Ethnobotany of dioecious species: Traditional knowledge on dioecious plants in India

Gopalakrishnan Saroja Seethapathy[a,b,c,*], Kaliamoorthy Ravikumar[c], Berit Smestad Paulsen[a], Hugo J. de Boer[b,†], Helle Wangensteen[a, †]

[a] Department of Pharmaceutical Chemistry, School of Pharmacy, University of Oslo, P.O. Box 1068, 0316 Oslo, Norway

[b] Natural History Museum, University of Oslo, P.O. Box 1172, 0318 Oslo, Norway

[c] The Institute of Trans-Disciplinary Health Sciences and Technology, Foundation for Revitalisation of Local Health Traditions (FRLHT), 74/2 Jarakabande Kaval, Post Attur via Yelahanka, Bangalore 560064 India

*Corresponding author e-mail addresses, phone number

g.s.seethapathy@farmasi.uio.no; seethapathygs@gmail.com; +47-22856567

† These authors contributed equally to this work

Abstract

Ethnopharmacological relevance: More than 15,000 angiosperm species are dioecious, i.e., having distinct male and female individual plants. The allocation of resources between male and female plants is different, and also variation in secondary metabolites and sex-biased herbivory is reported among dioecious plants. However, little is known about the ethnobotany of dioecious species and whether preferences exist for a specific gender, e.g., in food, medicine or timber.

Aim of the study: The aim of this study was: 1) to study whether Indian folk healers have preference for plant genders, and to document their knowledge and use of dioecious species; 2) to understand the concept of plant gender in Indian systems of medicine and folk medicine, and whether Ayurvedic literature includes any references to gender preference.

Materials and methods: Lists of dioecious plants used in Indian systems of medicine and folk medicine were compiled. Ethnobotanical data was collected on perceptions and awareness of dioecious plants, and preferences of use of specific genders of dioecious species using semi-structured interviews with folk healers in Tamil Nadu, India. In addition, twenty Ayurvedic doctors were interviewed to gain insight into the concept of plant gender in Ayurveda.

Results: Indian systems of medicine contain 5-7% dioecious species, and this estimate is congruent the number of dioecious species in flowering plants in general. Informants recognized the phenomenon of dioecy in 31 out of 40 species, and reported gender preferences for 13 species with respect to uses as timber, food and medicine. Among informants different plant traits such as plant size, fruit size, and visibility of fruits determines the perception of a plant being a male or female. Ayurvedic classical literature provides no straightforward evidence on gender preferences in preparation of medicines or treatment illness, however it contains details about reproductive morphology and sexual differentiation of plants.

Conclusions: A knowledge gap exists in ethnobotanical and ethnopharmacological literature on traditional knowledge of dioecious plants. From this explorative study it is evident that people have traditional knowledge on plant gender and preferential usages towards one gender. Based on this, we propose that researchers conducting ethnobotanical and ethnopharmacological studies should consider documenting traditional knowledge on sexual systems of plants, and test the existence of gender specific usages in their conceptual framework and hypothesis testing.

Incorporating such concepts could provide new dimensions of scientific knowledge with potential implications to conservation biology, chemical ecology, ethnoecology and drug discovery.

Keywords: Ayurveda; Dioecy; Ethnopharmacology; Folk classification; Plant gender; Vernacular taxonomy.

1. Introduction

Enormous efforts are being made to document and systematically study the traditional uses of plants. Dioecy, where species have separate female and male plants, is widespread among flowering plants, and an estimated 6% of species are dioecious (Renner, 2014). Resource allocation, including trade-offs between allocation to defense, growth and reproduction, is different between genders of dioecious plants (Obeso, 2002). Several studies have shown that differences in reproductive demands between the genders of dioecious plants cause gender physiology divergence that in turn affects the production and concentration of secondary metabolites (Bajpai et al., 2016; Milet-Pinheiro et al., 2015; Simpson, 2013). Herbivory has been suggested as a selective pressure that has resulted in the evolution of dioecy (Bawa, 1980), and studies have utilized the plant resource allocation theory (Levins, 1968) to understand the patterns of plant-herbivore interaction (Obeso, 2002), herbivore plant gender preferences (Hjalten, 1992), plant browsers (Danell et al., 1991), folivores (Maldonado-López et al., 2014), pollinators (Milet-Pinheiro et al., 2015), and gall formers (Wolfe, 1997). Cornelissen and Stiling, 2005 reviewed the evidence of sex-biased herbivory in dioecious plants, and found that male plants exhibited significantly higher number of herbivores and herbivory in terms of plant damage compared to female plants, and showed that male plants exhibited significantly lower concentrations of secondary compounds and other defenses than female plants. However, there are also examples of the opposite, e.g., the male plants leaves of *Rhamnus alpinus* L. and *Juniperus macrocarpa* Sm. exhibited a higher concentration of anthraquinones, phenolics and terpenoids respectively than those of females, which contrasts with the resource allocation theory (Banuelos et al., 2004; Massei et al., 2006). Hence it is evident that resource allocation might have a profound effect on the composition and concentration of secondary compounds between individuals of dioecious species (Simpson, 2013).

Simpson, 2013 has highlighted the importance of gender in phytochemical research and its impact on pharmacological properties of a species. For example in the dioecious species *Cannabis sativa* L., the female plants are used for marijuana, whereas the male plants are preferred for fiber (Fetterman et al., 1971). In *Dodonaea polyandra* Merr. & L.M.Perry (Sapindaceae), labdane diterpenoids have been reported as major phytoconstituents, whereas female individuals contain clerodane diterpenoids (Simpson, 2013; Simpson et al., 2011; Simpson et al., 2012). Similarly, a significant variation in the concentration of alkaloids was

shown for the dioecious medicinal plant *Tinospora cordifolia* (Willd.) Miers (Menispermaceae). The mean abundances of magnoflorine, jatrorrhizine and oblongine were significantly higher in male plants while mean abundances of tetrahydropalmatine, norcoclaurine and reticuline were significantly higher in female plants (Bajpai et al., 2016). It has been suggested that female plants of *T. cordifolia* might be preferred for therapeutic use due to the higher accumulation of secondary metabolites and higher antioxidant activity (Choudhry et al., 2014).

The 15,600 dioecious angiosperms occur in 987 genera (6%) and 175 families (38%), with a number of families being entirely dioecious, e.g., Menispermaceae, Moraceae, Myristicaceae, and Putranjivaceae (Renner, 2014). Many of these dioecious species are well documented for their medicinal values (de Boer and Cotingting, 2014). In India, it is estimated that 8000 plants have medicinal usages. Some of these are codified in traditional pharmacopoeias, i.e., Ayurveda, Siddha, Unani, and Sowa-Rigpa, whereas others are part of oral traditions in different biocultural groups. Considerable evidence for sex-biased herbivory and variation in secondary metabolites in dioecious plants is available in scientific studies, but little is known about traditional concepts and preferences for dioecious plants, either male or female. Few studies on folk classification of plants and ethno-ecology report traditional knowledge associated with dioecy, and the importance of how the different genders of plant species are named and classified in local languages and how this reflects perceptions of the environment (Berlin et al., 1973), cultural values of biodiversity (Bjorå et al., 2015), and ecological characteristics (Khasbagan, 2008). Bernstein et al., 1997 used plot survey inventories in Brunei to show that their informants were able to accurately predict the gender of dioecious plants. In Northern Morocco, it was reported that the vernacular taxonomy is congruent with the biological classification of the dioecious species *Ficus carica* L. among three communities inhabited in three socio-geographic regions who speaks Arabic, Berber, and both Arabic and Berber, respectively (Hmimsa et al., 2012).

Several studies have highlighted the importance of understanding the ecology of plant biodiversity as a strategy for drug discovery (Coley et al., 2003), as well as ethnobotanical studies and/or traditional medicines for drug development (Patwardhan and Mashelkar, 2009). At the same time, erosion and deterioration of traditional knowledge threatens biocultural diversity and limits resilience in healthcare choices for local communities, which also can cause a loss in leads for drug discovery (de Boer and Cotingting, 2014; Srithi et al., 2009). In the context of

ongoing cultural, ecological, and socio-economical changes, particularly the influence of urbanization and influence of western lifestyles, the increasing reliance on biomedical healthcare, the devaluation of traditional practices, and diminishing cultural cohesion are weakening the frequency and scope of traditional plant use and this poses a serious threat to biodiversity-based cultural knowledge (Srithi et al., 2009; Vandebroek and Balick, 2012). Documenting the use of plants by ethnic communities is an important part in understanding and analyzing elements of traditional medicines, and also a way to perpetuate knowledge at risk of being lost (de Boer and Cotingting, 2014).

