ETHNOBIOLOGY AND CONSERVATION

RESEARCH ARTICLE

Ethnobiology and Conservation 2020, 9:3 (16 January 2020)
doi:10.15451/ec2020-01-9.03-1-15
ISSN 2238 4782 ethnobioconservation.com

Is there a biological basis in the selection of medicinal plants in the human species? An initial approach based on chemosensory perception of taste

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ABSTRACT

The ability to identify tastes associated with plant chemicals may have favored humans in identifying plant chemists with pharmacological activity throughout human evolutionary history. The genetic basis of taste perception influences people's varying sensitivity to perceive chemical stimuli of taste. This biological basis can play an important role in plant selection to compose local medical systems, given the argument in the ethnobiological literature that plant taste can influence their selection as a medicinal resource. Thus, we aimed to understand whether this biological basis influences on the selection of medicinal plants. Our investigation was made through the survey of ethnobiological data on the knowledge of medicinal plants and sensitivity data on the perception of bitter taste in two local communities. We tested whether local experts and active experimenters of medicinal plants are more sensitive to the perception of bitter taste than the rest of the population. Additionally, we evaluated whether this biological basis influences on the number of citations of plants with taste and on the versatility attributed to medicinal plants. Our assumptions were not corroborated by our results. It is likely that the bitter taste threshold is not relevant for the selection of medicinal plants.

Keywords: Evolutionary Ethnobiology; Ethnobotany; Taste Threshold; Taste Perception; Organoleptic Property; Local Medical Systems

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INTRODUCTION

The ability to detect tastes is a feature present in humans and other animals that enables them to perceive and deal with the surrounding chemical environment (Glendinning 1994; Mennella et al. 2013). Some behaviors, such as rejection of bitter taste and acceptability of sweet tastes, are innate and conserved in different animal species (Glendinning 1994; Hayes and Johnson 2017). When it comes to bitter taste rejection, this behavior represents an important biological function as it may allow humans to avoid involuntary ingestion of toxic compounds, as bitter taste is naturally associated with generally toxic secondary metabolites (Glendinning 1994).

The allelic diversity of the *TAS2R* gene (Behrens and Meyerhof 2006; Mennella et al. 2005) affects variations in the perception of bitter taste. Thus, there are individuals who are naturally very sensitive in the perception of bitter taste, identifying the chemical stimulus in a solution even if it is in small concentrations, whereas low sensitive individuals identify the chemical stimulus only in high concentration (Mennella et al. 2005). Bitter taste receptor cells are located in the oral cavity, mainly in the tongue, and have a set of *TAS2R* family receptors that can be activated by different chemical stimuli (Behrens et al. 2009). The *TAS2R* gene have probably been target of selective pressure since the evolutionary past of humans, favoring individuals who could identify toxic compounds and regulate their intake, avoiding poisoning (Richerson and Boyd 2005; Soranzo et al. 2005).

Through the taste threshold, it is possible to objectively measure the phenotypic expression of *TAS2R*. Two thresholds can be measured: taste detection threshold, which is the lowest concentration at which a substance can be distinguished from water (Harris and Kalmus 1949; Hong et al. 2005); and the taste identification threshold, which is the lowest concentration at which the taste quality of a substance can be identified (e.g. bitter, sour, etc.) (Hong et al. 2005). Thus, the taste threshold is a measure inversely proportional to the sensitivity in the perception of taste. The lower the threshold of an individual, the greater their sensitivity to perceive tastes. There is evidence in the literature that found a relationship between the bitter taste identification threshold and the other tastes threshold, especially sweet (Chang et al. 2006; Pasquet et al. 2002) and salty tastes (Pasquet et al. 2002).

The perception of bitter taste does not only appear to be a biological mechanism to prevent involuntary ingestion of toxic bitter substances (Behrens et al., 2018), but may play an important role in selecting plants for human populations and influencing the construction of local pharmacopoeias. Evidence has shown that plant taste is a strong attribute for identifying their medicinal potential (Ankli et al. 1999; Brett and Heinrich 1998; Casagrande 2000; Dragos and Gilca 2018; Geck et al. 2017; Gilca and Barbulescu 2015; Medeiros et al. 2015; Molares and Ladio 2009). The reason for this is likely to be linked to the fact that compounds having biological activity (Behrens et al. 2009; Drewnowski and Gomez-Carneros 2000) determine the taste of plants. For bitter taste, for example, there is evidence of two terpenoids found in Chinese medicinal plants (andrografolide and amarogentin) that are known to have bitter taste by activating bitter taste receptor cells (Behrens et al. 2009). Besides bitter taste, among the ethnobotanical evidences, Ankli et al. (1999) and Leonti et al. (2002) reported the importance of plant taste attributes for the distinction between medicinal and non-medicinal plants among local populations. Morales and Ladio (2009), in turn, reported that stomach problems are treated with strong-smelling and intense taste, usually sweet plants, in the arid Patagonia Argentina. Bitter-tasting plants are also indicated for the treatment of inflammation (Medeiros et al, 2015) and gastrointestinal disorders such as diarrhea and dysentery (Ankli et al. 1999; Heinrich et al. 1992; Medeiros et al. 2015).

