The baobab tree in Malawi

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Abstract — **Introduction**. The baobab tree's potential overexploitation has recently been reinforced by the acceptance of baobab fruit pulp in the EU and US food markets. Despite the number of recent studies on this species, *Adansonia digitata,* little is known from Malawi, the main exporter of baobab fruit pulp in Africa. **Materials and methods**. Information on distribution and density of baobab trees present in Malawi was gathered from field surveys. The Maxent software based on the maximum-entropy approach for species habitat modelling was used together with spatial environmental data and geo-referenced records of the baobab tree to analyse its ecological preferences and potential cultivation sites. Farmers were interviewed about who was using and buying baobab fruits in different areas. Fruit and leaf morphological diversity was assessed in eight study sites selected along a latitudinal gradient. **Results and discussion**. The baobab tree was found to be widely distributed in southern Malawi, with variable densities. Modelling results show that this species could be cultivated in most of the southern region. A large morphological diversity in both fruit and leaf characteristics was observed, which gives the opportunity to select more desirable characters for cultivation. **Conclusion**. Our study showed that, while some areas of high baobab tree density could be further exploited, its cultivation, however, should be recommended in areas with low density of baobab trees in southern Malawi because there is little natural regeneration. Moreover, this study suggested that there is room for selecting baobab planting material with desirable characteristics for cultivation purposes in Malawi.

Malawi / *Adansonia digitata* / geographical distribution / population density / traditional uses / multiple use / biodiversity / agronomic characters

Le baobab au Malawi.

Résumé — **Introduction**. Une possible surexploitation du baobab (*Adansonia digitata*) a récemment été renforcée par l'acceptation de la pulpe du fruit de baobab sur les marchés alimentaires de l'UE et américains. Malgré de nombreuses études récentes sur cette espèce, peu de choses sont connues sur *A. digitata* au Malawi, principal exportateur de pulpe de fruit de baobab en Afrique. **Matériel et méthodes**. Des informations sur la distribution et la densité des baobabs au Malawi ont été recueillies à partir d'enquêtes de terrain. Le logiciel Maxent, basé sur le calcul du maximum d'entropie pour la modélisation de l'habitat d'une espèce, a été utilisé en même temps que des données spatiales et géo-référencées de l'environnement étaient enregistrées sur les baobabs afin d'analyser leurs préférences écologiques et leurs sites de culture potentiels. Des agriculteurs ont été interrogés pour savoir qui exploitait et achetait les fruits de baobab dans différents régions. La diversité de la morphologie des fruits et des feuilles a été évaluée dans huit sites d'étude choisis le long d'un gradient latitudinal. **Résultats et discussion**. Le baobab s'est révélé être largement distribué dans le sud du Malawi, à des densités variables. Les résultats de la modélisation montrent que cette espèce pourrait être cultivée dans la plupart de la région-sud du pays. Une grande diversité morphologique des fruits et des caractéristiques de feuilles a été observée, ce qui offrirait la possibilité de sélectionner des caractères plus intéressants pour la culture. **Conclusion**. Notre étude a montré que, si certaines zones à forte densité de baobab pourraient être davantage exploitées, sa culture devrait être cependant recommandée dans les zones à faible densité de baobabs au sud du Malawi car il y a peu de régénération naturelle. Par ailleurs, notre étude suggère que, au Malawi, il existe une place pour la sélection de matériel de plantation de baobab ayant des caractéristiques intéressantes pour sa culture.

Malawi / *Adansonia digitata* / distribution géographique / densité de population / utilisation traditionnelle / utilisation multiple / biodiversité / caractère agronomique

1. Introduction

The baobab tree (*Adansonia digitata* L., family Malvaceae) is a prime candidate for domestication in the semi-arid regions of Africa [1]. Ecologically, the baobab tree can withstand drought more easily than many annual crops. It has no significant pests or diseases and it does not require water or fertiliser [2]. The fruits are economically important locally, where they can be used as food and medicine, and internationally, where the pulp can be used in the food, pharmaceutical and cosmetic industries [3, 4]. More than 300 uses have been reported for different baobab tree parts in a recent study carried out in West Africa [5]. At the moment, fruit production results from gathering activities which might lead to overexploitation of natural stands, a growing concern after EU acceptance of baobab fruit pulp as a food ingredient in July 2008 and the US acceptance in July 2009.

The domestication and cultivation of the baobab tree is necessary to protect the natural stands of this species and to provide a sustainable source of income to local populations. In order to contribute towards the effective domestication of this species, several studies have been focused on baobab tree ecology, morphological, chemical and genetic characterisation, utilisation, and indigenous knowledge, mainly in West Africa [5–10]. However, little information is available from Malawi, the main exporter of baobab fruit pulp to Europe (C. Dohse 2009, pers. comm.), a country where the baobab tree is one of the species used by commercial fruit processors [11] and the local consumption has dramatically increased in the last 5 years (D. Mauambeta 2009, pers. comm.).

