Evolutionary ethnobiology and knowledge about medicinal resources used to treat COVID-19 symptoms in Salvaterra, Marajó, Pará, Brazil

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Research Article

Keywords: coronavirus, evolutionary ethnobiology, ethnopharmacology.

Posted Date: November 10th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2167604/v1

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Abstract

The emergence of the COVID-19 pandemic has exerted selective pressure on local medical systems, encouraging human groups to seek alternative treatments, including traditional medicine. Natural treatments are critical alternatives for Amazonian populations due to the barriers they face to access health care services. Thus, this research aimed to carry out an ethnobiological study with evolutionary and ethnopharmacological approach on the selection processes and routes of knowledge transmission about treatments for COVID-19 to understand how local medical systems in the municipality de Salvaterra are adapting to the presence of COVID-19. Data collection was carried out through semi-structured interviews applied to residents of Salvaterra who tested positive for COVID-19. The interviews were conducted between July and October 2021. Sixty-two people, 31 living in urban and 31 in rural areas, were interviewed. Most respondents (74%) used natural treatments to treat the symptoms of COVID-19. Thirty-four plant species belonging to 21 botanical families were cited. Lemon \(\text{Citrus x limon} (L.)\) Osbeck, garlic \(\text{Allium sativum L.}\), and jambu \(\text{Acmella oleracea} (L.)\) R.K. Jansen were the most cited. The preference for using leaves and plants from managed environments in preparing herbal remedies reinforces theories that the environment can influence how people use natural resources in each biome. The prevalence of horizontal (37%) instead of vertical (30%) transmission of knowledge reinforces that more diffuse ways, such as the horizontal and diagonal, are favored in unstable environments such as those created when a new disease emerges. According to the data, age and familiarity were the most substantial biases influencing the learning of biocultural traits in the studied local medical system.

Background

Evolutionary ethnobiology is an interdisciplinary research field that uses ecological and evolutionary approaches to study the behavioral and cognitive elements that emerge from the relationships between human populations and biological resources \[1, 2\]. This branch of ethnobiology investigates human behavior and knowledge about the environment and its reciprocal influences, considering historical and contemporary factors that can influence these relationships \[3, 4\].

In ethnobiology, the different relationships between the human species and nature result from the complex and dynamic interaction between biology and culture at different temporal and spatial scales \[4, 5\]. Social-ecological systems rise from the interrelationship between the group of norms, practices, knowledge, and beliefs that form sociocultural systems and the biotic and abiotic elements that compose ecological systems \[6, 7\]. Considered by Albuquerque and Ferreira-Junior \[4\] as biocultural entities of a complex nature, social-ecological systems and their functioning, structure, and evolution are study objects of evolutionary ethnobiology \[8\].

Traditional ecological knowledge is one of the elements produced by the dynamic relationship between culture and environment. It consists of the set of knowledge, beliefs, and practices of human populations regarding the environment that can be socially transmitted and affected by selective pressures \[4, 1, 9, 2\]. While traditional ecological knowledge refers to the dynamic set of knowledge, beliefs, and practices,
certain pieces of cultural information associated with a biological element are called biocultural traits, and the understanding of how the transmission of these traits can change in time and space is one of the objectives of evolutionary ethnobiological studies [6].

According to Albuquerque and collaborators [10], biocultural traits or functional elements represent one of the structural components of local medical systems, consisting of information units, such as the use of a particular plant to treat a specific disease. Local medical systems encompass the open and dynamic set of knowledge and practices about the prevention and treatment of diseases in a given human population, as well as the perception of disease, the interpretation of symptoms, treatment strategies, and the evaluation of therapeutic results, which make up the socioecological system [8, 11, 12].

In the local medical systems structuring, biological adaptations occur within the cultural context that enables their expression. They are dynamic systems, and the social transmission of information and experimentation are how changes in these systems occur [13].

Diseases act as a selective pressure, and the selection of natural resources to treat diseases and the social transmission of this knowledge can be considered adaptive strategies [14, 15]. The main routes of knowledge transmission adopted in a population affect the time that a given social-ecological system takes to generate adaptive responses to an environmental change, such as the emergence of a novel disease [5, 16].

Thus, knowing the patterns that guide the processes of resource selection at the time of innovation and the social transmission of information is essential to understand the time the system takes to generate adaptive responses and the cultural biases that shape the evolutionary path [14].