Plant taste is generally related to certain secondary compounds such as terpenoids, flavonoids, tannins and other chemical components (Heinrich et al. 1992) that have pharmacological activity (Brett and Heinrich 1998). However, the same taste attribute may be related to different chemical compounds. The bitter taste of plants, for example, can be determined by the presence of compounds of the following classes: cyanogenic glycosides, polyphenols, terpenoids and alkaloids (Dragos and Gilca 2018), as well as methylxanthines and sulfonamides (Drewnowski 2009). Individuals with lower thresholds of bitter taste who could distinguish different tastes in plants, and thus make more taste-therapeutic indication associations, could best distinguish the diversity of chemical compounds. Thus, we believe that individuals who have a higher sensitivity to the perception of bitter taste would assign more therapeutic functions to medicinal plants, increasing their versatility in medical systems.

The process of selecting plants to treat diseases can be interpreted as an adaptive strategy, considering that diseases can be considered selective pressures that have always been present in human history (Wiley and Allen 2009). Throughout evolution, the pursuit of plants for nutrition has led humans to develop strategies to deal with plant chemicals to maximize the nutritional benefit of low intake of toxic compounds (Jonhs 1990, 1996), directly influencing individual survival. In his model of human chemical ecology, the development and transmission of practices for dealing with toxic compounds, such as plant fermentation and domestication, played a key role in minimizing the effects of toxins while searching for food (Johns 1990; see also Ferreira Júnior and Albuquerque 2018). This may have facilitated the safety of tasting with a larger set of new plants and favored the identification of resources that alleviated disease symptoms. Humans began to make an association between the taste of plants and their chemical substances, being able to identify possible toxins and plants with pharmacological properties (Ferreira Júnior and Albuquerque 2018).

It is possible that people with lower taste thresholds played a key role in the early use of plants to treat disease. Ferreira Junior et al. (2015) argue that, during human evolution, people who were genetically more sensitive to the perception of bitter taste were more likely to associate the taste of a plant with its medicinal properties and that they were possibly shamans or holders of vast knowledge on plants used for food and medicine. Nowadays, it is likely that these social roles would still be related to the bitter taste threshold, as this feature would facilitate the performance of their role in local medical systems. Heinrich (1994) reported that local specialists from Sierra Mixe in Oaxaca (Mexico) use taste and smell as criteria to decide which plant is useful for treating a particular disease. The authors argue that these organoleptic characteristics may guide specialists in the search for new medicinal plants.

In this study, we aimed to understand whether the biological base of chemosensory perception plays a role in the selection of medicinal plants in local populations in northeastern Brazil. Specifically, we are choosing the Bitter Taste Identification Threshold - which represents the phenotypic expression of the *TAS2R* gene - as our biological based measure to test some hypotheses related to the medicinal plant selection process. To the best of our knowledge, this is the first study to measure the bitter taste threshold *in situ* and to relate it to the selection of medicinal plants. We investigated the bitter taste threshold due to the large amount of knowledge in the literature on evolutionary, physiological, behavioral and genetic aspects of bitter taste perception. In addition, the bitter taste threshold correlates with the threshold of other tastes (Chang et al. 2006; Gent and Bartoshuk 1983; Pasquet et al. 2002).

We hypothesized that the biological base of chemosensory perception influences in assigning the social role of the local expert. We consider as experts those locally recognized as having extensive knowledge on medicinal plants. We expect people who play this social role to have lower thresholds of bitter taste than non-specialists. Alternatively, we hypothesize that the biological base of chemosensory perception influences in the habit of being an active experimenter of medicinal plants. In our study, the active medicinal plant experimenter is that individual who, regardless of his social role in the medical system, usually tastes new plants to identify their medicinal potential. This hypothesis does not nullify the first, since local experts and experimenters may use similar biological mechanisms in plant selection to treat diseases. Thus, we expect that an active experimenter of medicinal plants will present a lower bitter taste threshold compared to a non-experimenter. We also hypothesized that the chemosensory perception of taste influences on the selection of medicinal plants by taste. We expect an inverse relationship between the bitter taste threshold and the citation number of bitter and tasteful plants, that is, the higher the sensitivity of an individual, the more tasteful plants they cite. Finally, we hypothesized that individuals with lower bitter taste thresholds would assign more therapeutic targets to plants. We also expect an inverse relationship between our variables, that is, the higher the sensitivity of experimenters, the more therapeutic targets they will cite to the plants.

MATERIAL AND METHODS

Study area

Our study involves an experiment that usually takes place in reserved lab rooms or research centers. However, this is an *in situ* study conducted in two rural communities in northeastern Brazil. We selected communities that are already part of a larger project, coordinated by researchers from the National Institute of Science and Technology - Ethnobiology, Bioprospecting and Nature Conservation (www.inctethnobio.com/), to which this study is linked. The purpose of INCT is to meet the demand for systematic studies on the nature-society interface related to ethnobiology, bioprospecting and nature conservation.

We selected the local communities Sítio Igrejinha and Sítio Muquém (here referred to as Igrejinha and Muquém, respectively), located within the Catimbau National Park (Figure 1). The PARNA Catimbau covers approximately 62,000 hectares and is located in the municipalities of Buíque, Ibirimirim and Tupanatinga, in the state of Pernambuco, approximately 300 km from Recife (state capital). The vegetation is typical of Caatinga, a seasonally dry forest with semi-arid climate (BSH according to the Koppen classification). The region has an average temperature of 23°C and annual average rainfall ranging from 486 mm to 975 mm. PARNA Catimbau does not have a management plan yet, even though it was created since 2002 (a decree of December 13, 2002). There are still human populations living inside the park, distributed among 11 communities, even though this category of Conservation Unit does not permit the presence of human populations or particular areas.