The aim of this study was: 1a) to document traditional knowledge on dioecious plants among folk healers and 1b) to understand whether folk healers have preference for plant genders in food, medicines or timber; 2) to understand folk healers' perceptions of what are considered to be male and female plants in their community and traditions; and 3) to understand the concept of plant gender in Indian systems of medicine and folk medicine , and whether Ayurvedic literature contains any references to plant gender and preferences.

2. Methodology

2.1. Selection of Indian dioecious plants

Dioecious species in India were derived from the list of 15,600 dioecious angiosperms compiled by Renner (2014) by limiting to species occurring in India. Dioecious species in codified and non-codified Indian traditional medicine were mined from the Indian Medicinal Plant Database, National Medicinal Plants Board, Government of India, and full lists are provided in Supplementary Data S1.. Nomenclature follows The Plant List (The Plant List, 2013 http://www.theplantlist.org) and Angiosperm Phylogeny Group IV (Byng et al., 2016). The ethnobotanical study focused on 40 dioecious plants in 30 genera and 20 families (Table 1), which occurred in the study area (see below) and were reported to be used in traditional medicine in previous studies.

2.2. Study area for ethnobotanical study

The present survey was conducted in the Kolli Hills (11.105° N, 78.150° E), Servarayan Hills (11.455° N, 78.175° E), and Sittlingi Valley (11.543° N, 78.365° E), all of which are part of the Eastern Ghats in Tamil Nadu, India. The natural vegetation of the study area is categorized into shola (tropical montane forest), evergreen, semi-evergreen, deciduous, scrub, and plantation (Jayakumar et al., 2002). The main ethnic group in the study is the *Malayali* (lit. malai = hill, ali = dwells and/or malai = hill, alu = person), one of 36 scheduled tribal communities in Tamil Nadu. The *Malayali* is spread along the contiguous hills of the Eastern Ghats from Pachamalai, Kollimalai, Sitheri, Palamalai, Javvadhu to the Servarayan Hills (Xavier et al., 2015). The major livelihood and local economy of these *Malayali* communities are cattle farming, agriculture, fuel-wood and collection of non-timber forest products such as herbal medicines, honey and some edible fruits and tubers (Xavier et al., 2015).

2.3. Ethnobotanical data collection

Forty folk healers aged 40 to 80 (33 males and 7 females) were interviewed in 2016, and their knowledge documented using a semi-structured questionnaire aided by props consisting of live specimens and photo galleries of the selected 40 dioecious species (Table 1). Study participants were selected using the snowball sampling method (Berlin and Berlin, 2005), and we particularly focused on local people who are older than 40 years, regularly use plants for medicinal purposes, fuel-wood and non-timber forest product collectors, and plant harvesters. Sampling was initiated through the indication of community leaders. The semi-structured questionnaire assessed the informants' perception of dioecious plants, awareness about dioecious plants and, if aware, is their preference for choosing a specific gender of dioecious plants (Supplementary Data S2). Additional information such as the folk healers' perspective on gender in plants and its roles in their traditions were also recorded. The interviews were conducted in the informants' native language *Tamil*. Following the interviews, the plants mentioned during the interviews were collected and confirmed for identification. Prior to the ethnobotanical survey, the purpose of the study was explained to the informants and the consent to conduct the study was requested and agreed. The documented medicinal plants were collected and pressed for herbarium vouchers, and identified with the help of valid references. All collected specimens were vouchered and deposited in the FRLH-Herbarium and Raw Drug Repository of The Institute of Trans-Disciplinary Health Sciences and Technology, India (Table 1). Prior to the ethnobotanical data

collection, ethical approval for this study was obtained from the National Biodiversity Authority, Government of India (Refernce number: India/NBA/Appl/9/1032).

2.4. Plant gender and Ayurveda

Twenty Ayurvedic doctors, who were formally educated and qualified to practice Ayurveda, were interviewed using a semi structured questionnaire in order to gain insight into the concept of plant gender in Ayurveda and its literature. Before initiating the interview process, it was explained to the doctors that the biological classification of plants classifies plant gender on the basis of their floral sexual characters i.e. the presence or absence of the androecium and gynoecium.

3. Results and discussion

3.1 Indian dioecious plants

Among dioecious species sex ratios deviate from the mean, and species with a male bias are associated with long-lived growth forms (e.g., trees), biotic seed dispersal and fleshy fruits, whereas female bias is associated with herbaceous species, and abiotic pollen dispersal (Field et al., 2013). Plasticity in sex expression has also been reported for a number of species (Borges et al., 1997; Geetha et al., 2007; McArthur, 1977; Renner, 2014). In this study, out of 40 dioecious plants used in the ethnobotanical data collection, 31 plants belong to families or genera that are either strictly or completely dioecious (cf. *Dioscorea* and Menispermaceae). The sex ratio of these species is not well studied in the study area, but for example, *Mallotus philippensis* has been shown to be male-biased under low light environments and female-biased under more light environments in India (Pathak and Shukla, 2004). Biased sex ratios and plasticity in sex expression of a given dioecious plants might have a significant effect on informants observation and classification of a plant as male and female.

Supplementary Data S1 shows the list of dioecious plants that are documented for its medicinal values in folk medicine, Ayurveda, Siddha, Unani, and Sowa-Rigpa and it was found that that 5-7% of medicinal plants in Indian systems of medicines are dioecious plants, and this estimate is congruent with the diversification rate of dioecious species in flowering plants (Käfer et al., 2014; Renner, 2014). Based on this, we propose that these lists of species harness a

potential to be studied comparatively for their chemical composition between male and female plants and the pharmacological activities, and also provides a platform to document ethno-ecological knowledge, and traditional knowledge of dioecious plants with special reference to its gender.

3.2 Traditional knowledge and plant gender preference

To elicit knowledge on dioecy, informants were explained the phenomenon of dioecy in flowering plants, as correct knowledge was decisive for the outcome of the survey. They were informed that male and female plants exist separately as individual plants, that male plants only bear flowers that will not yield fruits and seeds, whereas female plants bear flowers, fruits, and viable seeds. The existence of monoecious and bisexual plants was explained as well, and they were explained that if the same plant bears male and female flowers it is monoecious, and if the same flower contains both reproductive organs it is bisexual. Plants such as papaya, palm trees, coconut trees, pumpkin, and goose berries were given as examples to explain the reproductive systems of flowering plants before initiating the interview process. Table 1 shows the details of 40 dioecious plants used in the ethnobotanical study, and it was found that the informants were aware of existence of the dioecious nature of many plants. Out of 40 plants used in the study, informants recognized the phenomenon of dioecy in 31 species (Table 1), and no significant variation was found between the 33 male and 7 female informants about their knowledge on the existence of dioecious species and the number of dioecious species reported for usages. Therefore male and female informants were considered as one category of informants for further analysis (Supplementary Data S3). However, Table 2 shows a significant variation among the age groups of informants. The informants below the age 50 had less knowledge on dioecious species, and used less number of dioecious species. On the other hand, a linear growth was observed between the age groups for preferring any one gender of dioecious plants, while using the plants which suggests that the age older informants had better perception on gender of plants and their unique uses (Table 2).

A number of studies has documented the lack of traditional knowledge among younger people, and this has been attributed to the expansion of modern education, cultural change, and the influences of modernization (Srithi et al., 2009; Voeks and Leony, 2004). As a result of changing realities, traditional knowledge of medicinal plants that was once embedded in

numerous indigenous cultures, is rapidly disappearing. It has been suggested that to avoid the loss of this intellectual heritage, it is necessary to either keep it alive, or at least to document and describe the traditional use of plants (Bussmann and Sharon, 2006).