According to Barros and collaborators [17], the pandemic caused by the spread of the virus responsible for COVID-19 constitutes a watershed moment in modern human history. During the period of the highest contamination rate, there was a shortage of personal protective equipment (PPE), medicines, pulmonary ventilators, physicians, Intense Care Unit (ICU) beds, an abusive increase in the prices of health products, and the collapse of the hospital care system in cities such as the capital of Pará, in Brazil [18, 19, 20].

According to Shadmi and collaborators [21] and Menezes-Navarro and collaborators [22], native Latin American populations living in rural areas face more significant barriers to access the conventional health care system due to the geographical distance to health care centers, unfavorable social and economic conditions, and difficult access to sanitation services. Thus, the emergence of the novel COVID-19 compelled human groups to seek alternative forms of treatment, including traditional medicine, a therapeutic option also used in previous epidemic outbreaks [23]. According to Gangal and collaborators [24], traditional knowledge can be an alternative form of bioprospecting in the search for substances that act to combat this new virus.

The scenario described above is typically observed in the Marajó archipelago in the Brazilian Legal Amazon. Marajó is composed of 16 municipalities and is considered one of the poorest regions of Pará.
and Brazil. Some of these municipalities have the lowest Municipal Human Development Indices (MHDIs) in the state, and one of them, Melgaço, has the lowest MHDI in the country [25, 26]. In the municipality of Salvaterra, the lack of public policies, especially in health and education, coexists with a great body of traditional knowledge about medicinal resources [27, 28, 26].

According to data available on the COVID-19 Transparency Portal of the State Department of Public Health, 646 confirmed cases of COVID-19 were recorded in Salvaterra, totaling 20 deaths [29]. In this scenario, alternative medical resources were sought when access to primary health care was impossible, according to reports during informal conversations with inhabitants of the municipality of Salvaterra. According to Pavão and collaborators [30], medicinal plants have been used by several human groups as alternative and complementary methods to treat and prevent COVID-19 infection.

Although respirators and hospitals with structures to assist severe COVID-19 cases are absent in Salvaterra, the mortality rate from COVID-19 in this municipality is 2.5%, lower than the mortality rates of the state of Pará (2.8%), the North region (2.6%), and Brazil (2.8%) [31, 29]. For this reason, the municipality of Salvaterra was chosen for the development of this research.

We carried out an ethnobiological study of an evolutionary and ethnopharmacological nature to understand the selection of biological material processes for use in the treatment of COVID-19 and to know the transmission routes of this knowledge in order to elucidate how local medical systems in human groups residing in the municipality of Salvaterra are changing to adapt to the environmental challenge posed by the emergence of the novel human coronavirus, the etiological agent of COVID-19.

**Materials And Methods**

**Study Area**

This study was developed in the municipality of Salvaterra, located in the Marajó Archipelago, state of Pará (Fig. 1). According to data from the 2020 statistical yearbook produced by the Amazon Foundation for Support of Studies and Research of Pará - FAPESPA, Salvaterra has an estimated population of 24,075 inhabitants and one hospital since 2017, with a total of 5.5 health centers and posts and 2.53 physicians for every 10,000 inhabitants and 0.84 hospital beds for every 1,000 inhabitants [32].

Source: Environmental Monitoring and Conservation Laboratory (LMCA/UEPA).

The climate in the Marajó archipelago is tropical humid, with an average temperature of 27 °C with slight monthly and annual variation, average annual rainfall of 3100 mm, with a rainier season between December and May and a less rainy season from June to November [33]. Several vegetation types are found in Salvaterra, including forest formations, savannas, mangroves, flooded fields, and grasslands [34], as well as agroforests and urban backyards that shelter considerable biological diversity.
According to Simões and collaborators [35], approximately 37.17% of the population of Salvaterra lives in the rural area without access to piped water supply and sewerage system. In the urban area, only 57% of the population has access to piped water and 5% to sanitary sewage. The population of Salvaterra is served by one municipal hospital and one health unit located in the urban area, and 12 health posts are distributed in communities of the rural area of the municipality [36].

**Exclusion criteria**

Data from 837 patients were collected during a visit to the Municipal Health Department of Salvaterra - SEMUSA. The cases excluded from the spreadsheet used to choose informants were nine patients without test result annotation, 14 registered deaths, and 70 patients who were underage at the time of the interviews.

