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Polynesian medicine used to treat diarrhea and ciguatera: An ethnobotanical survey in six islands from French Polynesia

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Abstract :

Ethnopharmacological relevance

In French Polynesia, many pathologies common or endemic to the territory cause diarrhea. This is the case for rotavirus gastroenteritis, salmonella food poisoning, ingestion of water contaminated by bacteria, and ciguatera. To treat these ailments, the population may employ traditional medicine for cultural reasons, geographical isolation, and poor health coverage. Polynesian remedies are often used without medical consultation and there is no data on their benefit-risk balance. A few ethnobotanical studies have been carried out in order to identify the traditional remedies used for various ailments, but few studies have focused on gastrointestinal pathologies. In this context, an ethnobotanical survey was carried out to identify treatments used for diarrhea and ciguatera, inventory the plants used, better understand the local representation of these remedies, and provide efficacy and safety data on these uses.

Materials and methods

From February to April 2021, a semi-structured survey was conducted on six islands in French Polynesia, including one island in the Windward Islands archipelago (Tahiti), three islands in the Marquesas archipelago (Hiva Oa, Nuku Hiva, Tahuata), and two islands in the Leeward Islands archipelago (Raiatea, Tahaa). A total of 133 people was interviewed including 34 specialists (of which 29 experts in herbalism).

Results

These people mentioned the use of 27 plants for the treatment of diarrhea, and 24 for the treatment of ciguatera. Citrus aurantiifolia, Psidium guajava and Cordyline fruticosa were the three most cited plant species used for treating diarrhea, while Cocos nucifera, Punica granatum and Barringtonia asiatica were the most cited for ciguatera. A large majority of plants are widespread and introduced plants, which is

congruent with the history of Polynesian people. While some plants are well known for similar uses (e.g. Psidium guajava for diarrhea, Heliotropium arboreum for ciguatera), others are less well known and may present toxicity risks (e.g. Barringtonia asiatica for ciguatera).

Conclusion

Traditional Polynesian medicine is an integral part of the local culture so important to be preserved and valued. However, more pharmacological and toxicological studies are still needed to determine the benefit-risk balance of some of these remedies and to allow their official integration into the Polynesian health system.

Graphical abstract

Keywords : French Polynesia, Marquesas islands, Society islands, Ethnobotany, Intestinal disorders, Healers classification

Introduction:

In French Polynesia, diarrhea can be caused by a variety of microbial pathogens and toxins. Among the microbial pathogens, bacteria are one of the main causes of diarrhea. From 2008 to 2013, several outbreaks of *Salmonella enterica* serotype *enteritidis* infections were reported and contaminated about a hundred of persons (Le Hello et al., 2015). In 2020, 40 cases of acute gastro-enteritis were recorded, among which 35 were due to *Salmonella* species contamination (BSS, 2021). To a lesser extent, *Escherichia coli* is also known to induce bacterial diarrhea in French Polynesia (BSS, 2021). Viruses are another important cause of diarrhea in the area. Hubert (2001) reported that rotaviruses represent one of the major causes of medical consultations in children in the French Polynesian territory. Also, the high prevalence of various human enteroviruses in the wastewater and surrounding seawater of Tahiti is potentially responsible for gastroenteritis (Kaas et al., 2019).

Besides diarrhea from microbial origin, ciguatera poisoning represents another cause of gastro-intestinal disorders in the area. Ciguatera is highly prevalent in French Polynesia, and its annual incidence varied from 26.3 to 41.9 per 10 000 person-years from 1992 to 2001 (Chateau-Degat et al., 2007). More recently, 253, 348 and 333 new cases were reported in 2019, 2018, 2017 respectively (Institut Louis Mallardé, n.d.). Marquesas islands is one of the most impacted area with an annual incidence of about 100 per 10 000 person-years in 2017 (Chinain et al., 2019). Ciguatera is caused by eating seafood (especially fish) contaminated with ciguatoxins produced by dinoflagellates of the genus *Gambierdiscus* and *Fukuyoa*. Clinical manifestations of ciguatera are highly complex and diverse with about 175 reported symptoms (Chinain et al., 2021). It mainly includes gastrointestinal, cardiovascular and neurological disorders lasting from a few days (e.g., nausea, diarrhea) to months or even years (e.g., paresthesia, dysesthesia, asthenia, anxiety, depression). To date, no specific treatments are available, and therapeutic management relies mainly on symptomatic and supportive care, with mannitol being the only therapy evaluated by rigorous clinical trials (Friedman et al., 2017).

To treat these gastro-intestinal disorders, Polynesians might rely mainly on their plant biodiversity. Polynesian traditional medicine is still used today to manage various ailments. This is explained by cultural reasons, geographic isolation, and poor health infrastructure in some islands. Although there are existing documents detailing the local traditional medicine and reporting the use of medicinal plants in French Polynesia, most of them date back from the 20th century, and do not focus on specific ailments (Grépin and Grépin, 1984; Lemaitre, 1985; Maclet and Barrau, 1959; Panoff, 1966; Pétard, 2019 (1986)). Regarding the recent and known herbal medicines used for diarrhea and ciguatera, Girardi et al. (2015) reported seven plants for treating ciguatera in the Marquesas archipelago; and Quenon (2020) mentioned the use of six plants for diarrhea in the Leeward Islands archipelago. Not only the number of plants described recently for treating diarrhea and ciguatera is scarce, but there is no data providing an evaluation of the benefit-risk balance for each remedy. This lack of data is an obstacle to the establishment of the Polynesian pharmacopeia and its integration into the official health care system.

Out of the five archipelagos of French Polynesia, the Society Islands and the Marquesas Islands are the two archipelagos with the richest plant biodiversity, with 545 and 314 native vascular plants respectively, and also the highest rate of archipelago endemism with 50 and 55% of endemic plants respectively (Florence and Moretti, 2013). The Marquesas archipelago is also one the most remote area in the Pacific and presents singular cultural traits compared

to the Society Islands (Girardi et al., 2015), which allow comparison between the two areas.

In this context, a study was performed in the two most biodiverse archipelago (Marquesas and Society) from French Polynesia to identify the remedies used to treat diarrhea and ciguatera, inventory the used plant species, compare ethnobotanical data from the two areas, and provide an assessment of their efficacy and toxicity in order to help their integration into the official health care system.

Materials and Methods:

1. Study site

French Polynesia is an overseas collectivity of the French Republic which covers 3,521 km² in the South Pacific Ocean and is located between 7°-28° south and 134°-155° west. It comprises 118 islands and atolls inhabited by almost 280,000 persons. Geographically, French Polynesia is subdivided into five archipelagos, namely the Society islands archipelago, comprising the Windward Islands (Îles du Vent) and the Leeward Islands (Îles Sous-le-Vent), the Marquesas archipelago (Marquises), the Austral archipelago (Australes), the Tuamotu archipelago, and the Gambier archipelago (Andréfouët and Adjeroud, 2019).

The study was carried out in six islands of French Polynesia including one island of the Windward islands (Tahiti), two islands of the Leeward islands (Raiatea and Tahaa), and three islands of the Marquesas archipelago (Nuku Hiva, Hiva Oa, Tahuata) (**Figure 1**). Tahiti has the largest population of French Polynesia with about 200,000 inhabitants and accounts for two-third of the total population. In 2017, Raiatea and Tahaa had 12,249 and 5,313 inhabitants respectively, while the population of Nuku Hiva, Hiva Oa and Tahuata was 3,120, 2,348 and 671 respectively (Philippe, 2017).

Altogether 39 villages were visited, including 18 in Tahiti (Arue, Faaa, Faarei Hitiaa, Mahaena, Mahina, Mataiea, Paea, Papara, Papeari, Papenoo, Papeete, Pirae, Pueu, Punaauia, Taravao, Tautira, and Teahupoo), 7 in Raiatea (Avera, Faaroa, Opoa, Tehurui, Tevaitoa, Uturoa, Vaiaau), 4 in Tahaa (Faaaha, Haamene, Patio, Tapuamu), 5 in Nuku Hiva (Aakapa, Hatiheu, Hooumi, Taiohae, Taipivai), 4 in Hiva Oa (Atuona, Hanaiapa, Taaoa, Tehutu), and 1 in Tahuata (Vaitahu).

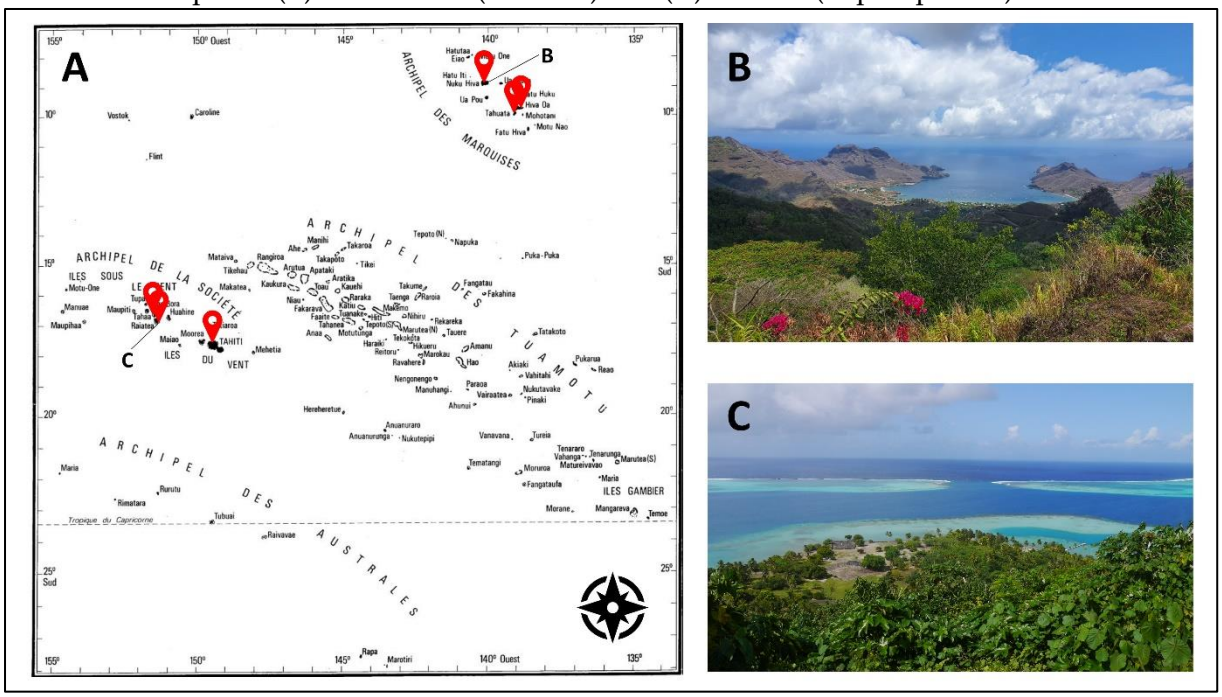
2. Data collection

The study was conducted from February to April 2021. To select informants, we either used a random approach by visiting household or street vendors in each previously cited town, or we followed the guidance of key informants (i.e., members of Haururu association and Académie Marquisienne) who helped us to find traditional healers or knowledgeable persons in the area. All the interviews were carried out by the first author of this study, and in a few cases, a translator (key informant or family member) was also asked to help.

