17	54	21
Others	16	35	9
Circulatory	16	31	14
General symptoms and signs	13	67	29
Endocrine	6	14	4
Cultural or spiritual	5	8	2
Neoplasia	3	11	4
Veterinary	2	3	1

Discussion

Numerous research efforts have underscored organoleptic characteristics, encompassing taste, as pivotal criteria for the selection of resources due to their possible correlation with the medicinal use of plants (Ankli *et al.* 1999, Dragos *et al.* 2022, Gilca & Barbulescu 2015). This notion becomes increasingly fascinating when pondering the fact that our archaic relatives, the Neanderthals, possessed the ability to discern the organoleptic qualities of flora (Hardy *et al*. 2013).

Globally, we have noted that the perception of taste can vary. Molares & Ladio (2009) reported that the most commonly used species around Lake Rosario, Argentina, were easily distinguishable by their rich organoleptic descriptions, most often associated with a sweet taste, which is primarily used to address stomach complaints. Ankli *et al.* (1999) stated that while astringent-tasting plants are used to treat diarrhea, sweet-tasting plants are preferably employed to address respiratory system diseases. However, Amazonian indigenous people report that in young children, gastrointestinal diseases should be treated with plants with a sour or sweet taste due to the high toxicity of very bitter plants. (Shepard Júnior 2004). Leonti *et al.* (2002) reported that medicinal plants with astringent and bitter properties were most frequently cited by Popoluca indigenous people in Mexico. The authors noted that bitter taste is perceived as "warm", as it has a warming effect and is typically associated with the treatment of body and stomach pains (Leonti *et al.* 2002). The bitter taste is also connected to the treatment of skin diseases and, in the case of venomous animal bites, especially snakes (Ankli *et al.* 1999, Farias *et al.* 2023). For two Amazonian indigenous populations, extremely bitter plants are perceived as highly toxic and hence are advised against oral consumption. As a result, they are recommended for external application, such as in the treatment of skin ailments (Shepard Júnior 2004).

In our study, we expected to find that the various flavors of plants would correlate with the treatment of specific diseases. However, this held true only for the bitter taste. Our findings align with what has been reported in the literature from the semiarid region of Brazil, which provides evidence that bitter taste is a driving force in the identification of medicinal plants (Caetano *et al.* 2020, Medeiros *et al.* 2015, Reinaldo *et al.* 2022). For instance, Medeiros *et al.* (2015) reported that bitter taste was associated with the treatment of more prevalent diseases, and the prevalence of bitter taste was mainly found in medicinal plants with anti-inflammatory and healing properties. In contrast, Ferreira Júnior *et al*. (2011) reported that for local populations in the semiarid region of Pernambuco, a "strong bitter taste" is the preferred criterion when selecting medicinal plants for anti-inflammatory use.

Moreover, the importance of bitter taste may be linked to the fact that humans possess a wide variety of receptors from the TAS2R family, primarily located in the oral cavity, which can be activated by different chemical stimuli of a bitter taste (Behrens *et al*. 2009, Silva *et al.* 2020). Certain polyphenols might interact with bitter taste receptors both within and outside the oral cavity. This interaction not only impacts the perception of bitter taste but also influences various aspects of health and physiology (Canivenc-Clavier *et al.* 2019). Therefore, it is possible that individuals can perceive various chemical stimuli that cause a bitter taste and link them with different therapeutic objectives, broadening treatment options. Although this is a plausible hypothesis, it was recently tested by Silva *et al.* (2020) within the same communities as in this study, and no significant results were found. The authors showed that local experts are not more sensitive to the perception of the bitterness threshold than nonexperts are (Silva *et al*. 2020). Thus, other factors might better explain the selection of medicinal plants in the region.

Many pieces of evidence have indicated that medicinal plants from semiarid regions of Brazil, such as the Caatinga, prioritize the production of phenolic compounds, especially tannins (Albuquerque *et al.* 2012, Almeida *et al*. 2005, Almeida *et al.* 2011, Siqueira *et al.* 2012). This can be explained by the region's typical conditions, as the synthesis of phenolic compounds is favored there (Zahedi *et al.* 2021).