Table 3 shows the overview of informants awareness, gender preference and the habit of the dioecious plants. Since, fruits being informed and considered as the main identity to distinguish male and female plants among the informants, it was observed that the visibility of fruit size, plant size and plant traits based uses of a particular plant determines the perception of a plant being male or female. For example, informants were unaware of dioecy for two shrubs (*Dodonaea angustifolia*, *Dodonaea viscosa*), two climbers (*Cocculus hirsutus*, *Cyclea peltata*), and two lianas (*Asparagus racemosus*, *Cissampelos pareira*) they are all sourced from the wild in the study area, but the useful part of these plants are not fruits or seeds. On the contrary, informants were aware of dioecy for *Celastrus paniculatus* (liana), and *Emebelia tsjeriam-cottam* (shrub), because the seeds are used as medicines from this plants, and informants were aware of a plant that did not produced seeds. Plant-based ecosystem services are crucial for satisfying human needs, and human utilization of a plant is highly influenced by its species traits. For example, humans have selected plant species with traits that maximize crop yield, such as large fruits or height, or large grain size (Díaz et al., 2013; Díaz et al., 2011). Cámara-Leret et al., 2017 tested the relationship between plant traits and its perceived value by people through an interdisciplinary perspective on the linkages between ecosystem services, human needs and species' traits. It was demonstrated that people preferentially use large, widespread species rather than small, narrow-ranged species, and that different traits are linked to different uses. For example, one would expect a species to possess traits that satisfy human basic needs such as food and health. Such traits are plant size, constantly high yielding subsistence, widespread and cost effective to gather, and in contrast a species trait have strong link to easy availability and weaker link to plant size for medicinal usages (Cámara-Leret et al., 2017).

3.3 Gender preference in food and medicinal usages

Table 1 shows the usages of plants under the categories of plants being utilized as food, medicine, rituals, and a category of others. Among the 40 dioecious species, informants have gender preference for 13 species (10 trees, 2 lianas, and 1 shrub), and it was found that the informants have better knowledge about the toddy (palm wine) prepared out of male and female

palm trees (*Borassus flabellifer* and *Phoenix* species). Toddy is a traditional alcoholic drink prepared by the fermentation of sap or exudate collected by slicing off the tip of unopened flowers of palm trees (Davis and Johnson, 1987). Informants reported that male palms yield comparatively less toddy than female palms, and the former are in higher demand among consumers because it is believed to be more potent. In this study, we observed that this knowledge is particular to elder informants, the reason for this was that in mid-20th century in India due to the increasing demand of toddy's, it was reported that the toddy often was adulterated with chemical substances, such as chloral hydrate and diazepam, and the adulteration had detrimental health consequences for toddy consumers (Rao et al., 2004). Therefore, the consumption and sale of toddy were prohibited from time to time in India, and the production of Indian-made foreign liquor such as whisky and brandy was promoted through industrialization (Mahal, 2000).

It has been reported that harvesters in Nilgiri Biosphere Reserve, India, were aware of male and female trees of *Canarium strictum*, and that resin yielding trees were female trees (Varghese and Ticktin, 2008). A similar case was observed in *Canarium strictum* in Kolli Hills and Servarayan Hills where the informants reported that male trees produce less resin than the female trees, and when inquired further about the quality variation between the two gender the informants did not comment on any quality variation in male and female plant resins, but informed about a general variation that based on the dryness of the resin that the fragrance it produces varies. For example, resin composition of male and female trees of *Austrocedrus chilensis* (D. Don) Florin & Boutelje (Cupressaceae) is reported to vary between genders and during different seasons of the year (Olate et al., 2014).

Interestingly, for medicinal usages informants reported a gender preference for *Piper betle* and *Tinospora cordifolia*, and the usage was rather complex and dependent on spiritual beliefs and medication. For example, informants believe that the *Piper betle* leaves of any one gender can be used to balance the hormonal imbalance of people with transgender sign. i.e., if a man is showing a sign of woman, prescribing a male leaf extract along with goat or sheep milk may cure the illness and vice versa. Similarly male plant leaves are prescribed to woman, and female plant leaves are prescribed to men with the purpose to act both as a sexual stimuli and to foster a good relationship between men and women. The informants reported male leaves as harder to chew than the female leaves, therefore female leaves are prepared to make paan (paan

is combination of betle leaves with areca nut or tobacco, chewed for its stimulant and psychoactive effects). However, when enquired about the taxonomic identity of male and female *Piper betle* leaves, it was found that informants segregate male and female leaves based on the venation pattern and number of veins in a leaf, i.e., the harder the venation pattern, and a minimum of 5 veins in a leaf is believed to be male leaf, and the softer venation pattern and less than 5 veins in a leaf is a female leaf. In India, despite its availability in the wild, *Piper betle* is vegetatively propagated for cultivation and no flowering is observed in the subtropics due to the lack of inductive photoperiods. The female plants rarely produce any flower or fruit in the Indian climate (Bajpai et al., 2012; Guha, 2006). Despite the absence of flower and fruiting to identify male and female *Piper betle*, sexual dimorphism for leaf character was reported in terms of length and breadth ratio of leaves. Male leaves are reported to be narrowly ovate with 1.84 ±0.21 length: breadth ratio and female leaves are cordate or ovate to round leaves with 1.26±0.13 length: breadth ratio. Leaves of the female plants are mostly pungent and male plants are less pungent (Krishnamurthy et al., 2008). However the congruency between folk healers identification, and biological identification of male and female *Piper betle* is yet to be documented. Jing and Coley, 1990 have reported that male and female trees of *Acer negundo* (Aceraceae) could be distinguished from one another solely based on leaf characters, and the largest difference between the sexes was the toughness of leaves. Leaves from female trees were on average tougher than those from male trees, and suggests that male trees commonly suffered greater herbivory than females due to toughness of leaves. Sexual dimorphism in vegetative growth for several dioecious plants were also reported (Jing and Coley, 1990).

3.4 Timber plants and gender preference

Table 4 shows the plants used for its timber and preferential gender usages. Out of 21 tree species used in the study, informants have reported 9 species for various construction purposes, and among these 6 species are preferred based on the gender (Table 4). Timber of male palm trees (*Borassus flabellifer* and *Phoenix* species) and *Drypetes sepiaria* is preferred for construction purposes such as houses, huts and furnitures because it is believed that male plants have expected size and more durable timber than female trees. On the contrary, female plant timber of *Diospyros ebenum* is preferred over male plants and it is believed that carving in male plant timber is tough. Informants preference on one gender in timber could be explained with

plant resource allocation theory that the male plants comparatively allocates more resource to vegetative growth than the female plants (Obeso, 2002). Obeso, 1997 have reported that mean annual tree-ring width of *Ilex aquifolium* L. was greater in males than in females for a 30-year period and that the male plants grew more than females. Similarly, male trees of *Bursera morelensis* Ramírez, and *Dacryodes excelsa* Vahl were significantly taller and larger than female trees (Forero-Montaña et al., 2010; Pavón and de Luna Ramírez, 2008). On the contrary male and female trees belonging to 16 species of Myristicaceae and *Cecropia schreberiana* Miq. showed no differences in annual growth rates implying that females can compensate the higher cost of reproduction (Forero-Montaña et al., 2010; Queenborough et al., 2007).

On the other hand informants reported that male plants of *Myristica dactyloides* are selectively chosen for fire wood considering that it has no other benefits for them. Similar information was documented for *Carica papaya* that the informants do not prefer the male plants to be grown in their garden since it yields no fruits to them. Selective logging is reported to be the far most common management strategies to exploit commercial timber trees in tropical regions (Putz et al., 2012), and woody plants are especially vulnerable due to selective logging, given their economic value as timber and their long regeneration time (Martínez Garza and Howe, 2003). Thus, selective logging and economic value increases the threat to dioecious taxa because of an underlying correlation between woodiness and dioecy (Martínez‐Garza and Howe, 2003). Among the threatened plants included in the IUCN Red List of Threatened Species, woody growth habit of dioecious species is contributing to the higher risk of extinction (Vamosi and Vamosi, 2005). Any anthropogenic activity that modifies the male–female distance, sex ratio, plant size and pollinator abundance or behavior could affect the long-term viability of dioecious plants, and endangers the species (Somanathan and Borges, 2000).

Apart from dioecious plants, informants had knowledge about the occurrence of monoecious plants (i.e., with separate male and female flowers on the same individual plant), especially about *Cocos nucifera* (coconut), and *Cucurbita* species (pumpkins). Informants aware of male flowers in coconut tree and pumpkins which will not bear fruits, and few informants have informed that male coconut flowers can be used as medicine to increase fertility for both men and women. On the other hand, the female informants specified their tradition of using male flowers of pumpkins as an ornamental.

