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RESEARCH ARTICLE

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Food tree species consumed during periods of food shortage in Burkina Faso and their threats

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Abstract

Aim of study: Edible products from tree species were identified in Burkina Faso and their contribution to the diet in the lean season was assessed. The main threats affecting most consumed food tree species were also documented.

Area of study: Six villages across two phytogeographic regions of Burkina Faso.

Material and methods: Focus group discussions and semi-structured interviews, including a 7-day dietary intake recall targeting women; semi-structured interviews targeting key male informants.

Main results: The number of edible tree products consumed was found to vary according to phytogeographic region and ethnic group. A few tree species played a disproportionally greater role in the diet and were characterized by very high frequency of consumption by the majority of households in both phytogeographic regions and across ethnicities: *Adansonia digitata*, *Parkia biglobosa* and *Vitellaria paradoxa*. These species are not critically endangered at country level but they are perceived as scarcely available at local level. Considering that the main threats on priority tree species (fires, drought, pest and diseases) vary across regions, to maintain sustainable sources of nutrients in the landscape, mitigation measures should be diversified and adapted to local pressures.

Research highlights: Priorities for conservation are emerging clearly, but research efforts should also target underutilized tree species for their potential to diversify nutrient-poor diets.

Additional keywords: edible tree products; livelihood; non-timber forest products; forest conservation.

Abbreviations used: HFIAS (Household Food Insecurity Access Scale); HH (Household); HHS (Household Hunger Score).

Authors´ contributions: Conceived and designed the experiments: BV, DA, NL. Performed the experiments: NT, DA. Analyzed the data: BV, CT. Wrote the paper: BV, CT. All authors read and approved the final manuscript.

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Introduction

Forests play a role in many food systems, through direct and indirect provisioning for human nutrition and through ecosystem services. Globally, 800 million people remain hungry, while 2 billion are suffering from hidden hunger (micronutrient deficiencies). Consumption of wild foods from forest landscapes has a large potential to contribute to mitigating nutritional deficiencies (Powell *et al.*, 2015). In most cases, these are due to a lack of diversity in the diet (Lachat *et al.*, 2017) and a poor supply of micronutrients (Black *et al.*, 2013). An increasing number of studies has documented the contribution of wild forest foods to the diet and suggested a link between forest cover and dietary quality (Johnson *et al.*, 2013; Ickowitz *et al.*, 2014). Assessments of actual quantities of forest foods consumed have been carried out (Termote *et al.*, 2012; Powell *et al.*, 2013; Rowland *et al.*, 2016) and it has been found that their contribution to the diet varies considerably. Semi-disturbed forested environments with anthropic influence and mixed land use types (*e.g.*, swidden agriculture, agroforestry, natural forest, tree crop plantations) seem to be associated with higher frequency of consumption of food groups rich in micronutrients (Ickowitz *et al.*, 2016).

Research on consumption of wild foods in dry forest areas, and on their nutritional importance, are very few (Rowland *et al.*, 2015) despite the large extension of dry forests and their relatively large supply of edible

products compared to alternative land uses in the same regions (Wunder, 2001).

Seasonality is a key element of food availability, especially in the Sahelian countries, and the contribution of food tree species to the diet is particularly important during periods of food scarcity or extreme drought (Faye *et al.*, 2010; Atato *et al.*, 2011; Agúndez *et al.*, 2016).

In West Africa, food tree species are valued by local people. Preferred trees are usually multifunctional (Gijsbers *et al.*, 1994; Faye *et al.*, 2010) and supply edible products (Kristensen & Lykke, 2003; Kristensen & Balslev, 2003). When the land is cleared for agriculture, favoured trees are retained and their natural regeneration in farmed fields is protected (Ræbild *et al.*, 2011). Indigenous communities appear to have favoured edible-fruit-yielding species normally found in the wetter Sudanian and Guinean phytogeographic zones (Maranz, 2009). Their density tend to be generally higher in farmed versus non-farmed areas (Maranz & Wiesman, 2003).

Based on increasing evidence, dry forests in tropical areas are vulnerable to several threats. Tree species richness and density declined in the West African Sahel in the second half of the 20th century (Gonzalez, 2001). About 97% of the remaining area of tropical dry forest is at risk from one or more of threats, with the largest effects attributable to habitat fragmentation and fire (Miles *et al.*, 2006).

In West Africa, dry forest cover coincides with areas of high population density. Southern Burkina Faso has experienced rapid population growth, mostly determined by immigration of farmers. Cropland has expanded at an annualized rate of 0.46% at the expense of forest cover, which decreased by 0.57% per year. In the same areas, migrant population has increased from 3% in 1976 to 57% in 2007 (Paré *et al.*, 2008; Ouedraogo *et al.*, 2009, 2010). In some regions, this has determined a considerable exploitation of non-timber forest products (NTFPs) and an associated decline in the density of some tree species (Boffa, 1999; Kristensen & Balslev, 2003; Lykke *et al.*, 2004; Paré *et al.*, 2010), with potential consequences on various ecosystem services, including nutrition security (Jones *et al.*, 2017).

The views of local people are central in providing information on general trends in vegetation dynamics and particularly on changes in occurrence of rare species (Lykke, 1998). Preferences of local people are also crucial in the definition of locally acceptable management solutions.

A first objective of this study was to identify tree species that provide edible products to rural communities during the lean season across two ecoregions of Burkina Faso. A second objective was to understand what household (HH) characteristics (*e.g.*, ethnicity, origin, ecoregion, level of education) had most influence in determining the observed patterns of consumption of edible tree products. Finally, based on the perception of local key informants, the main threats affecting the most consumed food tree species were documented, with the objective to assess 1) how threats varied across the ecoregions and villages investigated and 2) whether species-specific threats could be identified. The ultimate objective was to single out priority food tree species, relate these to their main threats and determine if implementation of conservation and mitigation measures would require adaptation to highly diversified contexts.

Material and methods

Study sites

The study included two regions, the Sahelian and Sudanian phytogeographic zones of Burkina Faso. The Sahelian region has an annual rainfall between 400 and 700 mm, the Sudanian between 700 and 1000 mm. The rainy season lasts 3 to 5 months and the dry season 9 to 7 months, for the Sahelian and Sudanian region respectively (Fontes & Guinko, 1995). The boundary between the two zones is defined by the 750 mm isohyet. The study sites were selected from the most recent national census database (INSD, 2010), based on the total number of inhabitants. A total of 3 villages were sampled in both the Sudanian (Barcé, Péni and Sara) and Sahelian phytogeographic zone (Barsalgho, Bourgou, and Pobé-Mengao) (Fig. 1). The study was conducted during the lean season (June-July 2011). In the Sahelian zone, the lean season extends from April to September, when harvest is good, and from February to September, when harvest is bad. In the Sudanian zone, the lean season lasts from May to September.