Thus, the total population eligible for participation in the study consisted of 744 adults living in the municipality of Salvaterra who tested positive for COVID-19 between April 2020 and April 2021. Of these, 62 people – 31 living in rural and 31 in urban areas – were interviewed.

**Data Collection**

Data were collected through semi-structured interviews [37] applied to people residing in the municipality of Salvaterra who tested positive for COVID-19. The interviews were applied from July to October 2021, using forms with open and closed questions [37] composed of four sections: a. general information; b. ethnopharmacology – treatment description, c. ethnopharmacology – data by species; and d. evolutionary ethnobiology.

The forms were previously tested with residents of the municipality of Salvaterra to verify the clarity of the questions and their adequacy to the objectives of the study.

Data on confirmed cases of COVID-19 obtained from SEMUSA were used to identify the total population to be sampled and the contact information and address.

Non-probabilistic sampling was used in this study [37]. The interviewees were selected among patients with confirmed COVID-19 infection over 18 years old, who lived in Salvaterra and did not progress to death, and whose information on telephone contact or address was complete in the dataset provided by SEMUSA.

After an initial telephone contact, a visit was made to the residence of the people who agreed to participate in the interview. The non-probabilistic snowball technique of informants selection, in which one interviewee indicates the next [37], was adopted. After the first informants responded the forms, they were asked to indicate the address of one of the persons who was on the list.

In the first part of the forms, the items addressed socioeconomic aspects and asked whether the interviewees sought the municipality’s health care system or used natural medicines for the treatment of COVID-19.
The interviewees who reported having used natural medicines also answered the questions about the treatments used and their composition, as well as how they obtained the species used to prepare the medicines.

A modified five-point Likert scale [38] was used to assess the perception of efficacy of the treatments adopted to combat COVID-19 as follows: 1. harmful, 2. ineffective, 3. a little effective, 4. fairly effective, 5. very effective. The scale was prepared taking into account what was exposed by Albuquerque and collaborators [39] about the fact that the local perception of efficacy of treatments is a variable that could provide important clues for bioprospecting but which is often omitted in ethnopharmacological studies.

During the interviews, the interviewer explained the criteria for rating the treatments with this scale, so that level 1 should correspond to treatments that had bad consequences for the body; level 2 to treatments that had no positive or negative effects; level 3 to treatments that caused temporary relief; level 4 to treatments capable of producing permanent relief, but which were not the main factor responsible for curing the disease; and level 5 to treatments considered decisive for curing the disease.

After identifying the most cited species, we searched in the literature the main bioactive compounds present in these plants and their pharmacological use with proven effectiveness.

To understand the ways of learning the biocultural traits related to the treatment of COVID-19, the informants were asked how they learned to use each treatment described during the interviews, showing how innovation is being generated and disseminated in the local medical systems studied.

A Likert scale was used to evaluate the criteria adopted in the selection of treatments used by the informants, according to the methodology proposed by Gomes and collaborators [40] to evaluate the criteria for the selection of food plants. Scores from 1 to 5 were assigned according to the importance of the criterion in the decision-making process regarding the use of the treatment for that purpose. This provides clues to the main biases acting in the adaptive processes of the local medical systems studied.

The guided tour technique [37] was used to collect the plants indicated for COVID-19 treatment, and the recommendations of Fidalgo and Bononi [41] were followed in the collection of plant material. Artificial keys, specialized literature, and comparisons with samples available in the Flora e Funga do Brasil online database (http://floradobrasil.jbrj.gov.br) were used to identify the species taxonomically. The botanical material was deposited in the Marlene Freitas da Silva Herbarium (MFS) of the State University of Pará (UEPA). The species not collected during the guided tour were photographed in fairs and markets in the municipality of Salvaterra.

**Data analysis**

After the application of the forms, the data were tabulated using Microsoft Office Excel 360 software. Statistical analyses were performed using the Minitab 19 software.
The treatments (modes of preparation, parts of the plant used, main botanical families and species mentioned) were analyzed by the proportional distribution of citations, while the perceived efficacy was analyzed by simple average.

The chi-square test was used to assess whether the distribution of ways of learning biocultural traits linked to the treatment of COVID-19 was significantly different between residents of rural and urban areas.