A semi-structured questionnaire was used to interview each informant. This questionnaire comprised different parts, including:

- Sociodemographic data: age, gender, place of residence, place of birth, number of children, occupation, level of education, religion, spoken language(s).
- General knowledge on diarrhea: definition, types of diarrhea, associated symptoms, causes of diarrhea, recommendations and avoidance.
- General traditional practices: source of knowledge, type of treated patients, type of other treated disorders, type of associated remuneration and cultural practices.
- Medical management of diarrhea: dietary recommendations, avoidance, advice, therapeutic management. For each cited remedy, the following questions were asked: vernacular name of plant species, part of plants used, method of preparation, method of administration, posology (including dosage and length of duration), local perception of the pharmacology and toxicology of the plant.

Figure 1: Figure showing (A) a map of the six islands visited in French Polynesia, and landscapes in (B) Nuku Hiva (Taiohae) and (C) Raiatea (Taputapuatea) islands.



Legend : Map is modified from © J-C.J. ORSTOM TAHITI (025/03-86). Note the fringing reef in (C) which is the hallmark of French Polynesian islands; and the absence of reef in (B) which is specific to Marquesans islands.

3. Ethical considerations

Before each interview, the objectives and the conduct of the study (length of the interview, data collected, etc.) was explained to each participant. Then, a prior informed consent was obtained from each informant. At the island level, local organizations (Association Haururu, Académie Marquisienne) or city officials were contacted to inform about the survey. At the government level, the Minister of Health and the Minister of Agriculture from French Polynesia were informed about the study, and the Environmental Direction (Direction de l'Environnement (DIREN)) approved the access to genetic resources and traditional knowledge associated with genetic resources (n°2238/MCE/ENV).

4. Botanical identification

For each new cited plant species, the informants were asked to show it in the field and photographies were taken. Then, two specimens of each plant species were collected following the methods described by Chassagne and Quave (2021). Later, the plant specimens were identified by the first author and the second author of this study. One specimen of each species was deposited at the Herbier de Polynésie française (PAP), Musée de Tahiti et des îles, Puna'auia, Tahiti, Polynésie française and another specimen was deposited at the herbarium from the Jardin Botanique Henri Gaussen (TLS), Museum d'Histoire Naturelle, Toulouse, France. All plants names have been crosschecked with Plants of the World Online (https://powo.science.kew.org/), the French inventory of natural heritage (INPN)

(https://inpn.mnhn.fr/accueil/index), and the Nadeaud database from French Polynesia (https://nadeaud.ilm.pf/).

5. Data analysis

Statistical analysis was performed by using a Student's t-test (unpaired, two-tailed) for comparing mean values (numerical data), Chi-squared or Fisher test for comparing frequency (categorical data). A difference was considered statistically significant when p-value was inferior to 0.05. GraphPad Prism software version 8 was used to make figures.

Results:

1. Sociodemographic features of informants

A total of 133 informants were interviewed, among which 68 (51.1%) were from the Society islands, and 63 (47.4%) were from the Marquesas archipelago (**Table 1**).

Table 1: Sociodemographic features of interviewees

Characteristics		Frequency	Percent (%)
Gender			
	Male	35	26.3
	Female	98	73.7
Age			
	25-35 years	11	8.3
	36-45 years	25	18.8
	46-55 years	24	18.0
	56-65 years	33	24.8
	66-75 years	31	23.3
	76-83 years	9	6.8
Residence			
	Society archipelago		
	Raiatea	19	14.3
	Tahaa	7	5.3
	Tahiti	42	31.6
	Marquesas archipelago		
	Hiva Oa	31	23.3
	Nuku Hiva	28	21.0
	Tahuata	4	3.0
	ND	2	1.5
Education			
	None	3	2.3
	Primary School	29	21.8
	Secondary School	53	39.8
	Vocational diploma	22	16.5
	High School	18	13.5
	University	7	5.3
	ND	1	0.8
Religion			
	Catholic	54	40.6
	Protestant	47	35.3
	Mormon	11	8.3
	Adventist	8	6.0
	Other	11	8.3
	ND	2	1.5

The mean age of all participants was 56.5 years old with a median of 57 years old and a range of 25-83 years old. A large majority of participants were females (98, 73.7%), and most of the informants (107, 80.5%) stopped their education before high school. The two most represented religions were Catholic (54, 40.6%) and Protestant (47, 35.3%).

Comparing informants from the Marquesas and the Society islands, we found some statistically significant differences in their sex ratio (SR) ($SR_{SOCIETY}$ = 0.17 vs. $SR_{MARQUESAS}$ = 0.62, p-value = 0.002) and their religion (Catholic: $N_{SOCIETY}$ = 14 vs. $N_{MARQUESAS}$ = 40, p-value = 0.005; Protestant: $N_{SOCIETY}$ = 34 vs. $N_{MARQUESAS}$ = 13, p-value = 0.02). Mean age, level of education, and type of informants (see next part) were similar among the informants.

2. Classification of informants regarding their traditional medical practices

During the survey, the informants mentioned various traditional medical practices including: a specialization in massage therapy (six informants, 4.5%), a specialization in apitherapy (defined as therapy of musculoskeletal disorders by using local bee stings) (two informants, 1.5%), and the use of herbal remedies (123 informants, 92.4%). Out of all participants, three (2.2%) indicated that they practice traditional medicine as a full-time job with two (1.5%) specialized in massage, and one (0.8%) practicing herbalism and massage.

Among the persons using herbal medicine, only 16 (12.7%) considered themselves as expert in herbalism, while 34 (27%) knew how to treat all types of diseases with herbs, 52 (41.2%) mentioned treating people outside of their family members, and 51 (40.5%) were known by other people in the area for being able to heal. It was also noted that 51 (40.5%) participants treated only their family (but not people outside their family) with herbal medicine, two (1.6%) were able to counteract evil spells with herbal remedies, and 91 (72.2%) could treat one or a few disorders with herbs.

Altogether, six (4.5%) informants reported that they got their knowledge through dreams, four (3%) indicated that they communicate with their ancestors to make the remedy work, and five (3.7%) had a notebook of homemade remedies.

Following these heterogenous results, we decided to categorize the informants by focusing on specific criteria:

-the type of medical practices used: apitherapy, massage, or herbalism

-the ability to treat all disorders

-the fact to treat all types of patients (and not just family members)

-the reputation for being able to heal people

Getting their knowledge through dreams, communicating with ancestors, or being a full-time traditional healer were not considered as important criteria to categorize them, as only a few informants mentioned these points.

An expert in herbalism was defined as a person having all of the three criteria, that is: the ability to treat all disorders, the fact to take care of all types of patients, and a reputation of healer in the area. A knowledgeable person was defined as someone having one or two of the three criteria above-mentioned, including people in a learning process, person counteracting spell, and owner of a notebook of homemade remedies. Non-specialists were defined as people using herbal or other type of therapies for their own family, and able to treat one or a few disorders.

As a result of this classification, 70 (52.6%) informants were categorized as non-

specialists, 29 (21.8%) were considered as knowledgeable (including one also specialized in massage therapy), and 29 (21.8%) were classified as expert in herbal medicine (including two protestant pastors). Among the latter category, one was also specialist in apitherapy, another one was also specialist in massage, and a third one was able to catch spell. Aside the herbal specialists and non-specialists, one (0.8%) informant was classified as specialist in apitherapy, and four (3%) were classified as specialists in massage therapy.

Sex ratio and mean age of the three types of informants were as follows: experts in herbalism: SR = 0.27, mean age = 69.6 years old; knowledgeable persons: SR = 0.30, mean age = 57.6 y. old; non-specialists: SR = 0.4, mean age = 50.6 y. old. The mean age of experts was significantly higher than the two other groups (p-value < 0.00005 for both).

While the mean age of each of the three types of informants were similar in the Marquesas islands compared to the Society islands, the sex ratio showed significant differences. In the Marquesas islands, a higher number of males were found in the non-specialists' group ($SR_{MARQUESAS}$ = 1.19 vs. $SR_{SOCIETY}$ = 0.03, p-value < 0.00001) and in the knowledgeable group ($SR_{MARQUESAS}$ = 0.42 vs. $SR_{SOCIETY}$ = 0.18, no significant difference) compared to the Society islands, while a higher number of males were found in the expert in herbalism group from the Society islands ($SR_{MARQUESAS}$ = 0 vs. $SR_{SOCIETY}$ = 0.5, p-value = 0.03). Overall, experts in herbalism and knowledgeable persons are mainly females in both archipelagos, but males are more represented in the Marquesas islands in the non-experts' groups.

3. General knowledge on diarrhea

3.1. Classification and causes of diarrhea

While 64 (48.1%) informants did not mention knowing different diarrhea types, the others (69, 51.9%) reported classifying diarrhea according to several factors. Among them, 29 (42%) cited their appearance and consistency (bloody [17 informants, 24.6%], watery [13, 18.8%], mixed [9, 13%], green [4, 5.8%], yellow [3, 2.2%], sticky [1, 1.4%], with mucous [1, 1.4%]), 28 (40.6%) mentioned their causes as the principal factor to differentiate diarrhea types (see below), 11 (15.9%) mentioned their severity (aggressive or slight [3, 2.2%], long or short [2, 2.9%], acute [1, 1.4%], high quantity excreted or not [1, 1.4%], out of control [1, 1.4%]), 8 (11.6%) mentioned their associated symptoms (pain [6, 8.7%], convulsion [3, 2.2%], vomiting [3, 2.2%], gas [2, 2.9%], hemorrhoids [2, 2.9%]), and 5 (7.2%) cited the type of affected persons (babies, children or adults [5, 7.2%]). It is important to note that 15 (21.7%) interviewees mentioned more than one of the factors described above.