The most typical configuration of the vegetation is represented by a savanna characterized by a decreasing tree density along the main bioclimatic gradient, from South to North (Guinko, 1984). Land that is converted to agriculture usually presents scattered trees. Other common land uses are fallow of different ages, forest reserves and plantations of exotic trees (*e.g.*, cashew nut) (Augusseau *et al.*, 2006). The spatial configuration of multipurpose trees, whose diversity in the landscape can be considerable [> 50 tree species recorded at village level by Boffa (1995)], is intimately linked to human influences (Lovett & Haq, 2000).

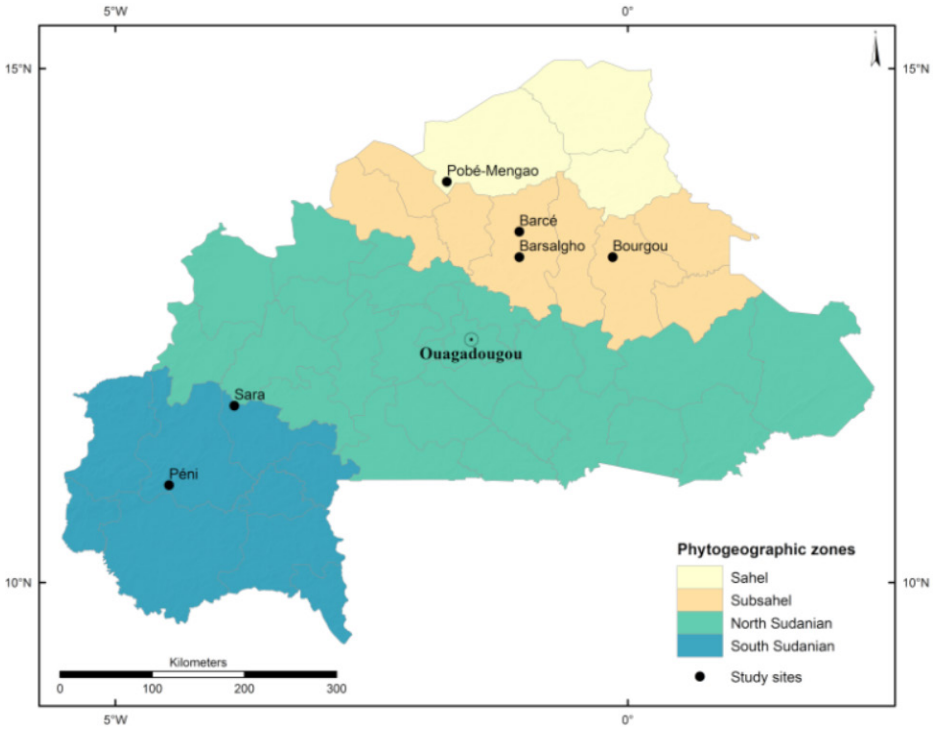

Figure 1. Location of the six selected study sites in Burkina Faso. The boundaries of the phytogeographic zones are adapted from White (1983) and Guinko (1984).

Methodology

Eighteen focus group discussion were organized across all villages (2 in both Barcé and Barsalgho, 3 in both Bourgou and Pobé-Mengao and 4 in both Péni and Sara) with 10 women of different age and ethnicity (see Table 1). The purpose of the discussion was to produce a list of the dishes most commonly prepared during the lean period and to identify a complete list of tree species commonly consumed during the lean season.

Subsequently, in each village, a total of 50 HHs were randomly selected for semi-structured interviews based on the most recent population census database (INSD, 2010). A total of 300 female informants were interviewed individually in their local language. In Burkina Faso, women take care of the cooking and have a central role in ensuring food security and nutrition (Savy *et al.*, 2005; Martin-Prével *et al.*, 2012), therefore the informants identified were all female. The first part of the questionnaire dealt with demographic and socio-economic characteristics of the HH (number of HH members, number of children, ethnicity, migration status, education level of the wife of the HH's head, her income activities and an evaluation of the last harvest). Then, a standard set of nine key questions were posed to assess the degree of food insecurity based on HH's experience of the problem, based on the Household Food Insecurity Access Scale (HFIAS, Coates *et al.*, 2007). The last three questions of the HFIAS, were used to calculate the Household Hunger Score (HHS, Ballard *et al.*, 2011).

The second part of the questionnaire consisted of a 7-day qualitative HH food intake recall, limited to the foods prepared at home and/or consumed at home. Respondents first answered spontaneously, describing HH food consumption over the past week, they were then prompted to be sure that no meal or snack had been forgotten. Next, a detailed list of all the ingredients of the dishes, snacks, or other foods mentioned was collected. Finally, the recall information was cross-checked with the list of dishes and ingredients collected during the focus group discussions to verify if nothing was omitted in the recall.

Total number of tree species and total number of tree products consumed per HH over a 7-day period in the lean season were calculated. Bivariate statistical analyses were performed to explore relationships between the dependent variables (*i.e.*, total number of tree products used per HH and total number of tree species consumed per HH during the lean season) and the independent variables collected in the HH survey (*i.e.*, socio-economic characteristics of the HH, HFIAS and HHS). The dependent variable being a count (number of species consumed) over a period of time (7 days), Poisson regressions were used. Subsequently, the independent variables with p-values 0.10 or lower in the bivariate analyses were entered together in a multivariate Poisson regression model run once for

Table 1. Ethnic composition of the six selected study sites (Burkina Faso).

Ecoregion	Province	Village	Ethnic groups
Sahelian	Soum	Pobé-Mengao	Fulsé, Mossi, Zarsé
Sahelian	Gnagna	Barsalgho	Gourmatchéma, Mossi, Fulani
Sahelian	Sanmatenga	Bourgou	Bissa, Mossi, Fulani
Sudanian	Tuy	Sara	Bwaba, Dafing, Koo, Mianka (Malienne), Mossi, Fulani
Sudanian	Zoundweogo	Barcé	Mossi
Sudanian	Comoé	Péni	Chin, Dioula, Kienkan, Mossi, Sambla, San, Tiego, Toussian, Turka, Wangan

tree products and once for tree species consumed as dependent variables. Significance levels were set at $p<0.05$.

A rapid market survey was conducted to observe what edible products derived from food tree species were available at the time the study was conducted. In addition, a total of 35 male key informants were interviewed individually in their local language about their perception of the most significant threats to a set of food tree species, whose list had been predetermined for each village, through focus group discussions and HH surveys. The assumption was that male farmers more frequently travel further away from the village, thus their observations and perception of changes in tree species density would relate to a wider area around the village. Local perception of threats affecting the most important food tree species was considered a reliable proxy for actual threats as assessed in similar studies in relation to climate change (West *et al.*, 2008).

Key informants were requested to attribute a score from 0 to 3 to a list of pre-defined threats (0 = not a threat, 1 = not important, 2 = important and 3 = very important threat). The 12 pre-defined threats, based on a screening of the literature, were the following: land clearance, fire, grazing, wood exploitation, consumption of fruits and flowers, harvest of leaves, exploitation of bark, charcoal production, pests and diseases, drought, aging, loss of soil fertility (Ræbild *et al.*, 2011). Key informants also had the possibility to add threats not yet listed.

