FORESTS, TREES AND LIVELIHOODS
https://doi.org/10.1080/14728028.2020.1737582

ARTICLE

Use and management of tamarind (*Tamarindus indica* L., Fabaceae) local morphotypes by communities in Tigray, Northern Ethiopia

Hailay Girmay[a], Sarah Tewolde-Berhan [b], Hadgu Hishe [a,c], Zemede Asfaw [d], Morgan Ruelle [e,f] and Alison Power[f]

[a]Department of Land Resources Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia; [b]Department of Food Science and Post Harvest Technology, Mekelle University, Mekelle, Ethiopia; [c]Division of Forest, Nature, & Landscape, Department of Earth and Environmental Sciences, Catholic University of Leuven, Leuven, Belgium; [d]Department of Plant Biology and Biodiversity Management, Addis Ababa University, Addis Ababa, Ethiopia; [e]International Development, Community & Environment Department, Clark University, Worcester, MA, USA; [f]Department of Ecology & Evolutionary Biology, Cornell University, Ithaca, NY, USA

ABSTRACT

The population structure, phenotypic differences and ethnobotanical knowledge of tamarind (*Tamarindus indica* L., Fabaceae) were studied in Kunama- and Tigrigna-speaking communities in the Tigray Regional State of Ethiopia. A vegetation survey on 902 plots of 400 m^2 each was conducted along riparian forests and farmlands. Seed and pod morphology of sweet and sour morphotypes was compared based on 6 pods/tree from 20 trees. Thirty-two key informants and 256 randomly selected general informants were interviewed about the use and management of tamarind. Tree densities differed significantly among sociocultural groups and land use. Relatively more trees (6.0–17.5 individuals per hectare) were found in riparian forests as compared to farmland (4.0–7.8). Stem diameter class distribution has a bell-shape, indicating a regeneration problem. Morphological characteristics (pod length, pod width, pod weight, seed weight, pulp weight, and the number of seeds per pod) differed significantly between sour and sweet tamarind morphotypes ($p < .05$). Interviews identified seven use categories of tamarind, including human and veterinary medicines and five food types, with a greater number of uses mentioned within Kunama communities. Results can be used to support the sustainable use of tamarind in riparian forests and on farms, including conservation of varietal diversity based on the complementary knowledge of both communities.

KEYWORDS

Ethnobotany; Kunama-speaking communities; Tigrigna-speaking communities; land use types; phenotypic traits; medicinal plants; traditional food

Introduction

Tamarindus indica (tamarind) is a pantropical species grown for its edible fruits, medicinal values, and commercial uses. Cultivation of tamarind is believed to have begun in Egypt by 400 BC (El-Siddig et al. 2006). Genetic analyses showed tamarind diversity in Africa is high. While there are arguments regarding its origin because it is more widely

CONTACT Sarah Tewolde-Berhan saratbge@gmail.com

used in Asia (India is the world's largest producer and exporter) tamarind is thought to have spread from Africa to Asia in the 1st millennium BC, with its presence reported in India by 650 BC (Diallo et al. 2007). Fossil records from north-western Ethiopia show that the legume tribe Detarieae (to which tamarind belongs) have diversified in northern and north-eastern Africa (Pan et al. 2010). In many parts of Africa, fruits from indigenous trees such as tamarind contribute to food security in rural areas (Ebifa-Othieno et al. 2017). Based on its medicinal and food values, it is one of the species conserved by farmers when forest and savanna vegetation is cleared for agriculture (Boffa 1999). In both Asia (Relwani 1993 cited in El-Siddig et al. 2006) and Africa (Fandohan et al. 2011b), tamarind is one of several tree species that farmers integrate with their agricultural crops and livestock in home gardens and parkland agroforestry systems. In Ethiopia, it is widely distributed in grasslands, woodlands, and *Combretum* bushlands, most frequently in riparian habitats up to 1500 meters above sea level (Thulin 1989; Bekele-Tesemma 2007) and where the annual rainfall is 500 to 1500 mm (El-Siddig et al. 2006). Its distribution has been recorded from upland areas of Tigray, Gonder, Wollo, Afar, Gojjam, Shewa, Illubabor, Keffa, Gamogofa, Sidamo, and Harerge floristic regions (Thulin 1989).

Throughout its range, tamarind has become an important species for livelihood diversification, yet unsustainable utilisation and habitat losses have led to the decline of its population and likely genetic erosion. Fandohan et al. (2010) reported that tamarind stem diameter distributions showed a non-normal shape in W National Park of Benin and surrounding areas, suggesting low levels of recruitment. In the lowlands of western Eritrea, tamarind is frequently used to make mortars for producing sesame oil, resulting in population decline in some areas (Bein et al. 1996). Studies of tamarind diversity across Asia and Africa indicate a genetic basis for variations in fruit morphology, flower colour and sugar ratio in its fruits (El-Siddig et al. 2006). However, strategies to document and conserve tamarind populations in Africa have yet to include the north-east of the continent, where fossil records indicate there may be genetic diversity worth exploring and conserving (Arbonnier 2004; Diallo et al. 2007; Pan et al. 2010; Fandohan et al. 2011a, 2011b).

Detailed knowledge on the population structure and diversity of tamarind, as well as its use and management by different sociocultural groups, are important for the identification of conservation strategies. For this reason, this study was undertaken to investigate tamarind population structure, phenotypic differences among local morphotypes, and farmers' knowledge on management and use. This is considered a first step toward a comprehensive conservation strategy for this useful species in different habitats. The objectives of this study were: 1) to assess differences in population structure and density of tamarind trees between riparian forest and farmland, 2) to assess phenotypic differences between sour and sweet morphotypes of tamarind, and 3) to examine the differences in use of tamarind as medicine, food and other purposes between Kunama-speaking communities (KSC) on the one hand and Tigrigna-speaking communities (TSC) on the other.

Methods

Study area

The study was conducted in the Western and North-western administrative zones of Tigray Regional State, Ethiopia. The communities within these zones speak Kunama and/or Tigrigna languages. These communities share a long history in the region and have distinct cultural traditions, including those related to values and uses of plants. Tahitay Adiabo, Qafta Humera, and Asgede Tsimbila districts were selected based on a preliminary assessment of tamarind distribution in Tigray. Within these three districts, four subdistricts were selected to include both KSC and TSC (Figure 1). The study area is characterised by hot to warm semi-arid lowlands and tepid to cool sub-moist mid-highland agro-ecological zones (EIAR 2011). The study area has a unimodal rainfall pattern (June to September) with an average annual rainfall of 676 mm and mean temperature of 27.7°C. The vegetation of the study area comes in three major types described as *Acacia-Commiphora* woodland, *Combretum-Terminalia* woodland, and riparian woodland (Friis et al. 2011). The woody species most frequently observed are *Tamarindus indica, Diospyros mespiliformis, Adansonia digitata, Acacia senegal, Acacia abyssinica, Acacia polyacantha, Balanites aegyptiaca*, and *Ziziphus spina-christi*. The land use of the study area is composed of mainly farmlands, grazing areas and forest (TAWoARD 2015; TAWoRLA 2015). Mixed crop-livestock farming is the primary livelihood system. Sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), pearl millet