Regarding the causes cited by the informants, a total of 58 different causes was cited by 129 participants. We could categorize them into different sections including diet, drink, infection, health disorders, environment and others (**Table 2**). The most cited causes of diarrhea were food intoxication (119 citations, 89.5%) and especially rotten food (25, 18.8%), tap water (63, 47.4%), catching cold at the navel (24, 18.1%), ciguatera poisoning (22, 16.5%), diarrhea outbreak (12, 9.0%), and microbial infection (10, 7.5%). Of note, a condition called "ira" was cited in the study and was defined as a childhood illness associated with nervosity, agitation, and convulsion.

Table 2: Most important causes of diarrhea mentioned by informants

Categories	Causes cited*	Frequency	Percent (%)
Diet			
	Food	119	89.5
	Rotten food	25	18.8
	Dairy products (milk, …)	8	6.0
	Fat food	4	3.0
	Papaya	3	2.3
	Too much food	3	2.3
	Fish (not fresh)	2	1.5
	Food poisoning	2	1.5
	Grapefruit	2	1.5
	New food	2	1.5
	Unhealthy	2	1.5
Drink			
	Tap water	63	47.4
	Beer	4	3.0
	Alcohol	2	1.5
	Seawater	2	1.5
	Wine	2	1.5
Infection			
	Microbes	10	7.5
	Flu	2	1.5
	Leptospirosis	2	1.5
	Viruses	2	1.5
Health disorders			
	Cold at the navel	24	18.1
	Ciguatera	22	16.5
	Diarrhea outbreak	12	9.0
	Diseases	4	3.0
	Ira	3	2.3
	Indigestion	2	1.5
Environment			
	Weather (rainy, cold)	3	2.3
Other			
	Teething	8	6.0
	Purge	3	2.3

*items cited only 1 time were not included

When comparing the Society and Marquesas islands, no significant differences were found in the most important causes of cited diarrhea.

3.2. Avoidance

Out of the 133 participants, a total of 95 mentioned different products (45 in total) or

situations (i.e., catching cold, air conditioning, massage, lift heavy things, smoking cigarette) to avoid when having a diarrhea. Among them, the most cited were dairy products (e.g., milk) (29, 21.8%), followed by sour fruits (i.e., grapefruit, oranges) (18, 13.5%), mango (15, 11.3%), fatty food (14, 10.5), and tap water (6, 4.5%).

4. Therapeutic management of diarrhea

4.1. Remedies used for diarrhea

A total of 414 remedies was reported to be used to treat diarrhea by the 133 informants. It represented an average of 3.1 remedies cited by participants. Among these remedies, 214 were unique (meaning that these remedies did not include the same ingredient(s), or the same quantity of ingredients used if their ingredients were similar).

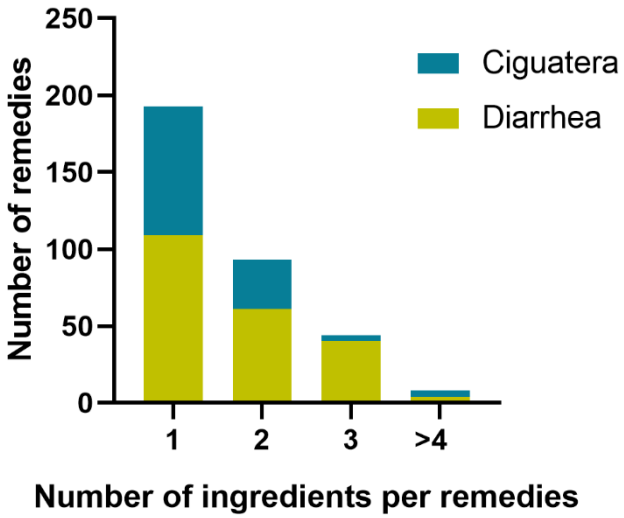
Most of the remedies cited for treating diarrhea were single-ingredient remedies (109, 50.9%), followed by two-ingredients remedies (61, 28.5%), and three-ingredients remedies (40, 18.7%). Only a small portion of the remedies had more than three ingredients (4, 1.9%), and the maximum number of ingredients was 10 (one remedy only) (**Figure 2**).

Regarding the ingredients found in the remedies, they can be classified into different categories: plants, processed food (defined by any agricultural products transformed into an edible or more complex food), non-processed liquid (e.g., seawater), Polynesian cosmetic products, conventional medicine, other traditional medical products.

Of note, no significant differences in the number of cited remedies were found between the Society and the Marquesas islands, and between the different types of informants (experts, knowledgeable persons, and non-specialists).

In the following sections, we will discuss firstly the plants and then the other types of used products.

Figure 2: Number of ingredients for each unique remedy cited for diarrhea and ciguatera



4.2. Plants used to treat diarrhea

In total, 27 plant species were mentioned by the informants for treating diarrhea in 169

304 remedies (**Table 3**).

Table 3: Plant species used to treat diarrhea

Scientific name	Botanical family	Voucher No	Origin	Tahitian name	Marquesan name	Parts used	Method of preparation	Method of administration	Total number of citations	Number of persons citing the plants
Annona muricata L.	ANNONACEAE	FC490	Mod.	corossol, totara	korosoni, manini tota'a	Leaf	Decoction	Bath, massage	4	3
Artocarpus altilis (Parkinson) Fosberg	MORACEAE	FC486	Pol.	'uru, maiore	me'i	Fruit/Sap	Decoction/Fry/ Mix with water/Wood-fire cooking	Oral	6	4
Carica papaya L.	CARICACEAE	FC492	Mod.	'i'i'ta	kiki'e, vi papai	Leaf/Ripe fruit/Seed	Crush/Decoction/Fry/ None	Oral	9	8
Catharanthus roseus (L.) G.Don	APOCYNACEAE	FC518	Mod.	pervenche	ND (perevai, tihapai)	Flower	Decoction	Oral	1	1
Citrus x aurantiifolia (Christm.) Swingle	RUTACEAE	FC495	Mod.	taporo	hitoro/fitoro	Fruit	Press	Oral	113	80
Cocos nucifera L.	ARECACEAE	FC487	Pol.	ha'ari	'ehi	Coconut water/Coconut milk	Decoction/Heat/Mix	Oral	10	9
Coleus barbatus (Andrews) Benth. ex G.Don	LAMIACEAE	FC516	Mod.	sauge doliprane	sauge doliprane	Leaf	Decoction	Oral	1	1
Cordia subcordata Lam.	BORAGINACEAE	FC504	Ind.	tou	tou	Bark	Crush	Oral	1	1
Cordyline fruticosa (L.) A.Chev.	ASPARAGACEAE	FC484	Pol.	'auti	ti, 'outi	Leaf/Leaf bud	Crush/Decoction	Oral	23	19
Erythrina variegata L.	FABACEAE	FC511	Pol.	'atae	kenae (N), anetae (S)	Branch	Crush	Oral	1	1
Euphorbia hirta L.	EUPHORBIACEAE	FC502	Mod.	e’ae’a	'eita epau	Whole plant	Decoction	Oral	1	1
Gardenia taitensis DC.	RUBIACEAE	FC493	Pol.	tiare tahiti	tia'e tahiti, tia'e	Flower/Flower bud	Crush	Oral	5	3

Hibiscus rosa-sinensis L.	MALVACEAE	FC514	Pol.	'aute	koute pupu	Leaf	Decoction	Oral, massage	1	1
Ipomoea batatas (L.) Lam.	CONVOLVULACEAE	FC527	Pol.	'umara	kuma'a, 'uma'a	Tuber	Decoction	Oral	1	1
Lantana camara L.	VERBENACEAE	FC525	Mod.	lantana	ND	Flower/Leaf bud	Decoction	Oral	2	1
Mangifera indica L.	ANACARDIACEAE	FC500	Mod.	vi ma'ohi, vi popaa	mako	Wood	Decoction	Oral	1	1
Microsorum grossum (Langsd. & Fisch.) S.B.Andrews	POLYPODIACEAE	FC505	Ind.	metuapua'a	papamoko (N), papamo'o (S)	Rhizome/Young frond	Boil in coconut milk/Crush	Oral	4	4
Morinda citrifolia L.	RUBIACEAE	FC488	Pol.	nono	noni	Ripe fruit/Unripe fruit/Stipule, fruit	Maceration/Press	Oral	6	5
Musa x paradisiaca L.	MUSACEAE	FC491	Pol.	mei'a	me'ika	Ripe fruit	Crush/Dry/Decoction/ Fry/None	Oral	15	13
Oxalis corniculata L.	OXALIDACEAE	FC517	Pol.	patoa 'ava 'ava	pakihi (N), kokihi (S)	Whole plant	Crush	Oral, massage	1	1
Physalis angulata L.	SOLANACEAE	FC499	Pol.	tamaru ha'ari	konini (N), kariri (S)	Leaf	Crush	Oral	2	2
Psidium guajava L.	MYRTACEAE	FC485	Mod.	tuvava	tuava	Bark/Ripe fruit/Young leaf	Chew/Crush/Decoction/ None	Oral	47	39
Rorippa sarmentosa (Sol.. ex G.Forst. ex DC.) J.F. Macbr.	BRASSICACEAE	FC506	Pol.	patoa purahi	mahi mahi	Whole plant	Crush	Oral, massage	4	3
Saccharum officinarum L.	POACEAE	FC520	Pol.	to	to	Young leaf/ Leaf/Stem	Crush/Decoction	Oral	7	4
Syzygium cumini (L.) Skeels	MYRTACEAE	FC528	Mod.	pistas	pistai	Fruit	None	Oral	1	1
Xanthosoma sagittifolium (L.) Schott	ARACEAE	FC526	Mod.	tarua	ND	Tuber	Decoction	Oral	1	1
Zingiber officinale Roscoe	ZINGIBERACEAE	FC498	Mod.	re'a tinito	'eka kira	Rhizome	Crush	Oral	3	3

Legend: A slash ("/") corresponds to the term "or" ; a comma (",") correspond to the term "and"; (N) = Northern part of Marquesas islands; (S) = Southern part of

8 Marquesas islands; Ind. = Indigenous; Mod. = Modern introduction; ND = Not documented; Pol. = Polynesian introduction.

The two most represented botanical families were Myrtaceae and Rubiaceae with two species cited in each family (i.e., *Psidium guajava* and *Syzygium cumini*; *Morinda citrifolia* and *Gardenia taitensis* respectively). The other families were represented by only one plant species. The five most cited plant species were: *Citrus aurantiifolia* (113 citations), *Psidium guajava* (47), *Cordyline fruticosa* (23), *Musa x paradisiaca* (15), and *Cocos nucifera* (10). Regarding part of used plants, fruit ranked first (173 citations), followed by leaf (43), leafbud (31), flower (7), and whole plant (6). Out of the 169 used remedies, the three most cited methods of recipe preparation were pressing and mixing (53 remedies, 31.3%), decoction (29, 17.2%), and pressing in a cloth a previously crushed plant (28, 16.6%). Almost all the remedies were taken orally (163, 96.4%), while a few were taken in a bath (5, 2.9%). The method of administration for one remedy was not determined. The length of treatment was of 3 days in most of the cases, except for a few remedies (regardless of the used species) taken until good recovery.