3.5 Vernacular names and plant gender

In this study, it was observed that based on different phenotypes, texture of different plant parts and morphological appearance of closely related species, people have the tendency to represent a particular plant species either as male or female by providing gender specific vernacular names, and such plant species are not dioecious. For example, the phenotypic variations in the flowers such as blue and white in *Clitoria ternatea* L., Leguminosae (*Shankapusphi*) is attributed to gender in Kolli Hills. They consider white flower phenotype as female (resembles the Indian female god Lakshmi) and blue flower phenotype as male (resembles the Indian male god Krishna). They prefer either one phenotype during the rituals and the choice of phenotype is based on the ritual process and whether the spiritual god is male or female. Similarly, *Mimosa pudica* L., Leguminosae (*thottasinungi*; *thottasuringi*) was also categorized into male and female based on the characteristic observations in movements in the pulvini of leaves, pinnae and pinnules of the plants in response to touch. If the leaf movement of shrinkage starts from top to bottom basal end upon the touch, it is called male variety (*munsuringi*), and if the shrinkage starts from bottom to top, it is called female variety (*pinsuringi*). On the other hand, two closely related monoecious species in Moraceae, *Artocarpus hirsutus* Lam. (*ayanipala*; *kattupala*; *peyppala*) and *Artocarpus heterophyllus* Lam. (*palamaram*; *narpala*), are considered to be male and female plants respectively based on the fruit texture and timber quality. Informants reported that the fruit of *Artocarpus hirsutus* is watery and mushy in nature, whereas the fruit of *Artocarpus heterophyllus* is fibrous. In addition, it was reported that the timber of *Artocarpus hirsutus* was more durable than that of *Artocarpus heterophyllus*.

3.6 Plant gender and Ayurveda

The interaction with Ayurvedic doctors indicated that the Ayurvedic classical literature has no straight forward evidence on gender preference to prepare medicine or to treat illness. However the concept of plant gender is mentioned in Ayurvedic literatures such as *Charaka Samhita, Vrikshayurveda,* and *Rajanighantu*. For example, *Charaka Samhita* describes the morphological appearance, properties, and uses of a particular medicinal plant called *Kutaja,* and the plant is described as male plant (*Pum-Kutaja*) and female plant (*Stri-Kutaja*), and these two plants are decoded as *Holarrhena pubescens* Wall. ex G.Don (Syn. *Holarrhena antidysenterica* (Roth) Wall. ex A.DC.) and *Wrightia tinctoria* R.Br. both belonging to the Apocynaceae family

(Samhita, 2001). These two species are not biologically dioecious. Therefore, it appears that the concept of gender differentiation in *Charaka Samhita* for *Kutaja* is not based on the floral sexual characters of the plants, rather based on the morphological appearance and properties of the plants. On the contrary, *Vrikshayurveda* and *Rajanighantu* describe the concept of reproductive morphology and sexual differentiation of plants (Prasad and Narayana, 2007; Sengupta, 2010). For example, *Rajanighantu* mentions the existence of male and female individuals of a dioecious species plant called *Ketaki* (*Pandanus odoratissimus* L.f. (Syn. of *Pandanus odorifer* (Forssk.) Kuntze) (Adkar and Bhaskar, 2014), but includes no indication on gender preferential usage.

Conclusions

During the last century, substantial ethnobotanical knowledge has been documented, and ethnobotanical studies have evolved to demonstrate the importance of traditional ecological knowledge to livelihoods around the globe, but also highlighted the rapid rate at which knowledge is being forgotten and lost. From this study, we identified the existence of a significant knowledge gap in ethnobotanical and ethnopharmacological literature on traditional knowledge of dioecious plants. Hence, an explorative study was conducted, and from this study it is evident that people have traditional knowledge on gender of plants and preferential usages towards one gender for some species. Based on this, we propose that researchers conducting an ethnobotanical and ethnopharmacological study should consider documenting traditional knowledge on sexual systems of plants, and test the existence of gender specific usages in their conceptual framework and hypothesis testing. The incorporation of such concepts could provide new dimensions of scientific knowledge with potential implications to conservation biology, chemical ecology, ethnoecology and drug discovery.

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Author contributions

GSS, KR, BSP, HdB and HW synthesized the study concept and designed the study methodology. GSS with the guidance of KR conducted the field study and collected the data. GSS, KR, BSP, HdB, and HW analyzed and interpreted the data. GSS wrote the manuscript, and all authors have contributed to the preparation and finalization of the article. All authors have read and approved the final version of the manuscript.

Conflicts of interest

The authors have no conflicts of interest.

References

Addis, G., Baskaran, R., Raju, M., Ushadevi, A., Asfaw, Z., Woldu, Z., Baskaran, V., 2009. Effect of blanching and drying process on carotenoids composition of underutilized Ethiopian (*Coccinia grandis* (L.) Voigt) and Indian (*Trigonella foenum-graecum* L.) green leafy vegetables. J. Food Process. Preserv. 33, 744–762.

Adkar, P.P., Bhaskar, V., 2014. *Pandanus odoratissimus* (Kewda): A review on ethnopharmacology, phytochemistry, and nutritional aspects. Adv. Pharmacol. Sci., 1-19.

Amresh, G., Reddy, G.D., Rao Ch, V., Singh, P.N., 2007. Evaluation of anti-inflammatory activity of *Cissampelos pareira* root in rats. J. Ethnopharmacol. 110, 526–531.

Arinathan, V., Mohan, V.R., De Britto, A.J., Murugan, C., 2007. Wild edibles used by Palliyars of the Western Ghats, Tamil Nadu. Ind. J. Trad. Knowl. 6, 163–168.

Bajpai, V., Pandey, R., Negi, M.P.S., Bindu, K.H., Kumar, N., Kumar, B., 2012. Characteristic differences in metabolite profile in male and female plants of dioecious *Piper betle* L. J. Biosci. 37, 1061–1066.

Bajpai, V., Singh, A., Chandra, P., Negi, M., Kumar, N., Kumar, B., 2016. Analysis of phytochemical variations in dioecious *Tinospora cordifolia* stems using HPLC/QTOF MS/MS and UPLC/QqQLIT‐MS/MS. Phytochem. Anal. 27, 92–99.

Bani, S., Kaul, A., Khan, B., Gupta, V.K., Satti, N.K., Suri, K.A., Qazi, G.N., 2007. Anti-arthritic activity of a biopolymeric fraction from *Euphorbia tirucalli*. J. Ethnopharmacol. 110, 92–98.

Banuelos, M.J., Sierra, M., Obeso, J.R., 2004. Sex, secondary compounds and asymmetry. Effects on plant-herbivore interaction in a dioecious shrub. Acta Oecol. 25, 151–157.

Bawa, K.S., 1980. Evolution of dioecy in flowering plants. Annu. Rev. Ecol. Syst. 11, 15–39.

Berlin, B., Breedlove, D.E., Raven, P.H., 1973. General principles of classification and nomenclature in folk biology. Am. Anthropol. 75, 214–242.

Berlin, L.A., Berlin, B., 2005. Some field methods in medical ethnobiology. Field Methods 17, 235–268.

Bernstein, J.H., Ellen, R., Antaran, B.b., 1997. The use of plot surveys for the study of ethnobotanical knowledge: A Brunei Dusun example. J. Ethnobiol. 17, 69–96.

Bjora, C.S., Wabuyele, E., Grace, O.M., Nordal, I., Newton, L.E., 2015. The uses of Kenyan aloes: an analysis of implications for names, distribution and conservation. J. Ethnobiol. Ethnomed. 11, 82.

Bopana, N., Saxena, S., 2007. *Asparagus racemosus* - ethnopharmacological evaluation and conservation needs. J. Ethnopharmacol. 110, 1–15.

Borges, R.M., Somnathan, H., Mali, S., 1997. Alternations of sexes in a deciduous tree: temporal dioecy in *Bridelia retusa*. Curr. Sci. 72, 940–944.

Bussmann, R.W., Sharon, D., 2006. Traditional medicinal plant use in Loja province, southern Ecuador. J. Ethnobiol. Ethnomed. 2, 44.

