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**ECOLOGICAL AND CONSERVATION PATTERNS OF
WILD PALM SPECIES IN THE CONTEXT OF CLIMATE
CHANGE IN BURKINA FASO (WEST AFRICA)**

Public defense on 9th March 2023

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THESE

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L'Université Félix HOUPHOUËT-BOIGNY

Option: Changement climatique et Biodiversité

Aboubacar-Oumar ZON

**DETERMINISMES ECOLOGIQUES ET DE CONSERVATION
DES ESPECES DE PALMIERS SAUVAGES DANS LE
CONTEXTE DU CHANGEMENT CLIMATIQUE AU
BURKINA FASO (AFRIQUE DE L'OUEST)**

Soutenance publique, le 9 Mars 2023

Membres de Jury

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«La tête dans le ciel, comme les palmiers et les philosophes, et les pieds sur la terre comme les paysans, et les palmiers. Un chercheur équilibré doit plus ressembler au palmier qu'au philosophe ou au paysan.»

Jean Benoist

DEDICATION

To my beloved parents ZON Ousmane and BISSOU Bibata for all their sacrifices

To my brother and sisters Akim, Aquila and Djamilatou for supports

To all my friends for being always where I need it

To those who work a lot for nature conservation

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ABSTRACT

Ecological and conservation patterns of wild palm species in the context of climate change in Burkina Faso (West Africa)

Wild palms occur in tropical and subtropical regions where people use them for many purposes. Despite their low diversity in semi-arid and arid areas, they highly contribute to the livelihoods of local people. Therefore, the overexploitation and climate change threaten palms in arid and semi-arid areas. This study investigates the ecological and conservation patterns of wild palm species under current and future climatic conditions in Burkina Faso in order to propose sustainable management strategies for their conservation. The methods consist in a combination of individuals' interviews (258 people surveyed), inventories (in 120 plots), direct observations, species distribution modelling and climate niche factor analysis. The interview reported the importance of seven palms species in Western Burkina Faso. The importance of wild palm species depends on socio-cultural factors such as ethnic group, gender and age category. Wild palms that are considered useful are the one benefiting much of conservation care (e.g. *Borassus akeassii* and *Elaeis guineensis*). The inventories showed that *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* and *Raphia spp.* had instable populations in Western Burkina Faso. A diversity of trees species co-occurred with palms with a significant lowest diversity in *Borassus akeassii* habitats (30 species) compared to *Elaeis guineensis* (97 species), *Phoenix reclinata* (63 species) and *Raphia spp.* (73 species). More than half (65%) of *Phoenix reclinata* juveniles come from tillering, while *Borassus akeassii*, *Elaeis guineensis* and *Raphia spp.* are regenerated only by seeds. The morphological assessment suggests that another species of *Raphia*, co-occurs with *Raphia sudanica* in Western Burkina Faso. This may increase the flora of native palms of the country to eight (8), including two species of *Raphia*. The species distribution models identified water related variables such as precipitation and topographic position index as determinant variables of palms distribution in Burkina Faso. The potential suitable areas of wild palms were comprised between 10 and 15 % of the country and are located in the Sudanian climatic zone under current climatic conditions. Climate change may induce range expansion (up to 28.51%) or contraction (up to -16%) depending on the palm species, global circulation models and climatic scenarios. The climate change vulnerability assessment indicates that *Borassus akeassii* is less vulnerable to climate change than *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica*.

Keywords: Arecaceae – Diversity – Vulnerability – Semi-arid areas – Climate change.

RESUME

Déterminismes écologiques et de conservation des espèces de palmiers sauvages dans le contexte du changement climatique au Burkina Faso (Afrique de l'Ouest)

Les palmiers sauvages sont présents dans les régions tropicales et subtropicales où les populations les utilisent à de nombreuses fins. Malgré leur faible diversité dans les zones semi-arides et arides, ils contribuent fortement à la subsistance des populations locales. Par conséquent, la surexploitation et le changement climatique constituent des menaces au devenir des palmiers dans les zones arides et semi-arides. Cette étude a examiné les déterminants écologiques et de conservation des espèces de palmiers sauvages dans les conditions climatiques présentes et futures au Burkina Faso afin de proposer des stratégies de gestion durable pour leur conservation. La méthodologie a consisté à une combinaison d'entretiens individuels (258 personnes enquêtés), d'inventaires forestiers (dans 120 placeaux), d'observations directes, de modélisation de la distribution des espèces et d'analyse des facteurs de niche climatique. Les enquêtes ont rapporté l'importance de sept espèces de palmiers à l'Ouest du Burkina Faso. L'importance des espèces de palmiers sauvages dépend des facteurs socioculturels tels que l'ethnie, le genre et les catégories d'âge. Les palmiers sauvages qui sont considérés comme utiles sont ceux qui bénéficient le plus des soins de conservation (par exemple *Borassus akeassii* et *Elaeis guineensis*). Les inventaires ont montré que *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* et *Raphia spp.* avaient des populations instables dans l'Ouest du Burkina Faso. Plusieurs espèces d'arbres cohabitent avec les palmiers avec une diversité significativement plus faible dans les habitats de *Borassus akeassii* (30 espèces) par rapport à *Elaeis guineensis* (97 espèces), *Phoenix reclinata* (63 espèces) et *Raphia spp.* (73 espèces). Plus de la moitié (65%) des juvéniles de *Phoenix reclinata* provient du tallage tandis que *Borassus akeassii*, *Elaeis guineensis* et *Raphia spp.* se régénèrent uniquement par les graines. L'évaluation morphologique suggère qu'une autre espèce du genre *Raphia* co-habite avec *Raphia sudanica* dans l'Ouest du Burkina Faso. Cela porte la flore native des palmiers du pays à huit (8), avec deux espèces de *Raphia*. Les modèles de distribution des espèces ont identifié les variables liées à l'eau telles que les précipitations et l'indice de position topographique comme des variables déterminantes de la distribution des palmiers au Burkina Faso. Les zones potentiellement favorables à la conservation des palmiers sauvages varient entre 10 et 15 % de la superficie du pays et sont localisées dans la zone soudanienne sous les conditions climatiques actuelles. Le changement climatique peut induire une expansion de ces aires favorables (jusqu'à 28,51%) ou une contraction (jusqu'à -16%) selon l'espèce de palmiers, les modèles de circulation globale et les scénarios climatiques. L'évaluation de la vulnérabilité au changement climatique indique que *Borassus akeassii* est moins vulnérable au changement climatique que *Elaeis guineensis*, *Phoenix reclinata* et *Raphia sudanica*.

Mots clés: Arecaceae – Diversité – Vulnérabilité – Zones semi-arides – Changement climatique

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Abbreviations

ANOSIM: Analysis of similarities

ANOVA: Analysis of variances

AUC: Area under curve

BCI: Boyce continuous index

Bio: Bioclimatic variable

CCVA: Climate change vulnerability assessment

CNFA: Climate niche factor analysis

DEM: Digital elevation model

FAMD: Factor analysis of mixed data

GCM: Global climate model

SDG: Sustainable Development Goals

SDM: Species distribution model

SPI: Standard precipitation index

SSP: Shared socioeconomic pathway

TPI: Topographic position index

TSS: True skill statistic

VIF: Variance inflation factor

INTRODUCTION

Documenting, explaining and projecting biodiversity changes under the increasing human and climate change pressures constitute urgent issues of biological research, biodiversity promotion and conservation (**Ouédraogo, 2006; Thiombiano et al., 2012; Schmidt et al., 2017; Dimobé et al., 2020; Lompo et al., 2021**). Indeed, the combination of climate change and overexploitation of natural resources causes the depletion of biodiversity and related ecosystem services (**Stauffer et al., 2017; Cosiaux et al., 2018**). It is widely accepted, that climate change will likely result in an increase of temperature and a decrease of rainfall causing an aridification of land (**Sylla et al., 2015; IPCC, 2021**). It is estimated that, by the 2080s, the proportion of arid and semi-arid lands in Africa is likely to increase by 5-8% (**Boko et al., 2007**). This aridification will influence water-dependent and useful plants such as palms (**Kreft et al., 2006**). Consequently, many important species may contract their range in response to global climate change (**Dimobé et al., 2020; Lompo et al., 2021; Balima et al., 2022**). Furthermore, the increasing human population and its impact on natural resources accelerate the loss of biodiversity already threatened by global climate change (**Ahissou et al., 2017; Mollet et al., 2000**). Thus, climate and biodiversity crises are inextricably linked with each other and with the future of humanity and their resolution requires efficient strategies of biodiversity conservation (**IPBES-IPCC, 2019**).

The conservation of biodiversity has been identified as the basis to achieved sustainability and the sustainable development goals (SDGs; **IPBES-IPCC, 2019; IPCC, 2022**). It is directly linked to the SDG 14 (life below water) and SDG 15 (life on land). In addition, the biodiversity acts on SDG 1 (no poverty) and SDG 2 (zero hunger) by providing financial and food resources to local people (**Kabré, 2021**). The importance of biodiversity conservation in SDG 13 (climate actions) is undisputed. However, when measures to reach other SDGs are taken without accounting for potential negative impacts on natural resources (eg. under SDG 6: clean water and sanitation, SDG 12: Responsible consumption and production), the latter are likely to suffer collateral damage (**Obriecht et al., 2021**). Hence, conservation of biodiversity become an important question at global scale as evidenced by the Strategic Plan for Biodiversity, including the Aichi Biodiversity Targets (<https://www.cbd.int/sp/>), and the IPBES framework (<https://ipbes.net/>). However, biodiversity conservation is implemented at local scales as published by **Cunningham (2001) and Pimm (2021)**. In Burkina Faso, many scientific contributions have been made in biodiversity conservation (**Ouédraogo, 2006; Thiombiano et al., 2012; Lankoandé et al., 2017; Balima et al., 2018; Ganamé et al., 2020; Tiétiambou et al., 2020; Tinguéri et al., 2022**). These studies focused on locally useful plant species, but usually they do not consider palms species. The no-inclusion of palms in these important

contributions is due to their intriguing morphology: having a stem, they are neither considered as real trees nor as herbaceous (**Ouattara et al., 2015**). Hence, palms are classified as the third useful plant family in the world after Poaceae and Fabaceae families (**Dransfield et al., 2008; Johnson, 2010**), in addition of being among the most appreciated non timber forest products in rural areas (**Yaméogo et al., 2008; Macia et al., 2011; Camara et al., 2017; Stauffer et al., 2017; Zongo et al., 2018**). Furthermore, wild palms are locally harvested for food production, construction, medicine, textiles, oils, and other applications for both domestic and commercial purposes, especially in rural regions (**Byg & Balslev, 2001; Macia et al., 2011; Ouattara et al., 2015; Mogue Kamga et al., 2020**). Unfortunately, palms are rarely cultivated and 90% of the species are exploited in wild particularly in West Africa (**Stauffer et al., 2017**). Then, it is crucial to undertake studies on wild palms in order to develop conservation strategies and sustainable exploitation guidelines.

Previous studies used various approaches to assess the conservation of particular palm species (**Salako, 2015; Idohou et al., 2015b; Donou Hounsodé, 2016; Idohou et al., 2016a,b,c; Martins, 2021**). They combined ethno-ecology, forest inventory and biodiversity modelling approaches to identify priority species and/or areas for conservation of palms. Recent studies on palms ethnobotany also highlighted their importance and usefulness in rural areas (**Yaméogo et al., 2008; Ouattara et al., 2015; Camara et al., 2017**). Many authors indicated that palms established their populations in various ecological conditions to which their population structure and abundance may depend on (**Barot et al., 1999; Salako et al., 2015**). Evidences exist on the declining trend of wild palms in face to climate change in Africa (**Blach-Overgaard et al., 2010; Salako et al., 2019**). Thus, studying palms at local scale by collecting various data could help for building sound management and conservation strategies.