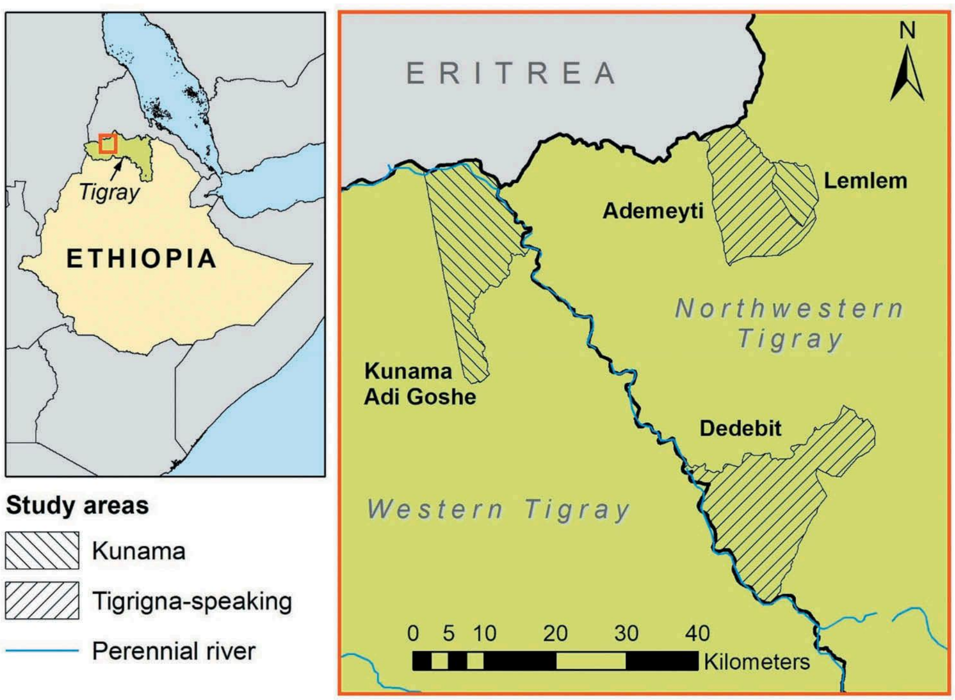

Figure 1. Map of Ethiopia showing the location of Tigray Region, the study area and the sample sites.

(*Pennisetum glaucum*) and maize (*Zea mays*) are the primary food crops, and sesame (*Sesamum orientale*) is the main cash crop in the area. Traditional gold panning and resin production from *Boswellia papyrifera* and *Acacia senegal* are additional sources of income.

Sampling design and data collection

Vegetation survey

Inventories of tamarind were conducted within 100 meters of the three major waterways that are adjacent to both farmland and forest in Lemlem and Ademeyti subdistricts. The midline of each waterway was digitized in Google Earth, and 100-meter buffer zones (including the right and left banks of each river) were generated in ArcMap 10.4 (ESRI). A 20 × 20 meter (400 m^2) grid was established within each buffer zone, resulting in 902 plots encompassing 36 hectares following the method used by Kendie et al. (2019) (Figure 2). The centre of each plot was assigned a unique code and uploaded to a Garmin eTrex Legend GPS, which was then used to navigate. Within each plot, the presence of tamarind and the land use type (farmland or forest) were recorded. For each tamarind tree found in the sample plot, the diameter at breast height (DBH) and tree height were measured.

Ethnobotanical survey

The communities in the study area identify two local morphotypes based on pod colour, pod length, pod size, and taste, which they refer to in the same manner as 'sweet' and 'sour' types as earlier shown by Fandohan et al. (2011b).

Pod collection and morphological measurements

Key informants who know the trees from past fruit collection were asked to identify 10 trees of each type. Before engaging informants, free, prior informed oral consent was obtained from each. Informants were asked to specify each based on the common criteria used by their community and their own experience. Six pods were collected from each tree (two from the top of the crown, two from mid-level branches and two from lower branches). Morphological characters were described following established protocols, including the length, width, and weight of each pod. Pods were dissected to measure seed weight, pulp weight, and the number of seeds per pod.

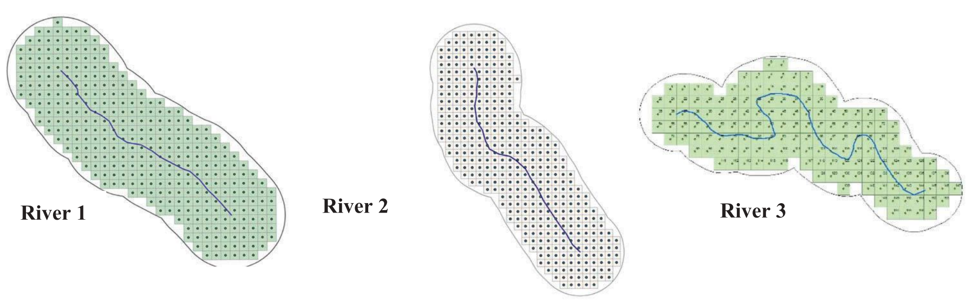

Figure 2. A grid scheme design for vegetation sampling along rivers.

Community knowledge regarding medicinal and food uses as well as management of tamarind was documented using a combination of structured interviews with general informants and semi-structured interviews with key informants. Structured interviews were conducted with 256 randomly-selected individuals, stratified by age, gender, and sub-district (Tongco 2007). Semi-structured interviews were conducted with eight key informants (four men and four women) in each sub-district, including two young adults (18 to 35 years old), four adults (36 to 60) and two elders (60 to 81).

Data analysis

Trees with DBH greater than 5 cm were included in further analysis following standard practice (Fandohan et al. 2010). To determine the population structure, diameter classes of 10 cm intervals were defined. Stem density was calculated as the number of tamarind individuals per hectare for each diameter class. To compare differences in density among land use types and sociocultural groups, the non-parametric Kruskal Wallis test was used, followed by the *post hoc* Dunn's Test, using the 'agricolae' and 'dunn.test' packages in R (version 3.5). The 'e1071′ R-package in R was used to test for the skewness of the diameter distribution. Two-sample t-tests were conducted to compare mean pod length, pod width, pod mass, pulp mass, seed mass, and the number of seeds per pod between sweet and sour morphotypes.

Frequency distributions of responses obtained during structured and semi-structured interviews were used to compare medicinal and food uses of tamarind between KSC and TSC. In addition, we analysed the explanations for change of tamarind populations provided by general informants in different communities and sociocultural groups. For those informants who reported a decline, explanations were coded following an open, iterative approach. Contingency tables of the number of informants providing similar explanations per community were subjected to correspondence analysis (CA) using the 'FactoMineR' and 'factoextra' packages in R.