Given that a great diversity of bioactive compounds determine the bitter taste of plants (Dragos & Gilca 2018), bitter plants may be chosen for specific ailments and were later tested for other therapeutic indications. The results of these experiments might explain why we found a significant representation of bitter plants across all disease categories, even if it was not the predominant taste. Among human populations, the use of medicinal plants for various therapeutic targets is a critical criterion for their selection (Maneenoon *et al.* 2015). However, since most plants in the Caatinga genus produce phenolic compounds, which have been linked to bitterness and astringency (Albuquerque *et al.* 2020, Silva *et al.* 2012), bitter taste might not be a good predictive factor for selecting medicinal plants for the treatment of specific diseases, at least in the semiarid region of Brazil.

Limitations

We encountered some challenges in categorizing flavors due to the subjectivity of individual perceptions, such as the concept of "travaso" or the plant's inherent taste. Furthermore, some informants could not accurately describe their taste ("do not know"), and another group mentioned that the perceived taste was "tasteless", meaning it "does not taste like anything."

Declarations

Ethics approval and consent to participate: We previously provided informed consent, as detailed in the manuscript.
Consent for publication: Not applicable in this section.
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Literature cited

Albuquerque UP, Cunha LVFC, Lucena RFP, Alves RRN (eds.). 2014. Methods and Techniques in Ethnobiology and Ethnoecology. Methods and Techniques in Ethnobiology and Ethnoecology. Springer, New York.

Albuquerque UP, Nascimento ALB, Silva Chaves L, Feitosa IS, Moura JMB, Gonçalves PHS, Silva RH, Silva TC, Ferreira-Júnior WS. 2020. The Chemical Ecology Approach to Modern and Early Human Use of Medicinal Plants. Chemoecology 30(2):89-102.

Albuquerque UP, Ramos MA, Melo JG. 2012. New strategies for drug discovery in tropical forests based on ethnobotanical and chemical ecological studies. Journal of Ethnopharmacology 140(1):197-201.

Almeida CFCBR, Amorim, ELC, Albuquerque, UP. 2011. Insights into the search for new drugs from traditional knowledge: an ethnobotanical and chemical–ecological perspective. Pharmaceutical Biology 49(8):864-873.

Almeida CFCBR, Silva TDL, Amorim ELC, Maia MDS, Albuquerque UP. 2005. Life strategy and chemical composition as predictors of the selection of medicinal plants from the caatinga (Northeast Brazil). Journal of Arid Environments 62(1):127-142.

Ankli O, Stich M, Heinrich M. 1999. Yucatec Maya Medicinal Plants Versus Nonmedicinal Plants: Indigenous Characterization and Selection. Human Ecology 27(4):557-580.

Behrens A, Brockhoff C, Batram *et al*. 2009. The Human Bitter Taste Receptor hTAS2R50 Is Activated by the Two Natural Bitter Terpenoids Andrographolide and Amarogentin. Journal of Agricultural and Food Chemistry 57(21):9860-9866.

Brett J, Heinrich M. 1998. Culture, Perception, and the Environment: The Role of Chemosensory Perception. Journal of Applied Botany 72:67-69.

Caetano RDA, Albuquerque UP, Medeiros PM. 2020. What Are the Drivers of Popularity and Versatility of Medicinal Plants in Local Medical Systems? Acta Botanica Brasilica 34(2):256-265.

Canivenc-Lavier MC, Neiers F, Briand, L. 2019. Plant polyphenols, chemoreception, taste receptors and taste management. Current Opinion in Clinical Nutrition & Metabolic Care 22(6):472-478.

Casagrande D. 2000. Human Taste and Cognition in Tzeltal Maya Medicinal Plant Use. Journal of Ecological Anthropology 4:57-69.

Dragoș D, Gilca M. 2018. Taste of Phytocompounds: A Better Predictor for Ethnopharmacological Activities of Medicinal Plants Than the Phytochemical Class? Journal of Ethnopharmacology 220:129-146.