Despite the huge contribution of previous studies on palms, developing broad guidelines is challenging because the effects of harvesting palm products on the population vary among species and regions based on the part harvested, the amount harvested, the technique of harvesting, and the local context (**Martins & Shackleton, 2017**). In addition, the conservation strategies should be developed at local scale depending on specific context and should be implemented by local people living with the diversity we want to conserve (**Cunningham, 2001; Pimm, 2021; IPCC, 2022**). Therefore, each species and context must be individually assessed before drawing any guidelines (**Martins & Shackleton, 2017**). Such assessments must include different data related to human-plant relationships, abundance and population structure, diversity and distribution to capture different dimensions of the conservation.

This study uses a multidisciplinary approach, combining ethno-ecological methods, inventories, individual observations and biodiversity informatics to understand the ecological pattern of wild palm species under current and future climatic conditions in Burkina Faso in order to propose sustainable management strategies for their conservation. Specifically, the study aimed:

- (i) to record the diversity of uses, the perceptions of stands dynamic, and the local conservation practices of the palms in different communities in Burkina Faso.
- (ii) to assess the population structure, habitat diversity, and the regeneration patterns of wild palm species in Burkina Faso.
- (iii) to assess the diversity of the genus *Raphia* P.Beauv. occurring in Burkina Faso.
- (iv) to determine the range change and the vulnerability of wild palm species to global climate change in Burkina Faso.

This dissertation is made up of four chapters in addition to the current introduction and the conclusion sections. The general introduction provides the rationale and background to the study, which lead to the objectives of the study. Chapter 1 provides a literature review on the study area and on palms. Chapter 2 focused on the methodological approach used in this study. It described the conceptual and theoretical frameworks used to conduct the study, the data collection and data analysis processes. In chapter 3, the results of the study are presented while, we discussed these results in chapter 4. Lastly, general conclusion and research perspectives, based on the results of this thesis are presented.

CHAPTER I: LITERATURE REVIEW ON THE STUDY AREA AND PALMS

I.1. Study area

I.1.1. Location

The fieldwork was carried out in Western Burkina Faso, which comprises the Cascades and Hauts-Bassins regions, located between 9° and 12° latitude North and 5° and 3° longitude West (Figure 1). This area has been selected because of its high diversity of plants and particularly palms (**Thiombiano et al., 2012; Zizka et al., 2015; Schmidt et al., 2017**).

II.1.2. Climate

Three climatic zones are described in Burkina Faso from the North to the South, the sahelian, the sudano-sahelian and the sudanian climatic zones. Western Burkina Faso belongs to the sudanian climatic zone characterized by 900-1100 mm range of mean annual rainfall and two contrasting seasons, a dry season and a rainy season (**Fontès & Guinko, 1995; Dipama, 2010**). According to **Ouédraogo et al. (2013)**, the rainy season lasts an average of 6-7 months, from May or June to November, with 90 wet days. The Standard Precipitation Index (SPI) of the study area shows a high inter-annual variation of precipitations that characterise the sahelian region (Figure 2). Western Burkina is one of the coolest areas of the country with a mean annual temperature ranging between 22 and 34°C. However, this area shows general trends towards the increase in mean annual maximum and minimum temperatures (Figure 3).

I.1.3. Vegetation and flora

Savannas, dry woods and isolated gallery forests make up the majority of the vegetation in the study area. The flora of the country counts 2067 species including seven wild palm species (**Thiombiano et al., 2012**). Western Burkina Faso is the richest regions of the country (**Zizka et al., 2015; Schimdt et al., 2017**). Common tree species include *Burkea africana* Hook. F, *Daniellia oliveri* (R.) Hutch. & Dalz. C, *Diospyros mespiliformis* Hoschst. ex A. DC., *Combretum glutinosum* Perr.ex DC, *C. nigricans* Lepr. ex Guill & Perr., *Isoberlinia doka* Craib. & Stapf, *Terminalia schimperi* (Hochst. ex Hutch. & Dalziel) Gere & Boatwr. and *Vachellia sieberiana* (DC.) Kyal. & Boatwr. (**Traoré et al., 2012**). The unique endemic species for the country occurs in the study area (*Isoetes jaegeri* Pitot), whereas the majority of the country flora grow throughout Africa (**Zizka et al., 2015**).

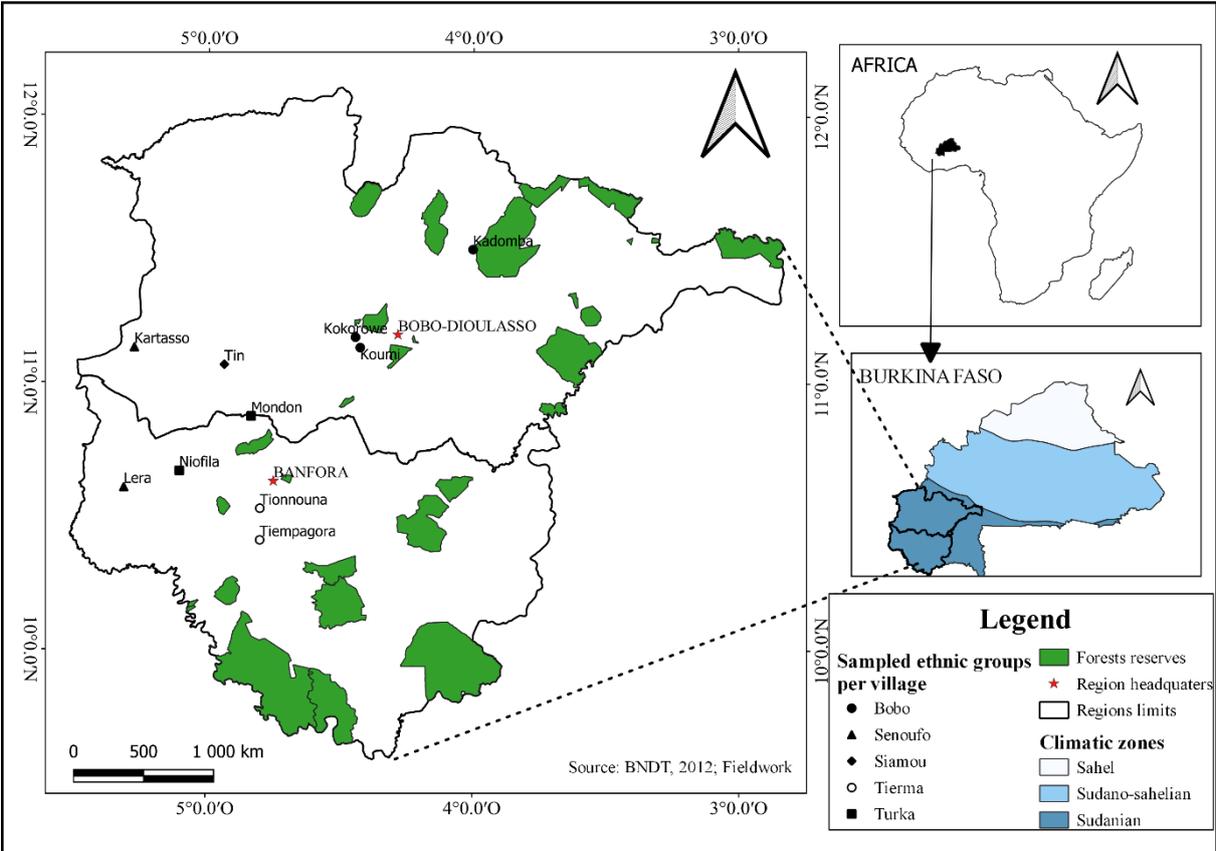


Figure 1: Location of the study area and sites

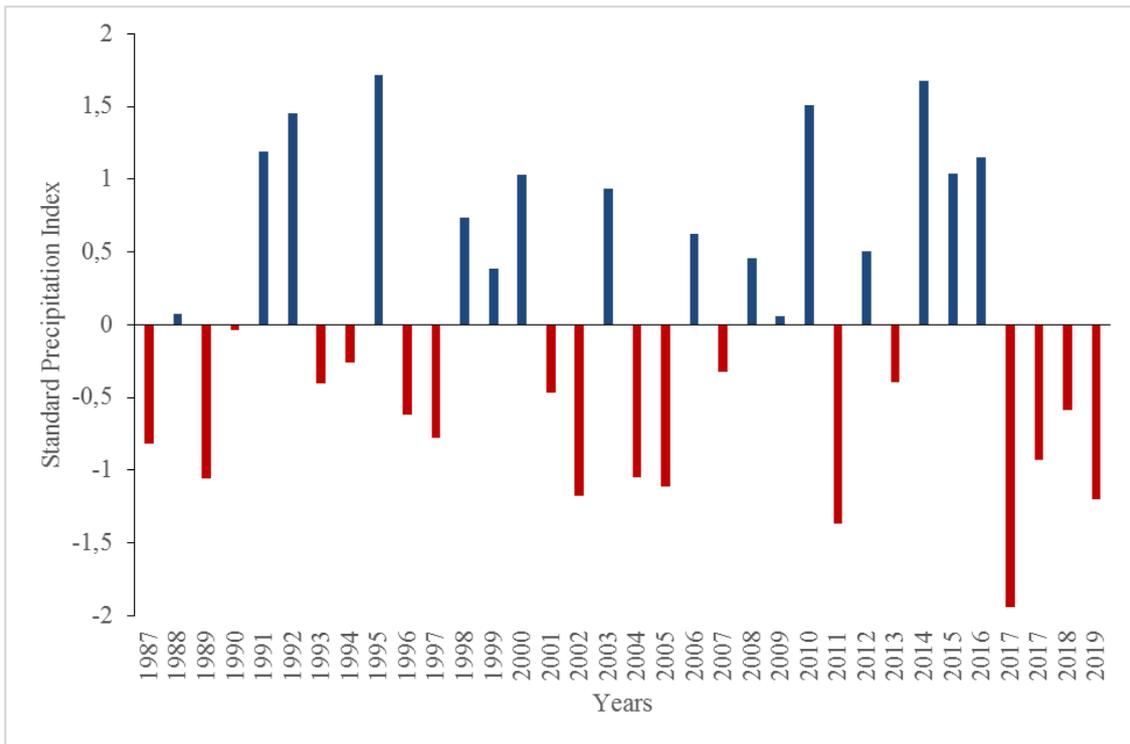


Figure 2: Standard precipitation index of the synoptic station of Bobo-Dioullasso, Western Burkina Faso

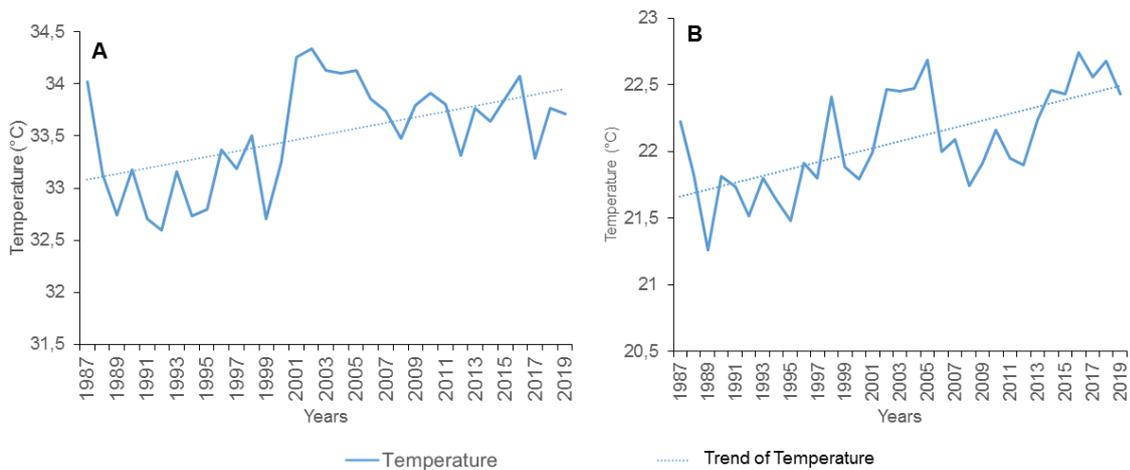


Figure 3: Evolution of the temperature in the synoptic station of Bobo Dioullasso, Western Burkina Faso

A) Mean maximal temperature in the study area, B) Mean minimal temperature in the study area

I.1.4. Topography and hydrographic networks

The region is located in the Comoé watershed and has two permanently flowing rivers: The Comoé and Leraba rivers (**Lankoandé, 2017**). In addition, to these permanent rivers, many temporal waterlines exist in the study area. Concerning the topography, the study area is among the most accidented zones of the country even if it is dominated with plains. In the study area, there are cliffs and hills with the highest point of the country, the Mount Ténakourou at 749 m (**Landoandé, 2017**).