Byng, J.W., Chase, M.W., Christenhusz, M.J., Fay, M.F., Judd, W.S., Mabberley, D.J., Sennikov, A.N., Soltis, D.E., Soltis, P.S., Stevens, P.F. and Briggs, B., 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Bot. J. Linn. Soc. 181, 1-20.

Cámara-Leret, R., Faurby, S., Macía, M.J., Balslev, H., Göldel, B., Svenning, J.-C., Kissling, W.D., Rønsted, N., Saslis-Lagoudakis, C.H., 2017. Fundamental species traits explain provisioning services of tropical American palms. Nature Plants 3, nplants2016220.

Choudhry, N., Singh, S., Siddiqui, M.B., Khatoon, S., 2014. Impact of seasons and dioecy on therapeutic phytoconstituents of *Tinospora cordifolia*, a Rasayana drug. Biomed. Res. Int., 902138.

Coley, P.D., Heller, M.V., Aizprua, R., Arauz, B., Flores, N., Correa, M., Gupta, M., Solis, P.N., Ortega-Barria, E., Romero, L.I., Gomez, B., Ramos, M., Cubilla-Rios, L., Capson, T.L., Kursar, T.A., 2003. Using ecological criteria to design plant collection strategies for drug discovery. Front. Ecol. Environ. 1, 421–428.

Cornelissen, T., Stiling, P., 2005. Sex-biased herbivory: a meta-analysis of the effects of gender on plant‐herbivore interactions. Oikos 111, 488–500.

Danell, K., Hjalten, J., Ericson, L., Elmqvist, T., 1991. Vole feeding on male and female willow shoots along a gradient of plant productivity. Oikos 62, 145-152.

Davis, T.A., Johnson, D.V., 1987. Current utilization and further development of the palmyra palm (*Borassus flabellifer* L, Arecaceae) in Tamil Nadu State, India. Econ. Bot. 41, 247–266.

de Boer, H.J., Cotingting, C., 2014. Medicinal plants for women's healthcare in Southeast Asia: a meta-analysis of their traditional use, chemical constituents, and pharmacology. J. Ethnopharmacol. 151, 747–767.

Díaz, S., Purvis, A., Cornelissen, J.H., Mace, G.M., Donoghue, M.J., Ewers, R.M., Jordano, P., Pearse, W.D., 2013. Functional traits, the phylogeny of function, and ecosystem service vulnerability. Ecol. Evol. 3, 2958–2975.

Díaz, S., Quétier, F., Cáceres, D.M., Trainor, S.F., Pérez-Harguindeguy, N., Bret-Harte, M.S., Finegan, B., Peña-Claros, M., Poorter, L., 2011. Linking functional diversity and social actor strategies in a framework for interdisciplinary analysis of nature's benefits to society. Proc. Natl. Acad. Sci. U.S.A. 108, 895–902.

Fetterman, P.S., Keith, E.S., Waller, C.W., Guerrero, O., Doorenbos, N.J., Quimby, M.W., 1971. Mississippi-grown *Cannabis sativa* L: preliminary observation on chemical definition of

phenotype and variations in tetrahydrocannabinol content versus age, sex, and plant part. J. Pharm. Sci. 60, 1246–1249.

Field, D.L., Pickup, M., Barrett, S.C., 2013. Comparative analyses of sex-ratio variation in dioecious flowering plants. Evolution 67, 661–672.

Forero-Montaña, J., Zimmerman, J.K., Thompson, J., 2010. Population structure, growth rates and spatial distribution of two dioecious tree species in a wet forest in Puerto Rico. J. Trop. Ecol. 26, 433–443.

Geetha, K.A., Josphin, M., Maiti, S., 2007. Gender instability in *Tinospora cordifolia* - an immunomodulator. Curr. Sci. 92, 591–592.

Getie, M., Gebre-Mariam, T., Rietz, R., Hohne, C., Huschka, C., Schmidtke, M., Abate, A., Neubert, R.H., 2003. Evaluation of the anti-microbial and anti-inflammatory activities of the medicinal plants *Dodonaea viscosa*, *Rumex nervosus* and *Rumex abyssinicus*. Fitoterapia 74, 139–143.

Grover, J., Vats, V., Rathi, S., 2000. Anti-hyperglycemic effect of *Eugenia jambolana* and *Tinospora cordifolia* in experimental diabetes and their effects on key metabolic enzymes involved in carbohydrate metabolism. J. Ethnopharmacol. 73, 461–470.

Guha, P., 2006. Betel leaf: the neglected green gold of India. J. Hum. Ecol. 19, 87–93.

Haynes, J., McLaughlin, J., 2000. Edible palms and their uses. Fact Sheet MDCE-00-50-1. Institute of Food and Agriculture Sciences, University of Florida, Homestead, FL.

Hjalten, J., 1992. Plant sex and hare feeding preferences. Oecologia 89, 253–256.

Hmimsa, Y., Aumeeruddy-Thomas, Y., Ater, M., 2012. Vernacular taxonomy, classification and varietal diversity of fig (*Ficus carica* L.) among Jbala cultivators in Northern Morocco. Hum. Ecol. 40, 301–313.

Jayakumar, S., Arockiasamy, D.I., Britto, S.J., 2002. Conserving forests in the Eastern Ghats through remote sensing and GIS - A case study in Kolli hills. Curr. Sci. 82, 1259–1267.

Jing, S.W., Coley, P.D., 1990. Dioecy and herbivory: the effect of growth rate on plant defense in *Acer negundo*. Oikos 58, 369–377.

Käfer, J., Boer, H., Mousset, S., Kool, A., Dufaÿ, M., Marais, G., 2014. Dioecy is associated with higher diversification rates in flowering plants. J. Evol. Biol. 27, 1478–1490.

Khasbagan, S., 2008. Indigenous knowledge for plant species diversity: a case study of wild plants' folk names used by the Mongolians in Ejina desert area, Inner Mongolia, PR China. J. Ethnobiol. Ethnomed. 4, 2.

Krishna, K., Paridhavi, M., Patel, J.A., 2008. Review on nutritional, medicinal and pharmacological properties of papaya (*Carica papaya* Linn.). Nat. Prod. Rad. 7, 364–373.

539 Krishnamurthy, K.S, Prasath, D., Kandiannan, K., Suseela Bhal, R., Sajl, K., Parthasarathy, V.,
540 2008. (Eds.) National seminar on Piperaceae – harnessing agro-technologies for accelerated
541 production of economically important *Piper* species. Indian Institute of Spices Research, Calicut,
542 India.

543 Kumar, S., Das, G., Shin, H.S., Patra, J.K., 2017. *Dioscorea* spp. (a wild edible tuber): A study
544 on its ethnopharmacological potential and traditional use by the local people of Similipal
545 Biosphere Reserve, India. Front. Pharmacol. 8, 52.

546 Lansky, E.P., Paavilainen, H.M., Pawlus, A.D., Newman, R.A., 2008. *Ficus* spp. (fig):
547 Ethnobotany and potential as anticancer and anti-inflammatory agents. J. Ethnopharmacol. 119,
548 195–213.

549 Levins, R. (1968). Evolution in changing environments : Some theoretical explorations.
550 Princeton University Press, Princeton, NJ.

551 Mahal, A., 2000. What works in alcohol policy? Evidence from rural India. Econ. Polit. Wkly,
552 3959–3968.

553 Maldonado-López, Y., Cuevas-Reyes, P., Sánchez-Montoya, G., Oyama, K., Quesada, M., 2014.
554 Growth, plant quality and leaf damage patterns in a dioecious tree species: is gender important?
555 Arth.-Plant Int. 8, 241–251.

556 Mallavadhani, U., Panda, A.K., Rao, Y., 1998. Pharmacology and chemotaxonomy of
557 *Diospyros*. Phytochem. 49, 901–951.

558 Martínez-Garza, C., Howe, H.F., 2003. Restoring tropical diversity: beating the time tax on
559 species loss. J. Appl. Ecol. 40, 423–429.

560 Massei, G., Watkins, R., Hartley, S.E., 2006. Sex-related growth and secondary compounds in
561 *Juniperus oxycedrus macrocarpa*. Acta Oecol. 29, 135–140.

562 Mcarthur, E.D., 1977. Environmentally induced changes of sex expression in *Atriplex canescens*.
563 Heredity 38, 97–103.