Results

Density of tamarind by cultural group and land use

The densities of tamarind differed significantly between KSC and TSC areas in the two land use types ($p < .05$, Kruskal Wallis test, Figure 3). The density of tamarind in the KSC forest was significantly higher than all others, including KSC farmland. Similarly, the TSC forest showed significantly higher numbers of trees per hectare as compared to farmland. Densities of tamarind in TSC forest and farmland were similar (not significantly different) to those in the KSC farmland (see data in supplemental file).

In both communities and land use types, the diameter class distribution of tamarind followed a bell-shaped curve rather than an inverted J shape, indicating recruitment or regeneration problems (Figure 4). In DBH class 0–9 cm there was no tamarind in the forest habitat, and only a few were observed in the farmlands, indicating serious recruitment problems. The localities of KSC had consistently higher densities per diameter class; the exceptions were in farmlands, where trees in the 0–9 or 10–19.9 cm DBH classes were found

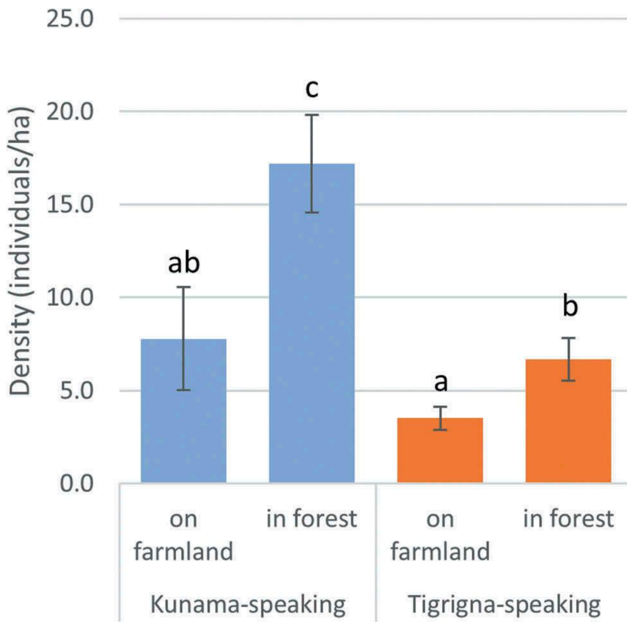

Figure 3. Mean density of tamarind by sociocultural group (KSC and TSC) and land use; error bars show standard error of the mean; letters indicate significant differences according to *post hoc* Dunn's test.

only in the TSC. Farmlands also had a slightly higher density of large diameter trees (DBH classes 70–79 and 80–89) than forest in both KSC and TSC (see data in supplemental file).

Phenotypic characteristics of the fruits of tamarind local morphotypes

Community knowledge of morphotypes

All informants in both KSC and TSC reported that there are two local morphotypes of tamarind with distinct local names. Key informants distinguished between sweet and sour trees by taste, pod number, pod size, and colour at ripening. The sour trees produce fewer fruits, have a thinner pod, and a light brown colour at ripening. In addition, the wood of sour trees is hard and brittle, meaning it is easily broken. Based on these characteristics, sour tamarind is considered to be 'male' by both KSC and TSC. By comparison, the sweet tamarind variety is considered female because it produces more fruits each year, has thicker pods that are reddish at maturity, and its wood is neither hard nor brittle.

Fruit morphology

Tamarind pods were observed to vary from curved to straight (Figure 5). The colour of the sour variety pods and fresh pulp are a light brown, while the sweet variety pods and fresh pulp are normally deep brown. Pod length, pod width, pod weight, seed weight, pulp weight, and the number of seeds per pod were consistently lower for sour tamarind compared to sweet tamarind ($p < .05$, t-test, Table 1). Average pod length of sour and sweet morphotypes was found to be 7.77 ± 0.09 cm and 8.52 ± 0.09 cm respectively (see data in supplemental file).

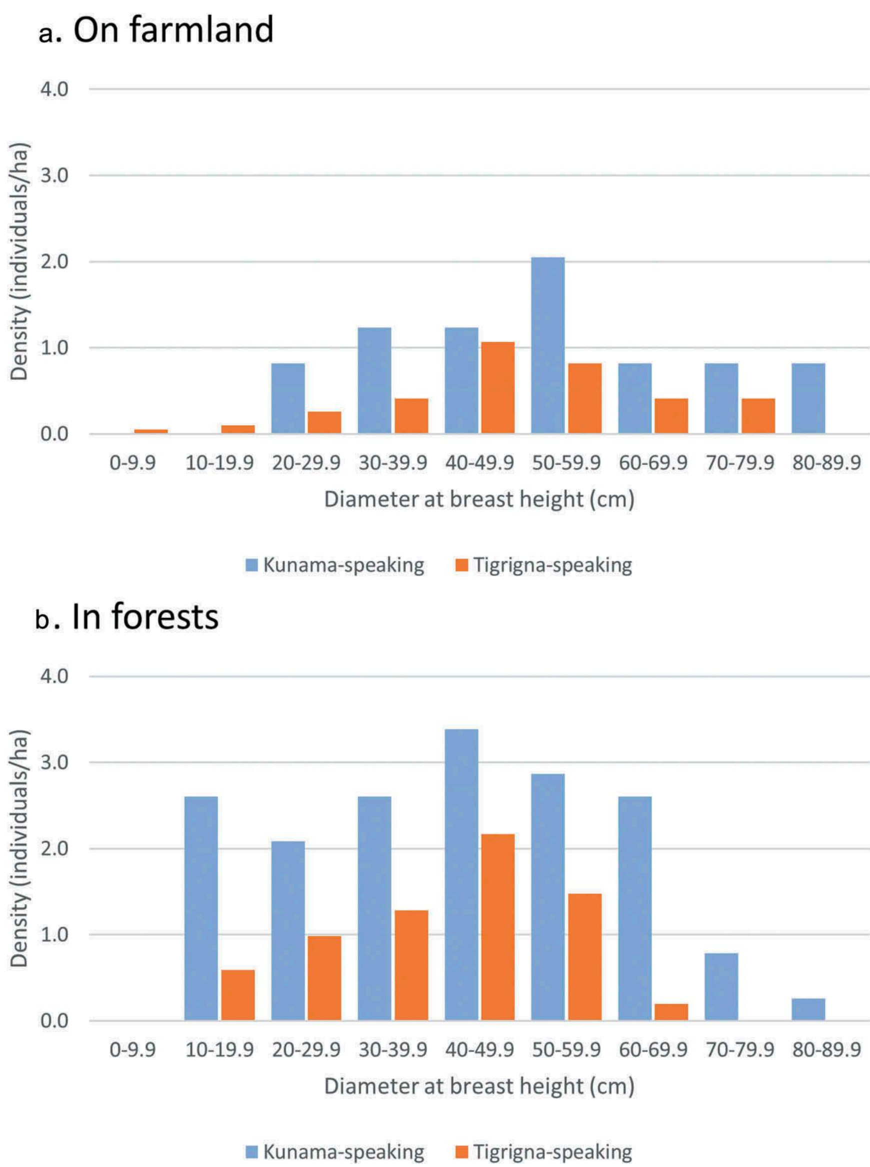

Figure 4. Comparison of population structure of tamarind (based on diameter size classes) in KSC versus TSC on farmland (a) and in forests (b).