The normal distribution and homoscedasticity of the scores of the treatment selection criteria on the Likert scale were checked with the Liliefors and Bartlett tests. When the data were normally distributed and had homogeneous variances, significant differences were investigated through ANOVA. For the statistical tests, we used the raw data of scores assigned by each informant for the selection criteria presented.

**Ethical Aspects**

The research project was submitted to the Research Ethics Committee - CEP/ National Research Ethics Commission - CONEP system through the Brazil Platform (CAAE: 45329421.8.0000.8767; Receipt Number: 032892/2021) prior to the application of the questionnaires and it was approved by the CEP of the Center for Biological and Health Sciences – CCBS of the State University of Pará – UEPA.

The results were registered in the National System of Genetic Resource Management and Associated Traditional Knowledge – SISGEN before their publication.

Each participant signed an Informed Consent Form (Annex 2) in which they were informed about the objectives, risks, and the guarantee of assistance in case of damage caused, according to the Resolution of the National Health Council number 466 of December 12, 2012.

During the interviews, all biosecurity rules were respected to avoid COVID-19 contagion, including the mandatory use of masks, hand hygiene, sanitation of objects used during interviews with 70% alcohol, and interpersonal distance of at least 1.5 m.

**Results And Discussion**

**General information**

Sixty-two people who tested positive for COVID-19, 31 living in the urban area and 31 in the rural area of the municipality of Salvaterra, were interviewed. Table 1 shows the distribution of the interviewers in urban and rural areas.
Table 1
Distribution of informants among the localities of the municipality of Salvaterra, Pará, Brazil.

<table>
<thead>
<tr>
<th>Rural area</th>
<th>Number of informants</th>
<th>Urban area</th>
<th>Number of informants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Água Boa</td>
<td>2</td>
<td>Caju</td>
<td>8</td>
</tr>
<tr>
<td>Bairro Alto</td>
<td>4</td>
<td>Centro</td>
<td>11</td>
</tr>
<tr>
<td>Caldeirão</td>
<td>6</td>
<td>Coqueirinho</td>
<td>1</td>
</tr>
<tr>
<td>Cururu Grande</td>
<td>1</td>
<td>Marabá</td>
<td>6</td>
</tr>
<tr>
<td>Joanes</td>
<td>7</td>
<td>Paes de Carvalho</td>
<td>5</td>
</tr>
<tr>
<td>Jubim</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monsarás</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
</tr>
</tbody>
</table>

Thirty-nine were female and 23 were male, with ages ranging from 19 to 81 years, and income between less than one and nine minimum wages. Regarding the source of income, 20 interviewees cited retirement, being the only source of income in the household in the case of 14, and an integral part of the income of the household in the case of six, while 20 people cited the civil service as a source of income, being the exclusive source of income in the families of 15, and an integral part of the income of the household in the case of five. Other sources of income were mentioned, such as the provision of services (17), fishing (seven), trade (six), and family farming (three), among others.

Regarding the use of health services due to symptoms of COVID-19, outpatient care was used by 18 people, mostly residents of rural areas (14), while clinical care was accessed by 16, most of them from urban areas (15). Two rural informants reported having received care by a health agent, while 26 interviewees did not receive any type of care in health services.

**Ethnopharmacology – treatment description**

Among the interviewees, 46 (74%) – 24 from the rural area and 22 from the urban area – reported having used natural treatments to combat the symptoms of COVID-19, while 16 (26%) – seven from the rural area and nine from the urban area – did not use this type of treatment.

Among the 46 people who reported the use of natural medicines, only nine – four from the rural area and five from the urban area – did not concomitantly use synthetic drugs, while the others did so. Among the latter, the drugs that made up the so-called “covid kit”, azithromycin and ivermectin, were the most used.

Three informants reported having received the “covid kit” after receiving the result of a test using the SARS-CoV-2 IgG reagent, months after the infectious period, and one of them reported not having taken it for not being sick anymore, while the other two ingested the drugs, although they were no longer in the...
period of active infection. One of the informants who took the drugs was a woman in her seventh month of pregnancy when the municipality’s health professional delivered the medications for use.

The combined use of herbal and modern synthetic drugs was also recorded in a study carried out in Northeastern Brazil, in a rural community and in the Fulniô indigenous people, as well as in studies carried out in the state of Pará in urban backyards of the municipality of Abaetetuba and in the Soure Marine Extractive Reserve (RESEX) [42, 43, 44, 45].