564 Milet-Pinheiro, P., Navarro, D.M.d.A.F., Dötterl, S., Carvalho, A.T., Pinto, C.E., Ayasse, M.,
565 Schlindwein, C., 2015. Pollination biology in the dioecious orchid *Catasetum uncatum*: How
566 does floral scent influence the behaviour of pollinators? Phytochem. 116, 149–161.

567 Moin, S., Devi, C.B., Wesley, S.P., Sahaya, S.B., Zaidi, Z., 2014. Comparative phytochemical
568 and antibacterial screening of important medicinal plants of Celastraceae. J. Biol. Act. Prod. Nat.
569 4, 37–43.

570 Namsa, N.D., Tag, H., Mandal, M., Kalita, P., Das, A.K., 2009. An ethnobotanical study of
571 traditional anti-inflammatory plants used by the Lohit community of Arunachal Pradesh, India. J.
572 Ethnopharmacol. 125, 234–245.

573 Obeso, J., 1997. Costs of reproduction in *Ilex aquifolium*: effects at tree, branch and leaf levels.
574 J. Ecol., 159–166.

575 Obeso, J.R., 2002. The costs of reproduction in plants. New Phytol. 155, 321–348.

576 Olate, V.R., Soto, A., Schmeda-Hirschmann, G., 2014. Seasonal variation and resin composition
577 in the andean tree *Austrocedrus chilensis*. Molecules 19, 6489–6503.

578 Pathak, S., Shukla, R., 2004. Population structure and sex-ratio of *Mallotus philippensis* Muel.
579 Arg. within forest vegetation of north-eastern UP, India. Trop. Ecol. 45, 271–280.

580 Patil, S.A., Sujaya, M., Patil, S.B., 2014. Aphrodisiac and phytochemical studies of *Cocculus*
581 *hirsutus* extracts in albino rats. Asian Pac. J. Reprod. 3, 23–29.

582 Patwardhan, B., Mashelkar, R.A., 2009. Traditional medicine-inspired approaches to drug
583 discovery: can Ayurveda show the way forward? Drug Discov. Today 14, 804–811.

584 Pavón, N.P., de Luna Ramírez, I., 2008. Sex ratio, size distribution and nitrogen resorption in the
585 dioecious tree species *Bursera morelensis* (Burseraceae). J. Trop. Ecol. 24, 463–466.

586 Prasad, P., Narayana, A., 2007. Biography of Narahari – the author of Raja-Nighantu. Bull.
587 Indian Ins. Hist. Med. Hyderabad 37, 1–8.

588 Putz, F.E., Zuidema, P.A., Synnott, T., Peña‐Claros, M., Pinard, M.A., Sheil, D., Vanclay, J.K.,
589 Sist, P., Gourlet‐Fleury, S., Griscom, B., 2012. Sustaining conservation values in selectively
590 logged tropical forests: the attained and the attainable. Conserv. Lett. 5, 296–303.

591 Queenborough, S.A., Burslem, D.F., Garwood, N.C., Valencia, R., 2007. Determinants of biased
592 sex ratios and inter-sex costs of reproduction in dioecious tropical forest trees. Am. J. Bot. 94,
593 67–78.

594 Rajkumar, R., Kumar, E.P., Sudha, S., Suresh, B., 2007. Evaluation of anxiolytic potential of
595 *Celastrus* oil in rat models of behaviour. Fitoterapia 78, 120–124.

596 Rao, R.N., Parimala, P., Khalid, S., Alvi, S.N., 2004. Detection of the adulteration of traditional
597 alcoholic beverages by the separation and determination of alprazolam, chloralhydrate and
598 diazepam using reversed-phase high-performance liquid chromatography. Anal. Sci. 20, 383–
599 386.

600 Rastogi, S., Kulshreshtha, D.K., Rawat, A.K., 2006. *Streblus asper* Lour. (Shakhotaka): A
601 review of its chemical, pharmacological and ethnomedicinal properties. Evid. Based
602 Complement. Alternat. Med. 3, 217–222.

603 Rathore, J.S., 1972. *Diospyros melanoxylon*, a bread-winner tree of India. Econ. Bot. 26, 333-
604 339.

Rauf, A., Uddin, G., Patel, S., Khan, A., Halim, S.A., Bawazeer, S., Ahmad, K., Muhammad, N., Mubarak, M.S., 2017. *Diospyros*, an under-utilized, multi-purpose plant genus: A review. Biomed. Pharmacother. 91, 714–730.

Renner, S.S., 2014. The relative and absolute frequencies of angiosperm sexual systems: dioecy, monoecy, gynodioecy, and an updated online database. Am. J. Bot. 101, 1588–1596.

Rhouma, S., Zehdi-Azouzi, S., Dakhlaoui-Dkhil, S., Salem, A.O.M., Othmani, A., Cherif, E., Marrakchi, M., Trifi, M., 2010. Genetic variation in the Tunisian date palm (*Phoenix dactylifera* L.), desert plants. In: Ramawat KG (ed) Desert plants. Springer, Berlin, pp 355–369.

Rhouma S, Zehdi-Azouzi S, Dakhlaoui-Dkhil S, Ould Mohaned Salem A, Othmani A, Cherif E, Marrakchi M, Trifi M (2010) Genetic variation in the Tunisian date palm (*Phoenix dactylifera* L.). In: Ramawat KG (ed) Desert plants. Springer, Berlin, pp 355–369

Sahoo, M.R., Dhanabal, S.P., Jadhav, A.N., Reddy, V., Muguli, G., Babu, U.V., Rangesh, P., 2014. Hydnocarpus: an ethnopharmacological, phytochemical and pharmacological review. J. Ethnopharmacol. 154, 17–25.

Samhita, C., 2001. Charaka Samhita. Vol. I. Chaukhamba Bharati Academy, Varanasi, India pp. 66–69.

Sarkar, M., Gangopadhyay, P., Basak, B., Chakrabarty, K., Banerji, J., Adhikary, P., Chatterjee, A., 2000. The reversible antifertility effect of *Piper betle* Linn. on Swiss albino male mice. Contraception 62, 271–274.

Sen, S., Chakraborty, R., De, B., Devanna, N., 2011. An ethnobotanical survey of medicinal plants used by ethnic people in West and South district of Tripura, India. J. Forestry Res. 22, 417–426.

Sengupta, P.K., 2010. History of science and philosophy of science: A historical perspective of the evolution of ideas in science. Pearson Education, New Delhi, India.

Simpson, B.S., 2013. Dioecy in plants-is it an important factor for phytochemists to consider? Planta Med. 79, 613–615.

Simpson, B.S., Claudie, D.J., Gerber, J.P., Pyke, S.M., Wang, J., McKinnon, R.A., Semple, S.J., 2011. In vivo activity of benzoyl ester clerodane diterpenoid derivatives from *Dodonaea polyandra*. J. Nat. Prod. 74, 650–657.

Simpson, B.S., Claudie, D.J., Smith, N.M., McKinnon, R.A., Semple, S.J., 2012. Rare, seven-membered cyclic ether labdane diterpenoid from *Dodonaea polyandra*. Phytochem. 84, 141–146.

Somanathan, H., Borges, R.M., 2000. Influence of exploitation on population structure, spatial distribution and reproductive success of dioecious species in a fragmented cloud forest in India. Biol. Conserv. 94, 243–256.

639 Srithi, K., Balslev, H., Wangpakapattanawong, P., Srisanga, P., Trisonthi, C., 2009. Medicinal
640 plant knowledge and its erosion among the Mien (Yao) in Northern Thailand. J.
641 Ethnopharmacol. 123, 335–342.

642 Swetha, V.P., Parvathy, V.A., Sheeja, T.E., Sasikumar, B., 2017. Authentication of *Myristica*
643 *fragrans* Houtt. using DNA barcoding. Food Control 73, 1010–1015.

644 Tag, H., Das, A., Kalita, P., 2005. Plants used by the Hill Miri tribe of Arunachal Pradesh in
645 ethnofisheries. Ind. J. Trad. Knowl. 4, 57–64.

646 Talukdar, S.N., Hossain, M.N., 2014. Phytochemical, phytotherapeutical and pharmacological
647 study of *Momordica dioica*. Evid. Based Complement Alternat. Med. 2014, 806082.

648 Vamosi, J.C., Vamosi, S.M., 2005. Present day risk of extinction may exacerbate the lower
649 species richness of dioecious clades. Divers. Distrib. 11, 25–32.