In Malawi, baobab fruit pulp is eaten raw or it is mixed with porridge [12, 13]. It is also processed into juice and ice-lollies. Seeds are roasted and eaten. Fruit shells are used as fuel in fish smoking, especially in the lakeshore areas. Shells can also be burned and the ashes turned into baking soda. Fibre from bark is used to make ropes, mats, hats and crafts [12]. Apart from these local uses, some baobab products are commercialised nationally or internationally. Among the nationally commercialised products there are baobab seed coffee, baobab seed oil for cooking, baobab juice, baobab jam and baobab fruit pulp powder (pers. obs.). Internationally, baobab fruit pulp powder and baobab seed oil are sold as a food ingredient and for cosmetic use, respectively. Sometimes, in order to meet the actual demand, local processors import fruits from Mozambique (D. Zuzanani 2009, pers. comm.). Without research, it cannot be determined if the resource base (baobab trees) will suffer because of an increase in harvesting or if harvesting can be supplemented by cultivation. The aim of our paper was: (i) to assess the distribution, density and ecology of *A. digitata* L. in Malawi, (ii) to predict potential sites for its cultivation, (iii) to determine the local utilisation of the fruits, and (iv) to help identify superior planting material.

2. Materials and methods

2.1. Study site

Malawi has a sub-tropical climate, with climatic differences more related to altitude than latitude. The climate changes from semi-arid in the Lower Shire Valley, semi-arid to sub-humid on the plateaus and sub-humid in the highlands. There is a warm-wet season during which 95% of the annual precipitation takes place, a cool dry season and a hot dry season. Humidity ranges from 50% (September-October) to 87% (January-February). Malawi's vegetation is reflective of its diverse climate and terrain**.** Dry lowland areas are largely savannah, while Miombo *(Brachystegia)* woodland stretches out along barren slopes, and plateaus, grassland and forest are found in the highlands. Although all of Malawi is in the Zambezian zone of White [14], Hardcastle [15] identified several silvicultural zones. Malawi is one of the most densely populated countries in southern Africa. The majority of the population relies on agriculture; most are subsistence farmers living on less than 1 USD per day [16].

2.2. Distribution and density

Information on distribution was gathered from several sources, including unpublished scientific reports, an NGO (Phytotrade Africa), a commercial firm (Tree Crops Ltd.), the National Herbarium, the Forestry Research Institute of Malawi (FRIM), KEW gardens and field surveys. Some of the acquired data contained GPS coordinates representing collection sites but others had to be geo-referenced using the Geographic Names database (from the National Geospatial-Intelligence Agency) and Google Earth. In total, 482 geo-referenced baobab presence records were assembled (*table I*) and used for the modelling (see section 2.4.).

In order to gather information on baobab tree densities, field surveys were conducted. During those, baobab locality data was obtained with a GPS and baobab density was estimated visually using a categorical scale: 0 (no trees), 1 (one isolated tree only in the landscape), 2 (2 or 3 trees only), 3 (a few scattered trees), 4 (about 1-2 trees per ha), 5 (> 2 trees per ha).

Table I.
Number of assembled records of geo-referenced baobab trees (*Adansonia digitata*) present in Malawi, presented per source (without duplicates).

Source	Number of records
KEW Herbarium	2
A.S. Larsen	2
Phytotrade Africa	8
Forest Research Institute of Malawi	24
National Herbarium of Malawi	4
Tree Crops Ltd.	25
A. Cuni Sanchez (the author)	417
TOTAL	482

2.3. Local utilisation of baobab fruits

With the aim of having a general view of who was using the baobab fruits and for what purpose, several farmers and baobab processing companies in different areas of Malawi were interviewed following a small semi-structured interview. Participants were interviewed on a voluntary basis; male and female, young and old farmers participated. As the aim of these interviews was to capture a broad view, results were reported qualitatively, not quantitatively.

2.4. Ecology and potential cultivation sites

Maxent (v. 3.2) [17], a niche-based model for presence-only data, was used to analyse baobab tree distribution in Malawi and its ecological preferences. Maxent predicts the potential distribution of a species by estimating the probability distribution of maximum entropy across a specified region, subject to a set of constraints that represent the missing information (lack of absence data) about the target distribution [17]. The Maxent method was selected because it outperforms other presence-only methods [18]. For the analyses, twenty GIS data layers (19 climatic and altitude) from the WorldClim Global Climate GIS database [19, 20], and one GIS data layer from the Harmonized World Soil Database [21] and the Soil Map of Malawi [22] were used. The resolution of the layers was ~1 km at the equator. Although 21 layers were used in the beginning, some were eliminated during modelling due to their low contribution to the final model. This was the case of the Soil Map of Malawi [22]. However, as this soil layer had very detailed information and it seemed interesting to analyse the characteristics of the soils the baobab tree prefers (which have been suggested to be a broad range, see Sidibé and Williams [2]), we analysed this soil layer separately. Maxent default settings were used. Model evaluation and the selection of a threshold between suitable and unsuitable areas were carried out following results published by Cuni Sanchez *et al.* [23].