Albuquerque and collaborators [42] warn that the concomitant use of herbal and synthetic drugs can bring negative consequences both by the adverse reactions caused by this drug-drug interaction and by the increased likelihood of poorly adapted biocultural traits establishment.

In the research carried out at Soure Marine Extractive Reserve, Marajó Island, the interviewed people reported believing that because medicinal plants are natural drugs, they are free from adverse effects, thus showing ignorance about the possibility of the interaction between plant bioactive substances and synthetic drugs [43].

A study conducted in a community in the state of Pernambuco which sought to generate explanatory models for the combined use of modern synthetic drugs and medicinal plants found that the frequency, severity, and form of manifestation of the disease were the factors that explained the decision to use the drugs concomitantly, and the guarantee of cure was the criterion most cited by the informants [44].

Informants living in rural areas cited 39 different treatments, while those living in urban areas described 40 ways to treat COVID-19.

The treatments used to combat the symptoms of COVID-19 involved a total of 45 different combinations of species. The combinations most cited by the informants were: use of lemon only [Citrus × limon (L.) Osbeck], with 15 citations; use of lemon with garlic (Allium sativum L.), with six citations; and use of lemon, garlic and jambu [Acmella oleracea (L.) R.K. Jansen], also with six citations.

Most of the mentioned treatments involved the use of only one species (47%), and in the case of mixtures, a maximum of six species were combined.

The most effective treatments perceived by the interviewees consisted of 23 different combinations, cited only once, with level of efficacy 5. Among the combinations with more than one citation, the ones with the highest perceived efficacy were lemon with jambu (four citations, average 4.75) and lemon with garlic (six citations, average 4.70).

The forms of preparation most used by the interviewees were tea by decoction (58%); juice (14%); and maceration (13%) in which the crushed species were, in general, mixed with water or honey; and mixing (13%). Tea infusion and syrup appeared in 1% of the citations.
The main route of administration was oral, with 76 citations (96%). Bathing was mentioned as a form of administration in two citations (3%), and topical use was reported only once (1%).

Teas usually prepared by decoction was also the most cited form of preparation of herbal medicines in other studies carried out in the state of Pará [43, 44, 45] and the oral route of administration was predominant also in the research carried out at Soure Marine Extractive Reserve [43].

**Ethnopharmacology – data by species**

Thirty-four plant species belonging to 21 botanical families were cited (Supplementary material 1). Asteraceae was the family with the highest number of species (four), followed by Fabaceae and Myrtaceae with three species each.

Asteraceae and Fabaceae were also among the families with the highest number of species cited for medicinal use in studies carried out in the municipalities of Soure and Abaetetuba [43, 45]. According to Albuquerque and collaborators [13], Asteraceae is often among the families overrepresented in local pharmacopoeias, which can be explained by the fact that members of this family produce a variety of secondary metabolites or present a wide ecological range.

The most cited species were lemon (*C. limon*), with 43 citations; garlic (*A. sativum*), with 25 citations; and jambu (*A. oleracea*) with 17 citations. The latter is a species native to the region. These species were also those that most appeared in combinations in the treatments mentioned, being part of 17, 15 and nine combinations, respectively. The data presented also showed the prevalence of these three species in the treatments used by the interviewees.

Studies have shown that flavonoids and their derivatives are the most important group of bioactive compounds present in the fruits of *C. limon*. This species acts as an enhancer for the topical administration of vitamins A, B6, C, and E, has antibacterial, antifungal, insect repellent, neuroprotective, antioxidant action, stimulates the increase of lipolysis in white adipose tissue, and has a cytotoxic effect against prostate, lung and breast cancer cells [46, 47]. When asked about the functions of lemon in the treatments used, the informants said that its fruit is used as an immune system enhancer and anti-flu agent.

*Allium sativum* has a great diversity of bioactive compounds (organic sulfides, saponins, phenolic compounds and polysaccharides) and hundreds of them are present in its bulb. Such compounds are responsible for several biological activities such as antioxidant, antihypertensive, anti-inflammatory, anticancer, antidiabetic, antibacterial, and antifungal action, besides presenting immunomodulatory properties [48, 49]. The interviewees reported using the species to combat sore throat, avoid the accumulation of intestinal gases, and help immunity as anti-flu, antifungal and anti-inflammatory agent.