650 van Heerden, F.R., Viljoen, A.M., van Wyk, B.E., 2000. The major flavonoid of *Dodonaea*
651 *angustifolia*. Fitoterapia 71, 602–604.

652 Vandebroek, I., Balick, M.J., 2012. Globalization and loss of plant knowledge: challenging the
653 paradigm. PLoS One 7, e37643.

654 Varghese, A., Ticktin, T., 2008. Regional variation in non-timber forest product harvest
655 strategies, trade, and ecological impacts: the case of black dammar (*Canarium strictum* Roxb.)
656 use and conservation in the Nilgiri Biosphere Reserve, India. Ecol. Soc. 13, 11.

657 Venkatasubramanian, P., Godbole, A., Vidyashankar, R., Kuruvilla, G.R., 2013. Evaluation of
658 traditional anthelmintic herbs as substitutes for the endangered *Embelia ribes*, using
659 *Caenorhabditis elegans* model. Curr. Sci. 105, 1593–1598.

660 Vijayalakshmi, T., Muthulakshmi, V., Sachdanandam, P., 2000. Toxic studies on biochemical
661 parameters carried out in rats with Serankottai nei, a siddha drug-milk extract of *Semecarpus*
662 *anacardium* nut. J. Ethnopharmacol. 69, 9–15.

663 Voeks, R.A., Leony, A., 2004. Forgetting the forest: assessing medicinal plant erosion in Eastern
664 Brazil. Econ. Bot. 58(sp1), S294–S306.

665 Wolfe, L.M., 1997. Differential flower herbivory and gall formation on males and females of
666 *Neea psychotrioides*, a dioecious tree. Biotropica 29, 169-174.

667 Xavier, T.F., Kannan, M., Auxilia, A., 2015. Observation on the traditional phytotherapy among
668 the Malayali tribes in Eastern Ghats of Tamil Nadu, South India. J. Ethnopharmacol. 165, 198-
669 214.

Tables

Table 1. Details of dioecious plants studied in Kolli hills (Namakkal district), Sittlingi Valley (Dharmapuri district) and Servarayan Hills (Salem district), Tamil Nadu with preference towards gender and uses.

Table 2. Total average number of dioecious plants recognized, used, and preferred for its gender by different age group of informants.

Table 3. Overview of dioecious plants based on their habit, and the informants awareness and gender preference.

Table 4. Timber yielding dioecious plants with preferential gender usage.

Supplementary Data

Supplementary Data S1. List of possible dioecious plants used in Indian systems of codified and non-codified medicine.

Supplementary Data S2. Study questionnaire on ethnobotany of dioecious plants.

Supplementary Data S3. Background details of informants, their knowledge on dioecious plants, and the category of preference for plant gender.

687 **Table 1.** Details of dioecious plants studied in Kolli Hills (Namakkal district), Sittlingi Valley (Dharmapuri district) and Servarayan Hills (Salem
688 district) of Tamil Nadu, India with preferences towards gender and uses.

Species; Family; Voucher	**Tamil name**	**Habit**	**Plants recognized as dioecious (%)**			**Gender preference**	**Specific use***
			Y	**N**	**Uncertain**		
Anamirta cocculus (L.) Wight & Arn.; Menispermaceae; Cl 776	*Kakamari, Nancukkottai*	Liana	35	58	8	Yes	O: Fruits and seeds are poisonous which are used to poison fishes[1,9,17,38] (Tag et al., 2005) R: ♂ and ♀ leaves are used to do black magic[1,4,7,13,14,31]
Aphanamixis polystachya (Wall.) R.Parker; Meliaceae; Cl 777	*Cemmaram, Civappurmaram*	Tree	33	58	10	Yes	M: Leaves are used to cure skin diseases, and stomach pain[2,3,18,24,32] (Sen et al., 2011) R: Flowers are collected for fragrance, in which ♀ flowers tend to contain more fragrance, and occasionally offered in rituals[2,8,13,29]
Asparagus racemosus Willd.; Asparagaceae; Cl 778	*Tannirvittankizhangu*	Liana	0	88	13	No	M: Tubers are used to cure white discharge, stomach pain, reduces body heat, rejuvinative, and enhances lactation[1-40] (Bopana and Saxena, 2007)
Bischofia javanica Blume; Phyllanthaceae; Cl 779	*Romaviruksha pattai, Milachadayan*	Tree	35	58	8	No	M: Stem bark is used to cure body ache, stomach ulcers, mouth ulcers and inflammatory conditions[4,9,13,17,26,30,31,36] R: Stem and leaves are used to black magic in terms of removing fear[1,4,7,9,13,14,31,36]
Borassus flabellifer L.; Arecaceae; Cl 780	*Panai maram*	Tree	100	0	0	Yes	F: ♂ plant toddy is more vibrant than ♀ [1,3,13,17,22,25,27,38,40]. Fruits and tuberous seedlings are edible[1-40] (Davis and Johnson, 1987) M: Fruits and roots are used as diuretic, and antidiabetic[1,11,23,31] (Davis and Johnson, 1987)
Canarium strictum Roxb.; Burseraceae; Cl 781	*karukunkiliyam*	Tree	68	15	18	Yes	M: Resin is used as anti-inflammatory and to cure skin diseases, against poisonous bites [1-10, 31,35,37.] (Namsa et al., 2009). O: ♀ tree yields more resin than ♂ plant[1-10, 23,33,36,37]
Carica papaya L.; Caricaceae; Cl 782	*Pappali pazham*	Tree	100	0	0	No	F: Fruits are edible[1-40] (Krishna et al., 2008) M: Latex are used to control tooth ache, fruits used as rejuvenative and pregnancy abortive agent[1,4,15,21,24,27,29,34] (Krishna et al., 2008)

Cassine glauca (Rottb.) Kuntze; Celastraceae; Cl 783	*Karuvali*	Tree	83	0	18	No	M: Leaves and stem are used against dysentery, for wound healing, against poisonous bites, headache, fever[5,11,12,13,21,23, 26,29] (Moin et al., 2014)
Celastrus paniculatus Willd.; Celastraceae; Cl 784	*Valuluvai*	Liana	70	23	8	No	M: Seeds are used in mental problems, joint pain, arthritis, skin diseases, wound healing[1,5,10,14,18,20,31,36] (Rajkumar et al., 2007)
Cissampelos pareira L.; Menispermaceae; Cl 785	*Vattattiruppi*	Liana	0	73	28	No	M: Root and whole plant are used as appetizer, antidiarrhoeal, antihelmintics, antiulcer, and to cure digestive complaints.[1,3,7,13,16,19,21,27,34,36] (Amresh et al., 2007)
Coccinia grandis (L.) Voigt; Cucurbitaceae; Cl 786	*Kovai, Kovaikkay*	Vine	0	60	40	No	F: Fruits are edible and used as vegetable[1-40] (Addis et al., 2009)
Cocculus hirsutus (L.) W.Theob.; Menispermaceae; Cl 787	*Kattukkoti*	Climber	0	83	18	No	M: Leaves and roots are used to cure skin diseases, skin irritation, [and] stomach ache [1,4,7,9,14,15,29,30,34] (Patil et al., 2014)
Cyclea peltata (Lam.) Hook.f. & Thomson; Menispermaceae; Cl 788	*Malaithangi, Vattattiruppi*	Climber	0	78	23	No	M: Leaves and roots are used to cure poisonous bites, indigestion, stomach pain, boils and blisters[2,5,7,8,14,25,28,34] (Xavier et al., 2015)
Dioscorea alata L.; Dioscoreaceae; Cl 789	*Vettilai-valli*	Vine	68	0	33	No	F: Cooked tuber is used as food, and rejuvenative [1-40] (Kumar et al., 2017)
D. bulbifera L.; Dioscoreaceae; Cl 790	*Verrilai valli*	Vine	60	0	40	No	
D. esculenta (Lour.) Burkill; Dioscoreaceae; Cl 791	*Mucilam valli*	Vine	65	0	35	No	
D. hispida Dennst.; Dioscoreaceae; Cl 792	*Kavalakodi*	Vine	63	0	38	No	
D. oppositifolia L.; Dioscoreaceae; Cl 793	*Maruvalli*	Vine	68	0	33	No	
D. pentaphylla L.; Dioscoreaceae; Cl 794	*Kattuvalli kalangu*	Vine	78	0	23	No	
Diospyros ebenum J.Koenig ex Retz.; Ebenaceae; Cl 795	*Karunkali*	Tree	100	0	0	No	F: Fruits are edible[12,13,19,22,29,30,32,35] (Mallavadhani et al., 1998; Rauf et al., 2017)