A deeper analysis of threat patterns was conducted for the most important tree species (*i.e.*, consumed by > 5% of the HHs). Average threat scores were presented as 1) individual species threat profiles, considering all villages together and 2) village threat profiles, considering all species together. Subsequently, the average threat scores were summed i) for each species (across all villages and including all types of threats); ii) for each village (across species and including all types of threats) and iii) for each type of threat (across all villages and including all species).

Results

Survey household characteristics

The majority of participants in both phytogeographic zones belonged to the Mossi ethnic group (49%) followed by Tiego and Bwaba in the Sudanian villages (both about 15%) and Gourmanthché and Fulsé in the Sahelian villages (30 and 18% respectively) (Table 2). In the Sudanian villages, 68 % of HHs had an immigration background and 27% stated to have migrated to the village less than 20 years before. These figures were 47% and 35% for the Sahelian villages and differences were statistically significant. A significantly higher percentage of participants was illiterate in the Sudanian zone (67%) than in the Sahelian zone (33%). Almost all women involved in the study had agriculture as their main income activity (97%). The last harvest was estimated as rather bad in the Sudanian zone (46%) and as good in the Sahelian zone (62%). The average number of HH members was 11 in both zones, with on average 4.5 children. The HH food insecurity scores were quite similar for the two zones, though the HH hunger score was significantly higher in the Sudanian (0.43) compared to the Sahelian (0.09) zone.

Commonly consumed ingredients from tree species during the lean period

The qualitative assessment of the diet showed that, during the lean period, this was mainly based on cereals (100% of the HHs interviewed had consumed cereals over the past week) and leafy vegetables (100% of HHs had consumed leafy vegetables over the past week), complemented by fruits (89% of HHs consumed at least 1 fruit over the past week) and accompanied by products of animal origin (eggs in 38% of HHs, milk in 62%, meat in 61% and fish in 91%).

Fruits consumed in the lean season by the majority of HHs were collected from the following tree species: *Lannea microcarpa* (76%), *Vitellaria paradoxa* (68%), *Parkia biglobosa* (48%). *Mangifera indica* was also

Table 2. Demographic data of the study sites. Values between parentheses are percentages calculated within a category (*e.g.* ethnicity) within the same ecoregion (*e.g.* Sudanian).

Variable	Sudanian (N=149)	Sahelian (N=150)	Total (N=299)
Ethnicity[1]*			
Mossi	76 (51.0)	70 (46.7)	146 (48.83)
Gourmantché	0	45 (30.0)	45 (15.05)
Tiego	21 (14.09)	0	21 (7.02)
Fulsé	0	27 (18.0)	27 (9.03)
Bwaba	23 (15.44)	0	23 (7.69)
Others	28 (18.79)	8 (5.3)	36 (12.04)
Missing values	1 (0.67)	0	1 (0.33)
Residence status*			
Autochtonous	48 (32.21)	79 (52.7)	127 (42.47)
Immigrant	101 (67.79)	71 (47.3)	173 (57.86)
Residence status*			
Autochtonous	48 (32.21)	79 (52.67)	127 (42.47)
Migrated > 20 year ago	20 (13.42)	10 (6.67))	30 (10.03)
Migrated < 20 year ago	47 (26.85)	53 (35.33)	100 (33.44)
Missing values	34 (22.82)	8 (5.33)	42 (14.05)
Education level*			
Illiterate	100 (67.11)	50 (33.33)	151 (50.50)
Literate	8 (5.37)	73 (48.67)	81 (27.09)
Primary school	35 (23.49)	21 (14.0)	56 (18.73)
Secondary school	6 (4.03)	5 (3.33)	11 (3.68)
Missing values	0	1 (0.67)	1 (0.33)
Income activity mother*			
Agriculture	145 (97.32)	146 (97.3)	291 (97.32)
Agriculture + small business	0	4 (2.7)	4 (1.34)
None	4 (2.68)	0	4 (1.34)
Evaluation last harvest*			
Bad	68 (45.64)	15 (10.0)	83 (27.76)
Average	41 (27.52)	42 (28.0)	83 (27.76)
Good	27 (18.12)	93 (62.0)	120 (40.13)
Missing values	13 (8.72)	0	13 (4.35)
Number of HH members [missing values]	10.71 ± 6.17 [0]	10.85 ± 5.17 [1]	10.78 ± 5.68 [1]
Number of children in HH [missing values]	4.45 ± 2.54 [1]	4.56 ± 2.56 [1]	4.51 ± 2.54 [2]
HH food insecurity score [missing values]	10.72 ± 6.26 [4]	10.53 ± 4.38 [2]	10.63 ± 5.39 [6]
HH hunger score** [missing values]	0.43 ± 1.15 [1]	0.09 ± 0.43 [0]	0.26 ± 0.88 [1]

[1] Ethnicity: only the five most represented ethnic groups are compared; the others are represented by few individuals and clustered into one group ('Others'). *Significant difference between Sudanian and Sahelian, X^2-test. **Significant difference between Sudanian and Sahelian, Mann-Whitney test.

largely reported by 68% of the HHs, although this is not a savanna tree species, but it is commonly planted by villagers nearby households or farmers' fields. Fruits were usually consumed raw but sometimes were cooked and added to porridges or combined with other foods (*e.g.*, *P. biglobosa* pulp was sometimes cooked and added to the couscous of maize). Vegetables and leafy vegetables were generally used in the preparation of sauces as side dishes. *Adansonia digitata* leaves were the most consumed leafy vegetables (96% of HHs had consumed *A. digitata* leaves over the past week). The seeds of *P. biglobosa* were transformed into a kind of mustard used as condiment in various dishes (70% of HHs consumed *P. biglobosa* seeds over the past week). Butter and oil were largely consumed. Approximately 40% of HHs consumed shea butter,

derived from the kernels of *V. paradoxa*. Alternatively, other types of oil (*e.g.*, red palm oil) were commonly used.

Food tree species consumed

The analysis of the composition of the diet during the lean season across the six study sites revealed that a total of 25 tree species contributed to it (Table 3). Across the two phytogeographic zones, only 10 species were consumed over the past week by a large part of the HHs surveyed (> 20%). All other species were consumed by a considerably lower percentage of HHs. The most widely consumed products were the leaves of *A. digitata*, eaten over the past week by > 96% of the HHs surveyed. The discrepancy between the few largely consumed species and all others was particularly remarkable for tree species consumed as leafy vegetables: of the 12 species reported, 10 were consumed by less than 10% of the HHs (Fig. 2b). The pattern was similar for tree species consumed for their fruits: of the 16 species reported, 13 were consumed by less than 10% of the HHs (Fig. 2a).