I.1.5. Human societies

Inhabitants were estimated to be 812 062 and 2 238 375 people, respectively in the Cascades and Hauts-Bassins regions (**INSD, 2020**) and are distributed among 15 ethnic groups. The dominant ethnic groups are Gouin, Senoufo and Bobo. Agriculture (subsistence and cash crops) and livestock raising are the two principal human activities. In addition to these two sources of income, the utilization of renewable natural resources contributes significantly to the direct and indirect wealth of local people.

I.2. Generalities on palms

I.2.1. Diversity of palms

The palms (Arecaceae) comprise 181 genera and approximately 2600 species belonging to five subfamilies namely Arecoideae, Calamoideae, Ceroxyloideae, Coryphoideae and Nypoideae (**Dransfield et al., 2008; Baker & Dransfield, 2016**). Arecoideae contains the half of the currently described palm species and therefore constitutes the most diverse of all subfamilies (**Dransfield et al., 2008**). Some important palm species belonging to the Arecoideae sub-family include the African oil palm (*Elaeis guineensis* Jacq.), the coconut palm (*Cocos nucifera* L.), the betel nut palm (*Areca catechu* L.) and the peach palm (*Bactris gaesipis* Kunth). The Calamoideae includes almost the quarter of the current recognized palm species (**Dransfield et al. 2008**). The largest genus *Calamus* L. and the socio-economically important genus *Raphia* P. Beauv. belong to the Calamoideae sub-family. The Coryphoideae is a sub-family that includes almost all the palmate-leaved palms and all its representative genera comprising *Borassus* L., *Hyphaene* Gaertn. and *Phoenix* L. that are economically important in Africa and Asia (**Dransfield et al., 2008**). The Ceroxyloideae is a sub-family that is mainly distributed in America and Madagascar. This sub-family is more endemic to Madagascar

particularly the genus *Ravenea* H.Wendl. ex C.D.Bouché. The subfamily Nypoideae contains the single monotypic genus *Nypa* (the single species is *Nypa fructicans* Wurm), a mangrove palm of Asia and the West Pacific, that has been introduced and naturalized in West Africa (**Dransfield et al., 2008**).

The number of species is in high dynamic due to the description of new species and taxonomic revision. For instance, **Baker & Dransfield (2016)** just reminded that 6 new genera and 200 new species have been described, whereas 8 genera have been sunk into synonymy in 8 years. Recently 10 new species of the rattan genus *Calamus* L. were described in the New Guinea and Salomon Islands (**Baker & Dransfield, 2017**). **Mogue Kamga et al. (2018)** also described two new species of the genus *Raphia* P. Beauv. in Central Africa.

I.2.2. Ecology and distribution

Palms are distributed in the tropics and sub-tropics (**Dransfield et al., 2008; Eiserhardt et al., 2011**). Palms grows in various ecosystems and habitats from the arid and semi-arid areas to the tropical humid forests. The latter constitute the centre of palm diversity with over 90% of palms' diversity restricted to humid forests (**Couvreur et al., 2011**).

I.2.3. Socio-economic importance

The evolution of palms is inextricably linked to the humanity. Indeed, palms provide a wide array of food, drink and medicines, resources for building, weaving for local people (**Chevalier, 1930; Yaméogo et al., 2008; Camara et al., 2017; Stauffer et al., 2017; Zongo et al., 2018**). Besides the provisioning service, palms are used as symbolism in various cultures and religions. The palm family represents the third useful botanical family after the Poaceae and the Fabaceae ones (**Johnson, 2010; Dransfield et al., 2008**). *Elaeis guineensis* and *Cocos nucifera* constitute important representative of palms in the top-ten cultivated crops worldwide. However, *Borassus spp.*, *Hyphaene spp.* and *Raphia spp.* contribute to the economy at rural scale.

I.2.4. Palms as the family of records

Palm family is an iconic and majestic plant family in the plant kingdom. The first fact is their intriguing morphology that makes them particular in the plant kingdom. Indeed, the presence of arborescent stem makes them long-life plants that missed the cambium and secondary growth

(Tomlinson, 2012). In addition, they hold many records in the plant kingdom that include (Tomlinson, 2006; Dransfield *et al.*, 2008):

- (i) The largest self-supporting leaves: this record is hold by *Raphia regalis* Becc, whose leaves can reach 25m.
- (ii) The longest unrooted aerial stem: the climbing palms of the genus *Calamus*, could measure 172m, and are thus considered as the record even if the stem is not usually self-supporting and winds through the forest canopy.
- (iii) The largest inflorescence: the hapaxanthic palm *Corypha umbraculifera* L. holds this record with inflorescence exceeding 8m.
- (iv) The largest seed: the largest seed in the plant kingdom is the seed of the Sea coconut, *Lodoicea maldivica* L. The seeds of this species are in the order of 10–25 kg.

I.3. Analytical review on West African palms

I.3.1. Temporal and spatial trends and focus of the papers

The number of papers on palms in West Africa increased generally, but with some fluctuations (Figure 4). About 73.83% of the papers included in our analytical review were published between 2008 and 2019. The highest number of papers ($n = 13$) was recorded in 2016 while the lowest ($n = 1$) in many years before 2007. In West Africa, the articles on palms come mostly from costal countries as Nigeria, Benin, Ghana and Cote d'Ivoire (Figure 5A). The Sahel is relatively less investigated with Burkina Faso holding the highest number of publications in that region with 16 papers, while no publication has been reported in Mali and Mauritania and only 4 publications in Niger (Figure 5A). Moreover, the number of species reported was lower in the Sahel compared to the coastal countries (Figure 5B). For instance, only 2 species were studied in Burkina Faso and in Niger while **Stauffer *et al.* (2017)** reported the presence of 8 and 7 species in these countries respectively.

Most of the publications focused on ethnobotany, and to some extent, on biochemistry and population structure (Figure 6). As compared to ethnobotany, there were fewer studies on distribution, and other fields such as biomass estimation, phenology and genetics (Figure 6).

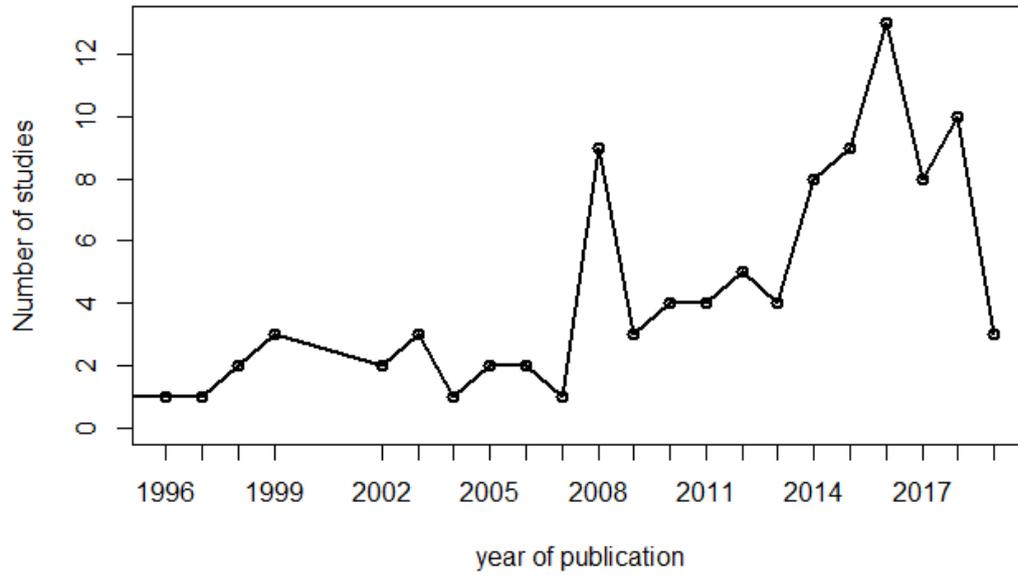


Figure 4: Temporal trends of publication on palms in West Africa from 1996 to 2019

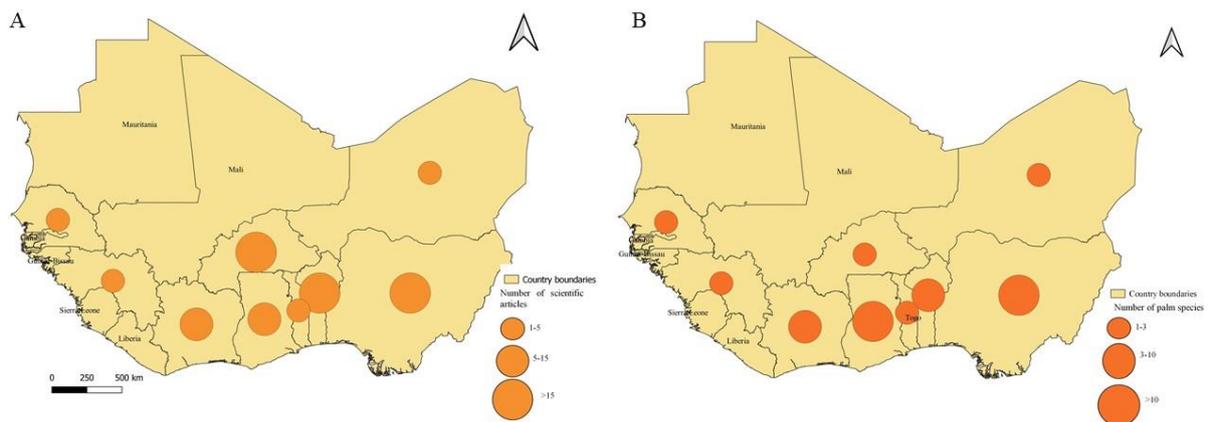


Figure 5: Spatial distribution of the number of publications (A) and the number of species (B) recorded from the literature per country