The main bioactive component of *A. oleracea* is spilanthol, of the alkylamide class. This substance has antimicrobial, insecticidal, antioxidant, and antinociceptive properties and it has been tested in rat models of acute inflammation with promising results, reducing alldynia and paw edema [50, 51]. Only three
informants cited a purpose of using of jambu, namely, anti-influenza action, chest pain relief, and immune enhancer.

The respondents living in the rural area cited 17 species, while those from urban areas cited 27 species. The greater diversity of species cited for the treatment of COVID-19 by inhabitants of the seat of the municipality of Salvaterra disagrees with the results found in several ethnobiological studies, which identified a negative effect of urbanization on traditional ecological knowledge [52, 53, 54]. However, Gaougue and collaborators [55] and Ferreira-Junior and collaborators [56] state that urbanization can lead to an increase in traditional ecological knowledge in some human groups, favoring some types of knowledge, as in the present study.

Palheta also recorded a high diversity of medicinal species in urban areas in the municipality of Abaetetuba, Pará, and attributed it to the rural and diverse origin of the interviewees and the maintenance of the habit of cultivating species in backyards [45].

According to Santoro and collaborators [2], through migration, urbanization enhances the diversification of biocultural traits. These processes influence local medical systems because they promote the exchange of elements of biodiversity and associated knowledge [5], since the increased contact with migrants brings the possibility of new biocultural traits absorption through the introduction of new species into the system or of new uses for already known species [57]. This may explain the greater diversity of species mentioned in the seat of the municipality of Salvaterra. This urban area houses migrants from communities of the countryside of the municipality and people from other cities. In this context, the intense search for treatment and relief of COVID-19 symptoms may have acted as a selective pressure, leading to the exchange of knowledge among human groups. According to Gandolfo and Hanazaki [54], the close interaction between culturally dissimilar groups in urban centers tends to promote heterogeneity in ethnobotanical knowledge.

Among the species cited by the interviewees, eight are in the National List of Medicinal Plants of Interest to the Unified Health System (Renisus), namely: *A. sativum*, *Aloe vera* (L.) Burm. f., *Carapa guianensis* Aubl., *Copaifera martii* Hayne., *Curcuma longa* L., *Psidium guajava* L., *Punica granatum* L., and *Zingiber officinale* Roscoe [58].

The plant parts most frequently used in treatments against COVID-19 symptoms were: leaf, with 51 citations (33%); fruit, with 44 (29%); and bulb, with 25 (16%). The other plant part categories mentioned were: branch (7%), rhizome (7%), flower (3%), oil (3%), latex (1%), bark (less than 1%), seed (less than 1%), and unspecified (less than 1%).

As for the way of obtaining the plants, the most cited was purchase in fairs and local markets, with 111 citations (72%), followed by collection in own yard, cited 27 times (18%), and donation from third-party yards, with 15 citations (10%).
Leaf has been reported as the plant part most used in treatments based on herbal medicine in several studies conducted in the Amazon [43, 44, 45, 59, 60, 61, 62].

In contrast with these studies in the Amazon, in seasonally dry forests of Caatinga, in Northeast Brazil, the part of the plant preferably used for medicinal purposes is the tree bark, according to Albuquerque and collaborators [13]. This is so because tree barks are always available in this type of environment, guaranteeing the possibility of use of the resource throughout the year.

This preference for the use of perennial medicinal resources in regions marked by seasonality such as the Brazilian semi-arid region reflects a response of human populations to local climatic conditions. Such selection of tactics that ensure the continuity of use of resources is known as the hypothesis of climatic seasonality, which sustains that human behavior linked to the selection of resources may be affected by ecogeographic issues [10, 13].

The interviewees did not mention areas of native vegetation as a source of the medicinal plants used to combat COVID-19, and although native species such as amapá [Parahancornia amapa (Huber) Ducke], copaíba (C. martii), and andiroba (Carapa guianensis Aubl.) were cited among the resources acquired in fairs and markets, they had few citations. This is in line with what is proposed by Voeks [63], who states that products of current and historical anthropogenic disturbance regimes (such as crops, transplanted plants in backyards and herbs) are the main herbal medicines used by people who inhabit tropical forests, while forests are the main suppliers of other types of products such as fiber, wood and fuel.

In this sense, a difference can be observed in the preferences related to the source of medicinal resources among different biomes. According to Albuquerque [64], populations living in the semi-arid region of Brazil prefer to use native plants, especially woody species from areas of natural vegetation.

