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Local perception of the current state and threat factors of a critically endangered species, *Celtis toka* (Forssk.) Hepper & J.R.I. Wood, in Burkina Faso: implications for species conservation

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Abstract

Celtis toka, the only species of the genus *Celtis* (family Cannabaceae) encountered in the flora of Burkina Faso, is critically endangered in the country. To engage the public for the future conservation and domestication of the species, knowledge of the factors threatening *Celtis toka* survival is necessary. Thus, the study objective was to identify the perceptions of local people concerning the current state and conservation strategies of *Celtis toka* in Burkina Faso.

To investigate potential solutions to the threats posed to *Celtis toka*, we randomly surveyed 405 consenting participants using a selected semi-structured interview. Moreover, field observations were performed to assess the threat drivers cited by local people of the Sudanian and Sudano-Sahelian climatic zones. Descriptive analyses (relative frequency and fidelity level) and generalized linear models (GLMs) were used to highlight the impact of sociodemographic factors and climate zones on the current state, threat drivers, and potential solutions. The chi-square test was used to assess whether to plant *C. toka*.

GLM analyses revealed that local knowledge about the current state, threat factors and potential solution to the threat as related to natural stand varied significantly according to ethnolinguistic group ($P < 0.000$), sex ($P = 0.01$) and age ($P = 0.01$). Rural people had varying perceptions of the current state of *C. toka*. Sixty-eight percent reported a decrease in population, ten percent reported scarcity, and five percent reported extinction. The views of local people were that the factors affecting *C. toka* were pruning (25%), climate change (14%), deforestation (10%), ageing (10%), debarking (9%), and agriculture (7%). Potential solutions included planting (45%), conservation of *C. toka* and its habitat (27%), sustainable use of *Celtis toka* (14%), promotion of education and awareness about *Celtis toka* (10%) and tree/crop association (5%).

The study concluded that the ethnobotanical knowledge of *Celtis toka* may play an important role in its conservation and domestication in Burkina Faso. Furthermore, its incorporation into reforestation and restoration programs is critical to species survival.

Keywords
climate, conservation strategies, COVID-19, decline, ethnobotany, extinction, West Africa

Introduction

Climate change is defined as a change in the weather pattern of a location or region that is related to average weather components such as temperature, wind patterns and precipitation (Ifeanyiobi et al. 2012). For instance, extreme weather events devastate the land and terrestrial ecosystems and exacerbate food insecurity for humanity. These changes, according to the United Nations' Intergovernmental Panel on Climate Change, have a large impact on many people who are thought to be disproportionately vulnerable to the effects of climate change (IPPC 2021). To cope with global change and mitigate its consequences, rural communities rely on forests, primarily in terms of multipurpose plants for medicine, food, fodder, shade, renewable energy, windbreaks, erosion control, carbon sinks, soil improvement, fertility restoration and conservation (Ifeanyiobi et al. 2012).

Ethnobotany, a branch of ethnobiology (Houéhanou et al. 2016), is the study of the relationships between plants and culture as well as the local perception of the use, management (Bridges and Lau 2006; de Albuquerque and Hanazaki 2009) and the state of plant resources. Moreover, ethnobotanical knowledge is critical for species conservation, mainly for endangered species that have been recognized by the Convention on Biological Diversity in Rio de Janeiro (CBD 1992). Furthermore, promoting endangered plants is critical to ensuring their sustainable conservation, domestication, and inclusion in reforestation and restoration programs. Therefore, plant promotion, conservation, domestication, and introduction through restoration and reforestation, necessitate a scientific approach based on local perceptions of the current state, threats, and potential solutions.

Celtis toka (Forssk.) Hepper & J.R.I. Wood belongs to the Cannabaceae family. The genus *Celtis* includes approximately 60–70 species worldwide (Mahre et al. 2017) and 12 species in Africa (Sattarian and Van Der Maesen 2005). This species is a very large tree with a compact crown (Sattarian 2006) and is usually monoecious (Alfaifi et al. 2021). It reaches 25 m in height and 2.2 m in diameter at breast height. The bole is either short or tall with ramifications (Dabré et al. unpublished). *Celtis toka* (*C. toka*) is an open gallery forest, dense dry forest, savannah, sacred grove, and rocky area species (Neumann 1992; Shepherd 1992; Rabeil 2003; Akoegninou et al. 2006; Savadogo and Thiombiano 2010; Höhn and Neumann 2016; Arbonnier 2019). It thrives in areas with low rainfall (110–960 mm yr.$^{-1}$) and high temperatures (26–30 °C) (Watrin et al. 2007). It is widely distributed and found throughout Benin, Burkina Faso, Central African Republic, Chad, Côte d'Ivoire, Eritrea, Ethiopia, Gambia, Ghana, Guinea (Conakry), Mali, Mauritania, Niger, Nigeria, Senegal, South Sudan, Sudan, Togo, Uganda, and Yemen (Sattarian 2006; IUCN 2019).

The species provides a variety of products used for food (leaves, fruit); medicine (leaves, barks, roots, flowers, seeds); construction (wood); firewood and charcoal for human cooking activities; and fodder (leaves) for animals and handicrafts (Blench 2000; Lykke et al. 2004; Teklehaymanot and Giday 2010; Seignobos 2014; Höhn and Neumann 2016; Piqué et al. 2016; Arbonnier 2019; Badiane et al. 2019). The fruits and leaves are considered edible in Sudan (Arkell 1947), Ghana (Irvine 1961), Senegal (Lericollais 1990), Nigeria (Kiee et al. 2000; Harris and Mohammed 2003; Kubmarawa et al. 2011), Cameroon (Nakagawa 2008; Neba 2009; Betti and Yemefa 2011), Benin (Djègo-Djossou et al. 2015) and Burkina Faso (Dabré et al. unpublished). Mballow et al. (2020) stated that *C. toka* is the most commonly used species by communities in west and east Africa. Moreover, tannins, glycosides, alkaloids, saponins, phenols, coumarins, flavonoids, mucilage, triterpenoids and steroids are phytochemicals extracted from leaves of *C. toka* (Fall et al. 2017; Abba Idris and Halima Mohammed 2020).

In addition, all organs of *C. toka* are used to cure diseases such as measles, chickenpox, malaria, back and eye aches, ringworm, fever sore, mycosis, headache, and mental diseases (Hahn-hadjali and Thiombiano 2000; Betti et al. 2011; Arbonnier 2019; Diatta et al. 2019). The roots, leaves and bark are used in Nigerian traditional medicine to treat various diseases, including epilepsy (Muazu and Kaita 2008). Additionally, the plant organs are used to treat trypanosomiasis (Osue et al. 2018). In Cameroon, the bark is also used to cure epilepsy (Tsabang et al. 2016). The medicinal use of *C. toka* was also highlighted by Bizimana et al. (2006) in Mali and Badiane et al. (2019) in Senegal. In Burkina Faso, leaves, bark, flowers, fruits, grains, and roots were used to heal 29 ailments, such as madness, yellow fever, eye ache, malaria, casting, vitamin deficiency, ringworm, diarrhea, backache, toothache, ulcer, measles, and chickenpox (Dabré et al. unpublished).

In Ethiopia, *C. toka* is a wild tree that provides an important economic service because it is preferred for the hanging of beehives (Bareke 2018), for timber, and for making local boats (Rolkier and Abebe 2015). In addition, *C. toka* has a mystical value in Burkina Faso (Savadogo and Thiombiano 2010). Cultural and mystical values were also highlighted by Dabré et al. (unpublished).

The International Union for Conservation of Nature (IUCN)'s forest work addresses the role of trees and forests in building resilience to climate change (IUCN 2021). Additionally, the IUCN sustainable use initiative has been successful in delivering conservation outcomes that benefit society (IUCN 2020). *C. toka* was assessed on the IUCN Red List of Threatened Species in 2023 as being of Least Concern (LC), and its current population trend is stable at present (IUCN 2019, accessed on January 25, 2023). According to the IUCN (2019), *C. toka* has a very broad distribution and a large population, with no major threats currently existing and no significant future threats being identified.

Even though *C. toka* is classified as LC at the global level (IUCN 2019), this species is either threatened, rare, critically engendered and even extinct in some temperate regions and the Sahelian region in Africa (Hahn-hadjali and Thiombiano 2000; Garzuglia 2006; Al-Khulaidi 2018; Alfaifi et al. 2021; Tchobsala et al. 2022). Nonetheless, the species seems to be lacking in Senegal, Guinea Sudan, and Uganda (Hauman 1942). Moreover, *C. toka* is threatened in Benin, northern Cameroon and the Sahelian region of Africa (Gonzalez et al. 2012; Dansi et al. 2013; Moksia et al. 2019). In Chad, the species is either extinct or endangered (Tchobsala et al. 2022). Although the species is important in Yemen, it is currently rare and must be evaluated and monitored regularly (Al-Khulaidi 2018). In Saudi Arabia, *C. toka* is thus a very rare and threatened species (Alfaifi et al. 2021). The reasons for the rarity and near local extinction of this species in some parts of Africa are understandable. This is because of the enormous dependency on this species and its products for ecological and economic purposes in some parts of African countries. This, leads to overexploitation, thus predisposing the species to a high risk of local extinction in Africa. This phenomenon is prevalent in west Africa, especially Burkina Faso, where the species is subject to overexploitation because of its medicinal, fodder, food, and mystical uses (Dabré et al. unpublished).

Only *C. toka*, one of the twelve species of the genus *Celtis* in Africa, is found in Burkina Faso, and it is on the verge of extinction. Several pieces of empirical evidence suggest that *C. toka* is rare, threatened, critically endangered or extinct in Burkina Faso. Authors have shown that in Burkina Faso, *C. toka* is a one-of-a-kind critically endangered species (Garzuglia 2006) and is threatened to the point of one day disappearing (Hahn-hadjali and Thiombiano 2000; Thiombiano et al. 2010; Bayala et al. 2011). Vodouhe et al. (2007) also stated that *C. toka* has been on the verge of extinction in Burkina Faso since 2007. For instance, Hahn-hadjali and Thiombiano (2000) also stated that since 2000, *C. toka* has disappeared in eastern Burkina Faso, except in sacred groves. Furthermore, Bayala et al. (2011) discovered that *C. toka* was the most threatened species in the agroforestry parkland of Burkina Faso. Additionally, Savadogo and Thiombiano (2010) specified that the wild plant *C. toka* is endangered in the Northern and Southern Sudanian zones of Burkina Faso. More recently, the studies of Savadogo et al. (2017) have shown that *C. toka* is rare in the communities of the strict Sahelian, southern and northern Sahelian regions of Burkina Faso. Therefore, given the socio-economic and ecological importance of *C. toka* to the teeming African populace, and given its potential high risk of local extinction in Africa, there is a need for its conservation. However, an effective conservation strategy of the natural resources must take into account the knowledge and opinions of the stakeholders, especially the local people who are the direct beneficiaries of the resources so conserved

(Amoutchi et al. 2021). These authors argued that indigenous people all over the world have preserved distinctive understandings, rooted in cultural experience, that guide relationships among human and non-human beings in specific ecosystems. Thus, their perception and knowledge of threats to any natural resources, and their subsequent contribution to designing a conservation action will produce a positive outcome. The local people (especially in Burkina Faso) depend directly on the services provided by *C. toka* for their livelihoods. Therefore, they are expected to be the most affected if the species becomes extinct, and also, they are expected to be well aware of the nature of the disturbances and threats the species is facing given their indigenous knowledge of it. Their perception of the threats (the impact and causes) and knowledge of anthropogenic activities impacting this species, being part of their indigenous knowledge, are essential for making and implementing decisions and policies related to the mitigation of these threats, and the management of this species in the ecosystem. Furthermore, the knowledge and perception of the local people represent the baseline information for motivating and directing any research projects regarding any conservation action targeted at this species.

Despite its socioeconomic and cultural importance and its role in mysticism, knowledge of the threat factors of *C. toka* in Africa in general and Burkina Faso, in particular, is lacking. In this regard, this study aimed to assess the diverse local knowledge and perceptions of the dynamics and threats to *C. toka* in west Africa (using Burkina Faso as a case study), with the view to recommending conservation strategies to mitigate the local extinction of this species in west Africa where the species is already reported to be critically endangered. Specifically, we seek to answer the following questions: (a) What are the perceptions of rural people regarding the status of *C. toka* in Burkina Faso? (b) What are the threats to the survival of *C. toka* in Burkina Faso? And (c) what are the perceptions of the local population concerning the potential solutions to the threats posed to *C. toka* in Burkina Faso?

We explicitly tested three hypotheses:

H1: Interviewees perceived the extinction of *C. toka* in the study sites.

H2: Anthropogenic activity is the main driver of species decline.

H3: Planting and the conservation of the species and its habitat are two of the most important solutions to the threats posed to the species.