Dragoș D, Petran M, Gradinaru TC, Gilca M. 2022. Phytochemicals and Inflammation: Is Bitter Better? Plants 11(21):2991.

Farias AS, Nascimento EF, Gomes Filho MR, Felix AC, Arévalo MC, Adrião AAX, Wen FH, Carvalho FG, Murta F, Machado VA, Sachett J, Monteiro WM. 2023. Building an explanatory model for snakebite envenoming care in the Brazilian Amazon from the indigenous caregivers' perspective. PLOS Neglected Tropical Diseases 17(3):e0011172.

Ferreira-Júnior WSF, Ladio AH, Albuquerque UP. 2011. Resilience and adaptation in the use of medicinal plants with suspected anti-inflammatory activity in the Brazilian Northeast. Journal of Ethnopharmacology 138(1):238-252.

Geck MS, Cabras S, Casu L, Reyes García, AJ, Leonti M. 2017. The taste of heat: How humoral qualities act as a cultural filter for chemosensory properties guiding herbal medicine. Journal of Ethnopharmacology 198:499-515.

Gilca M, Barbulescu A. 2015. Taste of medicinal plants: a potential tool in predicting ethnopharmacological activities?. Journal of Ethnopharmacology 174:464-473.

Glendinning, JI. 1994. Is the bitter rejection response always adaptive? Physiology & Behavior 56(6):1217-1227.

Hardy K, Buckley S, Huffman M. 2013. Neanderthal self-medication in context. Antiquity 87(337):873-878.

Hayes JE, Johnson SL. 2017. Sensory aspects of bitter and sweet tastes during early childhood. Nutrition Today 52(2):S41-S51.

Heinrich M, Edwards S, Moerman DE, Leonti M. 2009. Ethnopharmacological Field Studies: A Critical Assessment of Their Conceptual Basis and Methods. Journal of Ethnopharmacology 124(1):1-17.

Heinrich M, Rimpler H, Barrera NA. 1992. Indigenous Phytotherapy of Gastrointestinal Disorders in a Lowland Mixe Community (Oaxaca, Mexico): Ethnopharmacologic Evaluation. Journal of Ethnopharmacology 36(1):63-80.

Jeruzal-Świątecka J, Fendler W, Pietruszewska W. 2020. Clinical role of extraoral bitter taste receptors. International Journal of Molecular Sciences 21(14):5156.

Johns T. 1996. The Origins of human Diet & Medicine. The University of Arizona Press.

Laurentino M, Araújo EL, Ramos MA, Cavalcanti MCBT, Gonçalves PHS, Albuquerque UP. 2022. Socioeconomic and ecological indicators in willingness to accept compensation for the conservation of medicinal plants in a tropical dry forest. Environment, Development and Sustainability 24:4471-4489.

Leonti M, Sticher O, Heinrich M. 2002. Medicinal Plants of the Popoluca, México: Organoleptic Properties as Indigenous Selection Criteria. Journal of Ethnopharmacology 81(3):307-315.

Magalhães HF, Feitosa IS, Araújo EL, Albuquerque UP. 2021. Perceptions of risks related to climate change in agroecosystems in a semiarid region of Brazil. Human Ecology 49:403-413.

Maneenoon K, Khuniad C, Teanuan Y, Saedan N, Prom-In S, Rukleng N, Kongpool W, Pinsook P, Wongwiwat W. 2015. Ethnomedicinal plants used by traditional healers in Phatthalung Province, Peninsular Thailand. Journal of Ethnobiology and Ethnomedicine 11(1):1-20.

Medeiros PM, Santos Pinto BL, Nascimento VT. 2015. Can organoleptic properties explain the differential use of medicinal plants? Evidence from Northeastern Brazil. Journal of Ethnopharmacology 159:43-48.

Mennella JA, Spector AC, Reed DR, Coldwell SE. 2013. The Bad Taste of Medicines: Overview of Basic Research on Bitter Taste. Clinical Therapeutics 35(8):1225-1246.

Missouri Botanical Garden. Tropicos.org. https://tropicos.org. (Accessed 30/08/2023).