2.5. Fruit and leaf morphological diversity

Eight study sites were selected following a latitudinal gradient with the main criterion being high baobab tree density and accessibility (*table II*). Five trees with 2.5–3.5 m DBH (diameter at breast height) and 100 m

Table II.
Ecological characteristics of eight study sites selected along a latitudinal gradient in Malawi, where baobab trees were observed, with respect to the silvicultural zones of Hardcastle [15]. (Zone Ba: altitude range of 200 m to 700 m, mean annual temperature of 22–25 °C, annual precipitation between 700 mm and 840 mm; zone A: average altitude of less than 200 m, mean annual temperature of 25 °C, annual precipitation between 700 mm and 840 mm.)

Study site	Latitude	Longitude	Silvicultural zone	Altitude (m)[a]	Annual rainfall ($mm \cdot year^{-1}$)[a]	Mean annual temperature (°C)[a]
Balaka	15°7'52'' S	35°1'40'' E	Ba	520	981	23.5
Chantulo	14°19'31'' S	34°46'52'' E	Ba	500	886	24.5
Chipoka	14°0'10'' S	34°30'0'' E	Ba	500	1012	24.5
Kalasamba	15°23'14'' S	34°47'36'' E	Ba	400	940	24.3
Likoma	12°3'59'' S	34°43'59'' E	-	407	1244	25.2
Mangochi	14°25'17'' S	35°12'43'' E	Ba	490	843	24.5
Mtonga	13°45'44'' S	34°20'11'' E	Ba	530	1017	23.9
Nchalo	16°20'11'' S	34°51'37'' E	A	95	794	26.2

[a] Data obtained from the Worldclim data [19, 20].

apart were randomly selected in each study site for fruit analyses and 10 trees for leaf analyses. The height of each tree and the DBH were recorded using an electronic clinometer and a decametre. Ten ripe fruits were selected from each tree and several characteristics were measured: fruit length, fruit weight, pulp weight, pulp percentage (of the total fruit weight), number of seeds, single seed weight and seed length. Single seed weight was calculated by dividing the combined seed weight by the number of seeds in the fruit. Due to the limited number of fruits available from some trees, more fruits were collected from some trees than from others in order to have 50 fruits per study site. Ten fully developed leaves were selected from ten trees in seven of the eight study sites analysed for fruit morphological characterisation. Therefore, the Likoma site could not be included due to time constraints. Leaf size and shape measurements and stomatal characteristics were determined following the methodology of Cuni Sanchez *et al.* [24].

2.6. Data analyses

Even though samples were collected from individual trees, fruit and leaf morphological data were pooled over study sites. Due to lack of normality and homogeneity of variance, Kruskal-Wallis tests were used to determine significant differences in fruit and leaf morphology among study sites. Post-hoc pairwise multiple comparisons were performed using Mann-Whitney tests. Correlations were tested using Spearman's rank correlation coefficient. Statistical analyses were carried out using SPSS for Windows v. 17.0.

3. Results

3.1. Distribution and density

The baobab tree was found to be widely distributed in the southern region of Malawi, and along the lakeshore in the central and northern regions (*figure 1*). High baobab tree densities were mainly observed in the southern lakeshore (black squares, *figure 1*). It should be noted that baobab tree distribution is often clumped. Thus, a few adjacent hectares might have high baobab tree density, whereas a few kilometres away from this location, baobab tree density might decrease to 1 individual per ha or even less. In total, more than 2 individuals per ha were found in 39 out of 437 sites surveyed. As we estimated maximum densities, our estimates are not representative of the whole area or district.

3.2. Local utilisation of baobab fruits

Areas with high baobab tree density seem to be exploited at different intensity levels. Fruits from the Mangochi area and the southern lakeshore were commonly collected and sold to: (i) vendors who take them to other major cities, (ii) two commercial companies (based in Mangochi) producing baobab juice, and (iii) a commercial company (based in Lilongwe) which produces baobab fruit pulp powder. Baobab fruits from Mangochi were even used by a small company in Kwam'mbamba (close to Kalasamba) producing fruit juice. However, baobab fruits from other high-density areas (Nchalo and Lisungwi River, the latter being close to Kalasamba) were not sold far from the harvesting area.

3.3. Ecology and potential cultivation sites

The Maxent model performed well in terms of Area under the ROC curve (AUC) values (0.94). The AUC is a measure of model performance; the closer the AUC's value to 1 the better [24]. The partition of some records in testing and training locations, also used in model evaluation [24], gave high AUC values (> 0.9). The predicted present distribution also showed good agreement with data from the literature.