Description of the study site

This study was conducted from November 2020 to January 2022 in villages near Kou, Dinderésso, Sourou, Sâ and Koulbi classified forests located in the Sudanian and Sudano-Sahelian climatic zones of Burkina Faso (Fig. 1). In both climatic zones (BCZ), the climate is tropical with two separate seasons: rainy and dry periods. The principal rivers are Kou and Mouhoun, and the main soils are leptosols, vertisols, ferralsols, luvisols,

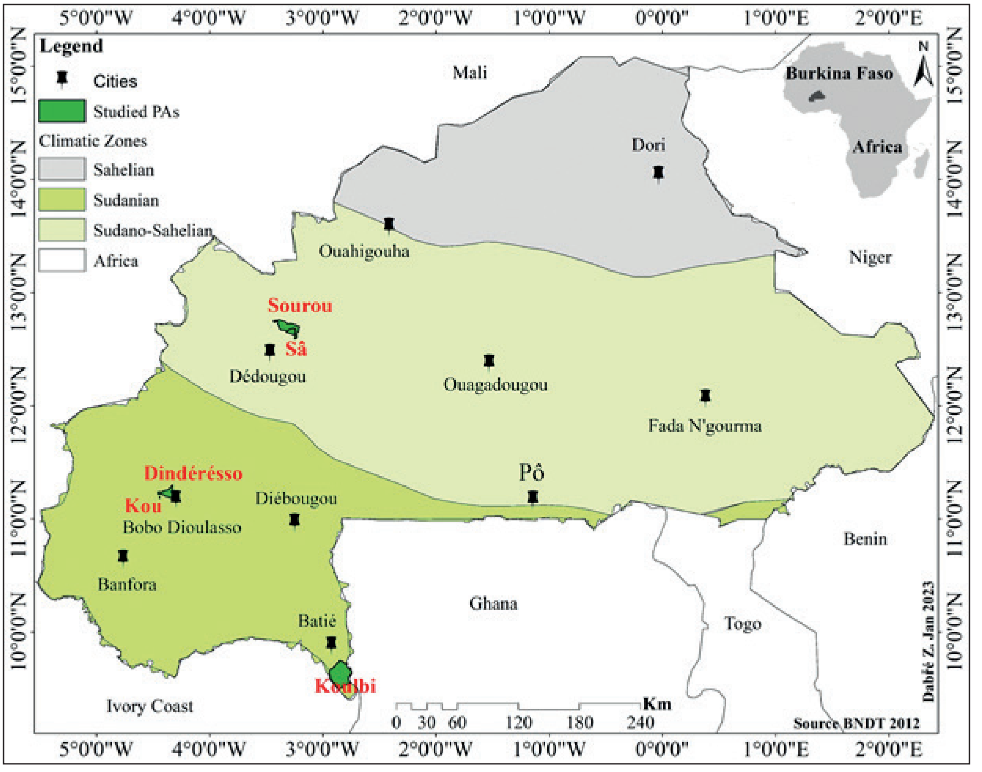

Figure 1. Localization of the study sites in Burkina Faso. (Studied PAs: studied protected areas).

lithosols and hydromorphic soils (Savadogo and Thiombiano 2010). The vegetation types include various savannahs, dry forests, and gallery forests.

The flora consists of some Sahelian, Sudanian and Guinean species, such as *Vitex chrysocarpa* Planch, *Antiaris africana* Engl., *Parkia biglobosa* (Jacq.) R.Br. ex G. Don, *Lannea microcarpa* Engl. & K. Krause, *Dialium guineense* Willd., *Cola laurifolia* Mast., *Carapa procera* DC., *Vachellia seyal* (Delile) P.J.H Hurter, *Detarium microcarpum* Guill. & Perr., *Balanites aegyptiaca* Del. (Nacoulma et al. 2018). The sociolinguistic groups are Dafing, Gourmantché, Gourounssi, Bobo, Bozo, Dioula, Sambla, Senoufo, Bambara, Marka and Bwaba. The key livelihoods are traditional subsistence farming, principally of cereals (millet, sorghum, and maize), livestock breeding and trade.

Materials and methods

Materials

Celtis toka is a wild plant that thrives in a variety of environments. It has different local names around Africa (Table 1).

Table 1. Some local names of *Celtis toka* in Africa.

Countries	Dialect	Vernacular names	Sources
Benin	Dendi	Séékossou	Dansi et al. 2013
	Yoruba	Afoufè	Djègo-Djossou et al. 2015
		Bousamsambou	Achigan-Dako et al. 2010
Burkina Faso	Mooré	Pargandé	Thiombiano et al. 2012
	Mooré	Silsaka	Thiombiano et al. 2012
Cameroon	Arabe	Ngouso	Betti and Yemefa 2011
		Aboum gatou	Vivien 1990
		Hala	
	Fulfuldé	Djiho	
	Haoussa	Douki	
	Toupouri	Likan	
		Loubour	
	Kanouri	Ngouzo	
	Mofu	Sabak	
	Mafa	Shéshébé	
		Wanka	
	Fulfuldé	Ganki	Gilbert et al. 2019
	Fulfuldé	Wanko	Gilbert et al. 2019; Seignobos and Tourneux 2002
	Mofou	Mebed	Gilbert et al. 2019
	Arabe	Falmaro	Betti et al. 2011
Ethiopia	Anywaa	Laero,	Awas 1997
	Kara (people)	Zuguay,	Teklehaymanot and Giday 2010
	Kwego (people)	Lompo	Teklehaymanot and Giday 2010
Nigeria		Aápe	Ogungbenro et al. 2018
Mali		Kamaua, Gamya	Bizimana et al. 2006
Senegal	Wolof	Mbul	Gonzalez 2001
	Diola	Busingilit	Diatta et al. 2019
	Sereer	ngan	Lericollais 1990
South Sudan	Mabanese	Shaw	Bloesch 2014
	Arabe	Tekey	Bloesch 2014
South Kordofan Sudan		Mohagria	Ismail and Elawad 2015
Sudan		Mohagria, Lipingo	Hamid and Kordofani 2015

Methods

Sampling strategy and data collection

A preliminary assessment was carried out in November 2020 to obtain an overview of the availability and distribution of *C. toka*. Furthermore, this assessment allowed us to obtain approval from authorities and village leaders, as well as to fine-tune the questionnaire. The preliminary assessment and survey were carried out while maintaining social distancing and other preventive measures (wearing a nose mask and using hand sanitizer) to avoid the spread of COVID-19. From the three climatic zones of Burkina Faso, two climatic zones (the Sudanian climatic zone (**SCZ**) and the Sudano-Sahelian climatic zone (**SSCZ**)) were chosen considering the accessibility of the areas and the occurrence of *C. toka*. A discussion was held with the administrators, environmental officers, forest officers, farmers, fishermen/women, hunters, traditional healers, and

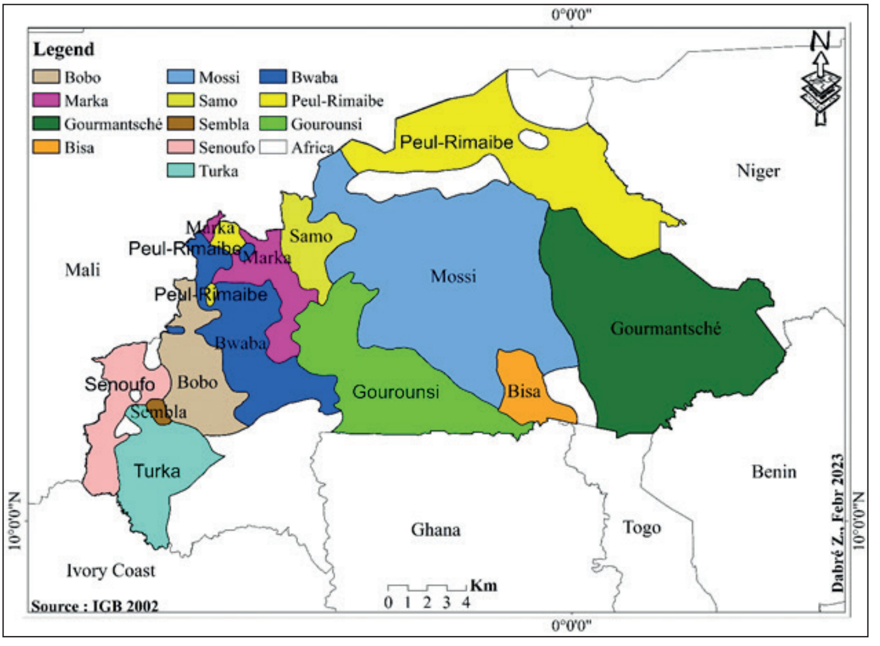

Figure 2. Map of the ethnolinguistic groups questioned in the study areas.

elders. Next, field observations were made cooperatively with field guides, farmers, village leaders and elders to look for *C. toka* availability, accessibility, distribution, threat drivers and potential solutions within the study sites. Thirty-four villages were included in the survey, comprising twenty-five ethnolinguistic groups (Fig. 2).

The ethnolinguistic groups Bambara and Bozo represent immigrants from Mali.

Villages were chosen based on the presence of the multipurpose species *C. toka*. Overall, 405 (148 female and 257 male) consenting local people who knew *C. toka* were randomly selected. Data were collected using a selected semistructured interview (Sop and Oldeland 2011; Theodory 2016) and direct field observation. It was impossible to interview an equal sex ratio in each village because the investigations were based on the knowledge of *C. toka*. All respondents were at least 30 years old because they were the only ones who knew about *C. toka* and its status. Data for age, sex, career, education level and ethnolinguistic group of the informants were recorded. Ethnolinguistic groups that were represented by few individuals were classified as "other" for the purpose of performing the statistical analysis. Proficient local translators were used to translate French into the local languages.

Photographs of the leaves (Fig. 3), the trunk (Fig. 4), and the fruits (Fig. 5) of *C. toka* were taken during the prospection, kept, and shown to each household in both climatic zones to ensure that local communities were familiar with *C. toka* (Arbonnier 2019). The respondents were questioned about the following:

- current state of *C. toka* in their community,
- factors affecting *C. toka* survival,
- potential solutions to the threat.

Figure 3. Pictures of leaves used for quick identification by local people during the survey. Pictures: Z. Dabré, 2020.

Figure 4. Pictures of the trunks used for quick identification by local people during the survey. Pictures: Z. Dabré, 2020.

Figure 5. Pictures of fruits used for quick identification by local people during the survey. Pictures: Z. Dabré, 2020.

Data analysis

Before the analyses, the interviewees were divided into two generations: adults (30–55 years) and older adults (≥ 55 years) (Sop et al. 2012). Three and four Sudanian and Sudano-Sahelian ethnolinguistic groups, respectively, were considered major ethnolinguistic groups, with the remainder classified as "other" (Fig. 2, Table 3).

The relative frequency and fidelity level (Table 2) were employed to analyse the most destructive threats to *C. toka*. GLMs with Poisson errors and chi-square tests at a threshold equal to 0.05 were used to detect sociodemographic parameter (ethnolinguistic groups, age, and sex) effects on the current state, threat, and potential solutions in the BCZ. Chi-square analysis was also used to determine whether to plant *C. toka* in the study areas. All statistical analyses were performed using R version 4.1.1 (R Core Team 2021).

Results

Sociodemographic characteristics and local perception of the status of *C. toka* in Burkina Faso

Sociodemographic characteristics of local populations

In total, 405 people were interviewed in this study, with 203 in the SCZ and 202 in SSCZ (Table 3). Most of the interviewees were male (72.77%), autochthonous (81.19%), and farmers (75.74%) with no formal education (80%). Bozo (8.37%) were immigrants, and those classified as "other" were autochthons (Table 3).

Table 2. Formulas related to relative frequency (RF) and fidelity level (FL).

Index	Computation	Explanation	R
RF = (FC/SF) × 100	Frequency of citation (FC) quoted by a given informant divided by the sum of uses times 100.	Measures the ratio of the number of times a use pattern of *C. toka* appears in the set of overall use patterns. The value ranges from 0 to 100.	A
FL = (Ip/Iu) × 100	Number of informants (Ip) connected to a specific use divided by the total number of informants (Iu) times 100.	Measures the grade of consensus between informants. FL is significant when this is directly above 5% (FL > 5%).	B

R: References, A: (Thiombiano et al. 2016), B: (Friedman et al. 1986).

Table 3. Sociodemographic characteristics of informants and study design.