D. melanoxylon Roxb.; Ebenaceae; Cl 796	*Kattupala*	Tree	100	0	0	No	F: Fruits are edible [12,13,19,22,29,30,32,35] (Mallavadhani et al., 1998; Rauf et al., 2017) M: Leaves are used to cure stomach pain[7,11,25,28] (Mallavadhani et al., 1998; Rauf et al., 2017). Leaves are used to as regional cigarette for psychoactive effects [21,23,27,33] (Rathore, 1972)
D. montana Roxb.; Ebenaceae; Cl 797;	*Vakkanai, Vakkanathi*	Tree	100	0	0	No	F: Fruits are edible[12,13,19,22,29,30,32,35] (Mallavadhani et al., 1998; Rauf et al., 2017) M: Bark and stem are used to cure fractured bones, act as anticoagulant, and to relieve body pain[11,18,19,21,23,25] (Mallavadhani et al., 1998; Rauf et al., 2017)
Dodonaea angustifolia L.f.; Sapindaceae; Cl 798	*Virali*	Shrub	0	93	8	No	M: Leaves are used as wound healing, relieves body pain, anti-inflammatory. Pregnancy abortive agent, cleanse the womb[1,2,5,8,11,14,17,18,21,24,26, 37,38] (Getie et al., 2003; van Heerden et al., 2000)
D. viscosa (L.) Jacq.; Sapindaceae; Cl 799	*Velari*	Shrub	0	93	8	No	
Drypetes sepiaria (Wight & Arn.) Pax & K.Hoffm.; Putranjivaceae; Cl 800	*Kalvirai*	Tree	100	0	0	No	F: Fruits are edible[11-30] (Arinathan et al., 2007)
Embelia tsjeriam-cottam (Roem. & Schult.) A.DC.; Primulaceae; Cl 801	*Vaivilangam*	Shrub	78	0	23	No	M: Seeds are anthelmintic[1,4,5,9,16,19,21,27,34] (Venkatasubramanian et al., 2013)
Euphorbia tirucalli L.; Euphorbiaceae; Cl 802	*Tirukukalli*	Tree	0	100	0	No	M: Latex is used to cure neural dysfunction, joint pains, skin disease, and act as neural stimuli[2,3,4,5,11,13,17] (Bani et al., 2007)
Ficus hispida L.f.; Moraceae; Cl 803	*Peiatthi*	Tree	18	65	18	No	M: Fruits are eaten to cure male impotent and also to increase fertility [1,8,12,18,24,30,35] (Lansky et al., 2008)
Hydnocarpus pentandrus (Buch.-Ham.) Oken; Achariaceae; Cl 804	*Neeradimuthu*	Tree	70	23	8	No	F: Fruits are edible[3,8,32,35] (Sahoo et al., 2014) M: Leaves and seeds are used to cure skin diseases, chest pains, joint pains[1,33,34,37,38] (Sahoo et al., 2014)
Lannea coromandelica (Houtt.) Merr.; Anacardiaceae; Cl 805	*Odiyamaram*	Tree	58	35	8	No	M: Leaves and stem bark are used to cure fever, dysentery, and anti-inflammatory[7,9,15,28,33]
Mallotus philippensis (Lam.) Müll.Arg.; Euphorbiaceae; Cl 806	*Kamala, Manjanathi*	Tree	53	13	35	No	M: Leaves and stem bark are used to cure stomach ache. Fruits are used as antidiabetic[3,6,12,15,20,32,35,38,39]

Momordica dioica Roxb. ex Willd.; Cucurbitaceae; Cl 807	*Pakarkoti, Pakarkai*	Climber	23	73	5	No	F: Fruits are used as vegetable[1-40]. (Talukdar and Hossain, 2014) M: Fruits are used as antidiabetic [1-40]. (Talukdar and Hossain, 2014)
Myristica dactyloides Gaertn.; Myristicaceae; Cl 808	*Jathikai*	Tree	68	20	13	No	F: Mace and kernel is used in food[1-40] (Swetha et al., 2017)
Phoenix loureiroi Kunth; Arecaceae; Cl 809	*Malai eecham*	Tree	100	0	0	Yes	F: Fruits are edible[1-40], ♂ plant toddy is more vibrant than ♀ plant toddy[1,3,5,13,22,25,27,35,38,40] (Haynes and McLaughlin, 2000; Rhouma et al., 2010)
P. pusilla Gaertn.; Arecaceae; Cl 810	*Icham*	Tree	100	0	0	Yes	
P. sylvestris (L.) Roxb.; Arecaceae; Cl 81	*Icham*	Tree	100	0	0	Yes	
Piper betle L.; Piperaceae; Cl 812	*Vettrilai*	Climber	100	0	0	Yes	F: ♀ leaves are preferred[10,11,12,14,20,26,33,36] M: ♂ plant leaves are preferred to increase male potency, and ♀ plant leaves are prescribed to male and ♂ leaves to female to act as sexual stimuli. ♂ and ♀ leaves are given in combination for hormonal balance among transgenders[1,2,8,13,25,27,29,34,35,37,39,40]. (Sarkar et al., 2000) R: ♀ leaves are preferred in rituals[2,8,29,39]
Semecarpus anacardium L.f.; Anacardiaceae; Cl 813	*Senkottai*	Tree	78	0	23	No	M: Seeds are poisonous, cures muscle spasm, skin diseases, and act as wound healing[9,32,33,38] (Vijayalakshmi et al., 2000)
Streblus asper Lour.; Moraceae; Cl 814	*Kuttipilaa*	Tree	0	48	53	No	M: Leaves and stem bark are used to cure urinary infections[8,13] (Rastogi et al., 2006)
Tinospora cordifolia (Willd.) Miers; Menispermaceae; Cl 815	*Cintilikkoti*	Liana	38	0	63	Yes	M: Stem acts as antidiabetic, immunomodulatory[1,9,12,15,40], ♂ and ♀ roots are used in combination to treat menstrual disorders[2,8,16,19,21,39]. (Grover et al., 2000)

*Superscript numbers are the identity of informants as shown in Supplementary Data S3; F: Food, M: Medicine, O: Others, R: Ritual

Table 2. Total average of dioecious plants recognized, used, and preferred for its gender by different age group of informants.

Informant age cohorts	Total number of informants	Species recognized as dioecious by informants	Average no. of species reported for usages	Average no. of species preferred for gender
41-50	17	19.35	21.47	2.71
51-60	10	24.2	23.1	3.5
61-70	6	23.5	21.17	4.17
71-80	7	24.14	22.14	5.71

Table 3. Overview of dioecious plants grouped on their habit, and the informants awareness and gender preference.

Habit	Dioecious species	Species reported as dioecious by informants	Species preferred for specific gender by informants
Tree	21	19	10
Vine	7	6	0
Liana	5	3	2
Climber	4	2	1
Shrub	3	1	0

Table 4. Timber species with preferential gender usage.

Species	Preferential gender usages*
Borassus flabellifer L.	♂ timber is preferred for construction [4,7,11,16,19,21,27,30,34]
Diospyros ebenum J.Koenig ex Retz.	♀ timber is preferred for construction [4,7,11,18,25,28,30,32,35,38]
Drypetes sepiaria (Wight & Arn.) Pax & K.Hoffm.	♂ timber is preferred for construction [13,15,16,18,22,23,26]
Lannea coromandelica (Houtt.) Merr.	♂ is preferred to make wooden vessels (mara-kuduvai) to farm animals[12,13,15]. ♂ preferred to be grown in farm land in order to avoid seedings [2,6,7,9,14,17,22,28,33,35]
Myristica dactyloides Gaertn.	♂ preferably cut for firewood [1,2,3,7,10]
Phoenix loureiroi Kunth	♂ timber is preferred for construction [5,6,12,13,17,24,28,33,40]
P. pusilla Gaertn.	
P. sylvestris (L.) Roxb.	

*Superscript numbers are the identity of informants as shown in Supplementary Data S3