The Maxent model indicated that the presence of the baobab tree in Malawi is mainly determined by the mean temperature of the warmest quarter (4-month period) and altitude, which contributed 36% and 29% to the final model, respectively. Precipitation of the drier quarter and precipitation seasonality (standard deviation of the annual precipitation) also significantly contributed to the final model (9% and 5.5%, respectively). Overall, the results indicated that the baobab tree has a preference for low altitudes (0–800 m), a mean temperature of the warmest quarter between 25 °C and 30 °C, low precipitation of the drier quarter (< 80 mm), high precipitation seasonality and low annual precipitation (600–1100 mm).

In regard to soil type (FAO classification [19]), which contributed 4% to the final model, the baobab tree has a preference for fluvisols (young soils in alluvial deposits). This type of soil type is found on the southern lakeshore, between Chilumba and Karonga (on the northern lakeshore), in

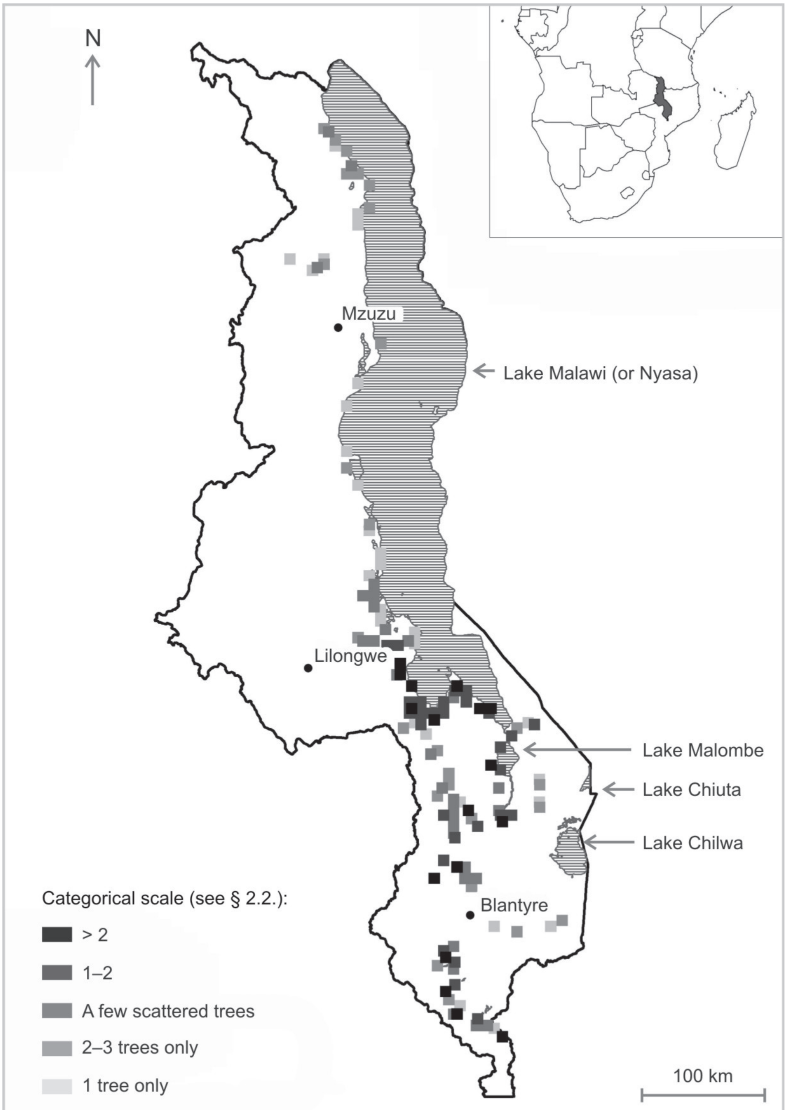

Figure 1.
Visually estimated maximum baobab tree densities and main cities in Malawi.