Demographic parameters	Variables	Sudanian	Sudano-Sahelian
Sex	Female	40.95	27.23
	Male	59.05	72.77
	Total	100	100
Residential status	Autochthon	65.02	81.19
	Migrant	34.98	18.81
	Total	100	100
Ages	Adult (30–55)	46.80	58.91
	Old (> 55).	53.20	41.09
	Total	100	100
Ethnolinguistic groups	Bobo	71.44	13.86
	Bozo	8.37	–
	Bwaba	–	31.68
	Dafing	–	23.27
	Dioula	10.34	–
	Mossi	–	12.87
	Others	9.85	12.87
	Total	100	100
School level	None	79.59	74.26
	Primary	15.75	21.28
	Secondary	4.37	3.47
	University	0.29	0.99
	Total	100	100
Main activity	Farming	61.44	75.74
	Trade	21.61	8.91
	Breeding	11.65	11.39
	Handwork	5.3	–
	Hunt	–	3.96
	Total	100	100

Local perception of the status of *C. toka* in Burkina Faso

Overall, 68% of informants (77.94% in the SCZ and 58.28% in SSCZ) (Fig. 6) widely expressed that the multiuse species *C. toka* was greatly decreasing (SCZ: 41% < FL < 90% and SSCZ: 52 < FL < 96) (Table 4). Thirteen percent of the participants expressed that the species is stable. In SSCZ, approximately 19% and 11% of the interviewees confirmed that the sacred tree *C. toka* was either rare or extinct, respectively. However, 4% of the local people (5.88% in the SCZ and 2.86% in SSCZ) highlighted that the species was increasing in abundance (Fig. 6, Table 4). As the most surveyed communities,

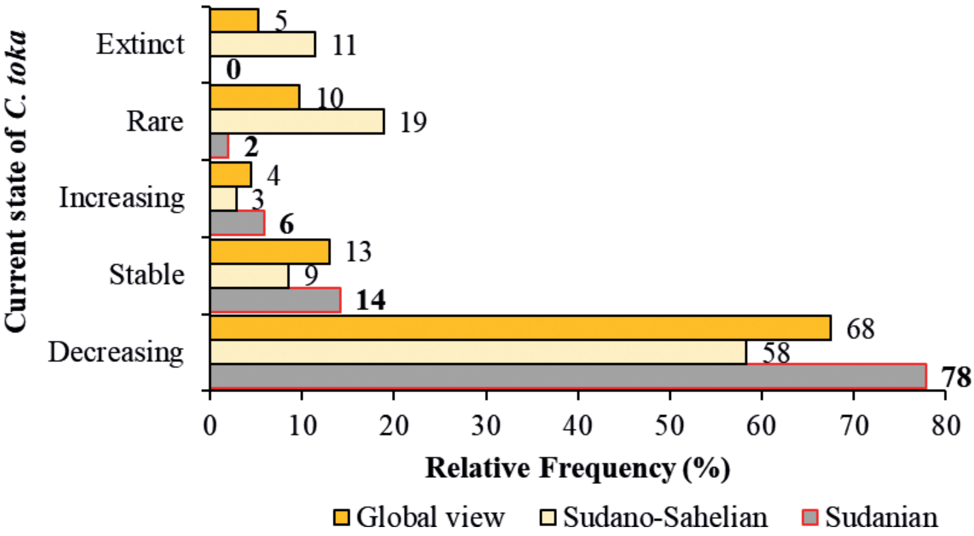

Figure 6. Local perception of the current state of the multiuse species *C. toka* in Burkina Faso.

Bobo, Bozo, Dioula, Bwaba, Dafing, Mossi, and Dioula represent the ethnolinguistic groups that perceived the most recent status of *C. toka* in the study areas. Ethnobotanical knowledge of the state of *C. toka* varied greatly across ethnolinguistic groups. However, Dioula (FL: 90%) and Bobo (FL: 62%), belonging to SCZ, perceived the decline of *C. toka*. However, in the SSCZ, Mossi (FL: 96%) and Dafing (FL: 81%) reported a decrease in the species. Respondents in the SCZ with an age above 55 years identified more of a declining status of the species than others. Regarding sex, men (SCZ) and women (SSCZ) reported more threatened status based on their traditional knowledge when compared to others. The rarity of the species was perceived by the Bwaba culture (FL: 42%), and extinction features of *C. toka* were mostly perceived by the Mossi (FL: 35%) and the “other” ethnolinguistic groups (FL: 35%) in the SSCZ (Table 4).

The GLM analysis revealed that local knowledge of *C. toka*’s status varied greatly across ethnolinguistic groups in terms of extinction and stable status, across sexes for all status levels, and across ages for all status levels except decreasing status (p–value < 0.05). Adults and elderly people in the BCZ had dissimilar perceptions of the declining, scarcity, and extinction aspects of *C. toka* (p–value < 0.05) (see Table 5).

Local perception of the threat factors of *C. toka* in Burkina Faso

According to the respondents, the sustainability of *C. toka* is threatened by some unfavourable factors, such as anthropogenic and natural factors. However, 4% of respondents indicated that there are no threats to the sustainability of *C. toka*. Globally, the threat features to *C. toka* were perceived as pruning (25%) for food and fodder, climate change (14%), deforestation (10%), ageing (10%), debarking (9%), agricultural expansion (7%), bushfires (6%), and “other” (6%) (Fig. 7). The “other” category referred

Table 4. Local knowledge of *C. toka* in two climatic zones of Burkina Faso.

Criteria / Patterns	Variants	Sudanian climatic zone								Sudano-Sahelian climatic zone									
		Bobo		Bozo		Dioula		Others		Bobo		Bwaba		Dafing		Mossi		Others	
		(n=145)		(n=17)		(n=21)		(n=20)		(n=28)		(n=64)		(n=47)		(n=26)		(n=26)	
		F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)
Current state of *C. toka*	Extinct	0	0	0	0	0	0	0	0	1	4	13	20	2	4	9	35	9	35
	Rare	2	1	1	6	1	5	1	5	2	7	27	42	2	4	8	31	6	23
	Decreasing	90	62	7	41	19	90	21	70	15	54	33	52	38	81	25	96	16	62
	Stable	37	26	6	35	1	5	4	20	8	29	5	8	5	11	0	0	1	4
	Increasing	10	7	1	6	0	0	1	5	3	11	0	0	2	4	0	0	0	0
	ΣF	139	-	15	-	21	-	27	-	29	-	78	-	49	-	42	-	32	-
Threat factors	Pruning	56	39	8	47	13	62	13	65	4	14	62	97	33	70	6	23	15	58
	Bushfire	20	14	0	0	2	10	1	5	1	4	2	3	7	15	0	0	0	0
	Ageing	21	15	2	12	2	10	1	5	0	0	13	27	13	28	8	31	7	26
	Debarking	35	24	2	12	3	14	15	75	6	21	4	6	12	26	4	15	3	12
	Climate change	23	16	3	18	4	19	3	15	2	7	20	31	15	32	5	19	2	8
	Deforestation	19	13	1	6	3	14	3	15	2	7	15	23	5	11	9	35	7	27
	Farming	7	5	2	12	5	24	3	15	1	4	17	27	4	9	10	38	7	27
	Lack of regeneration	9	6	0	0	0	0	1	5	2	7	7	11	4	9	0	0	0	0
	Settle of infrastructures	8	6	0	0	1	5	3	15	0	0	12	19	2	4	1	4	1	4
	Overgrazing	6	4	1	6	0	0	0	0	0	0	15	23	3	6	1	4	0	0
	Others	3	2	1	6	0	0	0	0	3	11	5	8	2	4	0	0	0	0
	Failure of *C. toka*	4	3	1	6	3	14	0	0	0	0	1	2	0	0	0	0	0	0
	ΣF	211	-	21	-	36	-	43	-	21	-	173	-	100	-	44	-	42	-
Potential solutions to the threats	Tree/crop association	9	6	3	18	1	5	1	5	0	0	2	3	2	0	2	8	0	0
	Planting	38	26	4	24	9	43	4	20	5	18	36	56	2	49	19	73	11	42
	Conservation of *C. toka* and its habitat	47	32	3	18	1	5	0	0	5	18	8	13	28	58	16	62	5	19
	Sustainable use of *C. toka*	22	15	3	18	1	5	0	0	3	11	7	11	4	9	2	8	1	4
	Promoting education, and awareness about *C. toka*	13	9	1	6	0	0	1	5	1	4	11	17	36	2	1	4	1	4
	ΣF	129	-	14	-	12	-	6	-	14	-	64	-	72	-	40	-	18	-

n: number of individuals interviewed, F: frequency, FL: fidelity level, and ΣF: sum of frequencies.

to the specific habitat of the species, infertility of soil, production of charcoal, diseases, attacks by parasites, fungi, epiphytes, termites, and invasion of *Azadirachta indica* and *Ficus*. In the SCZ, the main causes were pruning (21%), deforestation (13%), climate change (13%), debarking (12%), bushfire (9%), ageing (8%) and agriculture (8%) (Fig. 7). Pruning (FL:47%), climate change (FL:18%), debarking (FL:12%), and ageing (FL:12%) were emphasized by the Bozo, and debarking (FL:75%) was emphasized by others in the SCZ (Table 4). In the SSCZ, pruning (28%) and climate change (15%) were reported as the key drivers (Fig. 7). Pruning (FL: 70%), climate change

Table 5. Impact of socio-demographical factors and climatic zones on the current state of *C. toka* through GLMs analyses.

CZ	Variables	n	Extinct	Rare	Increasing	Decreasing	Stable
Ethnolinguistic groups							
S	Bobo	145	0 ± 0	0.014 ± 0.12	0.23 ± 0.42	0.47 ± 0.5	0.26 ± 0.44
	Bozo	17	0 ± 0	0.035 ± 0.22	0.47 ± 2.75	0.92 ± 5.63	0.48 ± 3.08
	Dioula	21	0 ± 0	0.048 ± 0.22	0.51 ± 0.51	1 ± 0.51	0.53 ± 0.22
	Others	20	0 ± 0	0 ± 0	0.3 ± 0.47	0.45 ± 0.51	0.25 ± 0.44
SS	Bobo	28	0.037 ± 0.19	0.074 ± 0.26	0.088 ± 0.27	0.56 ± 0.50	0.30 ± 0.47
	Bwaba	64	0.20 ± 0.41	0.42 ± 0.50	0.047 ± 0.21	0.47 ± 0.50	0.078 ± 0.27
	Dafing	47	0.043 ± 0.20	0.043 ± 0.20	0.064 ± 0.25	0.79 ± 0.41	0.11 ± 0.31
	Mossi	26	0.267 ± 0.46	0.133 ± 0.35	0.067 ± 0.26	0.67 ±0.49	1.333 ± 0.35
	Others	26	0.207 ± 0.46	0.103 ± 0.25	0.067 ± 0.26	0.57 ±0.39	1.303 ± 0.32
	X^2		7.83	2.1	1.15	2.98	6.08
	P value		0.00468	0.138	0.295	0.0804	0.02
Sexes							
S	Female	91	0 ± 0	0.011 ± 0.11	0.269 ± 0.44	0.314 ± 0.47	0.337 ± 0.47
	Male	112	0 ± 0	0.027 ± 0.16	0.230 ± 0.42	0.566 ± 0.50	0.168 ± 0.38
SS	Female	55	0.15 ± 0.36	0.1 ± 0.30	0.025 ± 0.16	0.7 ± 0.46	0.175 ± 0.38
	Male	147	0.123 ± 0.33	0.254 ± 0.44	0.078 ± 0.27	0.561 ± 0.50	0.114 ± 0.32
	X^2		23.406	39.03	15.41	4.67	10.64
	P value		0.00028	< 0.0000	0.00022	0.0309	0.00169
Age							
S	Old	108	0 ± 0	0.020 ± 0.14	0.215 ± 041	0.479 ± 0.50	0.243 ± 0.43
	Adult	95	0 ± 0	0.017 ± 0.13	0.322 ± 0.47	0.406 ± 0.50	0.237 ± 0.43
SS	Old	83	0.086 ± 0.28	0.272 ± 0.45	0.074 ± 0.26	0.530 ± 0.50	0.123 ± 0.33
	Adult	119	0.178 ± 0.39	0.151 ± 0.36	0.055 ± 0.23	0.671 ± 0.47	0.137 ± 0.35
	X^2		14.49	34.65	18.26	2.04	4.66
	P value		0.00055	< 0.00000	< 0.000	0.153	0.03407

CZ: Climatic zones, n: number of individuals surveyed, S: Sudanian, SS: Sudano – Sahelian, and X^2: chi-square.