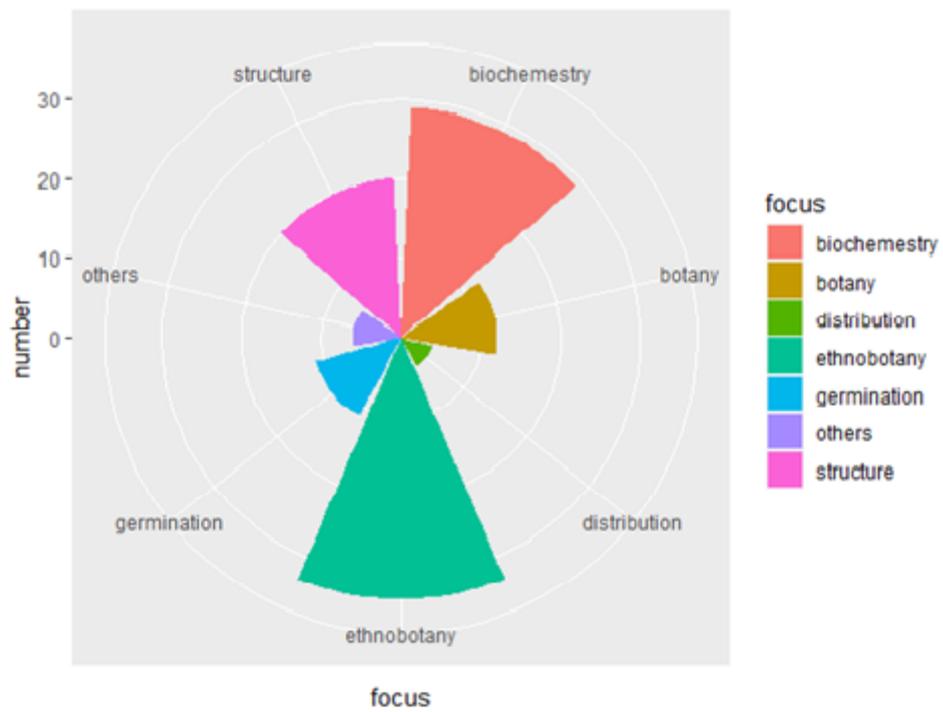


Figure 6: Number of studies on palms following the scientific focus in West Africa

I.3.2. Biological diversity of palms in West Africa

The biological diversity of the palm trees was estimated using the number of species, the number of genera and the proportion of species belonging to every subfamily or having a particular biological trait. From the literature, 25 species belonging to 12 genera classified in 4 subfamilies of palms trees were reported in West Africa (Table I). According to **Stauffer et al. (2017)**, 39 species belonging to 13 genera of palms are present in West Africa confirming that palms are under-investigated in this region. However, *Eremospatha dransfieldii*, *Hyphaene macrosperma* and *Oncocalamus wrightianus* were reported as the only endemic palm species in West Africa (**Stauffer et al., 2017**). No study was interested in the two last cited palm species. *E. dransfieldii* grows only in tropical rain forest in Ghana, Cote d'Ivoire and Sierra Leone (**Ouattara et al., 2015; Cosiaux et al., 2017**). It is an endangered rattan palm because of habitat loss and over exploitation of stems (**Cosiaux et al., 2017**). It is so important to assess the conservation status of these species due to their endemism in West Africa. In addition, the genus *Podococcus* G.Mann & H.Wendl. was not reported in our analytical review, even if *Podococcus barteri* barely reaches West Africa.

The palm family present one of the most important varieties of growth form in the plant kingdom. We identified five growth forms in West African palms among which erect and solitary stem are the most frequent (Figure 7). All species occurring in dry area (32%) have erect stem, making this growth form the most adapted growth form in dry area. The erect and branching stem was represented by one species namely *Hyphaene thebaica* L. The other growth forms constitute palms that grow specifically in wet areas. Regarding leaves forms, only the genus *Borassus* L. and *Hyphaene* Gaertn. representing 17.40% of species have costa-palmate leaves. The reproduction strategies are dominated by monoecy while hermaphroditism and dioecy are less represented. **Stauffer et al. (2017)** demonstrated the dominance of pinnate leaves and monoecy in African palm flora.

The morphological diversity of palms was assessed for *Borassus aethiopum* Mart. in Benin (**Salako et al., 2019a**) and *Hyphaene thebaica* in Benin (**Idohou et al., 2015b**). **Salako et al. (2019a)** identified five morphotypes of *B. aethiopum* based on fruits and concluded that environmental factors are not the major drivers of the morphological diversity. In contrary, **Idohou et al. (2015b)** found three morphotypes for *H. thebaica* in Benin based on fruits characteristics.

Table I: Diversity of palms and their occurrence in dry areas in West Africa

Species	Tribes	Subfamily	Occurrence in dry regions ¹
<i>Borassus aethiopum</i> Mart.	Borasseae	Coryphoideae	Yes
<i>Borassus akeassii</i> Bayt., Ouéd. & Guinko	Borasseae	Coryphoideae	Yes
* <i>Calamus deeratus</i> G.Mann & H.Wendl.	Calameae	Calamoideae	Yes
<i>Cocos nucifera</i> L.	Cocoseae	Arecoideae	Yes
<i>Elaeis guineensis</i> Jacq.	Cocoseae	Arecoideae	Yes
<i>Eremospatha dransfieldii</i> Sunderl.	Lepidocaryeae	Calamoideae	
<i>Eremospatha hookeri</i> (G.Mann & H.Wendl.) H.Wendl			
<i>Eremospatha macrocarpa</i> H.Wendl.	Lepidocaryeae	Calamoideae	
<i>Hyphaene guineensis</i> Schumach. & Thonn.	Borasseae	Coryphoideae	
<i>Hyphaene thebaica</i> (L.) Mart.	Borasseae	Coryphoideae	Yes
<i>Laccosperma acutiflorum</i> (Becc.) J.Dransf.	Lepidocaryeae	Calamoideae	
<i>Laccosperma leave</i> (G.Mann & H.Wendl.) Kuntze			
<i>Laccosperma opacum</i> Drude	Lepidocaryeae	Calamoideae	
<i>Laccosperma secundiflorum</i> (P.Beauv.) Kuntze	Lepidocaryeae	Calamoideae	
<i>Nypa fructicans</i> Wurm		Nypoideae	
<i>Oncocalamus mannii</i> (H.Wendl.) H.Wendl	Lepidocaryeae	Calamoideae	
<i>Phoenix dactylifera</i> L.	Phoeniceae	Coryphoideae	Yes
<i>Phoenix reclinata</i> Jacq.	Phoeniceae	Coryphoideae	Yes
<i>Raphia hookeri</i> G.Mann & H.Wendl	Lepidocaryeae	Calamoideae	
<i>Raphia palma-pinus</i> (Gaertn.) Hutch.	Lepidocaryeae	Calamoideae	
<i>Raphia sudanica</i> A.Chev.	Lepidocaryeae	Calamoideae	Yes
<i>Raphia vinifera</i> P.Beauv.	Lepidocaryeae	Calamoideae	
<i>Raphia farinifera</i> (Gaertn.) Hyl	Lepidocaryeae	Calamoideae	
<i>Raphia regalis</i> Becc	Lepidocaryeae	Calamoideae	
<i>Sclerosperma profiziana</i> Valk. & Sunderl	Sclerospermeae	Arecoideae	

¹ Following Arbonnier, 2009

*The report of *Calamus deeratus* in dry area is based on many field experiences.

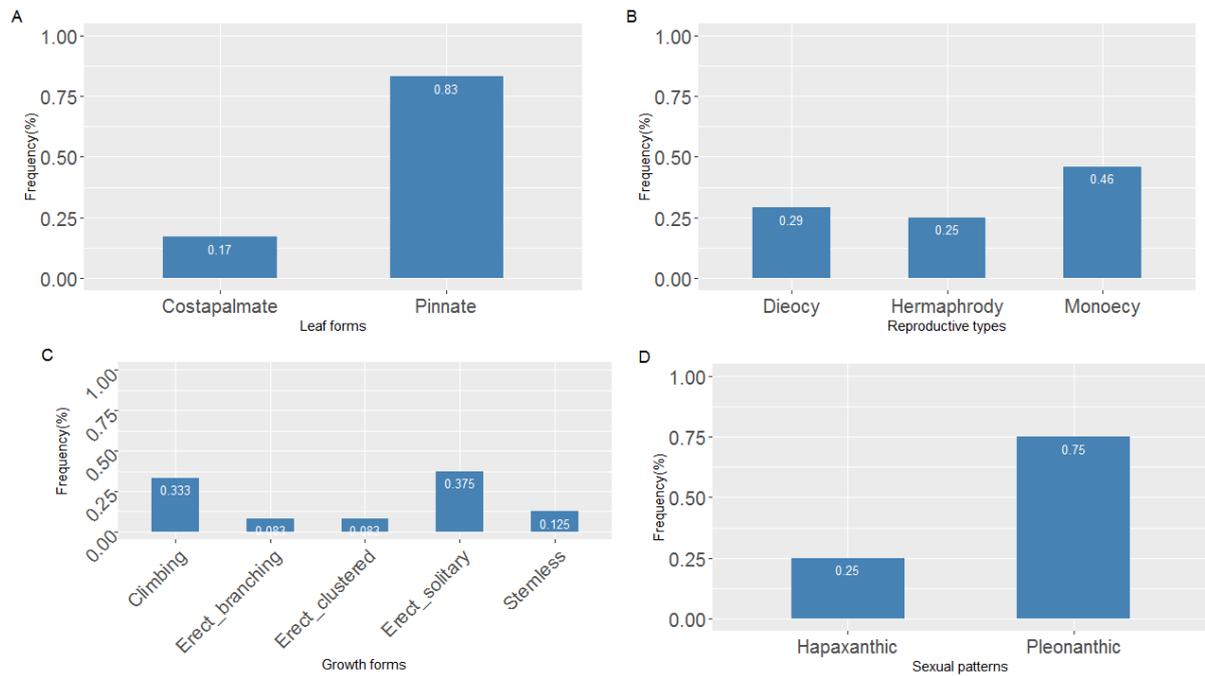


Figure 7: Biological diversity of palms in West Africa, A) Leaves forms, B) Reproductive types, C) Growth forms and D) Sexual patterns

I.3.3. Importance and traditional uses of palms in West Africa

I.3.3.1. Relative Importance of palms

The uses' information was extracted from articles that focus on ethnobotany and report palms' uses in different communities. The data extracted concerned the palm part used and the uses category for each reported palm. The frequencies of the plant parts according to the used categories were calculated. Besides, the relative importance index (RI) of each palm species was calculated according to the formula of **Tardio & Pardo-De-Santayan (2008)** adapted by **Zizka et al. (2015)**:

$$RI = \frac{[\max(FRC) + \max(RNU)]}{2}$$

With: RFC = relative frequency of citation (Frequency of citation/Number of References), RNU = Relative number of use-categories (Number of uses/Maximum number of uses of a species). The relative index of importance (RI) was calculated in order to classify the species of palm trees according to their importance.