Out of the listed 27 plants, six plants were mostly used in association with other ingredients, among which *Gardenia taitensis* (100% of remedies citing *G. taitensis* were in association with other ingredients), *Saccharum officinarum* (100%), *Citrus aurantiifolia* (91.8%, especially with cassava starch (48.2%)), *Cocos nucifera* (87.5%), *Cordyline fruticosa* (85.7%), and *Microsorum grossum* (75%).

Regarding their biogeographical origin, we found that 13 plant species (totalizing 82 citations) were from Polynesian introduction (meaning that they were introduced by Polynesians during their migration from the Western Pacific at the end of the first millenium), 12 (184 cit.) were from modern introductions (introduced during European explorations especially from the 18th century), and 2 (5 cit.) were indigenous (**Figure 3**). The number of citations of plants from modern introduction was significantly higher than the one from Polynesian introduction (p-value = 0.03).

Although most of the plant species had similar number of citations in the two archipelagos, some significant differences were found. *Cordyline fruticosa* was significantly more cited in the Society islands than in the Marquesas islands ($N_{SOCIETY}$ = 17, $N_{MARQUESAS}$ = 6, p-value = 0,05), and *Artocarpus altilis* was significantly more cited in the Marquesas islands than in the Society islands ($N_{SOCIETY}$ = 0, $N_{MARQUESAS}$ = 5, p-value = 0,02).

When comparing the plants cited by the different types of informants, we found that *Citrus aurantiifolia*, *Cordyline fruticosa* and *Cocos nucifera* were proportionally more cited by experts (28 persons) than non-specialists (70 persons) with 39 vs. 46 citations (p-value = 0.02), 13 vs. 5 citations (p-value < 0.0005), and 5 vs. 1 citation (p-value = 0.01) respectively. *Microsorum grossum* and *Zingiber officinale* were proportionally more cited by knowledgeable than non-specialists, with 3 vs. 0 citation (p-value = 0.03) for both plants. And *Saccharum officinarum* was proportionally more cited by experts than non-specialists, with 4 vs. 0 citation (p-value = 0.008).

4.3. Products (other than plants) used to treat diarrhea

Among the products (other than plants) used for treating diarrhea, we could classify them into different categories: processed food (defined by any agricultural products transformed into an edible or more complex food, and including imported food), non-processed liquid (e.g., seawater), Polynesian cosmetic products, conventional medicine, and other traditional medical products (**Table 4**).

355
356 **Table 4:** Products (other than plants) used to treat diarrhea
357

Categories	Products	Method of preparation	Method of administration	Total number of citations	Number of persons citing the products
Processed food/ Imported food					
	Rice	Boil in water	Oral	77	65
	Cassava starch	Mix with lime juice, water, sugar and/or honey	Oral	71	62
	Brown sugar	Mix with lime juice/Mix with *Cordyline fruticosa* and lime juice/Mix with cassava starch and lime juice	Oral	32	25
	Coca-Cola® (soft drink)	None	Oral	31	31
	Chocolate	None	Oral	23	23
	Carrot	Boil in water/None	Oral	14	14
	Honey	Mix with cassava starch and/or lime juice/Mix with guava/Mix with papaya	Oral	12	9
	Apple	None	Oral	8	8
	Vinegar (red)	Mix with iced water and honey, or sugar/Mix with cassava starch and brown sugar/None	Oral	4	3
	Sprite® (soft drink)	Mix with lime juice/None	Oral	3	3
	Salt	Add to boiled rice	Oral	2	2
	White sugar	Mix with water/Mix with multi-ingredients recipes	Oral	2	2
	Cookies	None	Oral	1	1
	Bread	None	Oral	1	1
	Chicken meat	Cook	Oral	1	1
	Milo®	None	Oral	1	1
	Nutella	None	Oral	1	1
	Pasta	Boil in water	Oral	1	1

	Pastis (alcohol drink)	None	Oral	1	1
	Red meat	Cook	Oral	1	1
	Whisky	Mix with a multi-ingredient recipe	Oral	1	1
Polynesian cosmetic products					
	Monoï	None	Local application	10	9
Liquid					
	Seawater	Mix with coconut water/None	Bath/Oral	4	3
	Iced water	Mix with vinegar, honey or sugar/Mix with lime juice and sugar	Oral	3	2
	Cold water	None	Bath	1	1
	Hot water	None	Bath	1	1
Conventional medicine					
	Efferalgan®	Mix with lime juice/Mix with *Cordyline fruticosa* and lime juice	Oral	4	3
	Doliprane®	Mix with lime juice/Mix with cassava starch and lime juice	Oral	2	2
Other traditional medical products					
	Chinese medicine	ND	ND	1	1

The most cited anti-diarrheal products were rice (especially water from boiled rice) with 77 citations, followed by cassava starch (71 citations), Coca-Cola® soft drink (31), chocolate (23), and carrot (14). Brown sugar and honey were the two most used ingredients employed in combination (as excipients or active principles) with 32 and 12 citations respectively.

When comparing the antidiarrheal products cited in the two archipelagos, only one food product showed significant differences. Carrot was more cited in the Society islands than in the Marquesas islands ($N_{SOCIETY} = 11$, $N_{MARQUESAS} = 2$, p-value = 0,03).

4.4. Types of treated diarrhea

Although most of the informants did not precise the types of diarrhea treated by the remedies, three persons cited a mix of *Cordyline fruticosa* (leafbud), *Psidium guajava* (leafbud),

lime juice and coconut water to treat bloody diarrhea. One person also mentioned the use of *Morinda citrifolia* (fruit) to treat diarrhea due to intestinal worms.

Eight informants mentioned using specific treatments to relieve diarrhea due to cold at the navel (*tupito*). Monoi application around the navel was considered by five informants to warm the belly and thus counteract the cold. Also, four informants cited the use of *Cordyline fructicosa* (leafbud) to treat the same disorder. During the survey, further information was obtained on the definition, causes, diagnostic, and prevention of this disorder. Participants explained that the navel is the most sensitive part of the body to the cold. Catching the cold at the navel can induce physiological disorders such as diarrhea, and can lead to convulsion if not treated. It is usually caused by staying too long in contact with cold water (e.g., wet clothes, seawater), or cold (e.g., air-conditioning, tiled floor, draft). To diagnose this disorder, people touch the navel, and can sense a contraction of the abdomen as well as the heartbeat. In prevention, they usually covered the belly of children with a cloth.

Three informants reported the use of specific remedies to treat a pediatric condition called "ira" that lead to diarrhea with green color. Among these remedies, one was a bath with *Annona muricata* (leaf), another one was a remedy with *Hibiscus rosa-sinensis* (flower) and *Gardenia taitensis* (leaf) taken orally and applied as a massage, and the last one combined *Microsorum grossum* (root) and coconut milk in a drink. Due to the low number of informants citing this disorder, we could not get more precise information on it.

5. Therapeutic management of ciguatera

In this section, we describe the therapeutic management of ciguatera, because remedies reported to be used for ciguatera (one of the most cited cause of diarrhea) are different from remedies reported to be used for other causes of diarrhea.

5.1. Remedies used for ciguatera

A total of 156 remedies was mentioned to be used for treating ciguatera. The average number of remedies cited per informant was about 1.2. Among these remedies, 124 were unique. A large part of the cited remedies were single-ingredient remedies (84, 67.8%), followed by two-ingredient remedies (32, 25.8%). Only a few remedies had more than two ingredients (8, 6.4%) (**Figure 2**).

We classified the ingredients into the following categories: plants, processed food, non-processed liquid.

Of note, the total number of remedies cited for ciguatera was significantly higher in the Marquesas islands than in the Society islands ($N_{SOCIETY}$ = 56, $N_{MARQUESAS}$ = 100, p-value = 0,006), and the average number of remedies by persons was significantly higher in the expert and knowledgeable groups than in the non-specialist group (N_{EXPERT} = 1,64, $N_{KNOWLEDGEABLE}$ = 1,47, $N_{NON\text{-}SPECIALIST}$ = 0,94, p-value = 0.02).

5.2. Plants used for ciguatera

A total of 24 plant species was reported to be used for treating ciguatera in 112 unique remedies (**Table 5**).

Five botanical families were represented by two plants species each including:

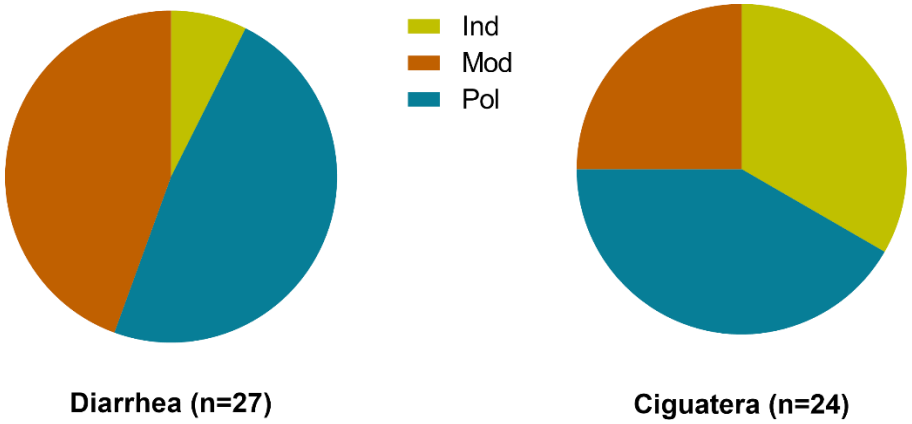
Anacardiaceae, Boraginaceae, Fabaceae, Malvaceae, and Zingiberaceae. The other plant families were represented by one plant species each. *Cocos nucifera* ranked first in terms of number of citations (38 citations), followed by *Punica granatum* (31), *Barringtonia asiatica* (20), *Zingiber officinale* (18), and *Heliotropium arboreum* (10).