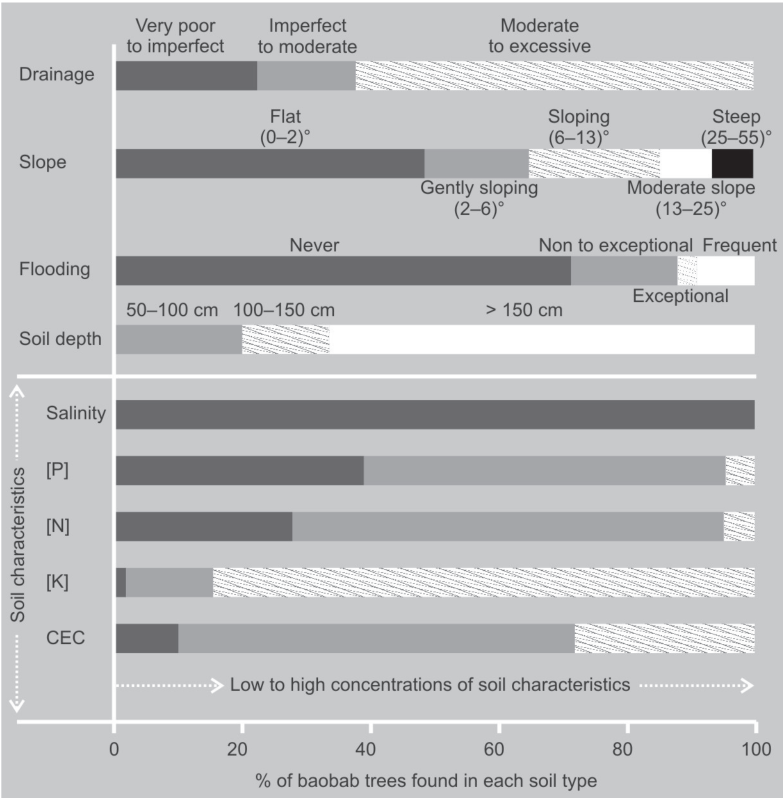

Figure 2.
Percentage of baobab trees found in each soil type, per soil characteristic (n = 473). Soil characteristics extracted from the Soil Map of Malawi [22]. CEC refers to cation exchange capacity, while [K], [N], [P] refers to potassium, nitrogen and phosphorous concentrations, respectively.

Balaka district and along the Shire River, especially in the Lower Shire Valley.

Among the studied Soil Map of Malawi [22] soil characteristics, flooding was the soil characteristic which contributed the most to the Maxent model. Baobab trees prefer soils which are never flooded (*figure 2*). It was also found that most baobab trees grew on non-saline, flat or gently sloping, moderately to well-draining soils with low cation exchange capacity (CEC), medium to high potassium concentrations, low concentrations of nitrogen and phosphorous, and soil depth between 100–150 cm (*figure 2*).

The resulting Maxent distribution map predicted the potential baobab tree occurrence in most of the areas known to have baobab trees (*figure 3*). Maxent predicted the potential occurrence of the baobab tree in Karonga district (northern region), in Salima and southern Nkhotakota districts (central region) and in Mangochi, Balaka, Chikwawa, Nsanje, Blantyre and Neno districts (southern region).

3.4. Fruit and leaf morphological diversity

There were significant differences among study sites in most fruit characteristics analysed (*table III*). Fruits from Balaka and Nchalo were the smallest overall (short in length and light) while fruits from Chipoka were the largest overall (long and heavy). Although there was a trend (the heavier the fruit, the greater the number of seeds), seeds from Balaka and Likoma were larger and heavier than those from other sites. The percentage of pulp was found to be significantly high in Likoma and significantly low in Kalasamba compared with other study sites.

With regard to leaf morphological diversity, there were significant differences among study sites in all leaf morphological characteristics measured (*table III*). In general, leaves from Balaka were smaller, while leaves from Chantulo and Mtonga were larger than those from other study sites. Leaves from Chantulo and Mangochi were found to have significantly high specific leaf weight (SLW). Significant differences were also observed in leaf shape and number of leaflets: *e.g.*, leaves from Kalasamba and Nchalo (the most southern study sites) had more leaflets than those from other study sites (more leaves had seven leaflets instead of five). There were also significant differences in stomatal density (*table III*). Leaves from Balaka and Mangochi were found to have significantly higher stomatal density than leaves from other study sites.

3.5. Correlations between morphology and the environment

Fruit weight, number of seeds and specific leaf weight (SLW) were found to be significantly positively correlated with mean annual temperature ($r_s = 0.46$, $r_s = 0.41$, $r_s = 0.2$, respectively, at $P < 0.01$). Fruit weight and stomatal density were found to be significantly negatively correlated with annual precipitation ($r_s = -0.22$ and $r_s = -0.3$, $P < 0.01$). However, percentage of pulp was found to be significantly positively correlated with annual precipitation ($r_s = 0.37$, $P < 0.01$).

4. Discussion

Baobab trees are widely distributed in southern Malawi. The results from our study support the distribution reported by Gondwe and Chanyenga [13]. Despite this 'quite' broad distribution, few areas were reported to have high baobab density, and all of them were in southern Malawi. High densities were mainly observed around Mangochi, along the southern lakeshore and along the Lisungwi River, the latter not being mentioned by Gondwe and Chanyenga [13]. When compared with other countries, it seems that areas with high baobab tree density in Malawi (10–12 individuals per ha, although it should be noted that few adjacent hectares have these densities) have indeed very high densities. While 2 individuals per ha were reported from northern Venda in South Africa [25], 0 to 2 individuals per ha were reported from agricultural land in the Kibwesi district of Kenya [26].