In Igrejinha and Muquém there are

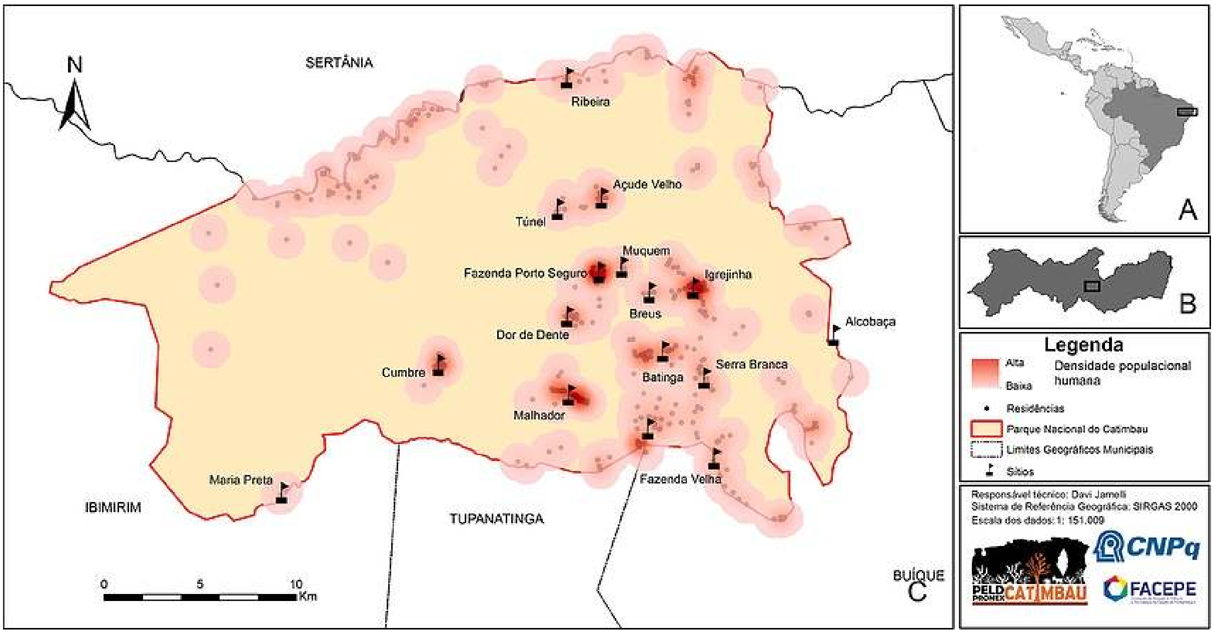

Figure 1. Location of the communities Sítio Igrejinha and Sítio Muquém in the Catimbau PARNA. (Source: PELD Catimbau / https: //www.peldcatimbau.org/).

approximately 56 and 20 families, respectively, living mainly from subsistence farming and goat raising. The population of Igrejinha and Muquém depends on natural resources for some basic demands such as the use of woody resources as plant fuels and for the construction of houses and fences, the collection of food plants and, above all, the use of plants to treat diseases. These populations have already experienced several conflicts with the management of PARNA Catimbau due to their dependence on natural resources to meet their subsistence demands. Because of this conflict, there is a fear among the people of the region to share information with researchers about the use of natural resources, especially hunting and woody resources. In addition, the population also has to deal daily with water shortages, which is a common problem in various locations in Brazil's semiarid region.

Both communities do not have a school, community association, health center or hospital. Health care is provided in Vila do Catimbau (a small village of 2,240 inhabitants (IBGE 2000) which is the main access to PARNA Catimbau and is 12 km from city center Buíque and approximately 15 km from the surrounding communities) or in the city center of Buíque. Thus, they are inaccessible to many families who do not have the financial resources to move frequently to these places. Medicinal plants end up being the most accessible resource for primary health care. These communities were chosen because of their receptiveness to the research group of the Laboratory of Ecology and Evolution of Social-ecological Systems that has been conducting studies at PARNA Catimbau since 2017. The communities also have a history of using medicinal plants to treat various diseases.

Ethical Aspects

We conducted our study following the rules and guidelines of the National Health Council (Resolution 466/12), through the Research Ethics Committee (CEP) of the

University of Pernambuco, which gave a favorable opinion for the execution of the research (CAAE: 89890917.1.0000.5207). Our study was also appreciated by the Biodiversity Authorization and Information System (SISBio), which granted authorization to undertake the research at PARNA Catimbau (No. 55107), as it is a Conservation Unit.

Recruitment of participants and data collection

We conducted visits in all homes of the two communities (16 in Muquém and 51 in Igrejinha) to invite people over 18 years old to participate in the study. We explained to each participant the purpose of the research and those who agreed to participate were invited to sign the Informed Consent Term (ICT).

We performed data collection in two steps, not necessarily consecutive. One of the steps was the use of the free listing technique (see Albuquerque et al. 2014) to record the medicinal plants known to each participant (Figure 2a). We carried out this step with other researchers who are also associated with the INCT, as well as gathering other information about the use of natural resources in the region. The guiding question of the technique was "which medicinal plants do you know?" Subsequently, we asked on the therapeutic indications of each plant and its taste attributes. This was a long phase, which took place between January and November 2017, and involved all 11 communities located within PARNA Catimbau. The total number of participants who agreed to participate in this phase were 32 (84.21% of the population over 18 years old) people in Muquém and 84 (75% of the population over 18 years old) people in Igrejinha. This was the total number of people we invited to participate in the second phase of the survey in both communities.