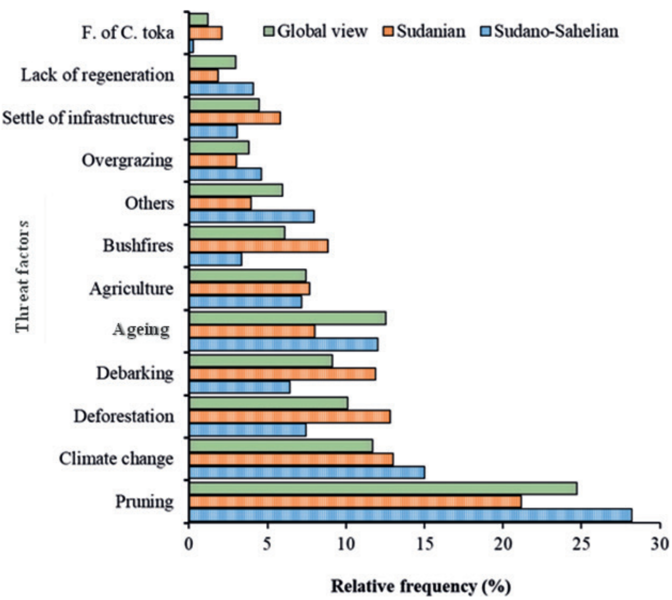

Figure 7. Threat factors by climate zone in Burkina Faso. F. of *C. toka*: failure of *C. toka*.

(FL: 32%), ageing (FL: 28%) and debarking (FL: 26%) were reported at a heightened level by the Dafing culture in the SSCZ (Table 4). These disturbances affect the survival of the critically endangered species *C. toka*.

The results globally suggested that pruning, climate change, deforestation, ageing, debarking, farming expansion and bushfires are the major factors that threaten the survival of *C. toka* in the study areas. Pruning, climate change, and deforestation ranked first, second and third, respectively, signifying that they are the most proximate threatening factors (Fig. 7). In the SCZ, ageing was perceived by Bobo culture; climate change by Bozo culture; debarking, pruning, farming and failure of *C. toka* by Dioula culture; and deforestation and settlement of infrastructures were mentioned by other ethnolinguistic groups as the main predictors of the decline of the species. However, in the SSCZ, deforestation, farming and pruning were the main causes of the extinction of *C. toka* identified by the Mossi. The Dafing culture believed that *C. toka* is threatened due to climate change and human activities (bushfires). According to the Bwaba culture, overgrazing and debarking are the key reasons for the threat in the study area (Table 6). In the BCZ, older people emphasized that the species has declined due to climate change, farming, ageing, deforestation, settlement of infrastructure, bushfires, failure of *C. toka*, pruning and other causes (Table 6). The overall threat factors of *C. toka* varied only across ethnolinguistic groups for ageing, pruning, climate change, farming, settlement of infrastructure, and lack of regeneration (p–value < 0.05). In addition, the threat drivers were statistically similar (p–value > 0.05) between both sexes and generations for identifying deforestation, settlement of infrastructures, lack of regeneration, failure of *C. toka* and bushfire as causes (Table 6).

Based on our observations in the field, the threat factor in the BCZ could be natural (hole, wind, drought, crown gall, fungi, and epiphyte) as well as anthropogenic. However, old *C. toka* trees contained very large hollows (Fig. 8) which weakens the species during wind (Fig. 9), or fire action (Fig. 10).

In addition to the hole, *C. toka* has a fasciculate root (Fig. 11) which accentuates the effect of wind. *Ficus thonningii* Blume (Fig. 12), fungi (Fig. 13), and crown gall and holes (Fig. 14) infest *C. toka* tree species.

In the study areas, some livelihoods result in the overharvesting of the leaves of this species either for food or fodder uses (Fig. 15), and the bark by traditional healers (Fig. 16). Furthermore, some individuals died, probably due to drought, ageing, or diseases (Fig. 17).

According to our field observations, the assessment of the threat by climatic zones showed that the SCZ was more exposed than the SSCZ (even though *C. toka* is less abundant in the SSCZ) due to anthropogenic activities such as artisanal activities (Fig. 18), and industrial mining (Fig. 19),and bushfire (see Fig. 10 above).

However, the exploitation of granite negatively affects seed germination and sometimes sapling growth. Some local people often cut *C. toka* (Fig. 20) for charcoal, firewood, or farm settlement purposes.

Epiphyte (Fig. 21), grazing by goats and cattle (Fig. 22), and biological invasion by *Azadirachta indica* A. Juss. (see Figs 11, 21, 22 above) of *C. toka* organs or saplings were noticed in some livelihoods of the study areas. Epiphytes (Fig. 21) infested *C. toka* trees to the point that they lost their leaves and remained apparently dead.

Table 6. Mean values (± Std) and results of GLM factors considered threats to *C. toka* in Burkina Faso.

CZ	Variables	n	Climate change	Farming	Deforestation	Settle of infrastructures	Ageing	Bushfire	Overgrazing	Lack of regeneration	Failure of *C. toka*	Debarking	Pruning	Others
Ethnolinguistic groups														
S	Bobo	145	0.131 ± 0.34	0. 048 ± 0.22	0.131 ± 0.34	0.055 ± 0.23	0.172 ± 0.38	0.137 ± 0.35	0.041 ± 0.20	0.062 ± 0.24	0.028 ± 0.16	0.180 ± 0.74	0.329 ± 0.47	0.062 ± 0.24
	Bozo	17	0.222 ± 0.43	0.111 ± 0.32	0.056 ± 0.24	0 ± 0	0.111 ± 0.32	0 ± 0	0.056 ± 0.24	0 ± 0	0.056 ± 0.24	0.222 ± 0.43	0.222 ± 0.43	0 ± 0
	Dioula	21	0.190 ± 0.40	0.238 ± 0.44	0.143 ± 0.36	0.048 ± 0.22	0.095 ± 0.30	0.095 ± 0.3	0 ± 0	0 ± 0	0.143 ± 0.36	0.381 ± 1.53	0.381 ± 1.53	0 ± 0
	Others	20	0.142 ± 0.36	0.190 ± 0.40	0.190 ± 0.40	0.190 ± 0.40	0.048 ±0.22	0.095 ± 0.30	0 ± 0	0.095 ± 0.30	0 ± 0	0.333 ± 0.97	0.367 ± 0.98	0.048 ± 0.22
SS	Bobo	28	0.071 ± 0.26	0.036 ± 0.19	0.071 ± 0.26	0 ± 0	0 ± 0	0.036 ± 0.19	0 ± 0	0.071 ± 0.26	0 ± 0	0.038 ± 0.19	0.077 ± 0.29	0 ± 0
	Bwaba	64	0.219 ± 0.42	0.265 ± 0.45	0.234 ± 0.43	0.188 ± 0.39	0.359 ± 0.48	0.031 ± 0.18	0.234 ± 0.43	0.109 ± 0.31	0.016 ± 0.13	0.188 ± 1.11	0.234 ± 0.43	0 ± 0
	Dafing	47	0.319 ± 0.47	0.085 ± 0.28	0.106 ± 0.31	0.043 ± 0.20	0.276 ± 0.45	0.148 ± 0.36	0.063 ± 0.25	0.085 ± 0.28	0 ± 0	0.26 ± 1.29	0.106 ± 0.31	0.043 ± 0.20
	Mossi	26	0.133 ± 0.35	0.267 ± 0.46	0.267 ± 0.45	0.067 ± 0.25	0.467 ± 0.52	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.2 ± 0.56	0.267 ± 0.45	0 ± 0
	Others	26	0.133 ± 0.35	0.267 ± 0.46	0.237 ± 0.41	0.056 ± 0.21	0.237 ± 0.24	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.2 ± 0.56	0.241 ± 0.36	0 ± 0
	X^2		6.41	17.7	2.39	3.7	7.03	2.14	0.44	0.896	0.37	1.15	7.65	1.06
	P value		0.00986	<0.000	0.117	0.0479	0.00699	0.152	0.499	0.01	0.548	0.301	0.00412	0.304
Sexes														
S	Female	91	0.144 ± 0.35	0.022 ± 0.15	0.067 ± 0.25	0.022 ± 0.15	0.167 ± 0.37	0.044 ± 0.21	0.022 ± 0.15	0.033 ± 0.18	0.044 ± 0.20	0.178 ±0.44	0.158 ± 0.37	0.040 ± 0.17
	Male	112	0.147 ± 0.36	0.139 ± 0.35	0.183 ± 0.39	0.095 ± 0.30	0.130 ± 0.34	0.174 ± 0.38	0.043 ± 0.20	0.070 ± 0.26	0.035 ± 0.18	0.252 ± 1.07	0.167 ± 0.39	0 ± 0
SS	Female	55	0.175 ± 0.38	0.125 ± 0.33	0.1 ± 0.30	0.025 ± 0.16	0.35 ± 0.48	0.025 ± 0.16	0.025 ± 0.16	0.075 ± 0.27	0 ± 0	0.075 ± 0.35	0.185 ± 0.37	0 ± 0
	Male	147	0.228 ± 0.42	0.184 ± 0.39	0.193 ± 0.40	0.123 ± 0.33	0.254 ± 0.44	0.079 ± 0.27	0.149 ± 0.36	0.088 ± 0.28	0.009 ± 0.09	0.219 ± 1.17	0.221 ± 0.40	0.009 ± 0.09
	X^2		1.64	5.27	2.12	2.53	2.9	0.05	6.67	1.13	2.12	7.52	0.38	1.26
	P value		0.195	0.0184	0.139	0.103	0.0844	0.832	0.00707	0.279	0.169	0.0159	0.3056	0.1504
Age														
S	Old	108	0.164 ± 0.37	0.103 ± 0.30	0.144 ± 0.35	0.068 ± 0.25	0.171 ± 0.37	0.089 ± 0.29	0.006 ± 0.08	0.048 ± 0.21	0.034 ± 0.18	0.171 ± 0.68	0.164 ± 0.37	0.034 ± 0.18
	Adult	95	0.101 ± 0.30	0.051 ± 0.22	0.102 ± 0.30	0.051 ± 0.22	0.085 ± 0.28	0.19 ± 0.39	0.102 ± 0.30	0.068 ± 0.25	0.05 ± 0.22	0.340 ± 1.18	0.101 ± 0.30	0.05 ± 0.22
SS	Old	83	0.284 ± 0.45	0.148 ± 0.36	0.136 ± 0.34	0.086 ± 0.28	0.309 ± 0.46	0.062 ± 0.24	0.136 ± 0.35	0.111 ± 0.32	0 ± 0	0.222 ± 1.25	0.284 ± 0.45	0.061 ± 0.20
	Adult	119	0.137 ± 0.34	0.192 ± 0.40	0.205 ± 0.41	0.110 ± 0.31	0.247 ± 0.43	0.068 ± 0.25	0.096 ± 0.30	0.055 ± 0.23	0.014 ± 0.117	0.137 ± 0.69	0.137 ± 0.34	0.014 ± 0.117
	X^2		3.89	0.77	0	0.14	4.2	1.71	1.4	0.95	1.71	0.17	4.51	2.65
	P value		0.0445	0.373	0.938	0.699	0.0372	0.2	0.227	0.321	0.215	0.681	0.0299	0.027

CZ: Climatic zones, n: number of individuals surveyed, S: Sudanian, SS: Sudano – Sahelian, and X^2: chi-square.

Figure 8. Risk factor: hollow in most of *C. toka* natural stands in the BZC. Pictures: Z. Dabré, 2020.

Figure 9. Risk factor: The effect of wind on *C. toka* in BCZ. Pictures: Z. Dabré, 2021.

Figure 10. Risk factor: ageing and fire effect on hollowed out *C. toka* in SCZ. Pictures: Z. Dabré, 2021.

Figure 11. Risk factor: ageing, action of the wind and *Azadirachta indica* A. Juss. invasion in SCZ. Pictures: Z. Dabré, 2021.

Figure 12. Risk factor: attack by *Ficus thonningii* on *C. toka* species in SCZ. Pictures: Z. Dabré, 2021.

Figure 13. Risk factor: attack of fungi on *C. toka.* Pictures: Z. Dabré, 2021.

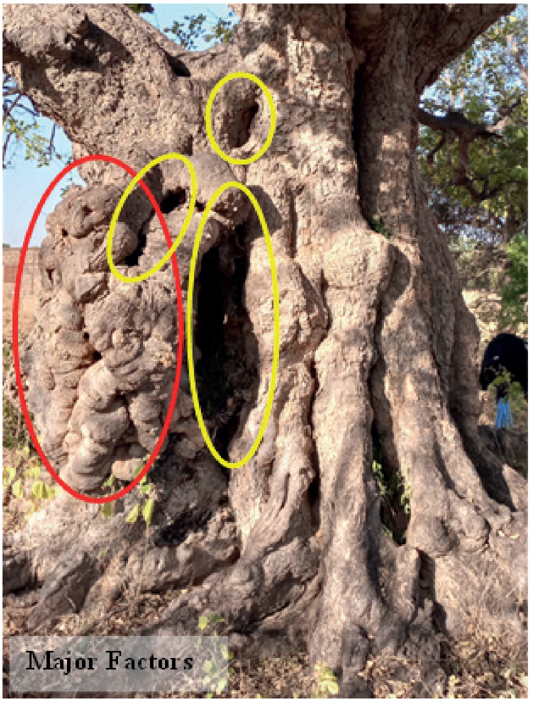

Figure 14. Risk factor: holes (yellow round), ageing, crown gall (red round) attacks coupled with debarking in the BCZ. Pictures: Z. Dabré, 2022.