Areas with high baobab tree density seem to be exploited at different intensity levels. While fruits from the Mangochi area and the southern lakeshore are sold to several commercial companies and vendors, fruits from the Nchalo and Lisungwi River areas are not commonly sold far from the harvesting area. It seems, therefore, that these latter areas producing high quantities of baobab fruits could be further utilised to generate income for local people. Transportation costs or lack of vendors might explain the current situation. However, these areas could be promoted as additional baobab fruit sources, instead of importing baobab fruits from Mozambique.

Although some areas where the density of baobab trees is high could be further promoted, it should be noted that, in our study, only a limited number of areas with high baobab tree density were identified, and, generally, tree density was only high for a few adjacent hectares or square kilometres. Wilson [27] and Barnes *et al.* [28] also reported that baobab densities were very variable in the landscape. Although in Malawi the baobab tree is locally abundant in some areas, it can be said that overall this species is 'scattered'.

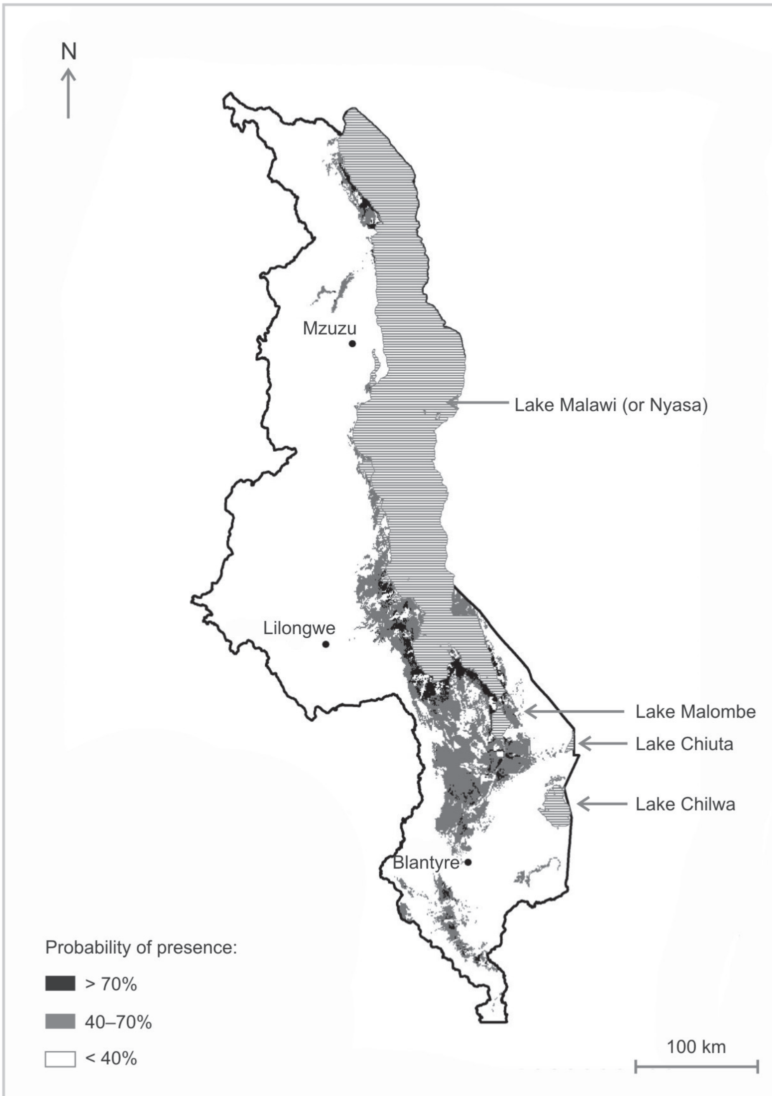

Figure 3.
The potential current distribution of the baobab trees in Malawi according to Maxent.

Results from recent studies carried out in Malawi suggest that the population faces a problem of natural regeneration [10, 29]. Several authors have noted a lack of natural regeneration of baobab trees in other parts of Africa [7, 30–32], which has been attributed to drought, overgrazing and changes in land use [3]. Considering that the baobab tree has, in general, a 'scattered' distribution in Malawi and that there is little natural regeneration, it could be argued that exploitation of this species might not be sustainable in the long term. One way to deal with this problem is to plant baobab trees.

Table III.
Fruit, seed and leaf characteristics of baobab trees from eight study sites selected along a latitudinal gradient in Malawi. Means are followed by the standard deviation.