Fruit was the most reported part of plants (58 citations), followed by leaf (24), rhizome (20), seed (13) and branch (12). Out of the 112 unique remedies, crushing and filtering in a cloth to extract a juice was the most cited method of preparation (46 citations), crushing was the second most cited method (27), and decoction was the third one (23). All the remedies were taken orally, and for 3 days (except for a few remedies taken until good recovery)

Among the most cited plant species, three were mostly used in combination with other ingredients, including *Barringtonia asiatica* (81.3%), *Morinda citrifolia* (80.0%), and *Cocos nucifera* (75.8%). For *Barringtonia asiatica*, the same two-ingredient recipe was reported 13 times, and included coconut water. At the other end, some plants were mainly included in single-ingredient recipes, such as *Heliotropium arboreum* (100%), *Punica granatum* (88.2%), and *Zingiber officinale* (76.9%).

Regarding their biogeographical origin, we found that 10 plant species (64 citations) were from Polynesian introduction, 6 (78 cit.) were from modern introduction, and 8 (41 cit.) were indigenous (**Figure 3**). No significant differences were found between the three biogeographical origins of plants.

Figure 3: Biogeographical origin of plant species cited for diarrhea and ciguatera



Legend: Ind = Indigenous, Mod = Modern introduction, Pol = Polynesian introduction

Interestingly, some differences were found in the type of plant species cited between the two archipelagos. In the Society islands, *Zingiber officinale* was less cited than in the Marquesas islands ($N_{SOCIETY}$ = 2 and 6, $N_{MARQUESAS}$ = 15 and 25, p-value = 0,005). Also, *Heliotropium arboreum* was largely cited in the Society islands but not at all in the Marquesans islands ($N_{SOCIETY}$ = 10, $N_{MARQUESAS}$ = 0, p-value < 0,0001)..

Regarding the type of informants, *Cocos nucifera*, *Spondias dulcis*, and *Morinda citrifolia*, three native or Polynesian introduction plants, were proportionally more cited in the experts' group than in the non-specialists' group, with 20 vs. 12 citations (p-value < 0.001), 6 vs. 2 citations (p-value = 0.007), and 5 vs. 0 citation (p = 0.003) respectively. *Cocos nucifera* was also

453 more cited in the experts' group than in the knowledgeable group (20 vs. 6 cit., p-value = 0.01),
454 and *Morinda citrifolia* was more cited in the knowledgeable group than in the non-specialists'
455 group (3 vs. 0 cit., p-value = 0.03).
456
457 ## 5.3. Products used to treat ciguatera
458
459 Among the products (other than plants) reported for treating ciguatera, four
460 informants mentioned the use of rhum (3 citations) or whiskey (1 citation) to mix with egg
461 yolk. For two informants out of four, lime juice and brown sugar were also added to this recipe.
462 A tablespoon or teaspoon of mustard absorbed orally was cited three times to treat ciguatera.
463 Aside these two recipes, a variety of products were mentioned only by one informant each,
464 including drinking beer, absorbing half glass of brown sugar with cold water, eating one
465 chicken egg, drinking coffee, drinking one teaspoon of *eau de cologne* (perfume lotion), taking
466 a steam bath with seawater previously boiled, eating two tablespoons of sweetened condensed
467 milk, and drinking one teaspoon of vinegar.

Table 5: Plants used for treating ciguatera

Scientific name	Botanical family	Voucher No	Origin	Tahitian name	Marquesan name	Parts used	Method of preparation	Method of administration	Total number of citations	Number of persons citing the plants
Artocarpus altilis (Parkinson) Fosberg	MORACEAE	FC486	Pol.	'uru, maiore	me'i	Bark/Leaf bud	Crush/Crush, decoction	Oral	2	2
Barringtonia asiatica (L.) Kurz	LECYTHIDACEAE	FC503	Ind.	hotu	hutu	Bark/Branch/ Fruit	Crush, filter in a cloth	Oral	20	20
Carica papaya L.	CARICACEAE	FC492	Mod.	'i'ita	kiki'e, vi papai	Flower/Fruit/ Leaf/Unripe fruit	Decoction/Crush, filter in a cloth	Oral	7	7
Citrus x aurantiifolia (Christm.) Swingle	RUTACEAE	FC495	Mod.	taporo	hitoro/fitoro	Fruit	Press	Oral	6	6
Cocos nucifera L.	ARECACEAE	FC487	Pol.	ha'ari	'ehi	Bark/Ripe fruit/Unripe fruit	Grate/None/Decoction/ Crush, filter in a cloth	Oral	38	34
Colubrina asiatica (L.) Brongn.	RHAMNACEAE	FC515	Ind.	tutu	tutu	Leaf	Crush, decoction	Oral	2	2
Cordia subcordata Lam.	BORAGINACEAE	FC504	Ind.	tou	tou	Leaf	ND	ND	2	2
Curcuma longa L.	ZINGIBERACEAE	FC522	Pol.	re'a tahiti	'eka toka toka	Rhizome	Grate, mix	Oral	2	2
Erythrina variegata L.	FABACEAE	FC511	Pol.	'atae	kenae (N), anetae (S)	Branch	Grate, filter in a cloth	Oral	8	8
Heliotropium arboreum (Blanco) Mabb.	BORAGINACEAE	FC521	Ind.	tahinu	ND	Leaf	Decoction	Oral	10	10
Hibiscus tiliaceus L. subsp. *tiliaceus*	MALVACEAE	FC509	Ind.	purau	hau, fau	Flower/Stem bark (from shoot)	Crush	Oral	3	3

Inocarpus fagifer (Parkinson) Fosberg	FABACEAE	FC523	Pol.	mape	ihi	Wood	Burn	Oral	1	1
Mangifera indica L.	ANACARDIACEAE	FC500	Mod.	vi popa'a	mako	Fruit (unripe)	Grate, filter in a cloth	Oral	8	8
Microsorum grossum (Langsd. & Fisch.) S.B.Andrews	POLYPODIACEAE	FC505	Ind.	metuapua'a	papamoko (N), papamo'o (S)	Leaf (1 digit)	Crush	Oral	1	1
Morinda citrifolia L.	RUBIACEAE	FC488	Pol.	nono	noni	Fruit (with flowers on it)/Leaf/Ripe fruit	Decoction/Grate, filter in a cloth/Press	Oral/ Steam bath	8	5
Pandanus tectorius Parkinson var. *tectorius*	PANDANACEAE	FC496	Ind.	fara	ha'a	Aerial root	Grate, filter in a cloth	Oral	2	2
Physalis angulata L.	SOLANACEAE	FC499	Pol.	tamaru ha'ari	konini (N), kariri (S)	Leaf	Crush, filter in a cloth/Decoction	Oral	3	3
Punica granatum L.	LYTHRACEAE	FC497	Mod.	remuna	kréna (N), remuna (S)	Ripe fruit/Unripe fruit	Decoction/Grate, filter in a cloth/None	Oral	31	31
Rorippa sarmentosa (Sol. ex G.Forst. ex DC.) J.F. Macbr.	BRASSICACEAE	FC506	Pol.	patoa purahi	mahi mahi	Whole plant	Crush, filter in a cloth	Oral	3	3
Saccharum officinarum L.	POACEAE	FC520	Pol.	to	to	Stem	Crush, filter in a cloth, cook	Oral	1	1
Spondias dulcis Parkinson	ANACARDIACEAE	FC501	Mod.	vi tahiti	vi tahiti	Leaf/Unripe fruit	Crush, filter in a cloth/Grate, decoction	Oral	9	8
Syzygium malaccense (L.) Merr. & L.M.Perry	MYRTACEAE	FC510	Pol.	'ahi'a	kehika	Leaf	Crush, filter in a cloth	Oral	1	1
Thespesia populnea (L.) Sol. ex Corrêa	MALVACEAE	FC508	Ind.	miro	mi'o	Unripe fruit	Grate	Oral	1	1
Zingiber officinale Roscoe	ZINGIBERACEAE	FC498	Mod.	re'a tinito	'eka kira (N), 'ena kina (S)	Rhizome	Grate, filter in a cloth/Decoction	Oral	18	18

Legend: A slash ("/") corresponds to the term "or" ; a comma (",") correspond to the term "and"; (N) = Northern part of Marquesas islands; (S) = Southern part of

Marquesas islands; Ind. = Indigenous; Mod. = Modern introduction; ND = Not documented; Pol. = Polynesian introduction.

5.4. Polynesian pharmacological actions of plants and products cited

Regarding mechanisms of action of plants and products used to treat ciguatera, nine informants cited that their remedy could act as a purge to eliminate the toxins. The purgative effect was associated with *Cocos nucifera* oil (3 citations), *Colubrina asiatica* mixed with coconut oil (2 citations), *Zingiber officinale* (2 citations), *Curcuma longa* (1 citation), *Mangifera indica* (1 citation), *Punica granatum* (1 citation), and *Spondias dulcis* (1 citation). The sourness of unripe fruits such as *Mangifera indica* or *Punica granatum* was also reported to help eliminate the toxins (1 citation each).

5.5. Recommendations

Some recommendations associated with ciguatera were reported by a few informants during the survey. Three informants mentioned the importance of purging the body at the beginning of the disease, three other informants reported waiting 1 to 6 months before eating fish again after the end of the symptoms. Other food to be avoided were corned beef (1 citation), eggs (1 citation), and red meat (1 citation).

6. Traditional medicine practices

In this section, we present some general information on the traditional medical practices reported by the 133 informants, including the source of knowledge, the other type of disorders treated, the financial or non-financial compensation asked for their services, and the recommendations provided to the patients.