Consumption patterns varied by ecoregion. The percentage of HHs consuming tree species as leafy vegetables was higher in the Sahelian region compared to the Sudanian region, but this difference was not statistically significant. The consumption of individual tree leafy vegetable species, however, could differ significantly between the two ecoregions. For example, *Bombax costatum* and *Leptadenia hastata* were consumed by a higher percentage of HHs in the Sahelian region where these two species were better represented compared to the Sudanian ecoregion (Fig. 2b). Grouping all species, the percentage of HHs consuming tree species for their fruits was remarkably higher in the Sahelian region, although some of the top ranking food tree species were consumed by a higher percentage of HHs in the Sudanian ecoregion where these species were better represented (*e.g.*, *V. paradoxa* and *P. biglobosa*) (Fig. 2a). A higher percentage of HHs was consuming tree species for their seeds and nuts in the Sudanian ecoregion, where the top ranking species (*V. paradoxa* and *P. biglobosa*) were mainly found. *V. paradoxa*, in particular, is almost absent from the Sahelian ecoregion) (Fig. 2c).

Modalities of procurement varied also by ecoregion. Fruits and leaves from *Vitex doniana* were available in the markets in the Sudanian zone. Several other food products derived from trees were also available in the market, not only in the wild (*e.g.*, *A. digitata, B. costatum, L. microcarpa, V. paradoxa*). In particular, the leaves of *A. digitata* could be easily transformed (dried and powdered), stored and sold later during the year, so when found in the diet, their source could be different (wild, farmers' fields, market).

Based on findings from focus groups discussions, some species appeared to be no longer available. In the Sudanian zone, the fruits of *Ficus sycomorus* and *Ficus ingens* in particular, were not consumed in the village of Barcé because these species were too difficult to find given their habitat is disappearing. In Péni, the fruits of *Ximenia americana* have become rare. In the Sahelian zone, the fruits of *Boscia senegalensis* and *X. americana* have become almost completely unavailable in the surroundings of Barsalgho. In this village, the fruits of *X. americana* were consumed by just 2% of the HHs surveyed. In the case of *B. senegalensis* only seeds were consumed by a very small fraction of the population surveyed in the Sahelian zone. In Bourgou, in addition to the products from the two species above, others were becoming less available, such as the leaves of *Crataeva adansonii* and the fruits of *P. biglobosa* (consumed by 16% of the HHs). In Pobé-Mengao, the fruits of *F. sycomorus* were no longer consumed as they were too rare.

Relationships between the consumption patterns of food tree species, and some socio-demographic variables

In the lean season, each household consumed on average 4.92 tree products during the 7-days preceding the interviews from on average 4.3 different tree species.

Bivariate Poisson regressions showed no significant relationships at $p<0.05$ level between the dependent variables 'total tree products consumed' and 'total tree species consumed' and the independent socioeconomic variables 'number of HH members', 'number of children', 'residence status', 'women education', 'women activities', 'evaluation of last harvest' 'HFIAS' and 'HHS' (Table 4). The only significant relationships were found between the dependent variable 'total tree products consumed' and the independent variables 'ethnicity' and 'ecoregion' ($p = 0.041$ and $p=0.000$, respectively).

In the bivariate analyses, the relationship between the dependent variable 'total tree products consumed' and the independent variables 'ethnicity', 'ecoregion' and 'residence status' obtained a p-value <0.1 (see Table 4). 'Ethnicity', 'ecoregion' and 'residence status' were entered in the multivariate Poisson regressions with 'total tree products consumed' as dependent variable. The multivariate model showed that ecoregion as well as ethnicity ($p=0.000$ and $p=0.015$, respectively) had a significant relationship with 'total tree products consumed' 'Residence status' was not significant in the multivariate regression. However, 'ethnicity', 'residence status',

Table 3. A list of all 25 indigenous food tree species mentioned as edible in the HH survey and the results of a literature review about their characteristics. Sources: Guinko, 1984; Lebrun *et al.*, 1991; Arbonnier, 2004; Nikiema, 2005; Akoègninou *et al.*, 2006; Orwa *et al.*, 2009; Sacande *et al.*, 2012; Global Plants, JSTOR, http://plants.jstor.org/; Plant Resources of tropical Africa – PROTA, http://www.prota.org/

Species name	Botanical family	Common names	Life form	Ecological zone	Plant part(s) used as food
Acacia macrostachya	Fabaceae	Ciidi (F); Zâmanega (M); Nsofaragoni (D, B)	Tree	Sahelian	Seeds consumed like vegetables.
Adansonia digitata	Malvaceae	Baobab (French); Tohèga (M); Sira yiri (D); Nsira (B)	Tree	Sahelian/ Sudanian	Leaves: used as condiment and seasoning. Young leaves used for soup vegetable. Fruit (pulp) used for preparation of tangy sweet drink and condiment. The 'flour' from ripe fruits is used to make a fermented porridge. Wood used as salt substitute. Seeds used to extract cooking oil.
Afzelia africana	Fabaceae	Kangala (M); Lengue yiri (D); Pettohi (F); Lenge (B)	Tree	Sudanian	Flowers used as vegetable for the couscous. Edible aril. The flour from seeds is used as a substitute for wheat flour in biscuits and doughnuts.
Annona senegalensis	Annonaceae	Barkudga (M); Mande sunsun (D); Dukumu, Doukouhi (F); Mande sunsun (B)	Shrub/ Small Tree	Sudanian	Leaves and flowers consumed as vegetables. Edible fruits (pulp).
Balanites aegyptiaca	Zygophyllaceae	Kia kalala, Tia galgha (M); Tale (F)	Tree	Sahelian/ Sudanian	Edible fruits: pulp eaten dried or fresh. Fruit processed into a drink (Ghana), liquor (Nigeria), and soup ingredient (Sudan). Seeds highly appreciated for oil extraction. Shoots consumed as vegetables. Young leaves and tender shoots are used as a vegetable, which is boiled, pounded, then fried or fat added to prepare it. The flowers are a supplementary food in West Africa and an ingredient of 'dawa dawa' flavouring in Nigeria. Flowers are sucked to obtain nectar. A greenish-yellow to orange-red resin is produced from the stems. It is sucked and chewed when fresh.
Bombax costatum	Malvaceae	Voaka (M); Bumbum (D); Bumbuwi (F); Bumu (B)	Tree	Sahelian/ Sudanian	Flowers (chalices) and fruits used to make condiments for sauce preparation.
Boscia senegalensis	Capparaceae	Ambriaka (M); Dafi sagwan (D); Dafi sangwane (B); Loucriwaali (SB)	Shrub/ Small Tree	Sahelian	Leaves consumed as vegetable. Edible fruits (pulp). Seeds used as substitute for coffee.
Ceiba pentandra	Malvaceae	Gunga (M); Banan (D); Banan (B)	Tree	Sahelian/ Sudanian	Leaves, flowers and fruits used to prepare food condiments. The seeds are also eaten roasted or they are pounded and ground into meal or cooked in soup.
Crateva adansonii	Capparaceae	Kalguem-tohèga (M); Gangolo (D); Naiko (F); Gamgolo (B); Soliguing (SB)	Shrub/ Tree	Sahelian	Leaves consumed as vegetable. They are eaten in soups or mixed with cereals. They are boiled and used to prepare sauces, condiments, spices, flavourings. Edible fruits and seeds.