The importance of 20 species was highlighted in this review (Table II). The relative importance index (RI) of each palm species, comprised between 0.09 and 0.80, was used to rank the species according to their usefulness in West Africa (Table II). Four species namely *Raphia regalis*, *Raphia farinifera*, *Raphia vinifera* P.Beauv. and *Phoenix dactylifera* L. were out of this assessment because no ethnobotanical study has reported any use of these ones. *B. aethiopum*, *E. guineensis*, *H. thebaica* and *C. deeratus* were the most important palms in West Africa while, some rattans (*E. dransfieldii*, *E. hookerii* and *L. opacum*), *P. reclinata* and *S. profiziana* possessed the least RI (Table II). The four first palm species ranked by RI in West Africa, namely *Borassus aethiopum*, *Elaeis guineensis*, *Borassus akeassii* and *Hyphaene thebaica* naturally grow in dry area. Before its description in 2006 as new species (**Bayton et al., 2006**), *B. akeassii* has been confused to *Borassus aethiopium* or *Borassus flabellifer* (**Aké Assi & Guinko, 1996; Ouédraogo et al., 2002**). However, these two species have been almost used in the same way by local people in West Africa and their RI should be treated with caution.

No RI was reported for *P. dactylifera*, *R. vinifera*, *R. farinifera* and *R. regalis* suggesting lower importance of these species in West African palm literature. The RI calculated is dependent of the number of studies and the number of uses reported. While a high number of studies mentioning use of a species and a large number of different use categories can be interpreted as indicator of species importance, a low number of uses or references does not necessarily mean

that a species is not of high value for specific purposes or on a local scale (Zizka *et al.*, 2015). The date palm *P. dactylifera* is a cultivated palm in West Africa, and its uses are not documented in West Africa (Ouattara *et al.*, 2015). The date palm is believed to have been domesticated in the Mesopotamian region more than 6,000 years ago, and is among the oldest cultivated tree crops. In desert oases of small-scale agriculture, where woody material is scarce, the date palm provides leaves for shading, thatching and weaving into baskets, mats, rope, hats (Johnson, 1998). Midribs and petioles have utility in construction and fencing. The entire date palm and date palm leaves have symbolic and ritual significance in major religions. The non-report of the uses of *R. vinifera* in the literature could be explained by its long misidentification (Mogue Kamga *et al.*, 2019). It has been recently reported that *R. hookeri* and *R. vinifera* are among the most exploited *Raphia* in Africa (Mogue Kamga *et al.*, 2020). The leaves of *R. vinifera* and *R. regalis* are used in construction, and their fruits are eaten (Mogue Kamga *et al.*, 2020). The epidermis of young leaflets yields raffia fibre, which is locally used for making baskets, mats, hats, bags, ropes, hammocks and ceremonial costumes. The Kuba people in Democratic Republic of Congo are well known for weaving beautiful raffia cloth used, such as ceremonial dance skirts and embroidered cloth panels for court rituals. In Europe, raffia fibre is used as tying material for horticulture and handicrafts. The leaves are highly valued for thatching. The petiole and rachis of the leaves of *Raphia vinifera* are often used as poles and rafters and for making furniture items such as stools, bedsteads and benches. Split midribs are woven into floor-mats. In addition, rattans have low relative index value due to the absence of consumed organs. Almost half of species in the rattan palm genus *Eremospatha* are poorly known and require further investigations (Stauffer *et al.*, 2017), which could also justify their low RI reported in our study. Rattan provides canes for flogging, ropes for tying hides to drum frames, fish traps, and loop for climbing palm trees (Babajide & Bamidele, 2004; Ouattara *et al.*, 2015).

Table II: Palm species in West Africa ranked using the Relative Importance index

Species	RNU	RFC	RI	Rank
<i>Borassus aethiopum</i>	6	0.375	0.80357143	1
<i>Elaeis guineensis</i>	7	0.05	0.55	2
<i>Borassus akeassii</i>	5	0.05	0.40714286	3
<i>Hyphaene thebaica</i>	5	0.05	0.40714286	4
<i>Calamus deeratus</i>	4	0.05	0.26428571	5
<i>Eremospatha macrocarpa</i>	3	0.05	0.26428571	6
<i>Laccosperma secundiflorum</i>	3	0.05	0.26428571	7
<i>Nypa frutiscens</i>	3	0.05	0.23928571	8
<i>Laccosperma acutiflorum</i>	3	0.025	0.23928571	9
<i>Raphia hookeri</i>	3	0.025	0.23928571	10
<i>Raphia sudanica</i>	2	0.05	0.19285714	11
<i>Cocos nucifera</i>	2	0.025	0.16785714	12
<i>Hyphaene guineensis</i>	2	0.025	0.16785714	13
<i>Oncocalamus manni</i>	2	0.025	0.16785714	14
<i>Raphia palma-pinus</i>	2	0.025	0.16785714	15
<i>Eremospatha dransfieldii</i>	1	0.025	0.09642857	16
<i>Eremospatha hookerii</i>	1	0.025	0.09642857	17
<i>Laccosperma opacum</i>	1	0.025	0.09642857	18
<i>Phoenix reclinata</i>	1	0.025	0.09642857	19
<i>Sclerosperma profiziana</i>	1	0.025	0.09642857	20

I.3.3.2. Usefulness of palm parts in different categories

A correspondence analysis was computed to appreciate the link between plant parts and use categories of palms through the package ‘*FactorMiner*’ in R program version 3.6.1 (**R Core Team, 2019**). The cumulative percentage of variance derived from the correspondence analysis (CA) revealed that the first two dimensions explain 57.41% and 30.48% of the total variation respectively (Figure 8). Therefore, these axes explaining 87.89% of the total variation were used to describe the links between palms parts and the uses categories. The correspondence analysis sustains that flowers, resin and roots were mainly used in traditional medicine while fruit, sap and hypocotyl were used in food and rites categories, and leaves and stipe were used as material for building and handicraft (Figure 8).

Hypocotyls

Hypocotyls are a palm part mostly used in human food, in traditional medicine, and trade. Indeed, hypocotyls of *B. aethiopum* are boiled and consumed in many parts of West African regions (**Guinko & Ouédraogo 2005; Salako et al., 2018a; Zongo et al., 2018**). In traditional medicine, they are used to treat sexual weakness (**Gbesso et al., 2016**). In Eastern Burkina Faso, the boiled hypocotyls are sold for 25FCFA (0.04USD) each (**Kansole, 2016**). In contrast, it ranges between 50–150 FCFA (0.07–0.25 €) in Benin (**Michon et al., 2018**), contributing enormously to local people’s income.

Fruit

The fruit is used in six categories: food, handicraft, traditional medicine, energy, trade and rites & ceremonies. The pulp of many palms such as *B. aethiopum*, *B. akeassii*, *H. thebaica*, *E. guineensis* and *R. sudanica* are consumed raw or cooked (**Yaméogo et al., 2008; Camara et al., 2017; Salako et al., 2018a**). The flours of *B. aethiopum* had a high amount of crude fibre, carbohydrates, energy, relatively high water absorption capacity, swelling power, oil absorption capacity, and good flowability (**Abe-Inge et al., 2018**). In craft, the fruit hull was used as a substitute for the corrozo and employed to manufacture the buttons (**Bellouard, 1950**). In energy sector, *E. guineensis* pulp was used to produce fire (**Camara et al., 2017**). *Elaeis guineensis* seeds were used as sacred objects in rituals involved in oracles, which helped to discover the cause of diseases or other calamities, this is the case for example, of the Afan oracle of the Ewe in Togo, or the Ifa oracle of the Yorubas and Fa oracle of the Fon in Benin (**Gruca et al., 2014**).

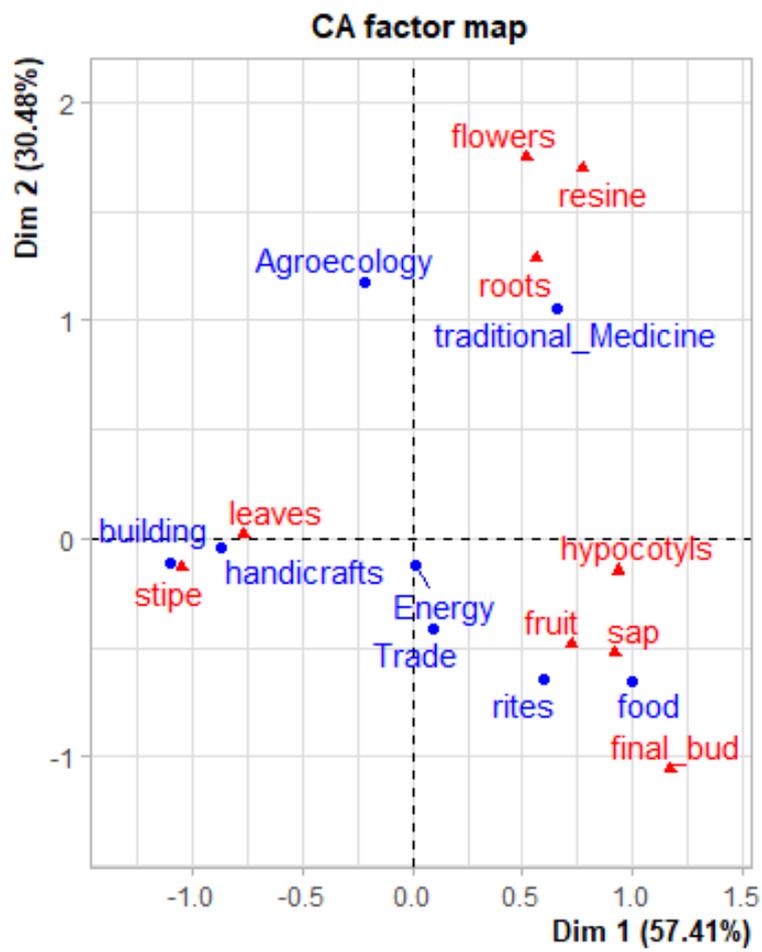


Figure 8: Relationship between used parts and use categories of West African palms

Sap

The sap is one of the most important products from palms (**Obahiagbon, 2009; Mogue Kamga et al., 2020**). In general, the sap is extracted from several palm species in West Africa such as *Borassus aethiopum*, *B. akeassii*, *E. guineensis*, *Phoenix reclinata*, *Raphia sudanica*, *R. hookeri* and *R. vinifera* (**Chevalier, 1930; Mollet et al., 2000; Ouattara et al., 2015; Mogue Kamga et al., 2020**). For **Bellouard (1950)**, *Borassus*' sap is the best one, and this palm produces on average 100 L of sap per year. The sap was used for beverages, medicine, ritual, and trading. The sap/palm wine is useful in curing jaundice, measles, and flow of mammalian glands in nursing mothers (**Obahiagbon, 2009**). The fresh sap of *B. aethiopum* contains less alcohol and some sugar (e.g. Sucrose, glucose and fructose), vitamin C, and minerals such as calcium, potassium, magnesium, and ammonium (**Zongo et al., 2019**). Thus, this sap presents a good nutritional value, and its consumption can improve the daily food intake of the rural population. The drinking of palm wine signals the start and end of all social activities undertaken by 50 million southern Nigeria people (**Obahiagbon, 2009**). Sap can be used as vehicle for other medicines. In the trading, even if sap price varies according to the season, sap extraction seems to be the most remunerative activity compared to crafts (**Yaméogo et al., 2008**).

Leaves and stem

Palm leaves are widely used in handicrafts and construction (**Guinko & Ouédraogo, 2005; Yaméogo et al., 2008; Michon et al., 2018; Salako et al., 2018a; Zongo et al., 2018**). For example, in Ghana, the petioles of *Raphia* are used to establish the dwelling's wall as well as the framework to the roof (**Ouattara et al., 2015**). In Côte d'Ivoire, the petioles of *B. aethiopum* are employed to build fences of fields (**Portères, 1964**). In agroforestry, leaves of *E. guineensis* are burnt and used as fertilizer (**Camara et al., 2017**). In medicine, young leaves of *B. akeassii* are used to treat earaches beginning of deafness (**Yaméogo et al., 2008**). Palm stem are mostly used as material for construction and crafts. In construction, erect stems of male individuals of *Borassus* were mostly used to build house (**Yaméogo et al., 2008; Salako et al., 2018a**). Male individuals' preference was justified by the fullness and resistance of trunk non-attacked by pests (**Chevalier, 1930**).