The second stage of data collection involved the execution of the experiment on bitter taste identification threshold, designed to determine how sensitive each participant is to the perception of bitter taste, in addition to identifying local experts and active experimenters in the communities.

We measured the bitter taste identification threshold using phenylthiocarbamide (PTC) solutions diluted in distilled water. PTC is a synthetic compound and is not found in nature (Tepper 1999), but the ability to detect PTC is correlated with the ability to test other bitter compounds that occur in nature (Bartoshuk et al. 1988; Drewnowski 2009; Wooding et al. 2004). We acquired PTC in its commercial form from “ACS Científica”. Dilutions were prepared according to the

Figure 2. Illustration of procedures performed in local communities in northeastern Brazil. A. Free listing of medicinal plants; B. Logistics to transport the materials of the bitter taste threshold experiment; C. Participant of the study during bitter taste threshold experiment. (Photos: first author).

method of Harris and Kalmus (1949). Firstly, we prepared a 13% PTC solution that was our stock solution and from it we made 13 serial dilutions at a 1:2 ratio. Thus, the most concentrated solution, “C1”, had 1300 mg/L while the most diluted concentration at C14 was 1.6 mg/L. The solutions were prepared at the Laboratory of Applied Ecology and Phytochemistry, Federal University of Pernambuco. All solutions were stored at 4°C in amber flasks and brought to room temperature prior to use. We pre-tested the bitter taste threshold experiment to validate concentrations, test possible dynamics, and get an idea of how long each procedure would take. The pre-tests were conducted with students from the Petrolina Campus of the University of Pernambuco.

Before the start of the experiment we ensured that the participant was fasting for at least 1 hour. When this did not happen, we sought to schedule visits, advising participants to keep fasting until the scheduled time. Additionally, we made sure that the participant was healthy, did not receive prescription drugs or received medical treatment, and, in the case of women, was not pregnant or nursing. The experiments were conducted individually, avoiding distractions and influences from others as much as possible.

To determine the threshold of identification of bitter taste we followed the procedures proposed by Mennella et al (2005). We offered 5ml of PTC test solution in 50ml disposable cups. The first cup offered contained only distilled water as our control measure. The second cup offered contained solution C14 (0.16 mg/L). Participants were instructed to bring the contents of the cup to their mouths, to rinse and spit, never swallowing (Figure 2c). When trying the cup with the first solution, we asked, "Does it taste like water, yes or no?" If the participant answered “yes”, the procedure continued with the offer of the next solution (C13 = 0.065 mg/L), in ascending order of concentration. If the participant answered “no”, we would ask “do you feel any taste?”. If the participant answered yes (it had a taste), we would ask what the taste of that solution was like. If they stated that the solution had a bitter taste, the test would be interrupted, and that concentration would be considered his bitter taste identification threshold. If the participant could not identify the bitter taste, we would offer the next solution, in ascending order of concentration, until it reached the concentration where the bitter taste in the solution could be identified. Participants always rinsed their mouth with distilled water before tasting each new concentration. The total number of participants who agreed to participate in the experiment were 27 people in Muquém and 9 people in Igrejinha. We conducted the bitter taste threshold experiments between October 2018 and January 2019.

We sought to identify active medicinal plant specialists and experimenters among the people who participated in the first stage of the research. We identified the specialists through local legitimation of this social role by asking each participant who they consider to have extensive knowledge of medicinal plants. Thus, we considered as a specialist the participant who was cited by at least 25% of the total sample (nine people). The dataset showed a very clear threshold, which separates some individuals (eight) from the rest of the sample that received citation. We identified eight experts in our sample. We needed to innovate to measure the habit of an active experimenter as there is no validated method in the literature. Active experimenters were identified by self-declaration through the following objective question: "Do you have the habit of tasting new plants to find out if they are medicinal?" To make sure that the participants understood the question, we asked a second question with a brief contextual example: “There are curious people who like to test new plants. Do you have this habit? We then consider as an experimenter the participant who held the affirmative answer after the second question. We identified seven experimenters in our sample. Although we cannot rule out the possibility of a type of error due to the sample size, we sought the independence and randomness between the samples with methodological rigor, ensuring the quality of the data obtained.

Data analysis

We tested the normality of our data using the Kolmogorov-Smirnov test and found that none of the variables that would be tested had a normal distribution. Thus, we chose to use only nonparametric tests in all analyzes. We applied the Mann-Whitney test to test the hypothesis that there is a biological basis in assigning the social role of medical systems specialist. We opted for the Mann-Whitney test because it is able to determine if samples from both groups (experts and non-specialists) were selected from populations that have the same distribution. We used the same test to see if there were differences in the bitter threshold between people who have the habit of tasting medicinal plants (experimenters) and those who do not have this habit (non-experimenters).

We used the simple linear regression test to verify if there is a relationship between the number of citations of plants with taste and the threshold of bitter taste. We opted for this test because it is able to verify if two variables are related. For this, we counted the plants that were cited by each participant with some attribute of taste, even if it was a comparative taste (e.g. mint taste, earth taste, etc.) or when the participant stated that the plant had an unknown taste. We did the same procedure to check whether there is a relationship between the number of citations of bitter and astringent plants and the taste threshold. We have decided to analyze the bitter and astringent tastes together because there is already evidence in the literature that many bitter-tasting secondary compounds also cause a sense of astringency in the mouth, such as phenols and alkaloids (Shepard Jr. 2004). Most likely, the plants that were cited as astringent by the participants also have a bitter taste.