Uses of tamarind by Kunama- and Tigrigna-speaking communities

Both the KSC and TSC use tamarind for medicine, food, timber, fodder, soil fertility, fuelwood, and shade (Figure 6). When asked about its primary use, among the KSC, most frequently it was cited for use in the order of medicine (28%), food (26%) and fodder (12%). By comparison, the TSC frequently said they use tamarind primarily as food (22%), medicine (17%) and timber (15%). Similar percentages of both groups mentioned using tamarind to improve soil fertility (14% KSC & 16% TSC), as fuelwood (17% both), and for shade (20% both). Analyses of informant characteristics showed no significant

Figure 5. Fruits from sweet (left) and sour (right) varieties of tamarind.

Table 1. Morphological characterization of tamarind fruits (n = 120), showing independent t-test values.

No	Variables	Variety	Mean±SE	p-value from t-test
1	Pod length (cm)	Sour	7.77 ± 0.09	$p = 1.134 \times 10^{-07}$
		Sweet	8.52 ± 0.09	
2	Pod width (cm)	Sour	1.43 ± 0.02	$p = 4.536 \times 10^{-07}$
		Sweet	1.64 ± 0.03	
3	Pod weight (g)	Sour	10.49 ± 0.37	$p = 9.501 \times 10^{-11}$
		Sweet	14.79 ± 0.47	
4	Seed weight (g)	Sour	2.95 ± 0.12	$p = 2.012 \times 10^{-13}$
		Sweet	4.76 ± 0.18	
5	Pulp weight (g)	Sour	4.76 ± 0.16	$p = 1.939 \times 10^{-10}$
		Sweet	6.62 ± 0.22	
6	Number of seeds/pod	Sour	5.52 ± 0.18	$p = 3.741 \times 10^{-07}$
		Sweet	6.91 ± 0.19	

relationships between reported use and the village, ethnicity, age, wealth class, gender or education of the informant as related with the level of tamarind use, on the whole, providing no evidence that tamarind use is determined by these factors and this translates to the entire population of the study area.

When it comes to the parts used for medicinal and food purposes, informants most frequently mentioned using tamarind fruits (73% in KSC and 67% in TSC) followed by pulp (15% in KSC and 20% in TSC) (Figure 7). The leaves, fruit, seed, and pulp of the tamarind are made into a drink to treat human ailments, whereas only the leaves are reported for use to treat livestock ailments (Figure 8).

The food use of tamarind was similar between KSC and TSC (Figure 9). KSC and TSC most commonly mentioned using tamarind as a sauce (38% and 56% respectively) and juice (31% and 19%).

The use of tamarind as a medicine varied between KSC and TSC (Figure 10). Tamarind is used as medicine for humans and livestock by both sociocultural groups. The KSC most frequently mentioned using tamarind for abdominal pain (31%), followed by skin

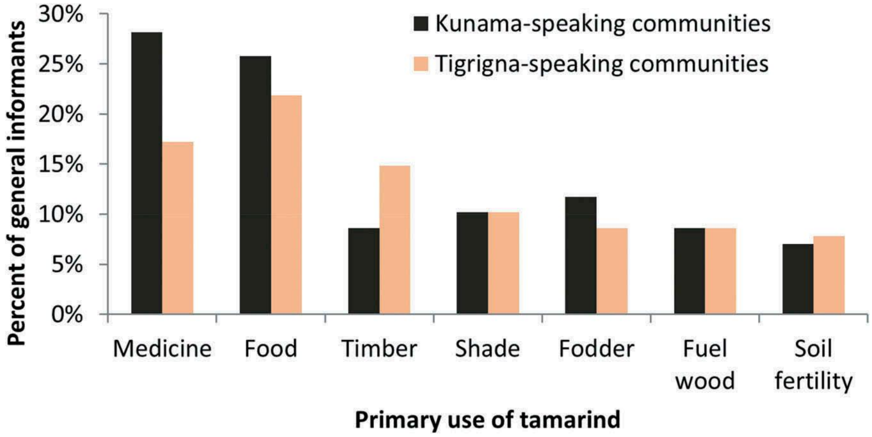

Figure 6. Primary use of tamarind by Kunama-and Tigrigna-speaking communities(n = 256).

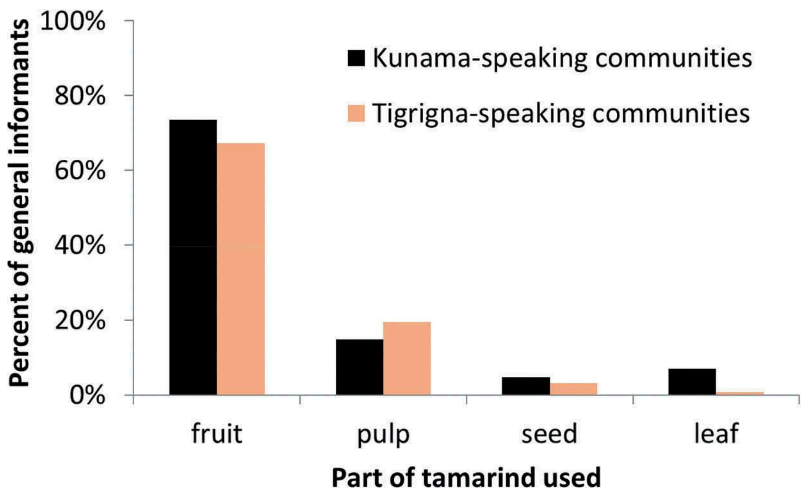

Figure 7. Tamarind parts used for food and medicine by Kunama- and Tigrigna-speaking communities (n = 256).

problems (13%) and malaria (13%), whereas the TSC reported using tamarind to treat abdominal pain (31%), malaria (31%), and giardia (13%). The KSC reported three medicinal uses of tamarind (for heart pain, as an anti-emetic, and to treat tapeworm) that were not mentioned by the TSC.