Study site	Fruit length (cm)	Fruit weight (g)	Pulp percentage (%)	Number of seeds	Dry weight one seed (g)	Seed length (mm)	Pedicel length (cm)	Number of leaflets	Medial leaflet length (cm)	Specific leaf weight (mg·cm^{-2})	Leaf shape[a]	Stomata per mm^2
Balaka	13.1 ± 0.8 a	101.2 ± 44.7 c	13.7 ± 1.9 a	42 ± 8 d	0.46 ± 0.06 b	12.62 ± 0.42 b	10.84 ± 2.78 b	5.4 ± 0.9 c	11.84 ± 2.37 c	6.14 ± 0.68 ab	2.8 ± 0.5 ab	243.4 ± 29.4 c
Chantulo	16.6 ± 3.2 bc	194.8 ± 43.7 ae	18.9 ± 6.3 a	139 ± 42 ab	0.45 ± 0.05 b	11.34 ± 0.7 c	12.09 ± 1.86 ac	5.5 ± 0.8 ac	15.63 ± 2.58 a	7.06 ± 0.64 c	2.7 ± 0.4 b	225.7 ± 26.1 b
Chipoka	17.5 ± 2.0 c	321.9 ± 120.8 d	20.6 ± 3.7 a	249 ± 72 e	0.47 ± 0.09 ab	11.1 ± 0.87 c	11.53 ± 2.05 bc	5.6 ± 0.8 ac	14.04 ± 2.14 d	5.96 ± 0.89 b	3.1 ± 0.4 c	218.8 ± 18.5 b
Kalasamba	15.8 ± 2.3 b	176.4 ± 44.6 be	15.2 ± 4.1 b	134 ± 41 bc	0.47 ± 0.1 b	11.57 ± 0.51 ac	11.04 ± 2.12 b	6 ± 0.8 b	12.94 ± 1.77 b	6.32 ± 0.64 a	2.9 ± 0.5 a	225.2 ± 18.7 b
Likoma	16.7 ± 3.6 bc	217.6 ± 52.4 a	28.0 ± 3.9 c	113 ± 33 bc	0.52 ± 0.04 a	12.02 ± 0.43 a	–	–	–	–	–	–
Mangochi	15.8 ± 2.7 b	226.9 ± 73.4 a	18.6 ± 5.0 a	162 ± 78 ab	0.46 ± 0.08 b	11.62 ± 0.9 ac	11.4 ± 2.56 b	5.6 ± 0.9 ac	12.89 ± 1.81 b	6.89 ± 0.58 c	2.9 ± 0.4 a	250.9 ± 35.2 c
Mtonga	15.9 ± 2.4 bc	156.2 ± 25.8 b	19.4 ± 6.1 a	109 ± 47 c	0.51 ± 0.07 ab	11.85 ± 0.85 ab	12.33 ± 2.3 a	5.5 ± 0.8 ac	14.73 ± 2.06 ad	6.13 ± 0.84 ab	3.2 ± 0.4 c	211.9 ± 14.9 a
Nchalo	12.9 ± 1.6 a	213.3 ± 57.6 a	20.0 ± 3.3 a	165 ± 48 a	0.50 ± 0.05 ab	12.16 ± 0.62 ab	12.85 ± 2.96 a	5.8 ± 0.9 ab	15.79 ± 2.84 a	6.22 ± 0.91 ab	2.9 ± 0.4 a	209.4 ± 19.8 a

(n = 50 for fruit characteristics, n = 100 for leaf characteristics.)

Means followed by the same letter within a column are not significantly different at $P < 0.01$ (Mann-Whitney test).

[a] Leaf shape = [medial leaflet length / medial leaflet length to broadest part].

Indeed, the baobab tree can be easily cultivated from seed and through grafting [2, 3]. Several authors have reported successful seed germination and grafting experiments in Malawi [13, 33]. Despite this propagation success, locals do not propagate the baobab tree. Possible reasons include difficulties in germinating without seed pre-treatment and the long maturation period before fruit production [3]. However, results from preliminary interviews carried out along the southern lakeshore show that, due to its high commercial value, local farmers in that area are interested in planting this species (unpublished results).

Maxent modelling identified suitable habitats for planting the baobab tree in most parts of southern Malawi where baobab trees are present. Baobab trees could be planted in areas where the environmental conditions are good and baobab density is low, such as along the road between Blantyre and Balaka or Balaka-Golomoti. According to Maxent modelling, the main factors determining a suitable habitat for the baobab tree in Malawi are the mean temperature of the warmest four months and altitude. On a continental scale (whole of Africa), Cuni Sanchez *et al.* [23] determined annual precipitation and temperature seasonality as the key factors limiting baobab tree distribution. The fact that climate in Malawi is more related to altitude than to latitude might explain these differences. In terms of altitude, temperature and precipitation, the baobab tree in Malawi was found to be distributed within the range reported in the literature [2, 3]. However, in terms of soil characteristics, although it has been reported that the baobab tree tolerates a broad range of soil types [2], It was found that it prefers fluvisols (young soils in alluvial deposits) which are not subjected to flooding.