Learning and selection of biocultural traits

The predominance of one learning route of natural treatments to combat the symptoms of COVID-19 was not detected among the interviewees. Twenty-nine treatments were learned horizontally (37%), through neighbors and friends, with emphasis on social networks; 24 treatments were transmitted vertically (30%), reported as family knowledge; 20 treatments were learned diagonally (25%), especially from the elderly people of the locality; and six treatments were learned by innovation (8%), that is, treatments which were not learned from anyone, but rather discovered by the informants when they decided to use medicines already known for a new purpose.

The ways of learning biocultural traits – namely, horizontal (rural = 15 citations, urban = 14 citations), vertical (rural = 10 citations, urban = 14 citations), diagonal (rural = 10 citations, urban = 10 citations), and innovation (rural = 4 citations, urban = 2 citations) – did not differ significantly among the sampled groups in the rural and urban areas ($X^2 = 1.35$, DF = 3, $p = 0.71$).

Vertical transmission of knowledge has been identified as prevalent in several ethnobotanical studies [16, 65]. However, in this study, it was cited in less than one third of the treatments mentioned. This result may
be related to the fact that this transmission route is considered highly conservative because it slows down the diffusion of new biocultural traits, being rather favored in stable environments and associated with widely distributed knowledge in human groups [66, 67, 68], a context different from that of the current scenario of an environmental change caused by the emergence of a new disease.

Horizontal and diagonal modes of transmission of knowledge were cited in more than 60% of the treatments. This confirms that such routes stand out in unstable environments, due to their more diffusive characteristic, being related to the dissemination of new biocultural traits [27, 67, 69]. They constitute the most adaptive ways of knowledge transmission in the face of new selective pressures such as the emergence of new diseases.

Innovation was the form of learning with the least number of citations, which is expected because experimentation is costly. Trying new herbal treatments requires expenditure of energy since it involves a process of trial and error. In turn, learning by social transmission is less costly as allows the acquisition of different biocultural traits without the need to put them to the test [10, 70].

A significant difference between the selection criteria of natural treatments was detected in the ANOVA (DF = 6, F-value = 13.66, p < 0.0001). The means of the criteria familiarity and age were higher among the analyzed scenarios (Table 2).

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Rural area</th>
<th>Urban area</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person Prestige</td>
<td>2.8</td>
<td>2.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Person Success</td>
<td>4.3</td>
<td>3.6</td>
<td>3.9</td>
</tr>
<tr>
<td>Familiarity</td>
<td>4.5</td>
<td>4.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Age</td>
<td>4.5</td>
<td>4.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Organoleptic Characteristics</td>
<td>3.0</td>
<td>3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Combating similar diseases</td>
<td>3.4</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Success in a known person</td>
<td>3.6</td>
<td>2.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>

The influence of age on ethnobotanical knowledge has been frequently reported [43, 59, 71, 72]. This relationship between age and knowledge about medicinal plants was perceived by the interviewees in the present study, who considered the age of the transmitter an important factor to decide whether to use or not a learned treatment.

Seeking older people to obtain knowledge about disease treatments is an adaptive behavior. As older people have more years of life to learn both by experimentation and social transmission, they accumulate
experiences and this is reflected in greater confidence when it comes to inform treatment types and the most appropriate forms of use for the treatments [73, 74].

Considering the greater vulnerability of elderly people to COVID-19, a substantial portion of the knowledge associated with biodiversity may be lost as a consequence of this pandemic [75]. In this context, it is urgent to develop actions that promote the effective implementation of the guidelines of the National Policy on Medicinal Plants and Herbal Medicines, especially those aimed at safeguarding knowledge about medicinal plants through the transfer of knowledge across generations [76].

Familiarity was an important criterion according to the interviewees’ answers when they were asked about how they learned each treatment. They reported using medicines learned from people they trusted, such as close friends, neighbors, family members, brothers and sisters of the church, and so on.

Thus, the data showed that the biases that most influenced the learning of biocultural traits in the local medical systems studied were familiarity and age. The lower influence of criteria such as organoleptic characteristics and usefulness in similar diseases may be related to the low frequency of innovation in the process of learning biocultural traits, since these factors are linked to experimentation processes.