Factors threatening tamarind populations

The vast majority (87.1%) of general informants reported that tamarind populations are in decline, while 7.4% said that they are relatively stable and only 5.5% that they are increasing. Informants who reported decline provided 21 explanations, of which the most frequent (43.8%) was that tamarind is cut to fashion a traditional mortar (known locally as a MOGUE) to press sesame (*Sesamum orientale*) oil, a valuable agricultural

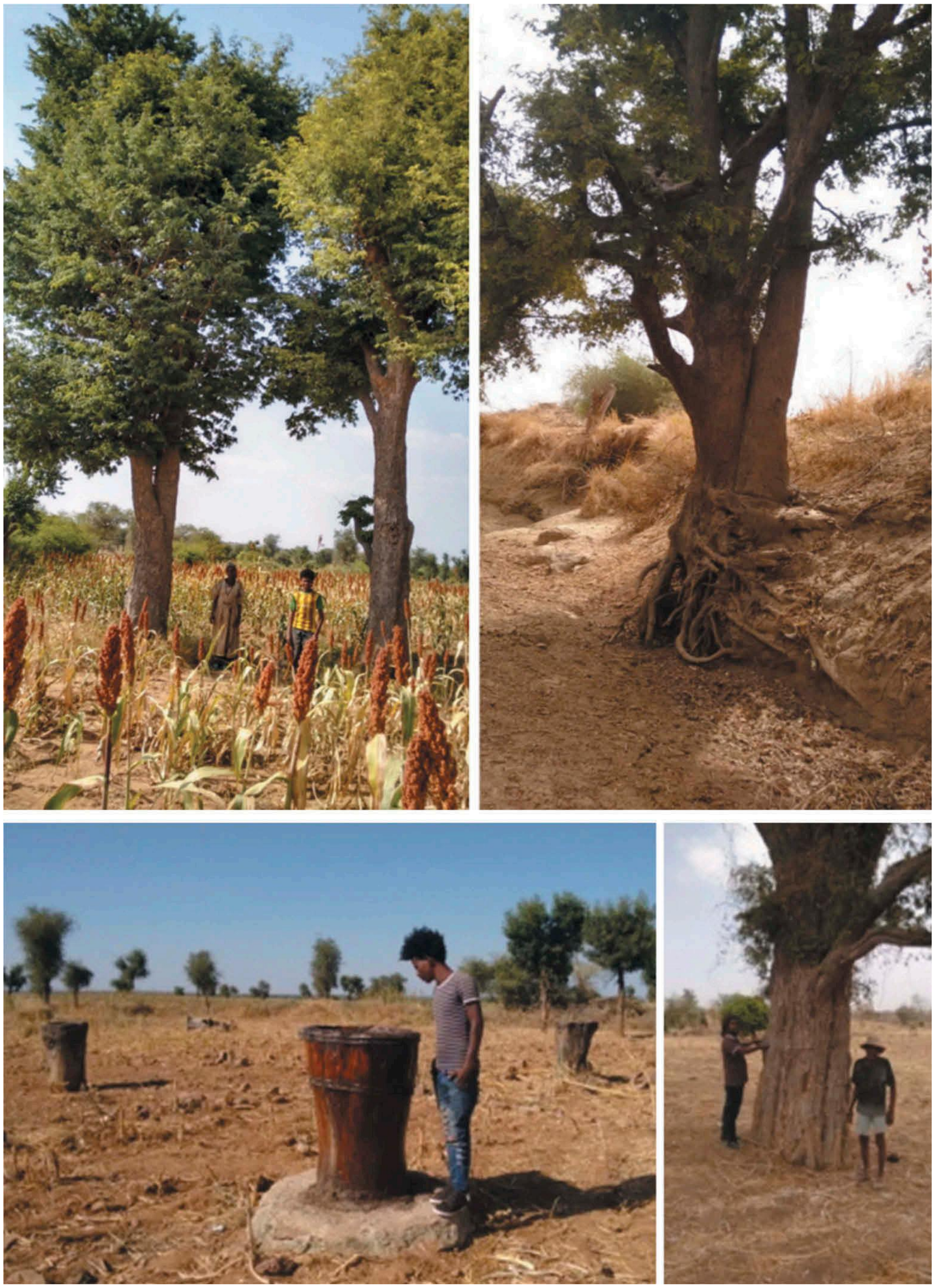

Figure 8. Tamarind (*Tamarindus indica*) in farmland (top left) and along a dry river bank (top right); stumps used for pressing sesame oil in the study areas (bottom left) and a large diameter tree (bottom right).

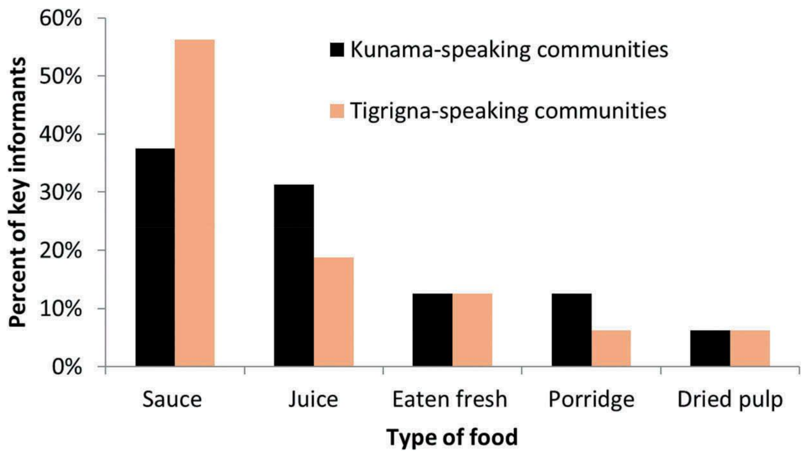

Figure 9. Types of foods prepared from tamarind fruit by Kunama- and Tigrigna-speaking communities (n = 32).

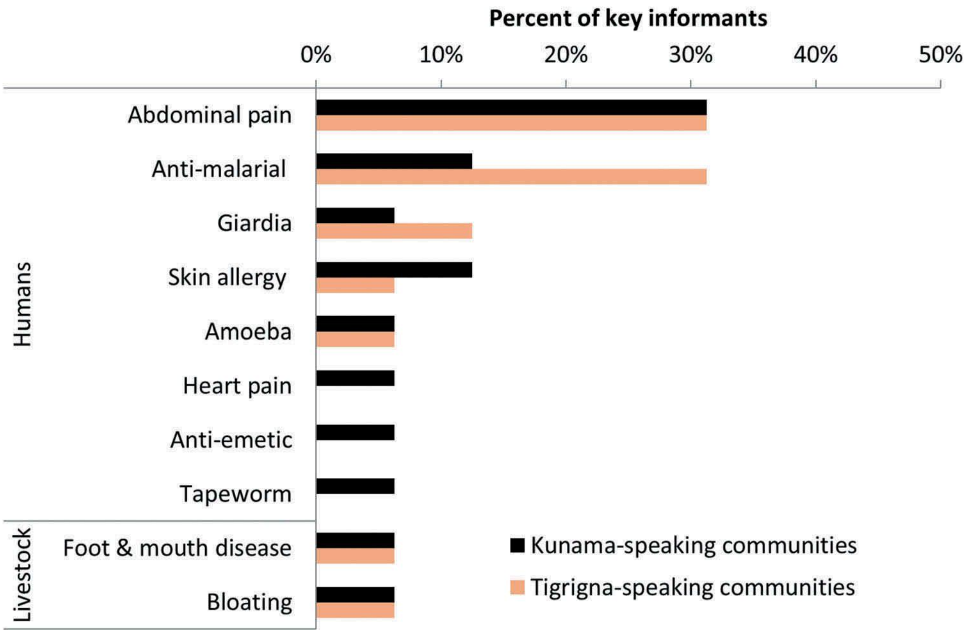

Figure 10. Use of tamarind as medicine for humans and livestock by Kunama- and Tigrigna-speaking communities (n = 32).

product. The next most common explanations were that tamarind is harvested for use as timber (35.9%), fuelwood (14.8%) and fodder (7.8%). In addition, 9.4% of informants attributed tamarind decline to illegal cutting and 6.3% to flooding (91.4%).