Figure 15. Risk factor: heavy pruning of *C. toka*'s leaves in BCZ. Pictures: Z. Dabré, 2021.

Figure 16. Risk factor: debarking for traditional medicinal purposes in the BCZ. Pictures: Z. Dabré, 2020.

Figure 17. Risk factor: natural death due either to drought, diseases, or ageing of the hollowed out *C. toka* in the BCZ. Pictures: Z. Dabré, 2022.

Figure 18. Risk factor: Artisanal mining under *C. toka* tree in the SCZ. Pictures: Z. Dabré, 2021.

Figure 19. Risk factor: industrial mining in the habitat of *C. toka* in the SCZ. Pictures: Z. Dabré, 2021.

Traditional potential solutions to the threat

The conservation strategies proposed by the locals included the conservation of *C. toka* and its habitat, the sustainable use of *C. toka*, and the promotion of education and awareness about *C. toka*. However, planting was the most important solution expressed by all ethnolinguistic groups, as confirmed by the high FL (SCZ: 43%, SSCZ: 73%)

Figure 20. Risk factor: cutting of *C. toka* sapling in the SCZ. Pictures: Z. Dabré, 2020.

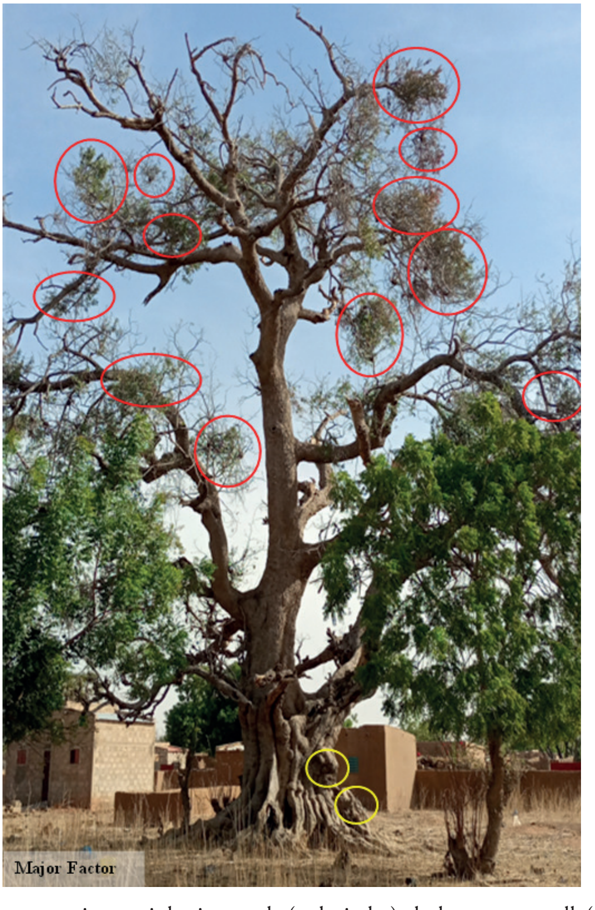

Figure 21. Risk factor: ageing, epiphytic attack (red circles), holes, crown gall (yellow circles), and *Azadirachta indica* A. Juss. invasion in SSCZ. Pictures: Z. Dabré, 2022.

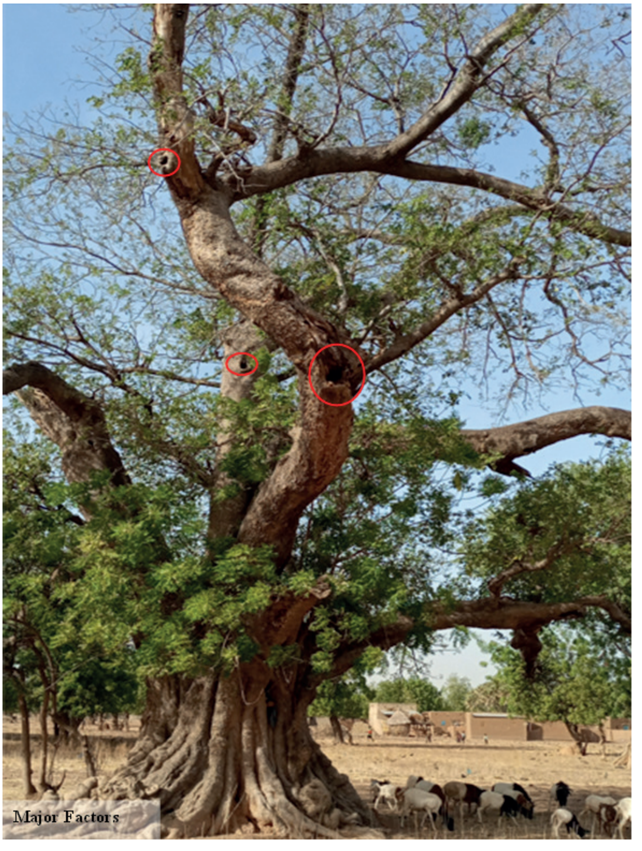

Figure 22. Risk factor: ageing, rotting, *Azadirachta indica* A. Juss. invasion and animal grazing in the SSCZ. Pictures: Z. Dabré, 2022.

value in the BCZ (Table 3). Planting (45%), conservation of *C. toka* and its habitat (27%), sustainable use of *C. toka* (14%), promoting education and awareness about *C. toka* (10%), and tree/crop association (5%) were the future potential solutions proposed to solve the threat posed to *C. toka* in the study areas. Moreover, potential solutions in the SCZ were planting (34%), conservation of *C. toka* and its habitat (33%) to protect it from human pressures such as cutting, fire, animal grazing and sustainable use of the species (16%) by avoiding overharvesting (pruning, debarking, and overusing the roots). In the SSCZ, planting (58%), conservation (19%), and sustainable use (10%) were the key solutions proposed to address the threats posed to the species (Fig. 23).

In the Sudanian climatic zone, conservation, sustainable use of the species, and planting were cited by the Bobo, Bozo, and Dioula cultures, respectively, as potential solutions to the threats posed to the species. According to the Sudano-Sahelian climatic zone, the conservation of the species and its habitat was mostly perceived by the Dafing and planting by the Bwaba as key solutions to address the threat. Most of the solutions were proposed by males in the BCZ. In the SCZ, older people proposed more solutions than younger adults. A contradiction was found in the SSCZ (Table 8).

The chi-square test results of the different responses of informants who were involved in answering whether to plant *C. toka* show that there is a significant relationship among the respondents in the study sites (Table 7).

The GLM analyses of respondents' perceptions of potential solutions to the threat posed to *C. toka* revealed that local perception varied significantly according to ethnolinguistic groups, sex, and ages for the solution of planting and ethnolinguistic groups for the solution of conservation of *C. toka* and its habitat (p–value < 0.05, Table 8). However, no differences in promoting education and awareness about *C. toka*, associating *C. toka* with crops, and sustainable use of the species were found among all the sociodemographic parameters (p–value > 0.05, Table 8).

Discussion

Local perception of the current state of the agroforest tree *C. toka* in Burkina Faso

The spatial dynamics of *C. toka* declined in the study area. This could be explained by the fact that the species was once rare. For instance, Gonzalez et al. (2012) emphasized

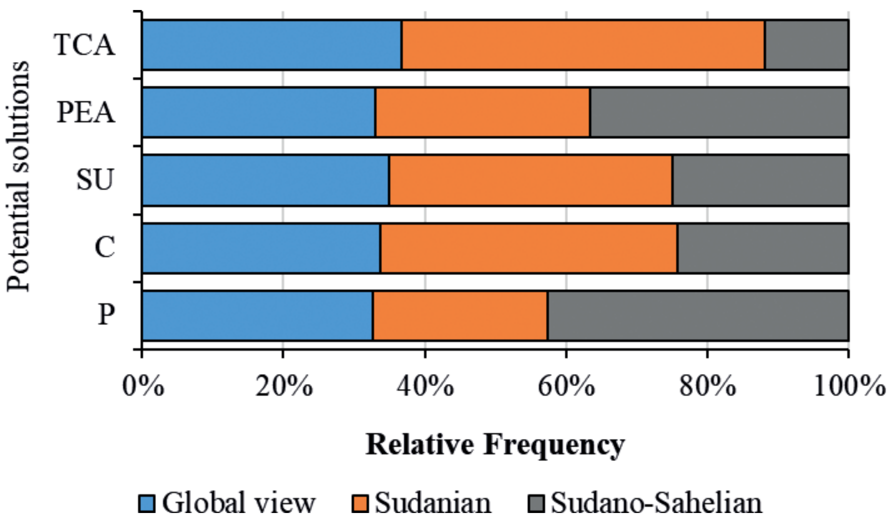

Figure 23. Traditional potential solutions to the threat according to climatic zones in Burkina Faso.

Table 7. Chi-square test showing whether to plant or not *C. toka* in Burkina Faso.

Climatic zones	% of respondents		Chi-square		
	Yes	No	DF	X^2	*P* value
Sudanian	77.02	23.91	1	27.94	< 0.0001
Sudano-Sahelian	99.61	0.39	1	98.43	< 0.0001

DF: degree of freedom, X^2: chi-square.

Table 8. Mean values (± Std) and results of GLMs of potential solutions to the existence of *C. toka* in Burkina Faso.

	Variables	*n*	Planting	Conservationof *C. toka* and its habitat	Promoting education, and awareness about *C. toka*	Tree/crop association	Sustainable use of *C. toka*
Ethnolinguistic groups							
S	Bobo	145	0.262 ± 0.44	0.152 ± 0.36	0.090 ± 0.29	0.062 ± 0.24	0.014 ± 0.11
	Bozo	17	0.235 ± 0.44	0.118 ± 0.33	0.059 ± 0.24	0.176 ± 0.39	0.059 ± 0.24
	Dioula	21	0.429 ± 0.51	0.048 ± 0.22	0 ± 0	0.048 ± 0.22	0 ± 0
	Others	20	0.2 ± 0.41	0 ± 0	0.05 ± 0.22	0.05 ± 0.22	0. 05 ± 0.22
SS	Bobo	28	0.179 ±0.39	0.107 ± 0.31	0.036 ± 0.19	0 ± 0	0 ± 0
	Bwaba	64	0.563 ± 0.5	0.094 ± 0.29	0.172 ± 0.38	0.031 ± 0.18	0.031 ± 0.18
	Dafing	47	0.489 ± 0.51	0.064 ± 0.25	0.021 ± 0.15	0 ± 0	0.021 ± 0.15
	Mossi	26	0.7 ± 0.51	0 ± 0	0.087 ± 0.26	0 ± 0	0 ± 0
	Others	26	0.6 ± 0.51	0 ± 0	0.067 ± 0.26	0 ± 0	0 ± 0
	X^2		19.55	15.56	1.41	4.21	0.48
	P value		< 0.000	< 0.00	0.244	0.051	0.477
Sexes							
S	Female	91	0.189 ± 0.39	0.111 ± 0.31	0.033 ± 0.18	0.044 ± 0.21	0.033 ± 0.18
	Male	112	0.336 ± 0.47	0.133 ± 0.34	0.106 ± 0.30	0.088 ± 0.29	0.009 ± 0.09
SS	Female	55	0.5 ± 0.51	0.1 ± 0.30	0.15 ± 0.36	0.025 ± 0.16	0 ± 0
	Male	147	0.464 ± 0.50	0.070 ± 0.26	0.070 ± 0.26	0.009 ± 0.09	0.026 ± 0.16
	X^2		6.09	0.29	0.29	0.27	0.05
	P value		0.013	0.596	0.587	0.613	0.831
Age							
S	Old	108	0.285 ± 0.45	0.118 ± 0.32	0.056 ± 0.23	0.063 ± 0.24	0.021 ± 0.14
	Adult	95	0.24 ± 0.43	0.136 ± 0.35	0.119 ± 0.33	0.087 ± 0.28	0.017 ± 0.13
SS	Old	83	0.469 ± 0.50	0.49 ± 0.21	0.135 ± 0.34	0.025 ± 0.16	0.012 ± 0.11
	Adult	119	0.479 ± 0.50	0.109 ± 0.31	0.041 ± 0.20	0 ± 0	0.027 ± 0.16
	X^2		5.53	1.31	0.2	2.24	0.01
	P value		0.018	0.260	0.650	0.151	0.913

CZ: climatic zones, n: number of individuals surveyed, S: Sudanian, SS: Sudano – Sahelian, X^2: chi-square.