We used the simple linear regression test to verify if there is a relationship between the versatility attributed to plants and the bitter taste threshold. We then calculated the average versatility for each participant by dividing the sum of the number of therapeutic targets cited by the number of plants cited. For this analysis, we selected only the most popular plants, avoiding possible idiosyncrasies from the free lists. This selection was based on the citation frequency of plants, selecting those that were present in at least 25% of the lists. This was based on the evidence found in the literature. Morales and Ladio (2009) showed that the most frequently used species in Lake Rosario are those that have more detailed taste descriptions to distinguish them. Medeiros et al. (2015) showed an association between plant taste and therapeutic indications only when they made a similar cut, based on popularity.

We performed again the same analyzes to test our hypotheses (except hypotheses involving experts and experimenters) using this selection of most popular plants. We performed all tests using R software, version

3.2.4 (R Core Development Team 2010). Table 1 presents a compilation of the ideas we tested, with the data and tests that were used.

RESULTS

Participant Profile and Descriptive Results

Our sample consisted of 19 women and 17 men, aged between 18 and 81 years old, averaging 49. All participants identified bitter taste at one of the different concentrations, so our sample had no non-tasters (individuals who cannot detect chemical stimuli of taste). More than half of the participants identified bitter taste in the first six concentrations, with C10 (2.54 mm/L) and C9 (5.08 mm/L) concentrations being the ones with the highest frequency (41.66% of the total)

Medicinal plants and their taste attributes

We cited 97 medicinal plants indicated to treat 141 distinct therapeutic targets. *Ximenia americana* L. was the most cited plant, reported by 71.4% of participants, followed by *Myracrodruon urundeuva* Allemão (54.3%), *Myroxylon peruiferum* LF (51.4%) and *Hymenaea courbaril* L. (48.57%). Bitter taste had the highest number of citations (28.25%), followed by astringent (23.8%), "tasteless" (9.04%) and sweet (3.71%). Among the most popular plants, all had some taste attribute.

Hypothesis results

Our results showed that the bitter taste threshold does not play a key role in

Table 1. Hypotheses tested to evaluate the role of the bitter taste threshold in the selection of medicinal plants in local communities in northeastern Brazil.

Question	Data	Test
1. Is there a biological basis in assigning the social role of medicinal plant experts in medical systems?	Bitter taste threshold of experts and non-specialists	Mann-Whitney
2. There is a biological basis in the habit of being an active experimenter of medicinal plants.	Bitter taste threshold of experimenters and non-experimenters	Mann-Whitney
3. Individuals with lower bitter taste threshold cite more tasteful plants	Bitter taste threshold and number of tasteful plants cited	Simple linear regression
4. Individuals with lower bitter taste threshold cite more plants with bitter taste	Bitter taste threshold and number of plants with bitter taste cited	Simple linear regression
5. Individuals with lower bitter taste thresholds indicate more therapeutic targets for plants	Bitter taste threshold and average participant versatility	Simple linear regression

assigning the social role of local specialists and selecting medicinal plants. We refute the hypothesis that We hypothesized that the biological base of chemosensory perception influences in assigning the social role of local expert, since local experts (n = 8) are no more sensitive than non-experts (n = 28) in the perception of bitter taste, as we expected (W = 92.5; p = 0.464). We also refute the hypothesis that the biological base of chemosensory perception influences in the habit of being an active experimenter of medicinal plants, since there are no differences in the bitter taste threshold of active experimenters (n = 7) and non-experimenters (n = 29) of medicinal plants (W = 123.5; p = 0.384).

We refute the hypothesis that individuals with lower bitter taste thresholds cite more plants with taste (regression F=0.325, p=0.578). We also refute the hypothesis that individuals with lower bitter taste thresholds cite more plants with bitter taste (regression F=1.049, p=0.3140), as well as the hypothesis that individuals with lower bitter taste threshold indicate more therapeutic targets for the plants (regression F=1,157, p=0.696). Our results showed that differences in the number of tasting plants citations, citations of bitter tasting plants and the versatility attributed to plants are not related to the bitter tasting threshold. When we analyzed the same variables (number of citations of plants with taste and bitter taste) only among the most frequent plants, we also found no relationship with threshold of bitter taste.

DISCUSSION

We do not corroborate the hypothesis that the biological basis of chemosensory perception is important to assign the specialist's social role in medical systems, given that local specialists did not present significant differences of bitter taste threshold from non-specialists. Thus, it is likely that other mechanisms are related to the attribution of this social role nowadays.

According to Wiley and Allen (2009), the way in which attribution of the social role of local experts varies between cultures is related to an individual vocation or spiritual heritage. Among the Luo, one of Kenya's largest ethnic groups, one can train an apprentice to become a local expert's successor by developing an herbal knowledge base used to treat a wide variety of therapeutic targets (Wiley and Allen 2009). To be considered a good candidate, among other characteristics, the learner needs to be intelligent, have a good memory, have a good heart and have a willingness to listen and learn. In different regions of Tanzania, the social role of healers, herbalists, midwives, and other types of local specialists may have different paths, such as inheritance within the family, initiation by ancestral spirits, the experience of being cured by the use of medicinal plants or even by their own decision after a period of learning (Prince and Geissler 2001). Based on this evidence, it can be seen that the social role of local medicinal plant specialist can be culturally assigned and not clearly rooted on the chemosensory perception of taste. Future studies could test the role of the bitter taste threshold in other medical contexts and systems, also considering the existence of this diversity of social role assignment as a local specialist. We must also consider that the selection of medicinal plants to form pharmacopoeia is not guided only by the taste (Bennet 2007; Hart 2005).