Molares S, Ladio A. 2009. Chemosensory Perception and Medicinal Plants for Digestive Ailments in a Mapuche Community in NW Patagonia, Argentina. Journal of Ethnopharmacology 123(3):397–406.

R: The R Project for Statistical Computing. [https://www.r-project.org/] Accessed September 04, 2023.

Reinaldo RCPS, Albuquerque UP, Medeiros, P. 2020. Taxonomic affiliation influences the selection of medicinal plants among people from semiarid and humid regions—a proposition for the evaluation of utilitarian equivalence in Northeast Brazil. PeerJ 8:e9664.

Reinaldo RCPS, Santoro FR, Albuquerque UP, Medeiros PM. 2022. Taste and Chemical Composition as Drives for Utilitarian Redundancy and Equivalence: A Case Study in Local Medical Systems in Northeastern Brazil. Journal of Ethnobiology and Ethnomedicine 18(1): 1-17.

Rito KF, Tabarelli M, Leal IR. 2017. Euphorbiaceae responses to chronic anthropogenic disturbances in Caatinga vegetation: from species proliferation to biotic homogenization. Plant Ecology 218:749-759.

Schaefer M, Kühnel A, Schweitzer F, Rumpel F, Gärtner M. 2023. Experiencing sweet taste is associated with an increase in prosocial behavior. Scientific Reports 13(1):1954.

Schmeda-Hirschmann G, Astudillo L, Rodríguez J, Theoduloz C, Yáñez T. 2005. Gastroprotective effect of the Mapuche crude drug *Araucaria araucana* resin and its main constituents. Journal of Ethnopharmacology 101(1-3):271-276.

Shepard Jr. GH, 2004. A Sensory Ecology of Medicinal Plant Therapy in Two Amazonian Societies. American Anthropologist 106(2): 252-266.

Silva JPC, Gonçalves PHS, Albuquerque UP, Silva RRV, Medeiros PM. 2021. Can medicinal use protect plant species from wood uses? Evidence from Northeastern Brazil. Journal of Environmental Management 279:111800.

Silva MI, Melo CT, Vasconcelos LF, Carvalho AM, Sousa FC. 2012. Bioactivity and potential therapeutic benefits of some medicinal plants from the Caatinga (semiarid) vegetation of Northeast Brazil: a review of the literature. Revista Brasileira de Farmacognosia 22:193-207.

Silva TLL, Ferreira-Júnior WSF, Albuquerque UP. 2020. Is there a biological basis in the selection of medicinal plants in the human species? An initial approach based on chemosensory perception. Ethnobiology and Conservation 9:1-15.

Siqueira CFDQ, Cabral DLV, Peixoto Sobrinho TJDS, Amorim ELC, Melo JG, Araújo TADS, Albuquerque UP. 2012. Levels of tannins and flavonoids in medicinal plants: evaluating bioprospecting strategies. Evidence-Based Complementary and Alternative Medicine 2012: 434782

Sousa BM, Albuquerque UP, Araújo EL. 2022a. Easy Access to Biomedicine and Knowledge about Medicinal Plants: A Case Study in a Semiarid Region of Brazil. Evidence-Based Complementary and Alternative Medicine 2022: 1–8.

Sousa BM, Albuquerque UP, Araújo EL. 2022b. Local knowledge about medicinal plants does not influence the self-reported well-being of inhabitants of the semiarid region of northeastern Brazil. Ethnobotany Research and Applications 24: 1–8.

The Taxonomic Name Resolution Service. iPlant collaboration. V5.1. http://tnrs.iplantcollaborative.org. (Accessed 30/08/2023).

Venditti C, Musa-Veloso K, Lee HY, Poon T, Mak A, Darch M, Juana J, Fronda D, Noori D, Pateman E, Jack M. 2020. Determinants of sweetness preference: A scoping review of human studies Nutrients 12(3):718.

Zahedi SM, Karimi M, Venditti A. 2021. Plants adapted to arid areas: specialized metabolites. Natural Product Research 35(19):3314-3331.