Conclusions

The data show that the selective pressure generated by the emergence of a new disease, COVID-19, is driving the studied local medical systems to adapt to the new environmental challenge through the emergence of new biocultural traits expressed in the treatments used to combat the symptoms of COVID-19.

Traditional medicines were used as therapeutic alternatives by most of the interviewees, what emphasizes the importance of this practice. We stress that this practice needs to be encouraged as a way to minimize the effects of socio-spatial vulnerability in the process of contamination, allowing access to therapeutic alternatives especially among populations established far from healthcare centers and with lower income, which aspects hinder their access to biomedical treatments.

It is noteworthy that, in Brazil, there is a policy that aims to ensure safe access and rational use of medicinal and herbal plants by the Brazilian population. This policy encourages the cultivation and targeted use of these biological resources, valuing the traditional knowledge and productive arrangements as well as research on traditional medicine. All these goals are foreseen as a public policy to be implemented throughout the national territory.

The evolutionary processes that took place to face the pandemic also led to the development of behaviors that are not adaptive, such as combining natural with synthetic drugs.

The three most cited species present several biological activities that may be associated with the perceived relief of COVID-19 symptoms. For example, *A. sativum* has immunomodulatory activity, *C. limon* has neuroprotective action and *A. oleraceae* has antinociceptive activity. The biological activity of
these species specifically over the symptoms of COVID-19 still needs to be studied in order to confirm or refute the existence of such a relationship.

The preference for using plants from managed environments and the main use of leaves in the preparation of herbal remedies reinforce theories that sustain that the environment can influence people's behavior in their use of natural resources. This hypothesis was evident in the divergence between preferences of Amazonian people and inhabitants of the Brazilian semi-arid region.

No significant differences were found between the learning processes used to combat COVID-19. There was no prevalence of vertical transfer of knowledge, as found in most studies of medicinal plants. This finding may reinforce the theory that unstable environments, such as the one generated by the emergence of a new disease, favor the horizontal or diagonal transmission of knowledge because they are more diffusive pathways and allow the faster spread of innovations in local medical systems.

Regarding the criteria adopted for selection of herbal medicines, no significant differences were found between residents of the urban and rural areas of Salvaterra. This result may be due to the fact that the rural area sample was concentrated in villages and communities with easy access.

The most influential criteria for the selection of natural remedies among the interviewees were familiarity and age. They were the biases with the greatest weight in the decision to use or not a certain treatment in the fight against COVID-19 symptoms.

In this context, it is necessary to protect and value the knowledge of older individuals, considered by the interviewees as an important source of knowledge about traditional medicine. Furthermore, they constitute a group especially vulnerable to COVID-19. This highlights the urgency of encouraging and creating spaces for the sharing of this knowledge in order to avoid the loss of important biocultural traits in the local medical systems held by the elderly members of the population.

Considering that COVID-19 is still a very new disease and that local medical systems take time to adapt to emerging diseases, new studies need to be carried out to analyze the dynamics of these socioecological systems. Research in different places, contexts, and biomes can also detect similar patterns and point out dissimilarities in the ways that varied local medical systems are responding to the presence of this disease.

**Declarations**

**Ethical Approval and Consent to participate**

The research project was submitted to the Research Ethics Committee - CEP/ National Research Ethics Commission - CONEP system through the Brazil Platform (CAAE: 45329421.8.0000.8767; Receipt Number: 032892/2021).
Before conducting the interviews, the free and prior informed consent terms were read, and the informant's authorization was requested.

**Consent for publication**

Not applicable

**Availability of supporting data**

Not applicable

**Competing interests**

The authors have declared that no competing interests exist.

**Funding**

Amazon Foundation for Studies and Research Support (FAPESPA) provided scientific initiation grants for the two undergraduate students.

**Authors' contributions**

1 - 4. collected data; 1. wrote the main manuscript text; 5. acted as research advisor and reviewed the manuscript.

**Acknowledgments**

The Environmental Sciences Post Graduation Program of Pará State University and the Environmental Conservation and Monitoring Laboratory for providing scientifical support and the necessary infrastructure for this research.

The Municipal Health Department of Salvaterra for providing data on positive cases of covid.

The Salvaterra people for welcoming us into their homes and talking to us about such a sensitive topic.

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**Figures**
Figure 1

Location of the municipality of Salvaterra, Marajó, Pará, Brazil.

Supplementary Files

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