We believed that even if the attribution of the social role of local expert was culturally legitimated, it had the biological basis of the bitter taste threshold, as this characteristic could favor the selection of medicinal plants and, therefore, the performance of their role in the medical system. Based on our findings, it is likely that these social roles are currently unrelated to the bitter taste threshold. If we think about a hypothetical scenario, a low threshold of bitter taste may have been important in our evolutionary past, when humans began to use medicinal plants to treat diseases, highlighting individuals in the population who could make more associations between plant taste and the symptoms of the diseases that could be treated from it. This may have brought recognition among peers and, later, the confidence of the population in the search for this individual to treat their diseases. Subsequently, recognition and trust in these individuals came to be designated and maintained by cultural mechanisms such as cultural transmission and symbolic and religious aspects.

Our findings also suggest that the habit of experiment medicinal plants does not have a biological basis. The process of experimenting with new medicinal plants can be risky, especially when it involves plants with bitter taste that may have high toxicity (Glendinning 1994). Therefore, an experimenter with a low bitter taste threshold could make it easier to identify the tastes of medicinal plants and still avoid ingesting toxic compounds. Thus, regardless of the social role in medical systems, the bitter taste threshold is not related to this profile of individuals who usually try medicinal plants. Ferreira Junior et al. (2015) argue that, in our evolutionary past, individuals who were more sensitive in the perception of bitter taste acquired knowledge about medicinal plants through experimentation, associating the taste of a plant with its medicinal property. Later this knowledge was culturally transmitted to other individuals.

Plant selection by experimenting and identification of bitter taste may be more relevant in populations living in unstable environments and dealing, for example, with local plant extinction or the frequent presence of new diseases. There is evidence that in unstable environments, the process of individual knowledge production is favored (Richerson and Boyd 2005), and that in stable environments individuals more often acquire information through different channels of cultural transmission (Richerson and Boyd 2005; McElreath and Strimling 2008). Thus, in nomadic and semi-sedentary societies, such as hunter-gatherer societies, which deal with new environments more often than sedentary societies, one would expect to observe the relationship between the habit of tasting new plants to identify their medicinal potential and a low bitter taste threshold. In these social contexts, the ability to detect bitter taste would be crucial in identifying the pharmacological and toxic potentials of plants.

However, Soldati et al. (2015) showed that in the populations of three traditional communities in northern Minas Gerais - Brazil, the process of individual knowledge production through experimentation was not favored in situations of social and environmental instability. The authors recorded a low expression of the experimenting process that could be related to the confidence in the use of previously known and validated plants, to the detriment of the risk of tasting with new plants. If there is a low proportion of experimenters (as in the population studied here) and also a low frequency of this behavior, understanding whether the process of tasting medicinal plants is related to the bitter taste threshold presents a challenge to current science.

We do not corroborate the hypothesis that the bitter taste threshold is related to a higher number of citations of bitter plants and plants with other tastes. Although many studies report that taste is used by traditional populations to select plants for medicinal use, the causal relationship is unclear (Casagrande 2000; Heinrich et al. 1992). Heinrich et al. (1992) reported that astringent-tasting plants are generally useful in treating dysentery and diarrhea in the Mixe ethnic group (Oaxaca, Mexico). However, not all plants that treat these therapeutic targets are astringent. Casagrande (2000) reports similar evidence indicating that even though bitter-tasting plants are widely used to treat gastrointestinal disorders, bitter tasting alone is not sufficient to predict the use of a medicinal plant to treat a disease. Another explanation to not having our hypothesis corroborated is that perhaps plant taste is just a mnemonic resource, not a determinant of its usefulness, in treating therapeutic targets (Casagrande 2000; Medeiros et al. 2015). According to Medeiros et al. (2015), taste, as well as other plant characteristics (smell, texture, color), can be understood as artifact of remembrance and association, and association between taste attributes and therapeutic indication would serve to remind people of the therapeutic indication of the plant.

We do not support the hypothesis that the bitter taste threshold is related to the versatility attributed to plants. We believed that individuals who are more sensitive to bitter perception could perceive the peculiarities of taste determined by the diversity of chemical compounds and thus make more associations between the perceived taste of plants and their therapeutic indications. Some participants in our study even reported that some plants have different tastes even if they are classified as bitter, that is, there are peculiarities in the bitter taste of plants. However, this has not resulted in a greater number of therapeutic indications for them nor is it related to the bitter taste threshold. Also, for this set of plants, people reported the taste attribute only as “bitter”. This brings us to a difficulty in studies of taste perception which is the linguistic dimension of taste. The scientific classification of five primary tastes (bitter, sweet, salty, sour and umami) is in many cases limited to represent local taste denominations. The Hindi vocabulary, for example, consists of six basic tastes: sweet, sour, salty, bitter, spicy and astringent (Gollin 2004). In our study, we have registered local denominations for tastes that do not fit the five basic tastes of Western science, such as “nauseated”, “pampered” and “different”. These terms probably hide a much greater diversity of perceived chemical stimuli than those expressed verbally.