that the density of *C. toka* has declined in the Guinea ecological zone of the African Sahel due to the climate. Moreover, human action could be the reason for the decrease in *C. toka* in Burkina Faso. Most youths were unaware of the value of this species; therefore, they cut saplings as well as adult trees. In addition, to establish agricultural land, some residents cut down *C. toka* individuals. Moreover, habitat loss could be the factor responsible for the changes in the species' population dynamics. However, the transformation of the species' habitat (gallery forests) by market gardening or exotic plants could explain its decline. For instance, in the Sudanian climatic zone, the habitat of *C. toka* was converted into vegetable crops (such as tomatoes, cucumbers, strawberries, eggplants, sorrels, carrots, papaya and others) and exotic tree plantations (*Mangifera indica* L., *Tectona grandis* L.f., *Anacardium occidentale* L., *Eucalyptus camaldulensis* Dehnh., *Annona muricata* L., *Annona squamosa* L., *Delonix regia* (Boj.) Raf., C*itrus lemon* (L.) Burm.f.). Dansi et al. (2013) demonstrated that the threat posed to *C. toka* may be due to forest destruction, bushfires, destructive harvesting methods and a lack of knowledge about the species. In the Sudano-Sahelian zone, *C. toka* was reported to be rare and even extinct. This extinction could be due to a lack of regeneration to replace the ageing population of the species. Research has shown that the threat posed to *C. toka* in northern Cameroon is due to the lack of regeneration. For instance, the regeneration was 0% in an unprotected area and 0.14% in protected areas (Moksia et al. 2019). According to the Mossi and other cultures from the SSCZ, the species was extinct due to overexploitation, the change in the environment and the failure of *C. toka* in the area. Hence, *C. toka* has extremely small population sizes and therefore is in extreme danger of extinction. For instance, it was difficult to obtain two or three individuals in the same area, and most of them were old and isolated in their communities. Additionally, the use of the species for traditional medicine may have contributed to its extinction in some study sites, mostly in the Sudano-Sahelian communal zone. Climate has a greater impact on the species abundance and distribution in the Sudano-Sahelian climatic zone than in the Sudanian climatic zone because *C. toka* is denser in the Sudanian than in the Sudano-Sahelian region. Deforestation caused by agricultural development, infrastructure installation, and climatic variability has an impact on the spatial dynamics of *C. toka*. Similar findings were reported by Hahn-hadjali and Thiombiano (2000); Garzuglia (2006); Vodouhe et al. (2007); Thiombiano et al. (2010); Bayala et al. (2011); Savadogo et al. (2017) in Burkina Faso. Moreover, *C. toka* is either extinct or endangered in Chad (Tchobsala et al. 2022), rare in Yemen (Al-Khulaidi 2018), and rare and threatened in Saudi Arabia (Alfaifi et al. 2021).

Hence, different ethnolinguistic groups, sexes and generations have diverse views on the status of *C. toka* due to cultural differences. Traditional knowledge of the dynamics of *C. toka* is influenced by ethnolinguistic groups over time. The scarcity and decline of *C. toka* have been perceived by most sociocultural groups. For instance, the declining factor of *C. toka* was perceived more strongly by the Bobo, Bozo, Dioula Dafing, and Mossi cultures. This is because those cultures are autochthonous and know the status of the species over time. Traditional healers (Bobo, Bwaba, Dioula, Mossi), hunters (Bwaba) and fishermen/women (Bozo) who interact with the habitat of *C. toka* have a better knowledge of the species' status. Knowledge of the declining characteristics of *C. toka* within a hamlet is similar from one generation to another. This could be explained by the fact that both younger adults and the elderly were aware of the species' status and thus noticed the decline and/or extinction of *C. toka*.

Threat to the sustainability of the sacred tree *C. toka* in Burkina Faso

Even though *C. toka* is a tree associated with mysticism, it faces diverse threats to its continued existence from various anthropogenic activities and natural factors. Extinction and decline of *C. toka* are due to a range of factors, including overharvesting (pruning, debarking, and rooting), climate change, deforestation, ageing of the population, and farming expansion. According to rural residents, overexploitation is the most serious threat because, in conjunction with the scarcity of *C. toka*, organs were harvested in an anarchic way. These findings were similar to those of Moksia et al. (2019). Respondents were confident that roots, leaves, and bark are a critical part of *C. toka*; therefore, its overharvesting may affect its reproduction.

Overharvesting of bark and leaves has been reported to have reduced fruit production in Burkina Faso (Nacoulma et al. 2017). Furthermore, heavy pruning could affect tree development and photosynthesis (Suchocka et al. 2021). Three percent (3%) of the rural community thought *C. toka* was endangered due to a lack of regeneration. Regeneration could be influenced by either seed availability or seed quality. *C. toka* has been overpruned to the point where it no longer produces fruits in some areas. The lack of seeds may be the primary cause of the lack of regeneration. Gaoue et al. (2011) demonstrated that the overharvesting of fruits and seeds exposes natural stands vulnerable to population ageing due to the threat to natural regeneration. Overgrazing may also contribute to a lack of regeneration. Four percent (4%) of locals believed that the scarcity of species was caused by overgrazing of seedlings and saplings. Harvesting roots, bark, and even leaves may expose *C. toka* to diseases such as fungal pathogens, galls, epiphytes, termite attacks, and others. These pathogens could drive the species to extinction by interfering with *C. toka* reproduction, increasing competition for nutrients, and most likely causing mortality. However, Boussim et al. (2004) indicated that *C. toka* is parasitized by a pest called *Tapinanthus globiferus* (A.Rich.) Tiegh. However, Otry and Laflamme (2009) confirmed that various fungi are pathogens of specific tree species and cause tree mortality in vulnerable trees. Approximately 12% of the respondents stressed that climate change is one of the reasons for the extinction of the taboo species. They noticed that during the past 30 years, there have been drastic changes in the frequency and volume of precipitation patterns, rising temperature and wind. Sop and Oldeland (2011) stated that drought is one of the primary causes of vegetation change in the Sub-Sahel of Burkina Faso. However, strong winds in the savannah and rocky zones cause the ageing population of the species to easily be uprooted because the species lacks a taproot, while drought causes the species to dry out. Furthermore, because the ideal temperature for *C. toka* is between 26 and 30 °C, an increase in temperature could inhibit regeneration (Watrin et al. 2007). According to respondents, floods have an impact on *C. toka* habitat by destroying habitat and uprooting any *C. toka* found on the banks because some of them had their roots hanging in the rivers in some way. In addition, ageing (13%) leads to the death of *C. toka*. Thus, drought and pathogens can hasten this death. Franklin et al. (1987) demonstrated that tree death is a natural ecological process involving one or more pathogens and other microbes. However, the proportion of farming expansion (7%) and urbanization (4%) was less of a contribution to the extinction of the sacred tree *C. toka*. These factors are still a major challenge today because the human population is growing, and forests are being destroyed to make way for infrastructure and farmlands. According to locals, previously, the *C. toka* tree was not widespread (1%) in different villages of Burkina Faso, and it was not accessible even for local food, fodder, firewood, and medical purposes. Most of the fishermen, hunters and traditional healers had to travel to other villages to look for the organs of *C. toka*. According to the respondents, fire (6%) may impact the seeds, seedlings, saplings and even the age population of the species. However, bushfires could reduce the abundance of seedlings by killing seedlings and decreasing the seed bank of *C. toka* in the soil. Furthermore, bushfires may influence the trunk and hollows of adult individuals, which could potentially lead to the death of the species. Fire triggers plant mortality throughout the crown, stem and root (Miller and Findley 2014). The severity and impacts, at the regional and global scales, of the burned area resulting from wildfires, have increased in recent decades (Doerr and Santin 2016). Wildfires have an impact on soil properties (Agbeshie et al. 2022), making plant species vulnerable to a decline (Miller et al. 2019). Local knowledge of the threat factors of *C. toka* was dissimilar among the ethnolinguistic groups, generations, and sexes due to the diversity of cultures.

Potential traditional solution to the threat

Three of the five concepts of the Global Strategy for Plant Conservation are the conservation of the species and its habitat, sustainable use, and promotion of education and awareness (CBD 2002). Planting remains the main solution to combat the threat in the BCZ. Although the sacred species *C. toka* was rare and extinct in some areas, no individuals were found planted near houses, such as in northern Cameroon, where *C. toka* was planted for agro-silvopastoral purposes (Neba 2009). Additionally, *C. toka* was planted in farmland in Ethiopia (Rolkier and Abebe 2015). Most rural residents agreed to plant *C. toka* on their farmlands and in public places (markets, administrations, and schools) because they believed it was the best way to save the species. Some rural residents have decided not to plant it in their compounds because they know that *C. toka* is a massive plant. Furthermore, the mystical nature of *C. toka* may have discouraged locals from domesticating it. The second possible solution was the in-situ conservation of *C. toka* and its habitat (13%) to protect it from all human activities, including animal grazing, bushfires, and cutting of saplings and adult trees. Farmers must respect the 100-metre limit on riverbanks for the conservation of natural habitat. Respondents believed that farming within 100 meters of the riverbanks could cause siltation of water bodies and affect species regeneration. Agricultural activities such as tillage and ploughing cause the siltation of streambeds, resulting in the loss of the original water source (Kumar et al. 2021) and shortening its useful life (Poleto and Beier 2012). However, the conservation of habitats may be the best solution to the threat because seeds could be obtained from the remains of individuals and could be used to produce seedlings in nurseries. Seedlings have the potential to aid in reforestation and soil restoration. For instance, *C. toka* could be used as a keystone plant to restore deeply destroyed ecosystems. Furthermore, reintroducing *C. toka* into a restoration framework can aid in the prevention of extinction. The main solution to extinction is in situ and ex-situ conservation of a species (Oldfield 2003). Furthermore, invasive species should be removed from the habitat to reduce competition. According to Barney et al. (2013), invasive alien species alter nutrient pools and fire regimes. However, rural people stated that *C. toka* is scarcer and more threatened than *Vitellaria paradoxa* C.F.Gaertn., *Lannea microcarpa* Engl. & K. Krause, *Parkia biglobosa* (Jacq.) R. Br. ex G. Don, *Bombax costatum* Pellegr. & Vuillet, *Adansonia digitata* L., and yet it is not protected. To reduce the rate of decline of *C. toka*, local people suggested associating crops with *C. toka*. We recommend in situ, ex-situ, and circa-situ conservation of *C. toka*. Circa-situ conservation is a successful conservation strategy in traditional agroforestry systems and backyard gardens (Sanchez et al. 2010; Lokonon et al. 2021). As such, we recommend that local communities increase their capacity to cultivate the species and replant it in traditional agricultural landscapes and home gardens, as well as promote youth education about good practices and harvesting techniques for plant parts used in food, fodder, medicine, or other specific uses.

Conclusion

This study has shown that the local people of the Sudanian and Sudano-Sahelian areas are aware of the ecological status of *C. toka*, as well as the potential driving factors influencing species dynamics. *Celtis toka* was described to be in a state of decline and extinction (in the Sudano-Sahelian zone) due to anthropogenic activities combined with climate change, lack of regeneration and species failure. Moreover, efforts should perhaps be concentrated on the domestication of *C. toka* to enhance regeneration and increase production. Conservation efforts should perhaps focus on *C. toka* and its habitat. However, most of the local future potential solutions included planting; conservation of the species, its seeds, regeneration, and its habitat; avoidance of the overuse of *C. toka*; fire protection; association of *C. toka* in farmland; and promoting education and awareness of youth about *C. toka*. The incorporation of local people's perceptions into policymaking is of critical importance in *C. toka* management and for its sustainable conservation strategies. The findings of this study will aid the conservation of the critically endangered species *C. toka* at the national level by informing future environmental and biodiversity conservation efforts. Moreover, *C. toka* could be used to rehabilitate and restore degraded ecosystems to promote the recovery of the species.