Flowers, resin, roots and palm heart

Palms flowers, resin and roots are used specifically in traditional medicine. The flower-bearing branches or rachillae of the staminate inflorescences of *B. aethiopum* are used to treat venereal diseases (**Sambou et al., 1992**). In Ghana, the Akan burn inflorescences from *Elaeis guineensis*, for the smoke to drive away evil spirits (**Gruca et al., 2014**). Uses of resin are reported by few studies (**Gschladt, 1972; Yaméogo et al., 2008**). The resin of *B. aethiopum* is used to delay

children's dental thrust (**Gschladt, 1972; Yaméogo et al., 2008**). Uses of *B. aethiopum* roots in medicine to treat malaria are reported by several ethnobotany surveys (**Salako et al., 2018a; Zongo et al., 2018**) and confirmed by a pharmacological approach (**Gruca et al., 2015**). They are also used to treat sexual weakness (**Gbesso et al., 2016**). Palm heart is used only in food. Indeed, palm heart of *B. aethiopum* and *H. thebaica* were rarely consumed by local people (**Giffard, 1966; Gschladt, 1972**).

I.3.4. Population structure of palm in West Africa

Palms stand structure is driven by natural and anthropogenic pressures which contribute to threaten palm populations in West Africa. It is evident that the extraction of non-timber forest products affects the palms' conservation. Indeed, the exploitation of palm heart, stem, roots, and hypocotyls can effectively lead to the palm's death. Therefore, the overexploitation of organs that can immediately lead to palm death can affect the palm population's conservation. Indeed, it is proved that the fruit exploitation influences the stand structure and regeneration potential of *B. aethiopum* (**Ahissou et al., 2017**). Sap extraction harms the structure of *E. guineensis*, *B. aethiopum* and *R. sudanica* in Côte d'Ivoire (**Mollet et al., 2000**). Nevertheless, sap extraction of *B. akeassii* in Burkina Faso is done by a sustainable practice that maintains the tree alive and exploitable for long years (**Guinko & Ouédraogo, 2005**). Other scientists were interested in the environmental patterns of the palm population's structure. Most of them studied the spatial pattern of palms (**Barot et al., 1999a; Idohou et al., 2016a; Salako et al., 2018b**). They mostly found that palms have an aggregative spatiality (**Barot et al., 1999b; Salako et al., 2018b**) with intraspecific competition between stages (**Barot & Gignoux, 2003**) for *B. aethiopum*. However, there is no association between doum palm and other species (**Idohou et al., 2016a**), suggesting that heterospecific tree density may negatively influence palm structure. **Salako et al. (2015; 2017)** showed that the influence of elephants on *B. aethiopum* structure in Benin causes a critical issue of conservation in protected areas. Besides, land use types and agricultural systems influence palms structure (**Madelaine et al., 2008; Idohou et al., 2016a, b, c**). For instance, the density of *B. aethiopum* was higher in protected areas than in agrosystems in Benin (**Salako et al., 2019b**). The influence of climate on palms structure has been sustained by many publications (**Idohou et al., 2016a; Salako et al., 2018b**). However, soil moisture and soil temperature affect the spatial abundance of *B. aethiopum* at Lamto Forest in Côte d'Ivoire (**Douffi et al., 2018**). In opposite, **Kouassi et al. (2008)** do not found any influence of soil moisture on rattans densities. That may be due to the different

ecology of those palm species. *B. aethiopum* with palmate leaves and erect solitary stem occurs in dry area although rattans with pinnate leaves and climbing growth form are mostly confined in swampy areas and occur in rivers border.

I.3.5. Impact of climate change on the distribution of palms

At the continental scale, climate constitutes the only strong environmental control of palm species distributions in Africa (**Blach-Overgaard *et al.*, 2010**). Water-related factors were the most important climatic factors of African palms distributions for 25 of the 29 species analysed (**Blach-Overgaard *et al.*, 2010**). Thus, climate change could influence the future distribution of palms. Indeed, on average, African palm species may experience a decline in climatic suitability in >70% of their current ranges by 2080 (**Blach-Overgaard *et al.*, 2015**). In West Africa, palms distributions are governed by a combination of effects of climate (temperature and precipitation) and substrates (soils) and others ecological factor such as Vegetation indices and gross primary productivity (**Idohou *et al.*, 2016b, c**). The impact of climate variables on palms distribution suggests that climate change will probably influence palms distributions. Unfortunately, **Idohou *et al.* (2016b)** concluded that palm species distributions would remain largely stable under future climate forecasts in West Africa. However, some species are expected to experience some retraction of present-day distributional areas. In Benin, **Idohou *et al.* (2016c)** showed that wild palms responded differentially to different suites of environmental factors. Indeed, some species showed best model performance with Vegetation indices, Gross Primary Productivity and Soil (*B. aethiopum*), others with Gross Primary Productivity and Soil (*H. thebaica*, *R. sudanica*) or Vegetation indices and Gross Primary Productivity (*P. reclinata*), or with only soil factor (*E. macrocarpa*, *L. opacum*, *Raphia hookeri* and *R. vinifera*; **Idohou *et al.*, 2016c**). In West Africa, most palm species' highest-priority areas are located along the coast (from Guinea to Nigeria) as published by **Idohou *et al.* (2016b)**. The decrease in habitat suitability of *B. aethiopum* was pronounced in the semi-arid zone where the species is currently widely distributed (**Salako *et al.*, 2019b**).

I.3.6. Propagation and regeneration mechanisms of palms tree in West Africa

It is known that palm propagate mostly by seed germination. However, palm seeds germination was confronted to dormancy, embryo immaturity, seed coat impermeability, and physiological events during seed storage (**Moussa *et al.*, 1998; Idohou *et al.*, 2015b**). It is reported that high temperature pretreatment was essential for the germination of *E. guineensis* seeds (**Labro *et***

al., 1964; Rees, 1961; Rees, 1962). The excellent germination rate of *E. guineensis* seeds was obtained by dry hot pretreatment at 40°C for 80 days afterward cooled at the optimum seed moisture content (Rees 1961; Rees, 1962). Rabéchaud (1962) described five stages in *E. guineensis* seed germination. Currently, germination of *E. guineensis* has been mastered, and this palm has been successfully grown and introduced in many areas for cultivation. Concerning the savanna palms, namely *B. aethiopum*, *H. thebaica*, *P. reclinata* and *R. sudanica* their germination is cryptogal and occurs in two stages (Tahir *et al.*, 2007). Among these savanna palms, *H. thebaica* attempts to draw more attention. Indeed, Moussa *et al.* (1998) carried out a study on the dormancy of doum palm seed and obtained good results for seed soaking pretreatments. Based on fruit characteristics, Idohou *et al.* (2015b) identified three morphotypes related to phytodistricts in Benin and their influence on germination rate and seedlings growth of *H. thebaica*.

In addition to seeds germination, some palms are able to regenerate vegetatively. Some multi-stemmed palms growth by branching basally. Each trunk develop an adventitious root system. This vegetative mechanism of regeneration of new stem is tillering and occurs in many palm species such as *Phoenix dactylifera*. Palms that exhibit that pattern are known as Tomlinson's model (Tomlinson, 1962). However, Russell (1965) think that *Raphia ssp.* are able of regenerating by suckering.

I.4. Native palms of Burkina Faso

Native palm flora of Burkina Faso counts seven wild species belonging to 6 genera, namely *Borassus aethiopum*, *Borassus akeassii*, *Calamus deerratus*, *Elaeis guineensis*, *Hyphaene thebaica*, *Phoenix reclinata* and *Raphia sudanica* (Figure 9).

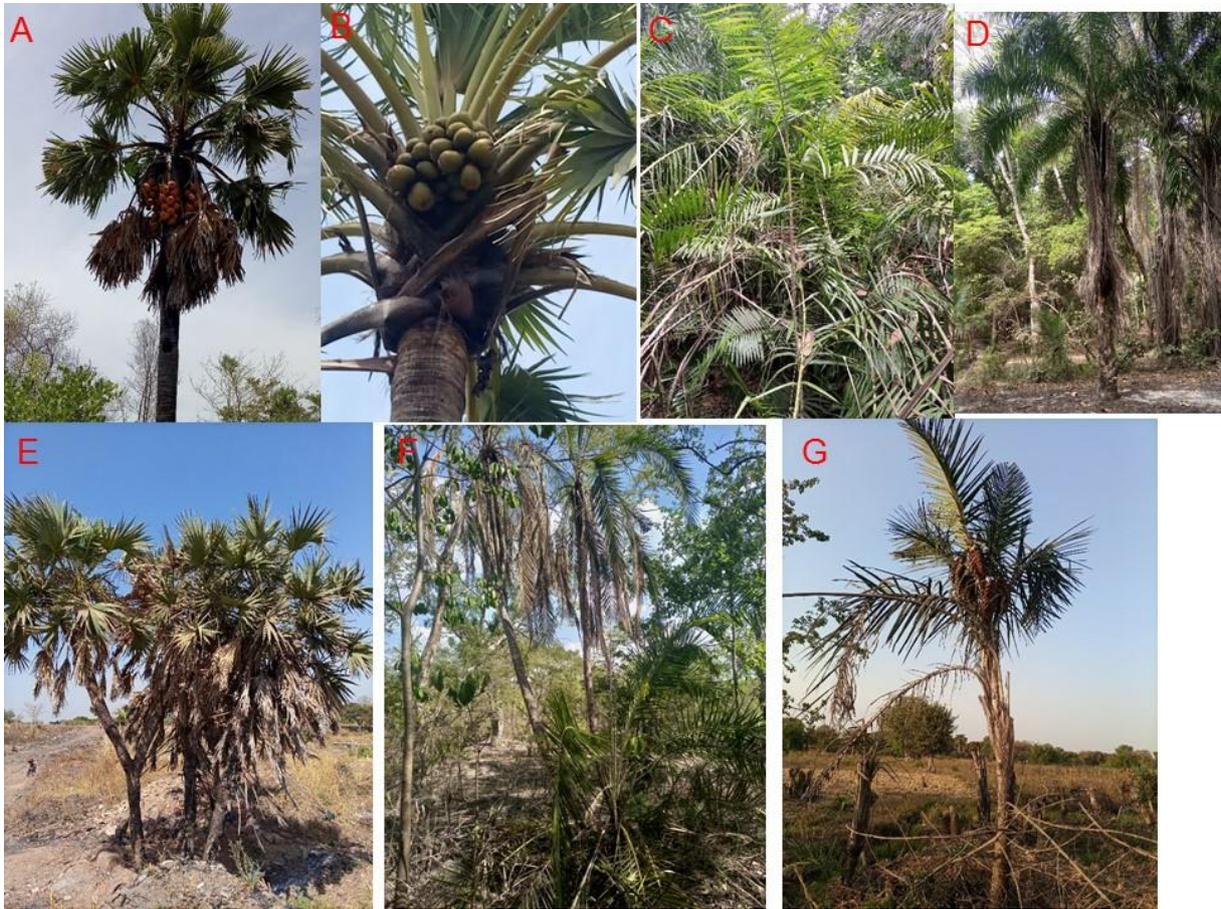


Figure 9: Native palm species of Burkina Faso

A) *Borassus aethiopum*, with fruits, B) *Borassus akeassii* with fruits, C) *Calamus deerratus*,
 D) *Elaeis guineensis*, E) *Hyphaene thebaica*, F) *Phoenix reclinata*, G) *Raphia sudanica*.