The linguistic dimension of taste is also important for information sharing within the local medical system. According to Osawa and Ellen (2014), even if people taste the same stimulus of taste, how it will be classified is influenced by the fact that people know the terms of taste to describe what they have tasted. Additionally, to what extent they have opportunities to share and compare taste experiences in order to agree at a pattern of the use of terminology. Thus, it is possible that a person can perceive a taste but cannot express anything other than the terms used in their culture. It is possible, then, that many taste sensory experiences are not shared in a population, being limited by local terminological diversity to classify the types of tastes.

Finally, it is possible that other factors, especially cultural ones, may help to understand the role of the bitter taste threshold in the selection of medicinal plants. Some authors have already stressed the importance of culture in understanding the biological process of taste perception (Brett and Heinrich 1998; Casagrande 2000; Hladik et al. 2002). According to Brett and Heinrich (1998), the perception of chemosensory stimulus is a physiological process, and its interpretation, evaluation and validation is determined by culture. For Shepard Jr (2004), sensations can be understood as biocultural phenomena rooted in human physiology, however, they are also constructed through individual and cultural experiences.

Study Limitations

Our sample did not have the planned size due to the difficulties faced to carry out this type of study in non-laboratory conditions beyond the population conflict with the current management of PARNA Catimbau. One of the challenges faced was the concern that individuals had to participate in the research because they thought it could endanger their health. In fact, the bitter taste threshold experiment is a bit invasive, requiring the participant to taste a liquid that is unknown by them. Thus, our sample was smaller than that commonly found in laboratory studies, which have a larger number of volunteers. This diminished the power of our analyzes.

It should be noted that the proportion of specialists is lower than that of non-specialists in traditional populations, and our sample comprised only eight specialists. A low proportion of experimenters is also expected as tasting new plants by trial and error carries risks to individuals (Soldati et al. 2015). Finally, even if we have a good sampling, we do not control the degree of kinship among the participants which may influence the phenotypic expression of chemosensory taste perception. Future studies could try to map the degree of kinship between individuals to reduce possible bias in the interpretation of their findings.

ACKNOWLEDGMENTS

The authors are grateful to Fundação de Amparo a Ciência e Tecnologia de Pernmabuco (FACEPE) for granting the doctoral scholarship to the first author, the University of Pernambuco for the infrastructure provided for the pre-testing of the bitter taste threshold experiment. We also acknowledge all residents of Sítio Muquém and Sítio Igrejinha who shared their knowledge with us by participating in the study. Professor Antonio Fernando Morais de Oliveira, from UFPE, made his laboratory available for the preparation of solutions. Biologist Ana Karina, from the Laboratory of Ecology and Evolution of Social-ecological Systems, assisted in preparing the solutions. In addition, Maria Socorro, Rivanildo dos Santos and Maria Frazão from Muqúem, kindly hosted INCT researchers. This work was supported by the INCT Ethnobiology, Bioprospecting and Nature Conservation, certified by CNPq, with financial support from FACEPE (Foundation for Support to Science and Technology of the State of Pernambuco) [grant number: APQ-0562-2.01/17].

REFERENCES

Albuquerque UP, Ramos MA, Lucena, RFP, Alencar NL (2014) **Methods and techniques used to collect ethnobiological data.** In Albuquerque UP, Cunha LVFC, Lucena RFP, Alves RRN. (eds) Methods and techniques in Ethnobiology and Ethnoecology. 1 ed. Humana Press, New York, pp. 15-37.

Ankli A, Stich O, Heinrich M (1999) **Yucatec Maya Medicinal Plants Versus Nonm edicin al Plants: Indigenous Characterization and Selection.** Human Ecology 27: 557-580..

Bartoshuk LM, Rifkin B, Marks LE, Hooper JE (1988) **Bitterness of KCl and benzoate: related to genetic status for sensitivity to PTC/PROP.** Chemical Senses 13:517–528.

Behrens M, Brockhoff A, Batram C, Kuhn C, Appendino G, Meyerhof W (2009) **The human bitter taste receptor hTAS2R50 is activated by the two natural bitter terpenoids andrographolide and amarogentin.** Journal of Agricultural and Food Chemistry 57:9860–9866.

Behrens M, Gu M, Fan S, Huang C, Meyerhof W (2018) **Bitter substances from plants used in traditional Chinese medicine exert biased activation of human bitter taste receptors.** Chemical Biology & Drug Design 91:422–433.

Behrens M, Meyerhof W (2006) **Bitter taste receptors and human bitter taste perception.** Cellular and Molecular Life Sciences 63:1501–1509.

Bennett BC (2007). **Doctrine of signatures: an explanation of medicinal plant discovery or dissemination of knowledge?** Economic Botany 61:246-255.

Richerson PJ, Boyd R (2005) **Not by genes alone: How culture transformed human evolution.** University of Chicago Press, Chigago, USA.

Brett JA, Heinrich M (1998) **Culture, Perception and the Environment The role of chemosensory perception.** Journal of Applied Botany: Angewandte Botanik 72:67–69.

Casagrande DG (2000) **Human taste and cognition in Tzeltal Maya medicinal plants use.** Journal of Ecological Anthropology 4:57–68.