Table 3. Continued.

Species name	Botanical family	Common names	Life form	Ecological zone	Plant part(s) used as food
Detarium microcarpum	Caesalpiniaceae	Kagadéga (M); Tamba (D); Kalahi (F); Ntamanjalen (B)	Tree	Sahelian/ Sudanian	Edible fruits (pulp). Leaves consumed as vegetable. Seeds used to make pastries.
Ficus ingens	Moraceae	Kunkwiiga (M)	Tree	Sahelian/ Sudanian	Fruits consumed.
Ficus sycomorus	Moraceae	Kankanga (M); Sutoro (D); Gaigai F); Sutoro (B)	Tree	Sahelian/ Sudanian	Leaves consumed as vegetable. Fruits mixed with soups or with couscous; used also to prepare a fermented beverage. Bark: chewed with kola nuts.
Gardenia erubescens	Aizoaceae	Subdega (M); Buremuso (D); Buremuso (B)	Shrub/ Small Tree	Sahelian/ Sudanian	Leaves used to prepare condiments. Edible fruits consumed raw or cooked.
Lannea acida	Anacardiaceae	Sabtulga (M); Npeku (D); Farouhi (F); Npekugwèlèn (B)	Tree	Sudanian	Edible fruits (pulp). Gum used to prepare drinks.
Lannea microcarpa	Anacardiaceae	Sabga (M); Npekuba (D); Inconu (F); Npekuba (B)	Tree	Sahelian/ Sudanian	Edible fruits: eaten raw or dried; a fermented drink is prepared from the pulp. The bark yields an edible gum with a sweet smell, which is soluble in water.
Maerua angolensis	Capparaceae	Zilogo (M); Berebere (D); Yelafitahi (F); Belebele (B)	Shrub/ Tree	Sahelian/ Sudanian	Leaves and seeds used to prepare condiments.
Maerua crassifolia	Capparaceae	Kessiga (M); Bérédiou (D); Sogui (F); Bélé bélé (B)	Shrub/ Tree	Sahelian/ Sudanian	Leaves appreciated as vegetable and locally commercialized. Edible fruits.
Parkia biglobosa	Fabaceae	Nèrè (French); Roanga (M); Nènè yiri (D); Niri (F); Nèrè sun (B)	Tree	Sahelian/ Sudanian	Seeds used to prepare a key component of a highly appreciated sauce. Edible fruit pulp
Piliostigma reticulatum	Fabaceae	Baghen (M); Nama iri (D); Nyamcè (B); Mécorceehe (F); Tiebe (Bo)Tjobowqng (SB)	Shrub/ Small Tree	Sahelian/ Sudanian	Leafy twigs used to sour maize dough or millet. Pods are used to make infusions.
Sclerocarya birrea	Anacardiaceae	Nobéga (M); Kunam yiri (D); Gurugahi (F); Nkunam (B)	Tree	Sahelian/ Sudanian	Edible fruit (pulp and almonds). Pulp used to make a local beer. Almonds used to extract oil.
Strychnos spinosa	Loganiaceae	Katin-poâaga (M); Gongoroba (D); Nkankoroba (B)	Shrub/ Small Tree	Sahelian/ Sudanian	Leaves and flowers vegetables used as vegetable. The sweet-sour fruit pulp is edible. Seeds and unripe fruit are toxic.
Tamarindus indica	Fabaceae	Pusga (M); Tomi yiri (D); Njamme (F); Ntomi (B); Ta (Bo)	Tree	Sahelian/ Sudanian	Fruit (pulp) used to make a juice for preparation of the dough millet or maize (to make it sour). The flowers, leaves and seeds can be eaten. Seeds are edible after soaking in water and boiling and can be roasted. Flour from the seed may be made into cake and bread.
Vitellaria paradoxa	Sapotaceae	Karité (French); Sii, Si yiri (D); Taanga, Taam (M); Kareje (F); Si (B)	Tree	Sahelian/ Sudanian	Fruit (pulp) eaten plain or made into jam. Nut used to extract oil and butter, used as condiment and also as an ingredient to make chocolate.

Table 3. Continued.

Species name	Botanical family	Common names	Life form	Ecological zone	Plant part(s) used as food
Vitex doniana	Lamiaceae	Aagda (M); Koro ni fin (D); Goumedji (F); Koro ba (B)	Tree	Sahelian/ Sudanian	Young leaves consumed as vegetable. Edible fruit pulp.
Ximenia americana	Olacaceae	Leenga (M); Minigoli (D); Tiarbuli (F); Ntonké (B)	Shrub/ Small Tree	Sahelian/ Sudanian	Edible fruit. Seeds used to extract cooking oil.

Common names: B (Bambara), Bo (Bobo), D (Dioula), F (Fulani), M (Mooré), SB (Senoufo Burkina).

'mothers' education level', 'activity of the mother' and 'evaluation of last harvest' as well as 'HHS' were all significantly different between phytogeographic zones (Table 2). The analysis was repeated for each of the zones separately. Within the Sudanian region, 'ethnicity' (p=0.01), 'residence status' (p=0.088) and 'mother's education level' (p=0.08) obtained p-values <0.1 in the bivariate Poisson regressions with 'total tree products consumed' as dependent variable. Entered together in a multivariate Poisson regression, none of them was significant at p<0.05 level. Within the Sahelian region, only 'mother's education level' obtained a p <0.1 (p=0.079). The bivariate Poisson regressions with 'total tree species consumed' as dependent variable did not show produce significant result at p <0.1, neither when both phytogeographic zones were considered together nor for each of the zones considered separately.

Main threats to food tree species based on the perception of farmers

Key informants did not indicate any additional threats beyond the 12 threats pre-identified. Results are only presented for the six tree species most consumed. In order of decreasing importance, these were: *A. digitata, P. biglobosa, L. microcarpa; V. paradoxa; B. costatum,* and *V. doniana.*

Based on the perception of local people, the most threatened species were those ranking highest in terms of consumption (% of HHs): *V. paradoxa, P. biglobosa* and *A. digitata* (Fig. 3a). The greatest threats for *V. paradoxa* were pests and diseases, drought and aging of tree individuals; for *P. biglobosa* as well as *A. digitata*, the main threats were drought, aging of trees, and loss of soil fertility.

The sum of average threat scores per type of threat indicated that the most significant threats, based on the perception of local people, were drought and aging of tree populations, followed by a decline in soil fertility and the effect of pests and diseases (Fig. 3b).