Regarding the source of knowledge, 109 informants (82%) reported to get their knowledge from their parents or their family, 6 (4.5%) cited friends, colleagues or acquaintances, 4 (3%) mentioned dreaming about remedies, 3 (2.3%) reported learning from themselves, 1 (0.8%) mentioned having heard voices at the church, and 1 (0.8%) cited intuition.

Participants reported using traditional medicine for treating 92 ailments. We classified them into different categories of disorders according to the ICPC (International Classification of Primary Care) 2nd edition (Staub et al., 2015). The most cited categories of disorders were musculoskeletal disorders (61 citations) with injury being the main type reported (37), followed by childhood illness (57), respiratory disorders (32), skin disorders (21) digestive disorders (18) and female genital disorders (18). Of note, cancer was mentioned 13 times.

Out of the 133 informants, only two informants reported that they accept money from their patients. These two informants were full-time traditional healers, one specialized in massage therapy and another one specialized in massage and herbalism. Also, 111 informants mentioned that they did not ask for money, and 20 did not respond to this question. Among the persons not asking for a financial contribution, several reasons were mentioned including that remedy comes from nature, which is a gift and free (16 citations), followed by the potential inefficiency of the remedy if money is given (10 citations), and the fact that God is the only one to be thankful (8 citations). Fifteen informants also mentioned that they accept gift or donation.

During the survey, different general recommendations were reported such as avoiding the concomitant use of traditional medicine and conventional medicine (6 citations), being in a positive mood when treating someone (5 citations), accepting and believing in the remedy

when taking it (5 citations), not using the remedy from another person without her/his consent (4 citations), not taking a remedy after 2PM or 5PM (2 citations) or on Sunday (1 citation), not preparing remedies when having your period (1 citation), not discussing with people when collecting plants (1 citation), throwing away plants, left after taking the remedy, at specific locations (1 citation).

Regarding the general avoidance when using traditional medicine, we can cite: eating canned food (3 citations), eating goat, fish from the sea, all types of meat (except chicken), salty food, soy sauce, tuna, or drinking alcohol, soda (2 citations each), eating beef, fatty food, ketchup, pig, sour fruits, spicy food, or sugar, and having sexual intercourse (1 citation each). One informant also mentioned that eating chicken or sprouted coconut is possible when taking traditional medicine.

Discussion:

This ethnobotanical survey was performed in six islands of French Polynesia and focused on remedies used to treat diarrhea and ciguatera (a foodborne illness most commonly found in the Pacific Ocean). This is the first comprehensive study focusing on these two diseases in French Polynesia in the 21th century. A total of 27 and 24 plant species were reported to be used for diarrhea and ciguatera respectively.

In the following sections, we discuss the most important outcomes from this study.

1. Classification of French Polynesian healers

Until now, only a few studies have focused on the different traditional medical practices from French Polynesians. This led us to investigate more deeply their practices and try to categorize them. W. Arthur Whistler was one of the first trying to categorize the traditional medicine from Polynesians. He worked on the systems of health care in the Cook islands, and classified their system into three categories: folk medicine, healers (including bone-setters, massage therapists, and herbalists), and psychic healers (with supernatural powers) (Whistler, 1985). Later, Paul Alan Cox added a new category (i.e., midwives) to the healers section, by studying the traditional medicine from Samoa islands (Cox, 1991). Regarding French Polynesia, two recent studies added some information to this classification. Grand (2007) proposed a classification of traditional healers into three categories: herbalists (*ta'ata ra'au*), massage therapists (*ta'ata taurumi*), and shamans (*tahu'a*), while Bambridge and Le Meur (2018) reported a specific feature of traditional healers: they are usually consulted by people outside of their family members. Although these categories are similar to those used in this study, some new information are emerging. First of all, a new category of healers (called knowledgeable) can be added in between the folk medicine and the healer's categories. This new category brings together people who cannot be considered as experts (due to their lack of reputation, or their narrow range of patients (family members), or their specialization for certain disorders), but have either a strong knowledge in traditional medicine and treat only their family members, or are known outside of their family to be specialized in the treatment of specific disorders. Secondly, the herbalist's category is now enriched with another type of healer: the protestant pastors. Unlike classic herbalists, protestant pastors have a syncretic knowledge in herbal medicine, and are especially known by the local protestant community as healers. Thirdly, apitherapists can be now included in the healer's category, and they can be defined as therapists of joint problems by using local bee stings. Finally, we propose in this study three criteria to help categorize the French Polynesian healers: the ability to treat all disorders, the fact to treat all types of patients (and not just family members), and the reputation for being able to heal people.

In the study, we found some differences between the specialists' (expert and knowledgeable) and the non-specialists' group allowing to better categorize them.

First of all, some plant species were mainly used by specialists. This was the case for *Cordyline fruticosa* and *Microsorum grossum*. The first one, *C. fruticosa*, a Polynesian introduction, has various traditional uses (medicine, food, ornamental, building, religious) and is of high cultural importance. It is known to be employed by Polynesian healers due to its magical power (Pétard, 2019). Its spiritual importance could explain why a few non-specialists use it. The second plant, *M. grossum*, a native fern, is mainly used for its medicinal properties such as

purge, vermifuge, and against vomiting, gastric disorders, liver disorders, asthma, sprain, fracture, and headache (Girardi et al., 2015; Pétard, 2019). This fern is known to be very effective against these diseases, but previous cases of intoxications have also been reported (Pétard, 2019). This makes it a powerful and dangerous plant, which could explain its use only dedicated to specialists.

Secondly, we found that females are more represented than males in the expert and knowledgeable persons groups, and it occurs in both archipelagos. Previous studies in Polynesia have already demonstrated that healers were mainly females (Cox, 1991; Girardi et al., 2015; Quenon, 2020; Whistler, 1985). However, we noticed that Marquesan's males were more involved in traditional medical practices than males from the Society archipelagos. This was also found in two other ethnobotanical studies, where only one male (out of 18) was interviewed in the Society islands (Quenon, 2020), while one third of the interviewees were males in the Marquesans islands (Girardi et al., 2015). Overall, Polynesian healers are mainly represented by females, but some variations occur depending on the islands. Also, more studies are needed to confirm the predominance of females in Polynesian medical practices as, in general, males are not as available and prone to answer than females.

Another observation from our study is that both experts and knowledgeable persons know a higher number of remedies for ciguatera than non-specialists. Although it was not the case for diarrhea, this could reflect a better knowledge on anti-ciguatera remedies from the two specialists' group, and thus indicate a specialization in ciguatera treatment by healers.

2. Diarrhea: local perception, facts and perspectives

In our study, diarrhea was mainly reported to be caused by food intoxication and tap water drink. This is consistent with the report of 11 cases of collective food poisoning in 2020 and the importance of *Salmonella* and *E. coli* contamination (BSS, 2021). In the same report, it was noted that several factors such as the break in the cold chain, and a long period of time between the preparation and the consumption could be responsible for this contamination. Regarding diarrhea due to tap water, the lack of wastewater treatment and the poor quality of drinking water in some islands (e.g., Nuku Hiva in the Marquesas archipelago) can explain this problem (Etienne and Reboud, 2009).

More generally, gastrointestinal disorders are expected to increase in the Pacific due to climate change and the lack of safe water supplies (Leddin and Macrae, 2020; Singh et al., 2001). Although the overall good sanitary infrastructure in French Polynesia will help to limit this issue, some islands might be more impacted than others. Also, Polynesians are highly dependent to seafood products, which make them more susceptible to changes in seawater quality (Dewailly et al., 2006). For example, ciguatera is now expanding in range of vector species with three new marine invertebrates (i.e., the giant clam, the trochus, the sea urchin) susceptible to bioaccumulate ciguatoxins (Chinain et al., 2019). These species are considered as food by Polynesians, and can represent another risk of contamination.

Another interesting results from this survey is the importance of some causes of diarrhea specific to the area, especially in children. First of all, catching cold at the navel was considered as an important source of diarrhea in children and adults. In other studies, this disorder was referred as "*to'eto'e*" or "*puta to'eto'e*" meaning cold or penetrate by cold in Tahitian (Lemaitre, 1985b; Panoff, 1966). It was referred as "*hautete*" in Marquesan (Girardi et al., 2015). Exposition to humid and cold environment is the major triggering factor, and its treatment consists of

warming the body (Roussey, 2018). As in our study, monoi oil was already reported to be one of the main treatment or preventive measures against cold thanks to its potential to maintain the body temperature by topical application and massages (Jost et al., 2016; Quenon, 2020). This hot-cold duality was also reported in Polynesian post-partum disorders in which cold drinks were given to pregnant woman to maintain a healthy pregnancy and prevent abortion (Baltrushes, 2006). Altogether, this hot-cold system might be reminiscent of ancient Asian medical concept from which Polynesians originate (Kayser et al., 2006; Van Esterik, 1988).

The other childhood illness responsible for diarrhea found in our study was a set of symptoms called "*ira*" in Tahitian. Lemaitre (1985b) reported 12 different types of "*ira*", and mentioned that they were mainly characterized by gastro-intestinal problems such as spasms as well as neurological disorders such as convulsions and agitation. In Marquesas islands, Girardi et al. (2015) also reported the association of diarrhea with a particular "*ira*" called "*ira niho*" occurring for baby teething, and described this disorder as a restlessness in children with fever, teething, loss of appetite, and diarrhea. In our study, informants also insisted on the green color of the stools. In Central America, this type of diarrhea was also reported as a criteria to classify the diarrheal illnesses in some communities (Burleigh et al., 1990; Scrimshaw and Hurtado, 1988). From a medical point of view, green color stools have been associated with an increase in bile acid concentration possibly due to a higher bile acid excretion or a bile acid malabsorption (Gryboski and Kocoshis, 1990).

3. Benefit-risk balance of the most cited treatments

While Polynesian medicine has been used for centuries and still plays an important role in the primary health care of French Polynesian, there is a need to provide updated data on their efficacy and safety in order to assess their risk-benefit balance and make sure these remedies are effective and harmless to the population. Among the various therapeutic products cited for diarrhea and ciguatera, we provide here a pharmacological and toxicological review of the most cited treatments.

Aside the classic use of water from boiled rice, two main remedies were cited in the treatment of diarrhea. These include a mix of cassava starch, lime juice, water, sometimes associated with honey or brown sugar, and the use of guava leaves, fruits or bark. We present here an analysis of their efficacy and toxicity.