Chang WI, Chung JW, Kim YK, Chung SC, Kho HS (2006) **The relationship between phenylthiocarbamide (PTC) and 6-n-propylthiouracil (PROP) taster status and taste thresholds for sucrose and quinine**. Archives of Oral Biology 51:427–432.

Dragos 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.

Drewnowski A (2009) The Science and Complexity of Bitter Taste. Nutrition Reviews 59:163–169.

Drewnowski A, Gomez-Carneros C (2000) **Bitter taste, phytonutrients, and the consumer: a review.** The American journal of Clinical nutrition 72:1424-1435.

Ferreira Júnior WS, Albuquerque UP (2018) **A theoretical review on the origin of medicinal practices in humans: echoes from evolution.** Ethnobiology and Conservation 7:1–6.

Ferreira Júnior WS, Campos LZO, Pieroni A, Albuquerque UP (2015) **Biological and Cultural Bases of the Use of Medicinal and Food Plants.** In: Albuquerque UP, Medeiros PM, Casas A (eds.) Evolutionary Ethnobiology. 1 ed. Springer International Publishing, Switzerland, pp. 175–184.

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.

Gent JF, Bartoshuk LM (1983). **Sweetness of sucrose, neohesperidin dihydrochalcone, and saccharin is related to genetic ability to taste the bitter substance 6-n-propylthiouracil.** Chemical Senses 7:265-272.

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 56:1217–1227.

Gollin L (2004) **Subtle and profound sensory attributes of medicinal plants among the Kenyah leppo'ke of east Kalimantan, Borneo**. Journal of Ethnobiology 24:173-201.

Harris H, Kalmius H (1949) **The measurement of taste sensitivity to phenylthiourea (P.T.C.).** Annals of Eugenics 15:24–31.

Hart BL (2005) **The evolution of herbal medicine: behavioural perspectives.** Animal Behaviour 70:975-989.

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

Heinrich M (1994) **Herbal and Symbolic Medicines of the Lowland Mixe (Oaxaca, Mexico).** Anthropos 89:73-83.

Heinrich M, Rimpler H, Barrera NA (1992) **Indigenous phytotherapy of gastrointestinal disorders in a lowland Mixe community (Oaxaca, Mexico): Ethnopharmacologic evaluation.** Journal of Ethnopharmacology 36:63–80.

Hladik CM, Pasquet P, Simmen B (2002) **New perspectives on taste and primate evolution: The dichotomy in gustatory coding for perception of beneficent versus noxious substances as supported by correlations among human thresholds.** American Journal of Physical Anthropology 117:342–348.

Hong JH, Chung JW, Kim YK, Chung SC, Lee SW, Kho HS (2005) **The relationship between PTC taster status and taste thresholds in young adults.** Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 99:711-715.

Johns T (1996) **The Origins of human Diet & Medicine**. The University of Arizona Press, Tucson, USA.

Johns T (1990) **With bitter herbs they shall eat it: chemical ecology and the origins of human diet and medicine**. University of Arizona Press, Tucson, USA.

Leonti M, Sticher O, Heinrich M (2002) **Medicinal plants of the Popoluca, México: organoleptic properties as indigenous selection criteria**. Journal of Ethnopharmacology 81:307-315.

McElreath R, Strimling P (2008) **When natural selection favors imitation of parents.** Current Anthropology 49:307-316.

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, Pepino Y, Reed DR (2005) **Genetic and Environmental Determinants of Bitter Perception and Sweet Preferences.** Pediatrics 115:e216-e222.

Mennella JA, Spector AC, Reed DR, Coldwell SE (2013) **The bad taste of medicines: Overview of basic research on bitter taste.** Clinical Therapeutics 35:1225–1246.

Molares S, Ladio A (2009) **Chemosensory perception and medicinal plants for digestive ailments in a Mapuche community in NW Patagonia, Argentina.** Journal of Ethnopharmacology 123:397–406.

Osawa Y, Ellen R (2014) **The cultural cognition of taste term conflation.** The Senses and Society 9:72-91.

Pasquet P, Oberti B, El Ati J, Hladik CM (2002) **Relationships between threshold-based PROP sensitivity and food preferences of Tunisians**. Appetite 39:167-173.

Prince R, Geissler PW (2001) **Becoming "one who treats": A case study of a Luo healer and her grandson in western Kenya.** Anthropology & Education Quarterly 32:447-471.

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

Soldati GT, Hanazaki N, Crivos M, Albuquerque UP (2015) **Does environmental instability favor the production and horizontal transmission of knowledge regarding medicinal plants? A study in Southeast Brazil.** PLoS One 10: e0126389.

Soranzo N, Bufe B, Sabeti PC, Wilson JF, Weale ME, Marguerie R, Meyerhof W, Goldstein DB (2005) **Positive selection on a high-sensitivity allele of the human bitter-taste receptor TAS2R16**. Current Biology 15:1257-1265.

Tepper BJ (1999) **Does Genetic Taste Sensitivity to PROP Influence Food Preferences and Body Weight?** Appetite 32: 422.

Wiley AS, Allen JS (2009) **Medical anthropology: A biocultural approach.** Oxford University Press, Oxford.

Wooding S, Kim U, Bamshad MJ, Larsen J, Jorde LB, Drayna D (2004) **Natural Selection and Molecular Evolution in PTC, a Bitter-Taste Receptor Gene.** The American Journal of Human Genetics 74:637-646.

Received: 13 December 2019
Accepted: 13 January 2020
Published: 16 January 2020