The sum of average threat scores per village indicated some variability across study sites (Fig. 3c). Based on the perception of local people, Péni had the highest burden of threats, followed by Bourgou, while Barcé was attributed the lowest threat score among all study sites.

The analysis of threat profiles for each village showed some differences between the two ecoregions investigated. While in the Sahelian villages, the most prevalent threat was aging followed by loss of soil fertility (in 2 out 3 villages) and pests and diseases in one village, in all three Sudanian villages, fire was the highest ranking threat (Fig. 4).

Discussion

The list of 25 indigenous tree species, mentioned as edible and consumed during the lean season shows that, during the lean season, edible products derived from trees are a significant supplement in the diet, mainly based on cereals. Leaves and fruits are particularly effective in diet diversification due to their rich content in micronutrients (Bvenura & Sivakumar, 2017).

The knowledge available in the literature on important food tree species in Burkina Faso is usually derived from small-scale case studies. The sampling in this research was designed to capture a representative diversity of contexts across phytogeographic regions and provinces with different ethnic composition. Nevertheless, the priority species that emerged from this study seem to be aligned with those derived from other ranking exercises carried out in Burkina Faso (Kristensen & Lykke, 2003; Lykke *et al.*, 2004; Thiombiano *et al.*, 2012, 2014). A total of 12 out of the 25 species identified as important in this study are considered among the top most useful plant species in Burkina Faso (Zizka *et al.*, 2015), all characterized by multiple uses (up to eight different uses for *A. digitata*). Interestingly, only a few species emerge for their considerably greater importance in the diet, *A. digitata* in particular, and their edible products are consumed by a very large percentage of HHs. Overall, only three tree species (*A. digitata, P. biglobosa* and *V. paradoxa*) are consumed by a large majority of HHs.

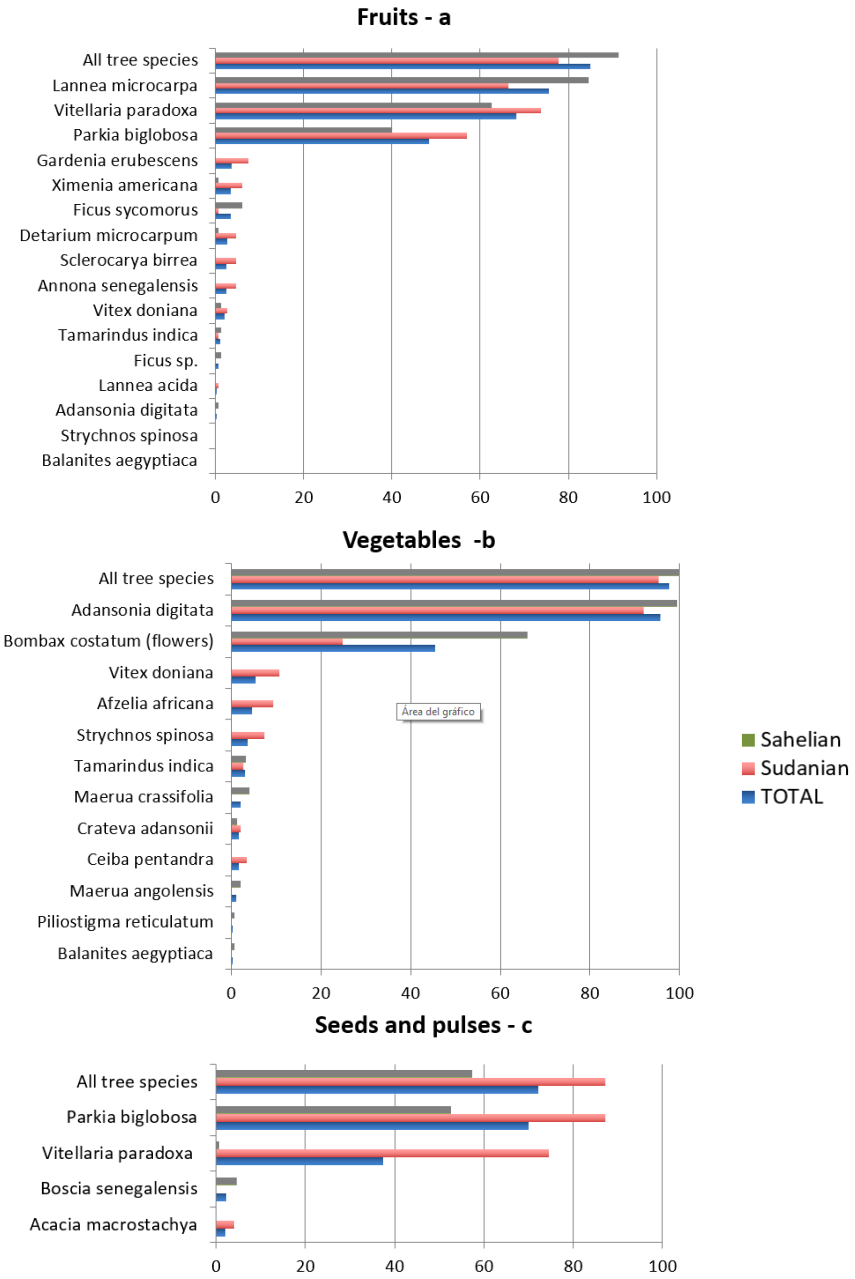

Figure 2. Percentage of HHs consuming different edible products from tree species in the Sahelian and Sudanian phytogeographic regions, during the lean season. Edible products are divided in three groups: a) fruits, b) vegetables and c) seeds and pulses.

This gap between availability and actual consumption has been observed in other environments (Termote *et al.*, 2012; Boedecker *et al.*, 2014). An explanation for this has not been provided but the pattern observed could be due to the fact that highly consumed species are actively favoured and maintained in the landscape by human activities, thus they are easier to access and collect, and their edible products can also be found in the market. On the contrary, various factors may constrain consumption of less common wild species and contribute to reduce their usefulness. For example, the excessive distance to be covered to harvest less common wild species (Thomas *et al.*, 2009; Termote *et al.*, 2012), the significant workload needed to process them into edible products, the progressive change in dietary habits in younger generations who move away from traditional foods (Lykke *et al.*, 2002), the declining knowledge about traditional plants, the progressive loss of habitat of some wild species (Barucha & Pretty, 2010) and the lack of information on their nutritional properties (Waswa *et al.*, 2015), are all factors that may contribute to limit interest and consumption.

Table 4. *p*-values of bivariate Poisson regressions with total tree products and total tree species as dependent variables and socio-economics as independent variables.

Variable	Tree products	Tree species
Ethnicity	0.041**	0.165
Ecoregion	0.000***	0.265
Residence status	0.084*	0.422
Mother education	0.314	0.906
Mother activities	0.332	0.417
Number of HH[1] members	0.567	0.358
Number of HH children	0.548	0.367
Evaluation last harvest	0.252	0.535
HFIAS[2]	0.441	0.980
HHS[3]	0.340	0.900

[1] HH: Household. [2] HFIAS: Household Food Insecurity Access Scale (Coates *et al.*, 2007). [3] HHS: Household Hunger Score (Ballard *et al.* 2011). *,**,***: significant at 0.1, 0.05 and 0.01 levels, respectively.