The use of cassava starch for treating diarrhea is common to the tropical countries. For example, in Madagascar, the roots or leaves can be used as a decoction in the treatment of diarrhea and dysentery (Rakotoarivelo et al., 2015). In Congo, cassava flour associated with cinchona bark is mixed in water and drunk to treat diarrhea. In Ecuador, the leaves are used for the same indication, while in Colombia, the whole plant is used (Paniagua-Zambrana et al., 2020). Cassava contains a large amount of starch which is a key anti-diarrheal product as it thickens the stools and reduce diarrhea. Other compounds could also be involved since the leaves have demonstrated an anti-diarrheal effect *in vivo* by decreasing the motricity and the intestinal fluid in rats (Bahekar and Kale, 2015). Altogether, ethnobotanical and pharmacological data support the efficacy of cassava in the treatment of diarrhea.

Lime juice is also involved in the pharmacological actions of this remedy, as it presents antibacterial effect, especially against *Vibrio cholerae* (Dalsgaard et al., 1997; Oikeh et al., 2016). A stem bark extract of *Citrus aurantiifolia* also showed antidiarrheal effect in rats validating its use in diarrhea (Adejoh et al., 2018). Besides, the high content of vitamin C and potassium of

lime juice is interesting to compensate the loss of electrolytes and minerals during diarrhea (Lim, 2012).

From a toxicological perspective, cassava contains cyanogenic glycosides that can induce neuropathy, goiter, cretinism and acute cyanide intoxication (Panghal et al., 2021). The concentration of these glycosides depends on the used variety, soil composition, geographical location, environmental conditions, age, and part of the plant. Specific methods of processing are needed to detoxify cassava. As French Polynesian used marketed and quality certified products, the risk seems to be low. Although rare, lime juice can induce phytophotodermatitis when in contact with skin exposed to sunlight (Hankinson et al., 2014), and can cause dental erosion when consumed frequently (Bamise et al., 2009).

Psidium guajava is one of the most used antidiarrheal plant species in tropical countries. Different parts of guava tree are used as remedies against diarrhea in Latin America (e.g., Panama, Mexico, Peru, Caribbean), in Asia (e.g., India, China, Bangladesh, Thailand), and in Africa (e.g., Niger, Ghana, Congo, South Africa) (Chassagne, 2022; Gutiérrez et al., 2008). From a pharmacological perspective, guava leaf demonstrated antibacterial activity against *Vibrio cholerae*, *Shigella flexneri* and diarrheagenic *Escherichia coli* (Birdi et al., 2010). The same part of plant also showed anti-rotavirus activity (Gonçalves et al., 2005). In animal models, *P. guajava* leaf extract showed antidiarrheal and antibacterial effect in models of diarrhea infected by *Citrobacter rodentium*, *Shigella flexneri*, or pathogenic *Escherichia coli* (Gupta and Birdi, 2015; Hirudkar et al., 2020a, 2020b). Most importantly, some clinical trials confirmed the antidiarrheal potency of guava by showing a reduction of abdominal pain and stool frequency in patients with acute diarrhea (Birdi et al., 2020; Lozoya et al., 2002). All this information is in favor of the efficacy of guava leaf. The toxicological profile of guava is less known, but the different studies indicate a safe use of guava if it can be consumed immediately, at a proper dose (8-10 g of fresh leaves in 150 mL of hot water per day), and in adults' patients without hypersensitivity to guava (Morais-Braga et al., 2016). Quercetin and quercitrin have been mentioned as responsible for the antidiarrheal activity (Naseer et al., 2018; Palombo, 2006).

Regarding treatment used for ciguatera, three plant species (*Barringtonia asiatica*, *Heliotropium arboreum*, and *Punica granatum*) are discussed below for different reasons: their high number of citations (*Punica granatum*, *Barringtonia asiatica*), their medicinal importance in the Pacific for ciguatera (*Heliotropium arboreum*) and their potential toxicity (*Barringtonia asiatica*).

The most cited plant species from our study is pomegranate fruit. It was already reported to be used in Marquesas islands and in New Caledonia as a remedy for ciguatera (Girardi et al., 2015; Laurent et al., 1993). In the study from New Caledonia, it is also mentioned as an antidiarrheal agent. Indeed, fruits of *Punica granatum* are widely used in traditional medicine for diarrhea (e.g., in Algeria, China, Mexico, Turkey), and various pharmacological tests have demonstrated its antidiarrheal activity (Qnais et al., 2007; Shaygannia et al., 2015; Zhao et al., 2018). Kumar-Roiné et al. (2011) proposed that the antidiarrheal and antispasmodic effect of pomegranate could play a role in the treatment of ciguatera. Regarding the per se anti-ciguatera potency of *P. granatum*, Boydron-Le Garrec et al. (2005) showed a protective effect of *P. granatum* fruit extract against the action of ciguatoxin or brevotoxin in neuroblastoma cells. Later, Kumar-Roiné et al. (2009) demonstrated an inhibition of nitric oxide production of *P. granatum* fruit in RAW 264.7 macrophages. These two studies are a first step towards the validation of pomegranate fruit in the treatment of ciguatera. However, both are *in vitro* studies, and more *in vivo* studies should be performed to confirm its anti-ciguatera potency.

From a toxicological perspective, pomegranate fruit seems to be safe if used at proper dose (2.5-4.5 g of dried pericarp per day), in adults without hypersensitivity to pomegranate (Vidal et al., 2003; WHO, 2006).

Barringtonia asiatica was the second most cited plant species for treating ciguatera in our study. Two main parts were used: seeds and branches. In Guam island, the stembark of *B. asiatica* is infused and drink to treat ciguatera (Bourdy et al., 1992). In Marquesas islands, the root of *B. asiatica* was reported to be used for the same indication (Girardi et al., 2015). Aside these two studies, no ethnobotanical or pharmacological data are available on this species to validate its anti-ciguatera potency. More importantly, *B. asiatica* is used as an ichthyotoxic in different islands such as Car Nicobar, Marquesas islands, Samoa and Vanuatu (Bradacs et al., 2011; Cox, 1979; Girardi et al., 2015; Ravikumar et al., 2015). The most active piscicidal compound from the seed extract was isolated recently and named ranuncoside VIII (Cannon et al., 2004). Following the lack of toxicological studies in humans, the use of these plant species is associated to potential health risks and thus should be avoided.

Last but not least, *Heliotropium arboreum* ranked fourth in terms of citations for ciguatera. In the Pacific, it is one of the most used plant species for treating ciguatera. In New Caledonia and Vanuatu, the leaves are infused in hot water and applied locally and/or drunk (Laurent et al., 1993). In Tonga, an oral administration of infused leaves is preferred (Bourdy et al., 1992). It was also reported as a fish poisoning remedy in French Polynesia, Micronesia and in the Ryuku islands from Japan (Kumar-Roiné et al., 2011). Not only this species is the most employed in ciguatera treatment, but it is also the most studied. It has been shown that an aqueous extract of *H. arboreum* leaves can prevent ciguatoxin-induced cell toxicity, and that this action may be due to the plant's affinity for voltage-gated sodium channels by preventing the toxin from binding to them (Rossi et al., 2012). The compound responsible for this activity is rosmarinic acid. This molecule, also present in other plants of the Boraginaceae, Lamiaceae and Apiaceae families, has demonstrated anti-inflammatory, anti-allergic, hypotensive and neuroprotective activity, which could also explain its action in the treatment of ciguatera (Braidy et al., 2014; Luo et al., 2020; Nadeem et al., 2019). One of the main problems is the presence in the plant of pyrrolizidine alkaloids (namely indicine and its derivatives) that are known to induce hepatotoxicity (El-Shazly and Wink, 2014). One study tried to demonstrate that these compounds are not present in the aqueous extract of senescent leaves of *H. arboreum* obtained by decoction, but further investigations are needed to confirm this result (Rossi, 2014). Altogether, the leaves of *Heliotropium arboreum* present good ethnobotanical evidence of efficacy, as well as some pharmacological data confirming its use in the treatment of ciguatera. However, further studies are needed to confirm its safety, then more research should be performed to move towards the development of a standardized phytomedicine.

To further analyze the role of the ten most cited plant species for ciguatera and diarrhea, we have described their ethnobotanical uses in French Polynesia and other Polynesian islands, along their bioactive compounds potentially responsible for the antidiarrheal and ciguatera protective effect (Table 6).

757 **Table 6**: Ethnobotanical uses and bioactive compounds of the ten most cited plant species used for ciguatera and diarrhea
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Scientific name	Reported for ciguatera (C) and/or diarrhea (D)	Ethnobotanical uses in French Polynesia	Ethnobotanical uses in other Polynesian islands	Bioactive compounds and relevant pharmacological activities	References
Artocarpus altilis	C, D	Fermented fruit: bewitchment Fruit: miscarriage Leaf (bud): asthma, chest disorders, cough, eye disorders, liver disorders, miscarriage, nevralgia, otitis, vaginal discharge Sap: contusion, fracture, joint pain	Leaf (ashes): pain, rash, sprain [Cook islands] Leaf (young): abdominal pain [Cook islands] Sap: broken limbs, injured muscles [Cook islands], cut [Hawaii]	morusin (antinociceptive), oxyresveratrol (anti-inflammatory and neuroprotective), starch (antidiarrheal)	de Souza et al., 2014; Girardi et al., 2015; Horowitz, 2001; Jagtap & Bapat, 2010; Panoff, 1966; Pétard, 2019; Whistler, 1985
Barringtonia asiatica	C	Fermented fruit: hemorroids Leaf: dislocation and sprain Leaf, seed: rheumatism Seed: contusion, lower back pain, sprain	Seed: burn [Cook islands]	ranuncoside VIII (ichtyotoxic)	Cannon et al., 2004; Girardi et al., 2015; Pétard, 2019; Whistler, 1985
Carica papaya	C, D	Flower: hypertension Fruit: liver disorders Leaf, seed: diabetes, gout, hypertension Seed: anthelminthic	Fruit (immature): boil, carbuncle, cut, sore [Cook islands] Seed: intestinal worms [Cook islands] Stem: increase lactation [Tonga]	carpaine (anthelminthic, reduce heart rate, blood pressure, and intestinal peristaltis)	Girardi et al., 2015; Haldar et al., 2020; Panoff, 1966; Pétard, 2019; Singh et al., 1984; Whistler, 1985