Correspondence analysis of the reasons for decline reveal differences among communities (Figure 11). The first two dimensions of the CA explained 48.1 and 33.1% of the variance in reasons for the decline (Figure 11a). Seven factors made more than a 5% contribution to the variance among communities, including illegal cutting, fuelwood

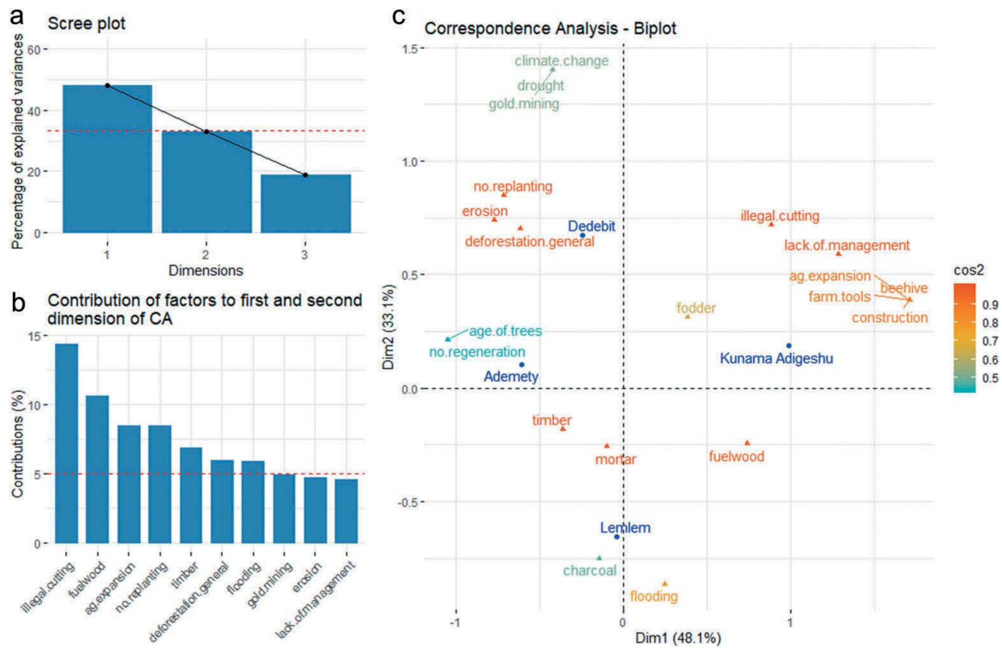

Figure 11. Correspondence Analysis (CA) of reasons for decline of tamarind populations reported by two Kunama- and two Tigrigna-speaking communities, including: (a) scree plot showing percent variance explained by the three dimensions of the CA, (b) Contributions of reasons for decline to the first two dimensions of the CA, and (c) Biplot of relationships between reasons for decline and communities, with colour indicating the degree of association.

collection, agricultural expansion, lack of replanting, timber harvest, deforestation in general, and flooding (Figure 11b). Reports of fuelwood collection were more frequently reported among the KSC (Lemlem and Kunama Adigesu, Figure 11c). Illegal cutting, lack of management, and agricultural expansion are associated with Kunama Adigesu, whereas soil erosion, lack of replanting, and general deforestation were more commonly reported in Dedebit (TSC). Use of tamarind as timber and specifically to fashion a traditional mortar were reported across all communities, hence their central location in the biplot (see data in supplemental file).

Discussion

Density of tamarind by cultural group and land use

The difference in density per hectare in this study showed differences according to land use type and ethnicity. Similarly, Fandohan et al. (2010) reported variation of tree density per hectare between habitat types in Benin: 18.2 ± 10 in gallery forests; 5 ± 4.5 in savannah woodlands; and 2.5 ± 0.4 in farmlands. Densities in forests in KSC areas are similar to those of gallery forests in Benin. Investigations of the factors contributing to tamarind growth have found higher densities along riverbanks (Axel and Maurer 2011), as well as associations with primates (Blumenfeld-Jones et al. 2006). The findings of this study and those cited above suggest that tamarind densities are higher in forests than farmlands, and therefore suggests that encroachment of farmers into riparian areas threatens the regeneration and *in situ* conservation of tamarind in their natural habitats (El-Siddig et al. 2006).

Overall, the data show that there are fewer larger diameter trees in the forest habitat as compared to the farmlands, even though there are more trees in the forest habitat. This may be an indicator that the larger diameter trees are selectively cut in the communal forest habitat and maintained in the private farmlands. The only 0–9 cm DBH tamarind stems were found in private farmlands, as opposed to communal forest habitats. Though the forest habitat is less disturbed than the farmlands, the lack of regeneration, particularly in the TSC, is a potential cause for concern. Fandohan et al. (2010) found that there was a serious regeneration problem in Benin, with the riverine forest having 10-fold higher rates of regeneration than the savanna woodland. They also found there was no regeneration in the farmlands, while in our study the only recent regeneration was found in farmlands. Though tamarind density is higher in the forest habitat, (Fandohan et al. 2010; Axel and Maurer 2011), the lack of regeneration suggests a lack of care given to emerging seedlings in the open-access forest habitat as opposed to care given in the privately-owned farmland. Other possible explanations are allelopathic competition (Shahnaz Parvez et al. 2003) and/or mycorrhizal associations (Bourou et al. 2010), both requiring further research to improve land management and ensure effective regeneration for the future.

Phenotypic characteristics of the fruits of tamarind local morphotypes

Community knowledge of morphotypes

Community knowledge and characterization of tamarind trees and fruits were consistent with studies by Fandohan et al. (2011b). It appears that the main criterion used by communities in differentiating between tamarind morphotypes is taste. Other studies have found variation in fruit tartaric acid and sugar content between genotypes, with the sweet morphotypes having more sugar and less tartaric acid (El-Siddig et al. 2006) than sour ones. In Ethiopia, it is common to name crop varieties ‘male’ or ‘female’ according to their characters and use, for example as has been documented with enset (*Ensete ventricosum*, Musaceae), a banana-like tree that is commonly cultivated in the south and southwestern parts of the country (Bizuayehu 2008). This has implications in conservation, as the local knowledge of diversity can be used to ensure it is monitored and maintained for future use and long-term sustainability.

Fruit morphology

Fruit morphology was significantly different between the two locally-recognized morphotypes. The two morphotypes observed were smaller than those measured in Uganda by Okello (2010), who reported an average pod length of 11.69 cm and width of 3.12 cm. A study of tamarind in India reported average pod length of 11.20 cm; pod width of 2.00 cm; pod weight of 18.15 gram; pulp weight of 9.65 gram; and seed weight of 5.9 gram, all higher than the measurements taken in our study (Sinha 2010). A third study from the humid Guineo-Congolian region found that pod and pulp mass, as well as the number of seeds per pod, varied significantly, but did not result in significant variation in fruit yield per tree (Fandohan et al. 2011b). In comparison, our study found that the sweet tamarind trees produced more fruit pulp, seed, seed size and weight than the sour trees. This has implications for the domestication, improvement, use, and development of the fruit of tamarind. For example, since it appears that pulp mass and sweetness are associated, breeders would likely be able to increase volume and improve the taste of Ethiopian tamarind.