The factors that most closely explain the patterns of consumption of edible tree products in this study are phytogeographic region and ethnicity. The average number of tree products consumed was slightly higher in the Sudanian villages (5.5 tree products) compared to the Sahelian villages (4.35 tree products), however the average number of tree species used was quite similar (4.14 in the Sudanian and 4.17 species in the Sahelian zone). HH hunger score was significantly higher in the Sudanian compared to the Sahelian zone and this could be possibly due to the different quality of the last harvest, which was rated as good by villagers in the Sahelian zone and bad by those in the Sudanian zone. The average number of tree species used did not depend on any of the independent factors entered in the Poisson regressions (ecoregion, socio-economics, HFIAS, HHS), while the number of tree products used was significantly correlated with phytogeographic region as well as ethnicity. This indicates that the

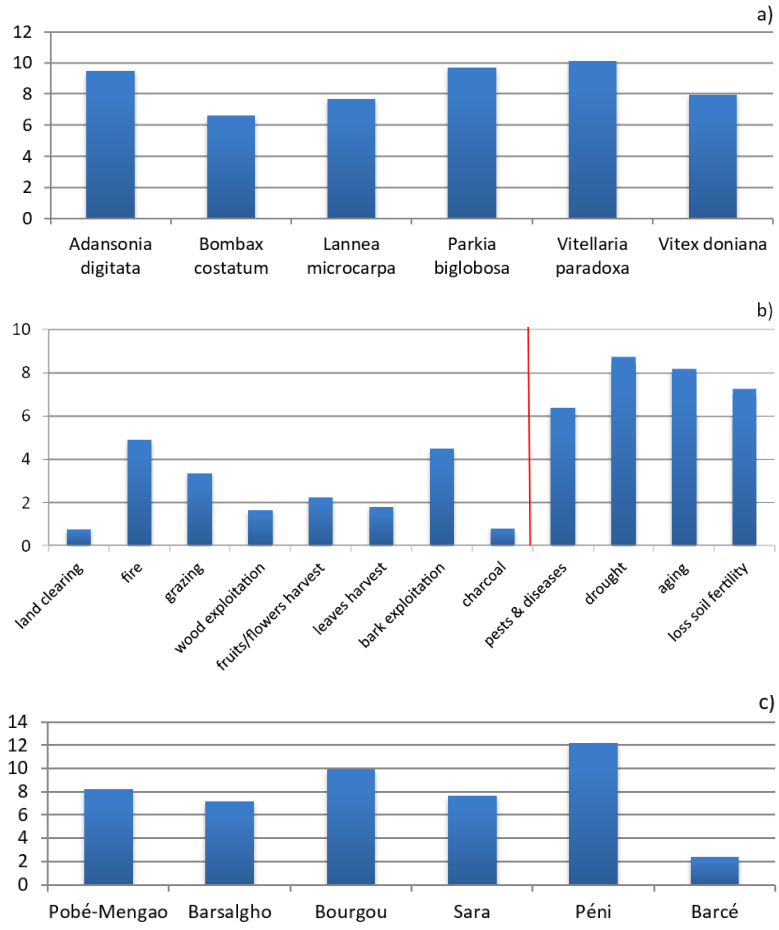

Figure 3. Sum of average threat scores per species, for each of the six most consumed tree species. Average values were summed across all villages and including all types of threats (a). Sum of average threat scores per type of threat, for the six most consumed tree species (b); the red line separates threats that are more directly linked to anthropic influence (on the left), from the others. Sum of average threat scores per village, for the six most consumed tree species (c).

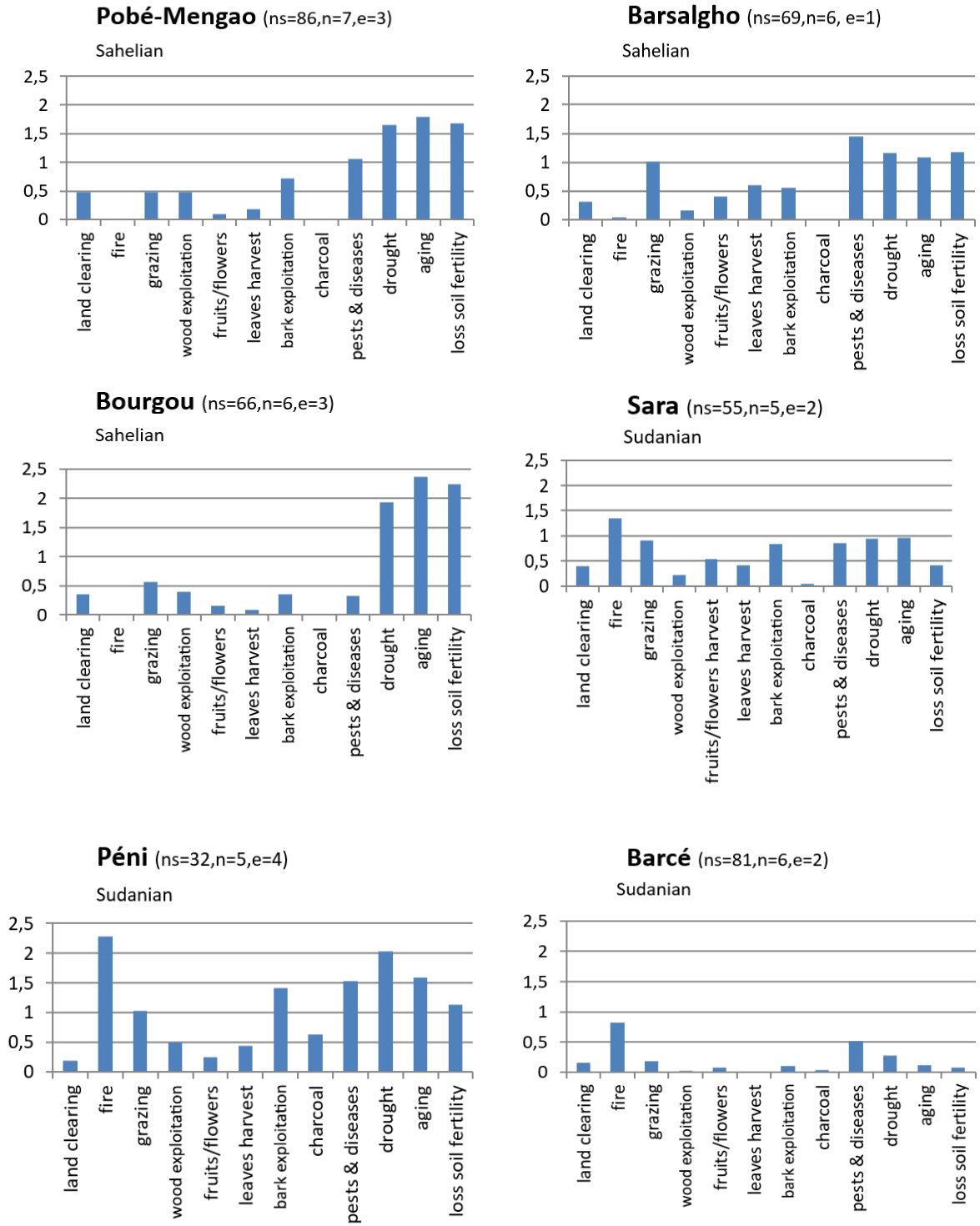

Figure 4. Sum of average threat scores presented by type of threat for all tree species jointly, displaying the different threat profile that characterizes each of the six villages investigated; ns: number of observations (n. of informants' answers about threats for each individual tree species in the village); n: number of informants; e: number of ethnic groups.