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References

Abba Idris S id, Halima Mohammed A (2020) Phytochemical screening, antimicrobial and antioxidant activities of Punica Grantum Peel. International Journal of Scientific Research and Engineering Development 4(2): 13–21. https://doi.org/10.46718/JBGSR.2020.01.000020

Achigan-Dako EG, Pasquini MW, Assogba-Komlan F, N'danikou S, Yédomonhan H, Dansi A, Ambrose-Oji B (2010) Traditional Vegetables in Benin. Institut National des Recherches Agricoles du Bénin. Imprimeries du CENAP, Cotonou, July 2014, 283 pp. https://doi.org/10.13140/RG.2.1.1803.1121

Agbeshie AA, Abugre S, Atta-Darkwa T, Awuah R (2022) A review of the effects of forest fire on soil properties. Journal of Forestry Research 33(5): 1419–1441. https://doi.org/10.1007/s11676-022-01475-4

Akoegninou A, van der Burg WJ, van der Maesen LJG (2006) Flore Analytique du Benin. 1063 pp. https://library.wur.nl/WebQuery/wurpubs/347966

Al-Khulaidi AWA (2018) Main vegetation types of the Wadi Rijaf, Jabal Bura' protected area, Yemen. Journal of Basic and Applied Sciences 2(1): 21–35. https://www.academia.edu/41063025/Main_Vegetation_Types_of_the_Wadi_Rijaf_Jabal_Bura_Protected_Area_Yemen

Alfaifi MM, Al-khulaidi AW, Alaklabi A, Al-Gifri AN, Al-Al Faify EA (2021) New record of vascular plant for the flora of Saudi Arabia: *Celtis toka* (Forssk.) Hepper and Wood, Cannabaceae. International Journal of Current Research in Biosciences and Plant Biology 8(7): 1–6. https://doi.org/10.20546/ijcrbp.2021.807.001

Amoutchi AI, Mehner T, Ugbor ON, Kargbo A, Paul KE (2021) Fishermen's perceptions and experiences toward the impact of climate change and anthropogenic activities on freshwater fish biodiversity in Côte d'Ivoire. Discover Sustainability 2(1): 1–18. https://doi.org/10.1007/s43621-021-00062-7

Arbonnier M (2019) Arbres, Arbustes et Lianes des Zones Sèches d'Afrique de l'Ouest, (Quatrième édition). Quae, MNHN, 779 pp. https://www.amazon.de/-/en/Michel-Arbonnier/dp/275922547X

Arkell AJ (1947) Early khartoum. Antiquity 21(84): 172–181. https://doi.org/10.1017/S0003598X00016653

Awas T (1997) A study on the ecology and ethnobotany of non-cultivated food plants and wild relatives of cultivated crops in gambella region, southwestern Ethiopia. Degree of Master of Science in Biology in the Addis Ababa University (Issue June), 132 pp. http://etd.aau.edu.et/handle/123456789/8073

Badiane M, Camara B, Ngom D, Diedhiou MAA (2019) Perception communautaire des parcs agroforestiers traditionnels à *Faidherbia albida* (Del.) Chev. en Basse Casamance, Sénégal. Afrique Science 15(1): 214–226. http://curis.ku.dk/ws/files/20647024/faidherbia_albida_int.pdf

Bareke T (2018) Lowland semi–evergreen forest of Ethiopia. Forestry Research and Engineering: International Journal 2(5): 244–248. https://doi.org/10.15406/freij.2018.02.00057

Barney JN, Tekiela DR, Dollete ESJ, Tomasek BJ (2013) What is the "real" impact of invasive plant species? The Ecological Society of America. Frontiers in Ecology and the Environment 2005(6): 322–329. https://doi.org/10.1890/120120

Bayala J, Kindt R, Belem M, Kalinganire A (2011) Factors affecting the dynamics of tree diversity in agroforestry parklands of cereal and cotton farming systems in Burkina Faso. New Forests 41(3): 281–296. https://doi.org/10.1007/s11056-010-9222-z

Betti JL, Yemefa ASRM (2011) Contribution à la connaissance des produits forestiers non ligneux du parc national de Kalamaloué, Extrême-Nord Cameroun: Les plantes alimentaires. International Journal of Biological and Chemical Sciences 5(1): 291–303. https://doi.org/10.4314/ijbcs.v5i1.68105

Betti JL, Yemefa'A SRM, Tarla FN (2011) Contribution to the knowledge of non wood forest products of the far north region of Cameroon : Medicinal plants sold in the Kousséri market. Journal of Ecology and the Natural Environment 3(7): 241–254.

Bizimana N, Tietjen U, Zessin K, Diallo D, Djibril C, Melzig MF, Clausen P (2006) Evaluation of medicinal plants from Mali for their in vitro and in vivo trypanocidal activity. Journal of Ethnopharmacology 103(3): 350–356. https://doi.org/10.1016/j.jep.2005.08.023

Blench R (2000) Trees on the March: the Dispersal of Economic Trees in the Prehistory of West-Central Africa. Odi, 15 pp.

Bloesch U (2014) Forest Mapping and Pre-Inventory of the Sudanese Refugee Hosting Areas in Maban and Pariang Counties. South Sudan Mission report part A (Issue May), 34 pp. https://doi.org/10.13140/RG.2.1.1013.0327

Boussim IJ, Guinko S, Tuquet C, Sall G (2004) Mistletoes of the agroforestry parklands of Burkina Faso. Agroforestry Systems 60(1): 39–49. https://doi.org/10.1023/B:AGFO.0000009403.36419.20

Bridges KW, Lau YH (2006) The skill acquisition process relative to ethnobotanical methods. Ethnobotany Research and Applications 4: 115–118. https://doi.org/10.17348/era.4.0.115-118

CBD (1992) 8th convention on biological diversity. Rio de Janeiro, 5 June 1992 (Vol. 2, Issue June), 214 pp. https://treaties.un.org/doc/Treaties/1992/06/1992060508-44PM/Ch_XXVII_08p.pdf

CBD (2002) Report of the Sixth Meeting of the Conference of the Parties to the Convention on Biological Diversity, 341 pp. https://www.cbd.int/meetings/COP-06

Dansi A, Adjatin A, Adoukonou-sagbadja H, Adomou AC, Yedomonhan H, Akpagana K, Foucault BDe, Dansi A, Adjatin A, Adoukonou-sagbadja H, Adomou AC, Yedomonhan H, Akpagana K, Foucault BDe (2013) Traditional leafy vegetables in Benin: folk nomenclature, species under threat and domestication. Acta Botanica Gallica 8078(156:2): 183–199. https://doi.org/10.1080/12538078.2009.10516150

de Albuquerque UP, Hanazaki N (2009) Five problems in current ethnobotanical research – And Some Suggestions for Strengthening Them. Human Ecology: an Interdisciplinary Journal 37(5): 653–661. https://doi.org/10.1007/s10745-009-9259-9

Diatta K, Diatta W, Fall AD, Ibra S, Dieng M, Mbaye AI, Manga I (2019) Ethnobotanic Survey of Aids Opportunistic Infections in the Ziguinchor District, Sénégal. Asian Journal of Research in Medical and Pharmaceutical Sciences 8(1–2): 1–10. https://doi.org/10.9734/ajrimps/2019/v8i1-230130

Djègo-Djossou S, Koné I, Fandohan AB, Djègo JG, Huynen MC, Sinsin B (2015) Habitat Use by White-Thighed Colobus in the Kikélé Sacred Forest: Activity Budget, Feeding Ecology and Selection of Sleeping Trees. Primate Conservation 29(1): 97–105. https://doi.org/10.1896/052.029.0106

Doerr SH, Santin C (2016) Global trends in wildfire and its impacts: Perceptions versus realities in a changing world. Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences 371(1696): e20150345. http://dx.doi.org/10.1098/rstb.2015.0345

Fall AD, Ibra S, Dieng M, Diatta-badji K, Diatta W, Bassene E (2017) Phytochemical screening, phenol content and antioxidant studies of ethanol leaf extract of *Celtis toka* (Forssk.) Hepper & J.R.I. Wood. Journal of Pharmacognosy and Phytochemistry 6(1): 488–492. https://www.phytojournal.com/archives/2017/vol6issue1/PartG/5-6-58-561.pdf

Franklin JF, Shugart HH, Harmon ME (1987) Death as an ecological process: The causes, consequences, and variability of tree mortality. Bioscience 37(8): 550–556. https://doi.org/10.2307/1310665

Friedman J, Yaniv Z, Dafni A, Palewitch D (1986) A preliminary classification of the healing potential of medicinal plants, based on a rational analysis of an ethnopharmacological field survey among Bedouins in the Negev Desert, Israel. Journal of Ethnopharmacology 16(2–3): 275–287. https://doi.org/10.1016/0378-8741(86)90094-2

Gaoue OG, Sack L, Ticktin T (2011) Human impacts on leaf economics in heterogeneous landscapes: The effect of harvesting non-timber forest products from African mahogany across habitats and climates. Journal of Applied Ecology 48(4): 844–852. https://doi.org/10.1111/j.1365-2664.2011.01977.x

Garzuglia M (2006) Threatened, Endangered and Vulnerable Tree Species: a Comparison Between FRA2005 and the IUCN Red list. FAO Forestry Department, 108/E, Rome, 18 pp. http://azkurs.org/pars_docs/refs/26/25854/25854.pdf

Gilbert T, Flore NJ, Claudette B, Pierre K, Moksia F, Adamou I (2019) Ethnobotanical study of indigenous woody plants in traditional agroforestry of the Sudano-Sahelianzone of Cameroon: Case of Mandara Mountains. International Journal of Agriculture & Environmental Science 6(6): 1–8. https://doi.org/10.14445/23942568/IJAES-V6I6P101

Gonzalez P (2001) Desertification and a shift of forest species in the West African Sahel. Climate research. Climate Research 17: 217–228. https://doi.org/10.3354/cr017217

Gonzalez P, Tucker CJ, Sy H (2012) Tree density and species decline in the African Sahel attributable to climate. Journal of Arid Environments 78: 55–64. https://doi.org/10.1016/j.jaridenv.2011.11.001

Hahn-hadjali K, Thiombiano A (2000) Perception des espèces en voie de disparition en milieu gourmantché (est du Burkina Faso). Berichte des Sonderforschungsbereichs 268(14); 285–297. https://d-nb.info/1106135997/34

Hamid MMA, Kordofani MAY (2015) Taxonomic Study of Trees and Shrubs of Zalingei Area West Darfur State- Sudan. International Journal of Scientific Research 4(10): 2319–7064. https://www.ijsr.net/archive/v4i10/SUB159038.pdf

Harris FMA, Mohammed S (2003) Relying on nature: Wild foods in northern Nigeria. Ambio 32(1): 24–29. https://doi.org/10.1579/0044-7447-32.1.24

Hauman L (1942) Note sur les Ulmacées du Congo Belge. Botanic Garden Meise 16(4): 407–412. https://www.jstor.org/stable/3666743

Höhn A, Neumann K (2016) The Palaeovegetation of Janruwa (Nigeria) and its Implications for the Decline of the Nok Culture. Journal of African Archaeology V 14(3): 331–353. https://doi.org/10.3213/2191-5784-10296

Houéhanou DT, Assogobadjo AE, Chadare FJ, Zanvo S, Sinsin B (2016) Approches méthodologiques synthétisées des études d'ethnobotanique quantitative en milieu tropical. Methods for sampling and analysis of field data to evaluate and monitor vegetation in Africa 20, 195–205.

Ifeanyiobi CC, Etuk UR, Jike-wai O (2012) Climate change, effects and adaptation strategies; Implication for agricultural extension system in Nigeria. Greener Journal of Agricultural Sciences 2(2): 053–060. https://doi.org/10.15580/GJAS.2013.3.1234

IPPC (2021) Climate Analytics (2021) 1.5°C to survive: evidence from the IPCC Special Reports. https://climateanalytics.org/publications/2021/15c-to-survive-evidence-from-the-ipcc-special-reports/

Irvine FR (1961) Woody Plants of Ghana with Special Reference to Their Uses. Oxford University Press, London, 143–144. https://www.scirp.org/(S(vtj3fa45qm1ean45vvffcz55))/reference/ReferencesPapers.aspx?ReferenceID=1769954

Ismail MI, Elawad AA (2015) Checklist of plants of Rashad and Alabassia localities (eastern Nuba Mountains). Check List 11(6): 1–9. https://doi.org/10.15560/11.6.1805

IUCN (2019) Botanic Gardens Conservation International (BGCI) & IUCN SSC Global Tree Specialist Group. 2019. *Celtis toka*. The IUCN Red List of Threatened Species 2019: e.T144137137A149001782. [The IUCN Red List of Threatened Species 8235: 7.] https://doi.org/10.2305/IUCN.UK.2019-2.RLTS.T144137137A149001782.en

IUCN (2020) Guidance for using the IUCN Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of Nature-based Solutions. 1st edn. IUCN, Gland, Switzerland, 78 pp. https://doi.org/10.2305/IUCN.CH.2020.09.en

IUCN (2021) Issues briefs. Forests and climate change. IUCN, Gland, Switzerland, 2 pp. https://www.iucn.org/resources/issues-brief/forests-and-climate-change

Kiee M, Zach B, Neumann K (2000) Four thousand years of plant exploitation in the Chad Basin of northeast Nigeria I: The archaeobotany of Kursakata Marlies. Vegetation History and Archaeobotany 9(4): 223–237. https://doi.org/10.1007/BF01294637