Uses of tamarind by Kunama- and Tigrigna-speaking communities

Studies from other parts of Africa have documented how tamarind provides multiple uses to local communities. For example, a study in Uganda listed 18 uses of tamarind, including as a beverage, food, windbreak, for oral hygiene, shade, flavouring, aesthetic purposes, firewood and charcoal, teaching aid (the seeds are used as beads for counting and educational games), food preservative, source of income, construction material, feed for livestock, tool handle, mulch, support for plants, and a medicine for both humans and livestock (Ebifa-Othieno et al. 2017). Although 100% of the Ugandan respondents reported using tamarind for food, only 15% reported using it for medicine, including 13% who use it for veterinary medicine. By contrast, the present study shows that tamarind is valued as both a food and medicine in Tigray. In this case, tamarind is not only an agroforestry tree, but also a valuable nutraceutical plant.

The food use of tamarind is one of its primary values. In a study in Uganda (Ebifa-Othieno et al. 2017) tamarind was mentioned for being used as a beverage by all respondents, whereas in our study, only 31% of key informants in KSC reported drinking tamarind juice, and fewer in TSC. By contrast, the more common use of tamarind as food by both sociocultural groups is as a sauce; sauces are a prominent feature of Ethiopian cuisine. Finally, another food-related use of tamarind is that its stumps are used as a mortar for pressing sesame seeds to extract the edible oil. In a study in neighbouring Eritrea, this use was shown to have contributed to the destruction and loss of tamarind populations (Bein et al. 1996).

The uses of tamarind as medicine are similar to those reported by other cultural groups in Africa. For example, the Giziga of Cameroon use tamarind leaves, bark, and fruit pulp to treat malaria (Saotoing et al. 2011) a practice quite similar to the one reported by 31% of informants in the TSC. In Nigeria, because tamarind seeds are sources of zinc, they are used to make porridge commonly consumed during pregnancy (Keen and Zidenberg-Cherr 1994; Lockett et al. 2000). Also in Nigeria, tamarind is used to treat trypanosomiasis in domestic animals (Atawodi et al. 2002).

Medicinal use of tamarind, especially that of the sour morphotype, was appreciated by the informants in this study. Other ethnobotanical studies in the Tigray Region concur that tamarind fruits are used for treating abdominal problems and hypertension (Zenebe et al. 2012; Darcha and Birhane 2015). Tamarind is also used for abdominal problems in southern Ethiopia, as well as to treat diarrhoea and as an anti-emetic (Kidane et al. 2014). In our study, a small proportion of key informants from both sociocultural groups reported using tamarind leaves to treat livestock for foot and mouth disease (6%) and bloating (6%). Gidey et al. (2015) reported that KSC use tamarind as a medicine for humans and livestock since ancient times; however, their study found that tamarind's medicinal use was limited to dermal infections (locally called HAMOT). The present study documents its use to treat a wider array of ailments by both cultural groups.

Factors threatening tamarind conservation

This study clearly shows that tamarind in Tigray are under threat as there was little to no recent recruitment detected in the vegetation survey and close to 90% of general informants reported population decline. That nearly half of these informants explained that tamarind is used to fashion traditional mortars for sesame oil suggests that finding an alternative material to serve that purpose may contribute to tamarind conservation. Though not reported as one of the top factors the fuelwood deficit in Tigray is one of the main causes of deforestation and forest degradation, including in areas where tamarind grows (Zenebe et al. 2012). Although fuelwood collection was more frequently identified in KSC, general deforestation reported in TSC may be attributed (at least in part) to fuelwood collection. Key informants mentioned other practices (debarking for medicine, pruning for fodder and fruit harvest) that might pose threats to tamarind. Overall, the people using and living around tamarind recognize its value and that it is under threat from natural and anthropogenic factors, and identify improved riparian forest management and better management of individual trees on farm as the keys to protecting its populations.

Conclusions and recommendations

The future of tamarind populations in Tigray will likely rely on the protection of naturally-regenerating trees. Diameter size distributions showed a bell-shaped curve, indicating a serious problem in regeneration across both communities and habitats. However, there were significantly higher densities of trees in forest habitat, particularly in those associated with KSC, indicating that those communities may be particularly knowledgeable about how to manage its populations. Nonetheless, both communities recognize that tamarind is under threat and requires attention to improve possibilities for sustainable use. Conservation efforts should focus on identifying alternative timber and fuelwood sources, as well as materials for traditional mortars; enhancing recruitment by protecting seedlings and saplings; and supporting local governance to curb illegal cutting.

Significant differences in morphological characteristics were observed between sweet and sour morphotypes of tamarind. In general, sweet tamarind fruits were larger than those of sour morphotypes. The morphological evidence and community knowledge differentiating these two morphotypes highlights the need for conservation of their populations in northern Ethiopia. While this research demonstrated phenotypic variation between the morphotypes recognized by local communities, a more detailed study that includes genetic analyses is necessary for conservation of intraspecific diversity. In addition, further scientific analysis is needed to evaluate the uses of tamarind as medicine. Research to identify the active compounds responsible for the medicinal benefits identified by key informants can be used to encourage the sustainable use of the tree and make it available to a larger population.

Both KSC and TSC use tamarind for food, medicine, mortars, fuelwood, and fodder. Both communities use and therefore value the tree in similar ways and are concerned by recent population decline. New conservation strategies should be designed through discussion with the local communities, using their knowledge to ensure that recruitment is enhanced and diversity of morphotypes is maintained, so that this valuable resource continues to contribute to their food and livelihood security.

Acknowledgements

The research team would like to acknowledge all of the farmers in the study area, including the general and key informants who generously shared their knowledge about tamarind. We thank Muluberhan Tesfay, Awot Birhane, Muez Tesfay, and Zewde Simegnew for their assistance conducting interviews. We acknowledge support from Mekelle University, BoARD of Kolla Tembien Woreda (District), and the other members of the Legume Diversity Project team. We are grateful to Ric Coe for assistance with the sampling design for the vegetation survey. This work was supported by the McKnight Foundation Collaborative Crop Research Program under Grant #15-258.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the McKnight Foundation [Collaborative Crop Research Program under Grant #1 to 15-258].

ORCID

Sarah Tewolde-Berhan http://orcid.org/0000-0002-6296-3043
Hadgu Hishe http://orcid.org/0000-0002-4026-5957
Zemede Asfaw http://orcid.org/0000-0002-2469-8808
Morgan Ruelle http://orcid.org/0000-0002-4999-9308

References

Arbonnier M. 2004. Trees, shrubs and lianas of West African dry zones. France, Paris: Centre for International Cooperation in Research and Agricultural Development (CIRAD).