Citrus x aurantiifolia	C, D	Fruit (immature): ovarian insufficiency, testicular pain Fruit (mature): hernia, liver failure Fruit, leaf: postnatal antiseptic, prevention of puerperal infection Leaf: cold, convulsion, headache, influenza, sore throat, tuberculosis Leaf, seed: hemorroids		citronellal (antinociceptive), limonene, linalool (antimicrobial), quercetin (anti-inflammatory, antimicrobial) ascorbic acid (anti-oxidant)	Batiha et al., 2020; Girardi et al., 2015; Panoff, 1966; Pétard, 2019; Weimer et al., 2021
Cocos nucifera	C, D	Fruit: hemorrhage Fruit, seed: excipient, liver disorders, tooth decay Root: contusion, dislocation, fracture, skin ulcer, sprain	Bark, husk: fracture, sprain [Cook islands] Fruit: severe bleeding in early pregnancy [Tonga] Leaf: filariasis [Cook islands]	sterile and sweet water (rehydration), coconut oil (anti-inflammatory and anti-toxins)	Girardi et al., 2015; Lisboa-Neto, 2017; Panoff, 1966, Pétard, 2019; Singh et al., 1984; Whistler, 1985
Cordyline fruticosa	D	Fruit: flatulence, stomach cramp, umbilical hernia Leaf (young): abscess, anti-emetic, chest pain, gastric disorders, hernia, nail infection, nasal mucus, otitis, stomach pain with chest tightness, ulcer	Flower, leaf (young): asthma [Hawaii] Leaf: fever, nasal problems [Hawaii], neck pain, sore throat [Cook islands] Leaf (young): burn [Cook islands, Samoa]	steroidal saponins	Girardi et al., 2015; Guillaumin et al., 1946; Horowitz, 2001; Pétard, 2019; Ponou et al., 2019; Whistler, 1985
Erythrina variegata	C, D	Bark: stonefish sting Leaf: postnatal antiseptic, postpartum care, prevention of puerperal infection	Bark: infertility [Tonga]	alkaloids: erysotrine, erysodine, erythraline (neuromuscular blocking effect, smooth muscle relaxant, anticonvulsivant)	Ghosal et al., 1972; Girardi et al., 2015; Pétard, 2019; Singh et al., 1984

Heliotropium arboreum	C	Leaf (young): stonefish sting		rosmarinic acid (anti-inflammatory, neuroprotective, protective effect against ciguatoxin cytotoxicity)	Pétard, 2019; Rossi et al., 2012
Mangifera indica	C, D	Fruit: abscess, respiratory disorders, sore throat, wound	Leaf: insufficient rest during the puerperium, giving rise to fever, chills, dizziness, lower abdominal pain [Tonga]	mangiferin (analgesic, anthelminthic, anti-allergic, anti-inflammatory, neuroprotective), epigallocatechin gallate, gallic acid, and quercetin (anti-inflammatory)	Ediriweera et al., 2017; Quenon, 2020; Singh et al., 1984
Microsorum grossum	C, D	Leaf: asthma, headache, migraine, sinusitis, vertigo, woman infertility Leaf, rhizome: dislocations, fall, fracture, hematoma, purge, sprain, shock Rhizome: anti-emetic, leucorrhea		phytoecdysteroids: ecdysone, 20-hydroxyecdysone (steroid-like effect)	Girardi et al., 2015: Ho et al., 2010; Pétard, 2019
Morinda citrifolia	C, D	Flower (bud), fruit: burn, hemorroids, skin allergy, wart Fruit: abscess, nail infection, sore throat, stonefish sting Leaf: chest pain, gastric disorders, stomach pain with chest tightness, ulcers Leaf, fruit: backache, enteritis, joint problem, osteoarthritis, rheumatism	Fruit: abdominal swelling, hernia, urinary disorders [Cook islands], diabetes, digestive disorders, hypertension, skin conditions [Hawaii], tuberculosis [Pacific islands] Leaf: breast cancer, dysuria, postpartum disorders [Tonga], ringworm [Fiji] Root: stonefish sting [Cook islands]	quercetin (anti-inflammatory), rutin and scopoletin (antidopaminergic)	Abou Assi et al., 2017; Dixon, 1999; Girardi et al., 2015; Horowitz, 2001; Panoff, 1966; Pétard, 2019; Singh et al., 1984; Torres et al., 2017; Whistler, 1985

Musa x paradisiaca	D	Leaf (young): elephantiasis, filariasis, zona Sap: lymphangitis	Fruit (peel): wound [Hawaii] Stem (juice): cutaneous sore [Cook islands]	pectin and starch (antidiarrheal), quercetin (anti-inflammmatory)	Girardi et al., 2015; Horowitz, 2001; Imam and Akter, 2011; Pétard, 2019; Whistler, 1985
Psidium guajava	D	Bark, leaf: breast cancer, hemorrhoids, painful periods Fruit: hemorroids Leaf (bud): headache, infertility, miscarriage, urinary disorders, wasp sting, wound	Leaf: abdominal pain, cuts, postpartum disorders [Cook islands]	quercetin and quercitrin (antidiarrheal)	Girardi et al., 2015; Naseer et al., 2018; Palombo, 2006; Panoff, 1966; Pétard, 2019; Whistler, 1985
Punica granatum	C			gallic acid, punicalagin and quercetin (anti-inflammatory), rutin (antidopaminergic)	Ranjha et al., 2021
Saccharum officinarum	C, D	Juice, leaf: genital disease, girl's intimate hygiene, leucorrhea, vaginal discharge	Juice: cut [Hawaii] Shoot (young): reattach severed limbs and prevent scarring [Hawaii]	gallic acid, quercetin (anti-inflammatory), quercitrin (antidiarrheal), rutin (antidopaminergic)	Abbas et al., 2014; Girardi et al., 2015; Horowitz, 2001
Spondias dulcis	C	Fruit: food poisoning, liver disorders, neuralgia Leaf (bud): hemorragia after miscarriage, sore throat	Bark: metrorrhagia [Tonga], thrush [Samoa] Leaf: thrush, urinary disorders [Cook islands]	quercetin (anti-inflammatory), rutin (antidopaminergic)	Panoff, 1966; Pétard, 2019; Sameh et al., 2018; Singh et al., 1984; Whistler, 1985
Zingiber officinale	C, D	Rhizome: stomach pain with chest tightness, ulcer		gingerols and shogaols (anti-inflammatory, antinausea), zingerone (antidiarrheal)	Ali et al., 2008; Girardi et al., 2015

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4. Geographic and cultural origin of medicinal plants

All plants mentioned by the informants are common or widespread species, with no conservation issues. No endemic species have been cited to be used in this study, and the plants used are mainly introduced species. This is a distinctive feature of the traditional Polynesian medicine: most of their pharmacopeia rely on widespread and introduced plants so called "canoe plants" brought during their migration across Pacific Ocean and settlements. This was already noted by previous authors such as Girardi et al. (2015), and Jost et al. (2016). Indeed, Polynesian history is based on their migrations from islands to islands. It is known that Polynesians originate from Asia where they started their long journey by boats about 4500 years ago, and then settled from islands to islands in the Pacific (Conte, 2019; Kirch, 2017). They first arrived in the Society islands about 1000 years ago, then settled in the Marquesans islands between 700 to 900 years ago (Ioannidis et al., 2021). During their migrations, they brought various plant seeds and shoots with them for food, building, clothing, and medicine purposes (Whistler, 2009). Therefore, their traditional medical knowledge is mainly based on introduced plants, and indigenous species represent a small portion of their pharmacopeia.

Interestingly, we found some differences between the biogeographical origins of plants used for diarrhea and ciguatera. For diarrhea, a similar number of plants were either introduced by Polynesians or by Europeans. However, a highest number of citations was found for plants from modern introduction (e.g., *Citrus aurantiifolia*, *Manihot esculenta*, *Psidium guajava*), indicating that these species might be more effective to treat diarrhea than plants introduced by Polynesians. For example, cassava replaced the use of *Tacca leontopetaloides* (L.) Kuntze that was historically a great source of starch for Polynesians but needed more thorough preparations to eliminate the toxins than cassava (Pétard, 2019). It could also indicate that diarrhea became more frequent with the arrival of the Europeans. The latter is supported by Martin and Combes (1996) who noted that Polynesians "never heard of dysentery before" European explorations who were the starting point of various infectious epidemic diseases. Regarding ciguatera, a similar number of citations was found for the three different biogeographical origins (modern introduction, Polynesian introduction, indigenous). It could indicate that Polynesians have tried, since their settlement in these islands, the different types of plants around them in a trial and error process, in the hope to find a cure to an ancient and endemic disease.

Another interesting point is the total absence of citations for *Heliotropium arboreum* in the treatment of ciguatera in the Marquesas islands. As detailed above, *H. arboreum* is widely known throughout the Pacific as an effective anti-ciguatera remedy. Rossi (2014) noted that the plant is not present in the Marquesas islands. It could be explained by ecological factors as this species prefers soils mixed with coral sand or pure coral sand substrate which are very scarce in the Marquesan islands (Lorence D. H., pers. com.). It illustrates the particularity of the Marquesan pharmacopeia compared to other Polynesian pharmacopeias, and the link to its geobiodiversity. In other ethnobotanical studies from Marquesas islands, three and four endemic species to Marquesas islands were reported respectively by Girardi et al. (2015), and Jost et al. (2016). It thus confirms the originality of the Marquesan pharmacopeia despite the high use of introduced species.

Conclusion:

This is the first survey focusing on diarrheal diseases and ciguatera in French Polynesia in the 21th century. A total of 38 different medicinal plants were cited to treat diarrhea and ciguatera. In this study, a new classification of traditional healers was proposed, and some cultural perceptions of diarrhea were discussed. We also present updated information on the efficacy and toxicity of the most common used remedies. Altogether, Marquesas and Society islands present great traditional knowledge that should be preserved, because cultural traditions such as traditional medicine are important for the Polynesian identity and heritage. However, more studies are needed to evaluate the pharmacological and toxicological activity of Polynesian remedies as natural does not mean safe, and risky practices can lead to health problems. This is especially necessary if we want to officially recognize the Polynesian medicine and make it an integral part of our official health system.

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