Kubmarawa D, Magomya AM, Yebpella GG, Adedayo SA (2011) Nutrient content and amino acid composition of the leaves of *Cassia tora* and *Celtis integrifolia*. Internagtional Research Journals of Biochemistry and Bioinformants 1(9): 222–225. https://www.interesjournals.org/articles/nutrient-content-and-amino-acid-composition-of-the-leaves-of-cassia-tora-and-celtis-integrifolia.pdf

Kumar N, Kumar A, Marwein BM, Verma DKIJ, Kumar A, Ramamoorthy D (2021) Agricultural activities causing water pollution and its mitigation – a review. International Journal of Modern Agriculture 10(1 SE-): 590–609. http://modern-journals.com/index.php/ijma/article/view/632

Lericollais A (1990) La gestion du paysage : Sahélisation, surexploitation et délaissement des terroirs sereer au Sénégal. In: Richard J-F (Ed.) La Dégradation des Paysages en Afrique de l'Ouest: Points de vue et Perspectives de Recherches. Ministère de la Coopération et du développement; Presse Universitaires de Dakar, Paris (FRA) & Dakar, 151–169. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_7/b_fdi_03_01/35485.pdf

Lokonon BE, Sodoté FE, Kakaï RG (2021) Use of local knowledge for contributing to the conservation of *Caesalpinia bonduc* (L.) Roxb in southern Benin (West Africa). Global Ecology and Conservation 27: 1–14. https://doi.org/10.1016/j.gecco.2021.e01551

Lykke AM, Kristensen MK, Ganaba S (2004) Valuation of local use and dynamics of 56 woody species in the Sahel. Biodiversity and Conservation 13(10): 1961–1990. https://doi.org/10.1023/B:BIOC.0000035876.39587.1a

Mahre MB, Umaru B, Ojo NA, Saidu AS, Yahi D, Ibrahim RM, Mshelbwala P (2017) Acute Toxicity, Phytochemistry and Anti-diarrheal Effects of *Celtis integrifolia* Lam. Aqueous Leaf Extract in Wistar Albino Rats. British Journal of Pharmaceutical Research 14(5): 1–7. https://doi.org/10.9734/BJPR/2016/31222

Mballow AE, Kahwa I, Abdelgadir AA, Adelina T, Ogwang PE (2020) Traditional approaches and medicinal plants in treatment of epilepsy in West and East Africa. NeuroPharmac Journal 5: 121–130. https://doi.org/10.37881/1.521

Miller M, Findley J (2014) CHAPTER VI – PLANTS. Fire Effects Guide, 313 pp.

Miller RG, Tangney R, Enright NJ, Fontaine JB, Merritt DJ, Ooi MKJ, Ruthrof KX, Miller BP (2019) Mechanisms of fire seasonality effects on plant populations. Trends in Ecology & Evolution 34(12): 1104–1117. https://doi.org/10.1016/j.tree.2019.07.009

Moksia F, Azaria D, Konsala S, Yougouda H, Gilbert T Tchobsala (2019) Structure, dynamics and impact of the exploitation of the woody plants of woodlands in the Sudano – sahelian zones, North Cameroon. International Journal of Advanced Research in Biological Sciences 6: 201–220. http://dx.doi.org/10.22192/ijarbs.2019.06.03.011

Muazu J, Kaita AH (2008) A review of traditional plants used in the treatment of epilepsy amongst the hausa/fulani tribes of northern Nigeria. African Journal of Traditional, Complementary, and Alternative Medicines 5(4): 387–390. https://doi.org/10.4314/ajtcam.v5i4.31294

Nacoulma BMI, Lykke AM, Traoré S, Sinsin B, Thiombiano A (2017) Impact of bark and foliage harvesting on fruit production of the multipurpose tree *Afzelia africana* in Burkina Faso (West Africa). Agroforestry Systems 91(3): 565–576. https://doi.org/10.1007/s10457-016-9960-9

Nacoulma MIB, Ouédraogo I, Ouédraogo O, Dimobé K, Thiombiano A (2018) Phytodiversity of Burkina Faso: Selected Countries in Africa. Global Biodiversity 3: 1–33. https://doi.org/10.1201/9780429469800-1

Nakagawa N (2008) Despotic wild Patas Monkeys (*Erythrocebus patas*) in Kala Maloue, Cameroon. American Journal of Primatology 70(3): 238–246. https://doi.org/10.1002/ajp.20481

Neba NE (2009) Management of woody plants in indigenous land use systems of the Sahel : Example of north Cameroon. International NGO Journal 4(11): 480–490. [Management of woody plants in indigenous land use systems of the Sahel]

Neumann K (1992) Une flore soudanienne au Sahara central vers 7000 B.P.: les charbons de bois de Fachi, Niger, Bulletin de la Société Botanique de France. Actualités Botaniques 139: 2–4. [565–569] https://doi.org/10.1080/01811789.1992.10827128

Ogungbenro RO, Oluwalana SA, Adedokun MO, Omosekeji RB (2018) Ethnobotancial and Phytochemical studies of some blood-cleansing Herbs in Oyo and Ogun States, Southwestern Nigeria. Journal of Advanced Botany and Zoology 6(2): 1–8. https://doi.org/10.5281/zenodo.1250060

Oldfield S (2003) Plant extinction – threats and solutions. 3rd Global Botanic Gardens Congress, 7 pp. https://www.bgci.org/files/Wuhan/PlenaryAddresses/Oldfield.pdf

Osue HO, Lawani FAG, Njoku CI (2018) Factors Affecting Sustainable Animal Trypanosomosis Control in Parts of Kaduna State, Nigeria. Journal of Agricultural Extension 22(1): 157–174. https://doi.org/10.4314/jae.v22i1.1

Otry ME, Laflamme G (2009) Fungi and diseases – Natural components of healthy forests. Botany 87(1): 22–25. https://doi.org/10.1139/B08-090

Piqué R, Gueye M, Hardy K, Camara A, Dioh E (2016) Not Just Fuel: Food and Technology from Trees and Shrubs in Falia, Saloum Delta (Senegal). Ethnoarchaeological Research 6: 1–14. https://doi.org/10.1007/978-3-319-23153-2_17

Poleto C, Beier EV (2012) Siltation and Erosion Processes on a tributary of lake Itaipu due a dam reservoir. Lakes, Reservoirs and Ponds 6(2): 108–119. https://www.limnology.ro/Lakes/2012/201206207.pdf

R Core Team (2021) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. https://www.R-project.org/

Rabeil T (2003) Distribution potentielle des grands mammifères dans le Parc du W au Niger. Thèse. Université Paris VII – Dénis Diderot UFR GHSS. https://tel.archives-ouvertes.fr/tel-00006931/file/tel-00006931.pdf

Rolkier GG, Abebe T (2015) Agroforestry Potentials of Under-Exploited Multipurpose Trees and Shrubs (MPTS) in Lare Woreda of Gambella Region, Ethiopia. The International Journal of Science & Technoledge 3(9): 23–40. https://www.internationaljournalcorner.com/index.php/theijst/article/view/124648/85675

Sanchez AC, Osborne PE, Haq N (2010) Identifying the global potential for baobab tree cultivation using ecological niche modelling. Agroforestry Systems 80(2): 191–201. https://doi.org/10.1007/s10457-010-9282-2

Sattarian A (2006) Contribution to the Biosystematics of *Celtis* L. (Celtidaceae) with Special Emphasis on the African Species. PhD thesis Wageningen University, Wageningen, 150 pp. https://edepot.wur.nl/121819

Sattarian A, Van Der Maesen LJG (2005) Two new species of *Celtis* (Celtidaceae) from Australia and Madagascar. Blumea 50(3): 499–503. https://doi.org/10.3767/000651905X622752

Savadogo S, Thiombiano A (2010) Sacred groves and community forests. In: Thiombiano A, Kampmann D (Eds) Biodiversity Atlas of West Africa (Vol. II): Burkina Faso. Ouagadougou and Frankfurt/Main, 625 pp. https://publikationen.ub.uni-frankfurt.de/frontdoor/index/index/year/2019/docId/48641

Savadogo S, Kabore A, Thiombiano A (2017) Caractéristiques végétales, typologie et fonctions des bois sacrés au Burkina Faso. International Journal of Biological and Chemical Sciences 11(4): e1497. https://doi.org/10.4314/ijbcs.v11i4.8

Seignobos C, Tourneux H (2002) Le Nord-Cameroun à travers ses mots: Dictionnaire de termes anciens et modernes. Karthala, Dictionnaires et Langues, Henry Tourneux. 00458682 HAL, 334 pp. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_7/b_fdi_03_05/0100273

Seignobos C (2014) Essai de Reconstitution des Agrosystèmes et des Ressources Alimentaires Dans les Monts Mandara (Cameroun) des Premiers Siècles de Notre ère aux Années 1930. Revue d'ethnoécologie, 51 pp. https://doi.org/10.4000/ethnoecologie.1836

Shepherd G (1992) Managing Africa's Tropical Dry Forests: a review of indigenous methods. e Overseas Development Institute, Regent's College, London, 124 pp. https://odi.org/en/publications/managing-africas-tropical-dry-forests-a-review-of-indigenous-methods/

Sop TK, Oldeland J (2011) Local Perceptions of Woody Vegetation Dynamics in the Context of a "Greening Sahel": A Case Study from Burkina Faso. Land Degradation & Development, 21 pp. https://doi.org/10.1002/ldr.1144

Sop TK, Oldeland J, Bognounou F, Schmiedel U, Thiombiano A (2012) Ethnobotanical knowledge and valuation of woody plants species: A comparative analysis of three ethnic groups from the sub-Sahel of Burkina Faso. Environment, Development and Sustainability 14(5): 627–649. https://doi.org/10.1007/s10668-012-9345-9

Suchocka M, Swoczyna T, Kosno-Jonczy J, Kalaji HM (2021) Impact of heavy pruning on development and photosynthesis of *Tilia cordata* Mill. trees. PLoS ONE 16(8): e0256465. https://doi.org/10.1371/journal.pone.0256465

Tchobsala HB, Haman B, Gilbert H, Paul K, Danra DD, Denis K (2022) Socio-economic and environmental influences of firewood exploitation in Bongor and its surroundings (Chad). Environmental Challenges 6: e100406. https://doi.org/10.1016/j.envc.2021.100406

Teklehaymanot T, Giday M (2010) Ethnobotanical study of wild edible plants of Kara and Kwego semi-pastoralist people in Lower Omo River Valley, Debub Omo Zone, SNNPR, Ethiopia. Journal of Ethnobiology and Ethnomedicine 23(1): 1–8. https://doi.org/10.1186/1746-4269-6-23

Theodory TF (2016) Dealing with Change: Indigenous Knowledge and Adaptation to Climate Change in the Ngono River Basin, Tanzania. PhD Thesis, Rheinische Friedrich-Wilhelms-University of Bonn, Germany, 251 pp. https://nbn-resolving.org/urn:nbn:de:hbz:5n-44638

Thiombiano A, Schmidt M, Da S, Hahn-hadjali K, Zizka G, Wittig R (2010) Vascular plants: flowering plants. In: Thiombiano A, Kampmann D (Eds) Biodiversity Atlas of West Africa (Vol. II): Burkina Faso. Ouagadougou and Frankfurt/Main, 625 pp.

Thiombiano A, Schmidt M, Dressler S, Hahn K, Zizka G (2012) Catalogue des plantes vasculaires du Burkina Faso. 405 pp.

Thiombiano A, Kakai RG, Bayen P, Boussim JI, Mahamane A (2016) Méthodes et dispositifs d'inventaires forestiers en afrique de l'ouest: état des lieux et propositions pour une harmonisation. Methods for sampling and analysis of field data to evaluate and monitor vegetation in Africa (Vol. 20), 218 pp.

Tsabang N, Guedje MN, Fokunang C, Dongmo S, Tchokouaha YLR, Tsouh FPV, Jiofack R, Protus AT, Nouidui C, Fekam BF (2016) Ethnopharmacological and Ethnomedical Study of Anti- Epileptic Plants used in Traditional Medicine in Yaounde and its Surroundings Areas (Cameroon). Journal of Biological and Chemical Research 35(1): 496–509.

Vivien J (1990) Fruitiers sauvages du Cameroun. (fin). Agritrop 45(4): 413–426. https://agritrop.cirad.fr/436558/1/436558.pdf

Vodouhe R, Atta-Krah K, Achigan-Dako GE, Eyog-Matig O, Avohou H [Eds] (2007) Plant genetic resources and food security in West and Central Africa. Regional Conference, 26–30 April 2004. Bioversity International, Rome, 746 pp. https://www.bioversityinternational.org/e-library/publications/detail/plant-genetic-resources-and-food-security-in-west-and-central-africa/

Watrin J, Lézine A-M, Gajewski K, Vincens A (2007) Pollen – plant – climate relationships in sub-Saharan Africa. Journal of Biogeography 34(3): 489–499. https://doi.org/10.1111/j.1365-2699.2006.01626.x