Atawodi SE, Ameh DA, Ibrahim S, Andrew JN, Nzelibe HC, Onyike EO, Anigo KM, Abu EA, James DB, Njoku GC, et al. 2002. Indigenous knowledge system for treatment of trypanosomiasis in Kaduna State of Nigeria. J Ethnopharmacol. 79:279–282.

Axel AC, Maurer BA. 2011. Lemurs in a complex landscape: mapping species density in subtropical dry forests of southwestern Madagascar using data at multiple levels. Am J Primatol. 73:38–52.

Bein E, Habte B, Jaber A, Birnie A, Tengnas B. 1996. Useful trees and shrubs in eritrea. identification, propagation and management for agricultural and pastoral communities. Technical. Kenya, Nairobi: Regional Soil Conservation Unit, RSCU.

Bekele-Tesemma A. 2007. Useful trees and shrubs for Ethiopia: identification, propagation and management for 17 agroclimatic zones.Kenya, Nairobi: Regional Soil Conservation Unit, Swedish Development Authority.

Bizuayehu T. 2008. On Sidama folk identification, naming, and classification of cultivated enset (*Ensete ventricosum*) varieties. Genet Resour Crop Evol. 55:1359–1370.

Blumenfeld-Jones K, Randriamboavonjy TM, Williams G, Millhollen A, Pinkus S, Rasamimanana H. 2006. Tamarind recruitment and long-term stability in the gallery forest at Berenty, Madagascar.

In: Jolly A, Sussman R, Koyama N, Rasamimanana H, editors. Ringtailed lemur biol. 69-85. New York: Springer.

Boffa J-M. 1999. Agroforestry Parklands in Sub-Saharan Africa. In: FAO conserv guid. Kenya, Nairobi: Food and Agriculture Organization of the United Nations.

Bourou S, Ndiaye F, Diouf M, Diop T, Van Damme P. 2010. Tamarind (*Tamarindus indica* L.) parkland mycorrhizal potential within three agro-ecological zones of Senegal. Fruits. 65 (6):377–385.

Darcha G, Birhane E. 2015. Biomass and carbon sequestration potential of *Oxytenanthera abyssinica* in the homestead agroforestry system of Tigray, Ethiopia. J Nat Sci Res. 5:69–78.

Diallo B, Joly H, McKey D, Hosaert-mckey M, Chevallier M. 2007. Genetic diversity of Tamarindus indica populations: any clues on the origin from its current distribution? African J Biotechnol. 6:853–860.

Ebifa-Othieno E, Mugisha A, Nyeko P, Kabasa JD. 2017. Knowledge, attitudes and practices in tamarind (*Tamarindus indica* L) use and conservation in Eastern Uganda. J Ethnobiol Ethnomed. 13:1–13.

[EIAR] Ethiopian Institute of Agricultural Research. 2011. New agroecological map of Ethiopia. Coordination of national agricultural research system, Ethiopia. Addis Ababa:EIAR.

El-Siddig K, Gunasena HPM, Prasad AB, Pushpakumara DKNG, Ramana KVR, Vijayananand P, Williams JT. 2006. Fruits for the future. Tamarind. (*Tamarindus indica* L.). Southampton (UK): Southampton Centre for Underutilized Crops.

Fandohan AB, Assogbadjo AE, Glele Kakaï RL, Sinsin B, Van Damme P. 2010. Impact of habitat type on the conservation status of tamarind (*Tamarindus indica* L.) populations in the W National park of Benin. Fruits. 65:11–19.

Fandohan B, Assogbadjo AE, Kakaï RG, Kyndt T, Sinsin B. 2011a. Quantitative morphological descriptors confirm traditionally classified morphotypes of *Tamarindus indica* L. fruits. Genet Resour Crop Evol. 58:299–309.

Fandohan B, Assogbadjo AE, Kakaï RG, Sinsin B. 2011b. Geographical distribution, tree density and fruit production of *Tamarindus indica* L. (Fabaceae) across three ecological regions in Benin. Fruits. 66:65–78.

Friis I, Demissew S, Breugel P. 2011. Atlas of the potential vegetation of Ethiopia. Addis Ababa: Addis Ababa University Press and Shewa Press.

Gidey M, Beyene T, Signorini MA, Bruschi P, Yirga G. 2015. Traditional medicinal plants used by Kunama ethnic group in Northern Ethiopia. J Med Plants Res. 9:494–509.

Keen CL, Zidenberg-Cherr S. 1994. Should vitamin-mineral supplements be recommended for all women with childbearing potential? Am J Clin Nutr. 59:532S–539S.

Kendie G, Addisu S, Abiyu A. 2019. Biomass and soil carbon stocks in different forest types, Northwestern Ethiopia. Int J River Basin Manag. Online Fir:1–7.

Kidane B, van der Maesen LJG, van Andel T, Asfaw Z, Sosef MSM. 2014. Ethnobotany of wild and semi-wild edible fruit species used by Maale and Ari ethnic communities in Southern Ethiopia. Ethnobot Res Appl. 12:455–472.

Lockett CT, Calvert CC, Grivetti LE. 2000. Energy and micronutrient composition of dietary and medicinal wild plants consumed during drought. Study of rural Fulani, Northeastern Nigeria. Int J Food Sci Nutr. 51:195–208.

Okello J 2010. Morphological and nutritional characteristics of *Tamarindus Indica* (Linn) Fruits in Uganda [Master's thesis]. [Kampala]: Makerere University.

Pan AD, Jacob BF, Herendeen PS. 2010. Detarieae *sensu lato* (Fabaceae) from the late oligocene (27.23 Ma) Guang river flora of north-western Ethiopia. Bot J Linn Soc. 163:44–54.

Saotoing P, Toua V, Tchobsala FFNT, Nloga AMN, Messi J. 2011. Medicinal plants used in traditional treatment of malaria in Cameroon. J Ecol Nat Environ. 3:104–117.

Shahnaz Parvez S, Masud Parvez M, Fujii Y, Gemma H. 2003. Allelopathic competence of *Tamarindus indica* L. root involved in plant growth regulation. Plant Growth Regul. 41:139.

Sinha AK. 2010. Performance evaluation studies on tamarind dehuller-cum deseeder. [place unknown]: Indira Gandhu Krishi Vishwavidyalaya.

TAWoARD. 2015. Tahtay adiyabo woreda office of agriculture and rural development annual report. Sheraro, Tigray.

TAWoRLA. 2015. Tahtay adiyabo woreda office of rural land administration annual report. Sheraro (Tigray).

Thulin M. 1989. Papilionoideae. In: Hedberg I, Edwards S, editors. Flora Ethiop pittosporaceae to araliaceae. Addis Ababa (Ethiopia): The National Herbarium.

Tongco MDC. 2007. Purposive sampling as a tool for informant selection. Ethnobot Res Appl. 5:147–158.

Zenebe G, Zerihun M, Solomon Z. 2012. An ethnobotanical study of medicinal plants in Asgede Tsimbila District, Northwestern Tigray, Northern Ethiopia. Ethnobot Res Appl. 10:305–320.