Besides these wild palm species, many palms have been introduced in Burkina Faso such as *Cocos nucifera* (the coconut palm) and *Phoenix dactylifera* (the date palm) (Ouédraogo, 2010). Ganaba (2020) recently reported sixteen palm species introduced in different cities of Burkina Faso. Native palms are unequally distributed throughout the country with six over seven occurring in the Sudanian zone while only one species thrived in the Sahelian zone (Table III). The genus *Borassus* L. is the widely distributed and the richest of the native country's palm flora with two species, *Borassus aethiopum* and *Borassus akeassii*. *Borassus akeassii* is a pleonanthic dioecious palm with a ventricose stem. The leaves are costapalmate with up to 130 induplicate leaflets and green weakly armed petiole. The fruits have a pointed apex and are greenish when ripe, and the flowers of the pistillate inflorescence are arranged in three spirals (Ouédraogo *et al.*, 2002; Bayton *et al.*, 2006). *Borassus akeassii* shows a preference for well-drained soils and is fire-resistant (Arbonnier, 2009). The habitat of the species is the Sudan savannas with 800 – 1100 mm annual rainfall. In Burkina Faso, major populations of *Borassus akeassii* are found in Western Burkina Faso while major populations of *Borassus aethiopum* occurred in the Eastern part (Ouédraogo *et al.*, 2002; Bayton & Ouédraogo, 2009). *Borassus akeassii* provides sap and leaves that are mainly exploited for palm wine and basket-making respectively.

The monoecious pleonanthic palm *Elaeis guineensis* has a single stem and pinnate leaves (Stauffer *et al.*, 2014). The stem may reach a height of 30 m, and the diameter 40–50 cm, is nearly always straight, and is heavily coated in leftover leaf sheaths. The leaves, which may grow up to 8 meters long, typically have an arching rachis and leaflets that are inserted more or less regularly.

Phoenix reclinata has pinnate leaves, which have 30 to 50 leaflets on each side of the rachis. They are often found in scattered bunches near riverbanks and in lowlands, open grasslands that experiences seasonal flooding. It is a dioecious, typically clustered and a rarely solitary tree with a height up to 15 meters; the trunk is up to 10 meters tall, upright or oblique, unbranched, cylindrical, up to 25 to 40 centimeters in diameter (Barrow, 1998; Martins & Shackleton, 2017).

In Burkina Faso, *Borassus aethiopium*, *Borassus akeassii* and *Elaeis guineensis* are protected because of the over-harvesting of these palms.

Table III: Native palms of Burkina Faso with their distribution and global conservation status

species	UICN Conservation categories	redlist	Distribution in Burkina Faso
<i>Borassus aethiopium</i> Mart.	Least Concern		Sahelo-sudanian and sudanian
<i>Borassus akeassii</i> Bayt., Ouéd. & Guinko	Least Concern		Sahelo-sudanian and sudanian
<i>Calamus deeratus</i> G.Mann & H.Wendl.	Least Concern		Sudanian
<i>Elaeis guineensis</i> Jacq.	Least Concern		Sudanian
<i>Hyphaene thebaica</i> Mart.	Least Concern		Sahelian, sudano-sahelian, and sudanian
<i>Phoenix reclinata</i> Jacq.	Least Concern		Sudanian
<i>Raphia sudanica</i> A. Chev.	Near Threaten		Sudanian

CHAPTER II: MATERIAL AND METHODS

II.1. Material

II.1.1. Biological material

The plant material used in this study was made up of palms occurring in Western Burkina Faso. Thus, it included *Borassus akeassii*, *Calamus deerratus*, *Elaeis guineensis*, *Phoenix reclinata* and *Raphia spp.* The tree species identified in the palms habitats constitute also some biological material used in this study.

II.1.2. Field equipments

Questionnaire

Individual questionnaire (Appendix 2) was used in the ethnobotanical survey to collect the information related to human perceptions on wild palms.

Global Positioning system (GPS)

A GPS was used to record the geographic coordinate of each plot. It was also used to collect the geographic coordinates of palm individuals used in the distribution models.

Measuring tape

A measuring tape was used for all the measurements including the girth of trees, the leaf length and width. It was also used for measuring the dimension of the plots.

Calliper

A calliper was used to measure the section of the petiole in the morphological assessment of the genus *Raphia* P.Beauv.

Clinometer

A clinometer was used to estimate the height of individuals in the morphological assessment of the genus *Raphia* P.Beauv. in the field.

A botanical press

A botanical press was used when collecting herbarium specimen in the field.

A camera

A camera was used to capture image in the field.

II.1.3. Computer supports and map processing

A computer was used to analyses all the collected data and write the dissertation. Thus, the R software was used for all the statistical analysis. QGIS was used for mapping and geostatistics. Finally, the document was written using Microsoft Office program.

II.2. Conceptual and theoretical frameworks

The conception of the present study was based on five approaches. We adopted two ethnobotanical hypotheses, namely the plant use value hypothesis and the age, gender and dynamics of knowledge hypothesis, to examine the ethnobotanical knowledge and usefulness of the wild palms species (Gaoue *et al.*, 2017). To evaluate the population structure of the studied species, the life stage profile description was combined to three measures of population stability (Wiegand *et al.*, 2000). The morphological concept of species was used in species delimitation. The ecological niche theory (Hutchinson, 1957) that guides the species distribution modelling was coupled with the CNFA framework to assess the vulnerability of wild palms to climate change.

II.2.1. Plant use value and the age, gender and dynamics of knowledge hypothesis

Five different indices and values used by many authors (Byg & Balslev, 2001; Paniagua-Zambrana *et al.*, 2007; Araujo & Lopes, 2012) were employed in this study to analyse the palm species, the palm part harvests, the perception of dynamics and the local conservation practices of each palm species in the context of Western Burkina Faso. The plant use value hypothesis suggest that the usefulness of a plant in a given communities is linked to its botanical family, life form, local abundance and/or maximum size (Philips & Gentry, 1993; Camara-Leret *et al.*, 2017; Gaoue *et al.*, 2017). Previous works also suggested that the importance and knowledge of plants for local people are dependent on the socio-cultural features of the users such as ethnic group, gender and age (Ouédraogo *et al.*, 2013; Balima *et al.*, 2018; Ouédraogo *et al.*, 2019; Tiétiambou *et al.*, 2020). This hypothesis was further improved to include the socio-ecological characteristics such as proximity to market, geographic location and plant abundance (Tiétiambou *et al.*, 2020; Salako *et al.*, 2018a) and cultural change proxy such as education and kindship (Campos *et al.*, 2019) as determinant factors of a plant usefulness. Thus we adopted the two hypothesis, namely the plant use value hypothesis and the age, gender and dynamic of knowledge hypothesis in our study to understand the usefulness and importance of each palm species.

II.2.2. Life profile description and population stability

Static data from a snapshot survey may be used to understand population changes and dynamics (Shen *et al.*, 2013; Martins & Shackleton, 2017; Lankoandé *et al.*, 2019; Tinguéri *et al.*,

2022). Static approaches include the description of life stages profile and can reflect the level of recruitment, growth and mortality that a given species has undergone over several years or decades (Wiegand *et al.*, 2000). As palms are long-life species (Tomlinson, 2006), the mixture of different life stages in their population may represent the recruitment, establishment, and persistence processes that occurred over years. The life stages profile can be used to identify demographic shifts in the population and patterns in population growth. Several measures, including the Simpson index of dominance, the permutation index and the quotient between successive life stages are also helpful in adding interpretive insights into the dynamics and stability of a given population (Wiegand *et al.*, 2000; Botha *et al.*, 2002; Shen *et al.*, 2013; Martins & Shackleton, 2017).

II.2.3. Morphological concept of species delimitation

Delimitation of species is important to distinguish between the species of the same nature, and diagnostic characters are helpful to separate all sorts of species boundaries in biological sciences (Ullah *et al.*, 2022). Despite the increasing use of DNA barcoding to delineate extant species (Jiménez *et al.*, 2021; Helmstetter *et al.*, 2021) and because morphology is the first source of information available when organisms are discovered and described, diagnoses remain largely based on morphological criteria today (Palisot de Beauvois, 1804; Bayton *et al.*, 2006; Mogue Kamga *et al.*, 2018). The morphological concept is of practical importance in identifying species in the field and many characters have in general a genetic basis. Thus, we adopted the morphological concept of species in our work following several authors (Aké Assi & Guinko, 1996; Barrow, 1998; Ouédraogo *et al.*, 2002; Mogue Kamga *et al.*, 2018).

II.2.5. Ecological niche theory and climate Niche Factor Analysis

The CNFA (Climate Niche Factor Analysis) framework recently proposed by Rinnan & Lawler (2019) was combined to the state-of-the-art on species distribution modelling (SDM) in order to assess the vulnerability of wild palm species to climate change in Burkina Faso. We used the SDM to delimitate the suitable habitats under current and future conditions. The SDM was based on the ecological niche concept of Hutchinson (1957) and implemented through the Maximum Entropy (MaxEnt) algorithm (Phillips *et al.*, 2006; Phillips *et al.*, 2017). The choice of MaxEnt is justified by its numerous advantages that include: (i) the used of presence data only (Elith *et al.*, 2006; Philips *et al.*, 2017), (ii) its robustness when dealing with small size samples, (iii) its performance against other algorithms and ensemble modelling approach (Elith

et al., 2006; Kaky *et al.*, 2020). Despite the high use of SDM by researchers to assess the vulnerability of species (Idohou *et al.*, 2016a; Dimobé *et al.*, 2020; Lompo *et al.*, 2021; Balima *et al.*, 2022; Manda *et al.*, 2022), the SDM informed only about the exposure of species. Yet, the exposure is one aspect of the vulnerability assessment of species to climate change that includes also the sensitivity and adaptive capacity (Pacifi *et al.*, 2015). The CNFA works by estimating the species sensitivity and habitat exposure within the presence/absence maps. The CNFA is adapted in vulnerability assessment because of (i) the need of presence-only occurrence data and climate data, (ii) no need of detailed life history knowledge and absence data, (iii) the easy usage for wide variety of species in a way that allow direct comparison (Rinnan & Lawler, 2019). Thus, the current range maps generated from the Maxent model were used as the present distribution in the CNFA framework to calculate the overall vulnerability of species to different climate models and scenarios.

II.3. Methods

II.3.1. Uses, local perceptions and conservation practices of wild palms

II.3.1.1. Sampling scheme and data collection

In Western Burkina Faso, 258 informants were interviewed in ten villages from December 2020 to June 2021 using individual semi-structured questionnaires (Appendix 2). The villages were selected based on the presence of at least one palm species. The informants were selected in the village based on their knowledge of at least one palm species. Before the interview, the consent of each informant was obtained. A list of six palm species was used, based on literature and available knowledge, for the interviews. Prior to the interview in each locality, the local names of the palm species were recorded through a walk in the field with some informants and the local field guide. The list was opened for new palm species to be added by informants (Ouédraogo *et al.*, 2013). The information collected from the informants include: (i) The socio-cultural information such as ethnic group, age and gender, (ii) the different uses they know on each palm species cited, (iii) their perceptions of the population dynamics of each species and the reasons that underpin a decline, and (iv) the traditional management practices they adopt to conserve each palm species.