The results from this study indicate that there is considerable variation in both baobab fruit and leaf morphology. With regard to fruit morphology, baobab fruit and seed size were found to be within the range reported by Sidibé and Williams [2] but, in general, fruits from Malawi were found to be smaller than those from Benin [6] and Mali [34]. Differences in fruit morphology might be related to differences in genetics between baobabs from western and eastern Africa [35], as suggested by Cuni Sanchez *et al.* [36]. The general trend was the drier and hotter the environment, the larger and heavier the fruits, while the wetter the environment, the higher the percentage of fruit pulp. The largest fruits were found in Chipoka, while the fruits with the highest pulp percentage were observed in Likoma. The effect of provenance on the chemical composition of the baobab tree has also been observed in Malawi. Chikwawa provenance (close to Nchalo) was found to have significantly higher contents of vitamin C, while Mangochi provenance was found to have higher levels of vitamin A and iron [37]. Although further studies should be carried out to determine if the observed differences are due to plastic responses or they are only genetic, it seems that baobab trees with 'superior' fruit characteristics could be selected for cultivation purposes.

With regard to leaf morphology, baobab leaves from Malawi were found to be larger and thinner, and they had higher stomatal density than those from Benin [24]. As mentioned earlier, differences in leaf morphology might also be related to differences in genetics between baobabs from western and eastern Africa. Considering Malawian baobab trees only, trees from Mangochi were found to have leaf characteristics which suggest a better adaptation to drought than those from other study sites: they had small leaf size, high specific leaf weight and high stomatal density. While it is not clear if the observed variation in fruit characteristics is due to genetic differences only or if the environment also plays a role, for baobab leaf characteristics, it seems that some of them (*e.g.*, stomatal density) are genetically determined [24]. Thus, baobab trees from Mangochi could be selected as 'superior' planting material for cultivation purposes if the desired characteristic is adaptation to drought. A recent study on baobab seedling morphology suggests that this seems possible [38].

When considering planting baobab trees with desired characteristics from one area into another area, it should be considered that baobab trees which are not local might not be as well adapted to local climatic and edaphic conditions as the local ones. For example, it has been reported in Mali that survival of locally existing baobab trees is higher than those from other provenances [39]. However, in this experiment in Mali, baobab trees were from different species. Further research (*e.g.*, provenance trials) is needed to determine if baobab trees from the same species and from geographically close populations have high survival in nearby areas with different environmental conditions. If survival is not high, one option could be to graft different baobabs with different desired characteristics [36]. Moreover, when considering planting baobab trees with desired characteristics from one area into another area, genetically distinct populations could be mixed, with potentially negative effects on the populations. Therefore, more research on the genetic variation within and between baobab populations in Malawi and in eastern Africa in general is also recommended as, at the moment, most genetic studies have been focused on western Africa [40, 41].

My results suggest that some areas where baobab tree density is high could be further exploited while this species could be planted in most areas where the density is low in southern Malawi. It also seems that there is great morphological diversity in both fruit and leaf characteristics, and, thus, baobab trees with more desirable characters could be selected for cultivation purposes. Although further studies considering genetic variation between and within baobab populations in Malawi are recommended, provenance trials could also help identify and validate the best planting strategy.

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El baobab en Malaui.

Resumen — **Introducción**. Recientemente se ha reforzado un posible exceso de la explotación del baobab (*Adansonia digitata*), debido a la aceptación de la pulpa del fruto de baobab en los mercados alimentarios de la UE y americanos. A pesar de los numerosos estudios recientes de esta especie, aún se conoce poco de *A. digitata* en Malaui, el principal exportador de pulpa del fruto de baobab en África. **Material y métodos**. A partir de encuestas de terreno, se recopilaron datos sobre la distribución y la densidad del baobab en Malaui. Se empleó el programa Maxent, basado en el cálculo del máximo de entropía para la modelización del hábitat de una especie, a la vez que se tomaban datos espaciales y geo-referenciados del entorno acerca del baobab, de modo a analizar así sus preferencias ecológicas y sus potenciales lugares de cultivo. Los agricultores fueron interrogados con el fin de conocer los explotadores y compradores de frutos de baobab en las diferentes regiones. Se evaluó la diversidad de la morfología de los frutos y hojas en ocho lugares de estudio, seleccionados a lo largo de un gradiente latitudinal. **Resultados y discusión**. El baobab resultó estar ampliamente distribuido en el sur de Malaui, en densidades variables. Los resultados de la modelización revelan que esta especie podría cultivarse en la mayoría de la región sureña del país. Se observó una gran diversidad morfológica de los frutos y de las características de las hojas, lo que ofrecería la posibilidad de seleccionar los rasgos más interesantes para el cultivo. **Conclusión**. Nuestro estudio mostró que, a pesar de que haya ciertas zonas con una densidad fuerte de baobab que pudieran explotarse más, su cultivo debería recomendarse en las zonas de densidad más baja de baobab en el sur de Malaui, dado a que la regeneración natural allí es escasa. Por otro lado, nuestro estudio sugiere que, en Malaui, hay lugar para la selección del material de plantación de baobab con interesantes características para su cultivo.

Malawi / *Adansonia digitata* / distribución geográfica / densidad de la población / usos tradicionales / uso múltiple / biodiversidad / características agronómicas