number and type of species/products consumed in each village depend not only on local occurrence of a species and seasonality of the parts consumed as food, but also on a mix of cultural factors that are correlated with the spatial distribution of ecoregions. This is in line with results from a study about differences in the perceptions and valuation of woody plant species in three ethnic groups (Fulani, Mossi and Samo), in the sub-Sahelian region of Burkina Faso. The latter study revealed that the most important species, identified for conservation

priority, based on the informants' perspective, were food species with a high socioeconomic value: *V. paradoxa, A. digitata, Tamarindus indica, P. biglobosa, L. microcarpa* and *Ziziphus mauritiana* (Sop *et al.*, 2012) and preferences were similar for all ethnic groups, though plant use differed among ethnic groups, with age of respondents influencing plant knowledge in all three ethnic groups.

Some species are progressively disappearing. A review across West African countries (Burkina Faso, Mali and Niger) by Wezel & Lykke (2006) revealed that according to local perceptions 79% of the woody species mentioned were classified as having decreased or disappeared. An assessment of local perception of changes in distribution of socio-economically important tree species in the Sahelian region of Burkina Faso in three ethnic groups (Mossi, Fulani and Samo) (Sop & Oldeland, 2011) revealed a decline in occurrence of more than 80% of the 90 listed species; 40% of these were considered under threat, mainly from drought, deforestation and bushfires. Undoubtedly, the combination of future climate scenarios and land use changes is expected to have a strong negative impact on the flora of Burkina Faso (Heubes *et al.*, 2013).

It is yet not clear what drivers of change (whether climate change, human exploitation or livestock grazing) are leading to the disappearance of tree species and a senescing of savanna in the Sahel. In this study, overall, the most prominent threats cited by the experts interviewed tend to be less directly linked to the influence of human exploitation (*e.g.*, pests and diseases, aging of trees and loss of soil fertility). However, these threats are indirectly associated to particular practices (*e.g.*, the lack of regeneration is most likely related to grazing pressure).

It is important to note that those species considered highly threatened are the most important in the diet. The high value of these priority species, combined with a considerable competition for their exploitation, may induce a perception of scarcity and availability lower than the demand, as illustrated by Thiombiano *et al.* (2013), who showed how market channels largely mitigate lack of local supply of the most demanded species.

It is interesting to note that none of the species indicated as scarce or disappearing by the villagers involved in this study is considered critically endangered in Burkina Faso at country level, according to the checklist recently developed by Schmidt *et al.* (2017). These species may be locally scarce or lost due to localized over-exploitation. The findings from this study indicate that threats vary considerably across sites; forest clearing for agriculture is most pronounced in the South of Burkina, while livestock grazing in posing great pressure in the northern part of Burkina Faso, especially where pastoralists have become progressively more sedentary (Lykke *et al.*, 2004).

Regarding predominant threat types emerging from this research, the situation is indeed spatially patchy, as revealed by the diversity of threats profiles by village. In the Sudanian ecoregion, particularly in the Southern and South Western part of Burkina Faso, the main threat appears to be fire. The villages where fires is the most significant threat, Péni in particular, but also Barcé and Sara, are situated in the region neighboring the second largest city in Burkina Faso (Bobo-Dioulasso). These results seem to be validated by evidence from records on fires frequency made available by the NASA (2012). Furthermore, a spatially explicit threat analysis for food tree species in Burkina Faso (Gaisberger *et al.*, 2017) revealed that the areas with the highest incidence of fire are in the Southern and South Western parts of Burkina Faso. The high population density in these areas is associated to large immigration, especially from drier areas in the north. This is confirmed by the ethnic composition of the three selected villages located in the Sudanian ecoregion, characterized by a high presence of immigrants (*ca.* 68%) significantly greater than in the Sahelian villages.

Immigrants normally occupy forested areas and clear them using fire, to make space for new cropland, thus this practice could explain the patterns observed. Forest fires are considered a significant factor contributing to deforestation in Burkina Faso, despite the large attention to this challenging issue in the existing legislation (Kalame *et al.*, 2009). Specific management strategies are needed to contain the effects of fire on the vegetation, such as, for example, the adoption of longer intervals between fires. Droughts and aging are critical factors in the Northern part of the country, where precipitations are less and regeneration is generally more seriously compromised by grazing, due to a higher presence of pastoralists. High value species may experience particular threats across most of their range; for example regeneration of *P. biglobosa* is largely compromised by intensive seed harvest, so that only very few seeds germinate and survive browsing by animals (Ræbild *et al.*, 2011). For various useful tree species, it has been observed that where regeneration is present, in all land-use types (forest, fallow, field), small trees seem unlikely able to develop into mature tree individuals due to grazing, so a demographic bottleneck is affecting most species (Ouédraogo *et al.*, 2015).

Conclusions

This study highlights the important role of edible products harvested from trees in diversifying diets

of rural communities in Burkina Faso during the lean season. The number of edible products consumed varies according to phytogeographic region and ethnic composition of the community living in a particular site. This study shows that overall a few tree species play a disproportionally greater role in the diet and are characterized by a very high frequency of consumption by the majority of households in both phytogeographic regions and across ethnicities: *Adansonia digitata, Parkia biglobosa* and *Vitellaria paradoxa*. Although these species are not listed as critically endangered or vulnerable at country level, this study reveals that they are perceived as threatened and could become scarcely available locally due to the great competition for their consumption but also due to a variable combination of threats. Some tree populations with critical traits adapted to specific environmental conditions may be lost and limit future adaptive capacity of the species. Our findings indicate that effective conservation efforts are highly needed for these priority species. However, considering how nutrient poor is the diet of the communities investigated, it would be important to explore the nutrition potential of largely underutilized tree species. Fire seems to be a critical driver of change in the savannas of the Sudanian phytogeographic zone, while drought is affecting indigenous tree species in the Sahelian zone. Our results suggest that threats vary across regions and mitigation measures need to be highly diversified and adapted to local pressures.

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