II.3.1.2 Data analyses

The collected data were reorganized according to socio-cultural factors such as ethnic group, gender and age categories. Informants were classified according to age category as young (<30 years), adult (30-60 years), and old (>60 years) following previous authors (**Assogbadjo *et al.*, 2008; Salako *et al.*, 2018a**). A Kruskal-Wallis test was used to assess the variation of the mean number of palms cited according to the ethnic group, gender, and age category. Differences in wild palms knowledge among different socio-cultural factors were tested through the analysis of similarities (ANOSIM) based on Jaccard's dissimilarity distance using 999 permutations (**Clarke, 1993**). The ANOSIM was implemented in the '*vegan*' R package (**Oksanen *et al.*, 2020**). The inter-relationships between significant factors (identified from the ANOSIM results) and the palms cited were displayed using chord diagrams generated with the '*circlize*' R package (**Gu *et al.*, 2014**). In addition, five ethnobotanical values and indices related to the usefulness of palms and the distribution of the informants' knowledge on palm uses were computed for each palm species (Table IV). These measures of use and knowledge of palms were statistically assessed using a Pearson's correlation to detect any potential correlation (**Paniagua-Zambrana *et al.*, 2007; Araujo & Lopes, 2012**). The Kruskal-Wallis non-parametric test was performed to assess the influence of socio-cultural factors on the use values of palm species followed by a Dunn test (**Dunn, 1964**). A Fisher exact test was used to assess the significant difference between the local perception dynamics of palm species. The relative frequency of citation of the causes of the decline mentioned by local people was calculated and graphically presented. The local practices of conservation were presented using a relative frequency of citation of each practice. All the analyses were performed using R software version 4.0.4 (**R core Team, 2021**).

Table IV: Measures of importance and uses of palm species

Measure	Calculation	Description	References
Use value	$UV_s = \sum UV_{is}/n$ <p>n = total number of informants</p> <p>UV_{is} = number of uses informant i knows about species s</p>	Measures the average number of uses informants know for a species.	Philips & Gentry (1993)
Informant diversity value	$ID_s = 1/\sum P_i^2$ <p>P_i = contribution of informant i to the total knowledge pool of species s (number of reports of uses of species s by informant i divided by the total number of reports of uses of species s)</p>	Measures how many informants use a species and how its use is distributed among them.	Byg & Balslev (2001)
Use diversity value	$UD_s = 1/\sum P_c^2$ <p>P_c =contribution of use category c to the total uses of a species s (=number of times species s was mentioned within each use category, divided by the total number of reports of use of species s across all uses categories)</p>	Measures for how many use categories a species is used and how evenly these contribute to its total use.	Byg & Balslev (2001)
Relative Frequency of citation	$RFC = (n_{is}/n) \times 100$ <p>n_{is} = number of informants who cited the species s.</p>	Measures the proportion of informants who cited a species.	
Use consensus value	$UC_s = 2n_s/n - 1$ <p>n_s = number of people using a species s</p>	Measures the degree of accordance is between informants concerning whether they regard a species as useful or not.	Byg & Balslev (2001)

II.3.2. Population structure, habitat diversity and regeneration of wild palms

II.3.2.1. Sampling and data collection

An oriented sampling scheme was applied, based on the presence of each wild palm species in Western Burkina Faso. A total of 30 vegetation inventory plots distant from each other of at least 100 m was settled for each species (except *Calamus deerratus*, where only 4 plots were settled due to the scarcity of the species). Thus, a total of 124 plots were settled to collect data on the demography of wild palms. However, data on *Calamus deerratus* were not used in the population assessment because of fewer number of plots. All individuals in the plot were recorded. For each palm individual in the plots, the life stage, sex, and exploitation state were recorded. Life stages were described in table III following **Barot *et al.* (1999a)**. Sex was based on observation of flowering or fruiting individuals and was relevant only for dioecious palms at sexual maturity namely *Borassus akeassii* and *Phoenix reclinata*. Furthermore, all tree species co-occurring with the specific palms in the plot were systematically recorded and their girth at breast height (GBH) measured using a tape. The girth at breast height was then converted into diameter at breast height (DBH) using the following formula:

$$DBH = \frac{GBH}{\pi}$$

To assess the mechanism of natural regeneration of palms, all individuals from natural regeneration (seedlings and saplings) were examined and attributed to one mechanism of regeneration. Juveniles that come from seeds are considered as true seedlings and part of sexual reproduction. However, juveniles could come from tillering as already describe for *Phoenix dactylifera* (**Barrow, 1998; Faruquei *et al.*, 2020**). **Russell (1965)** also suggests that *Raphia spp.* are able of suckering, therefore, the link between juveniles' roots and the mother-tree roots was assessed. Thus, juveniles are excavated to see potential link with a mother-tree roots. If such link exist, the regeneration mechanisms may be suckering. If the link is at the base of the trunk, the mechanisms of regeneration is tillering.

Table V: Description of life stages of palms, adapted from **Barot et al. (1999a)**

Life stages	Description
Seedlings	Individual without apparent trunk, presence of young leaves (rachis not segmented)
Saplings	Individual without apparent trunk but leaves slitted.
Juvenile	Individual with trunk covered with remnant leaves, no reproductive
Sub-adult*	Individual with trunk covered with remnant leaves, reproductive
Adult	Individual with nude trunk, reproductive.

* Because the aboveground stem is typically hidden by old leaf sheaths in *Raphia spp.* and *Phoenix reclinata*, we do not considered the sub-adult life stage in these palms. Thus, the reproductive individuals are considered in the genus *Raphia* and the genus *Phoenix* as adult.

II.3.2.2. Data analyses

Population structure and stability

To analyse the population structure of wild palms, demographic parameters namely density of life stages, regeneration, and mortality ratios and the sex-ratio were used in addition to structural indices that describe the stability of the population (Table VI). For instance, the density was a proxy of the abundance of the considered palm species. The regeneration and mortality ratios were calculated to catch up the dynamic of the population and to assess the human pressure. We considered these ratios as indicator of palms dynamics because young trees (used to calculate the regeneration ratio) take a decade to become mature, while, stumps (used to calculate the mortality ratio) usually disappear within a decade (Camara *et al.*, 2019). The density of each life stage were compared among life stages using a Kruskal-wallis test followed by a Dunn test when the difference was statistically significant (Dunn, 1964). The sex ratio is calculated for dioecious species (*Borassus akeassii* and *Phoenix reclinata*) and deviation from evenness (i.e. 50:50) was tested using the exact binomial test.

The stability of the population was measured using three quantitative indices namely the permutation index (P), the Simpson's dominance index (S) and the quotient (Q) within consecutive sized classes (Table VI; Shen *et al.*, 2013). These indices provided a useful suite of measures sensitive to different aspects of life stages profiles and their interpretation (Shackleton *et al.*, 2005). The permutation index is the aggregation of the absolute distance between the predicted and the actual ranking of all life stages and assesses the departure from a uniform decline that is characteristic of an undisturbed population (Wiegand *et al.*, 2000; Martins & Shackleton, 2017). An undisturbed population will have a permutation index approaching zero, while a population with discontinuous distribution will have a permutation index above zero (Wiegand *et al.*, 2000; Botha *et al.*, 2002). The Simpson's dominance index evaluates the uniformity of the life stages irrespective of rank (Botha *et al.*, 2002; Martins & Shackleton, 2017). This index was compared to 0.1 (Botha *et al.*, 2002). Quotients between consecutive life stages were presented graphically and the shape of fluctuations was analyzed. All the statistical analyses were performed in R version 4.0.4 (R core Team, 2021).

Table VI: Description of demographic parameters and stability index for population structure

Parameters	Formula	Definition	References
Density	$D = \frac{n}{s}$	Availability of the species n is the number of individuals s is the size of the plot	-
Regeneration ratio (R)	$R = \frac{\text{seedlings} + \text{saplings}}{\text{adults}}$	-	Camara et al., (2019)
Mortality ratio (M)	$M = \frac{\text{Stumps}}{\text{living stems}}$	-	Camara et al., (2019)
Sex-ratio	$\text{sex-ratio} = \frac{\text{females}}{\text{males}}$	-	
Simpson index of dominance (S)	$S = \frac{1}{n(n-1)} \sum_{i=1}^5 n_i (n_i - 1)$	A measure of a size-class dominance, with n total number of trees and n _i the number of trees in class i	Botha et al., (2002)
Permutation index (P)	$P = \sum_{i=1}^5 j_i - i j_i$	J _i rank of sized classes i (i=1 for small stems), and the first rank (J _i =1) attributed to the mostly frequent sized class	Wiegand et al., (2000)
Quotient between successive size-classes (Q)	$Q = n_{i-1}/n_i$	n _i : number of individuals in class i n _{i-1} : number of individuals in preceding class	Shackleton et al., (2005)

Tree species occurring in palms stands

The nomenclature of **Thiombiano *et al.* (2012)**, **Kyalangalilwa *et al.* (2013)** and **Maurin *et al.* (2018)** and the angiosperm phylogenetic classification was adopted (**APG IV, 2016**) to characterize the trees species that co-occur with the considered palm species. The trees species occurring in palms stands were characterized through a set of variables including the number of species, the Shannon-Weiner index, the density, and the mean diameter. These variables were computed per plot and then compared between stands using one-way analysis of variance (ANOVA). Post hoc analysis of variables showing significant differences was carried out using Tukey's honestly significant difference (HSD) test. The frequency-rank diagrams of the co-occurring tree in the specific palm habitats were used to identify frequent species in the palm's habitats.

Regeneration mechanisms

The proportion of each mechanism of regeneration was calculated and presented for each palm species. Thus, the capacity of palms to regenerate by vegetative way in wild is described.

II.3.3. Morphological variation of the *Raphia* P.Beauv.

II.3.3.1. Data collection

Three populations of *Raphia* were selected in Western Burkina Faso. In each population and based on the variation observed, twenty individuals were selected in each population. For each individual, twenty vegetative characters were recorded, including 14 quantitative and 6 qualitative traits. The observations and measurements were made on the stem, the leaves, the petiole, the rachis and the leaflets of each individual (Table VII). The reproductive characters have not been used in this study because of the difficulty to get the reproductive organs in *Raphia*. Indeed, the genus *Raphia* is hapaxanthic (meaning the stem flowers once and subsequently dies). The maturity of fruit lasts between two and four years and there do not have synchrony in the phenology of different individuals in the same population. In addition, **Otedoh (1976)** revealed a great variation between fruit of a single individual, and between individuals of the same species in the *Raphia* genus. The vegetative features may also be enough to identify some species in the genus like *R. sudanica* (**Chevalier, 1908; Ouattara *et al.*, 2014**).

Table VII: Characters recorded on each *Raphia* individual

Plant parts	Characters	Type of data	Technic/material used
Stem	Growth pattern	qualitative	observation
	Height	quantitative	clinometer
Petiole	Presence of the petiole	qualitative	observation
	Petiole length	quantitative	tape
	Section of petiole	quantitative	caliper
	Shape of petiole	qualitative	observation
Rachis	Length	quantitative	tape
	Width	quantitative	tape
	Shape	qualitative	observation
	Spinescence	qualitative	observation
	Distance between three consecutive leaflets (at the base of the rachis) ¹	quantitative	tape
Leaflet	Shape	qualitative	observation
	Number of leaflets	quantitative	counting
Basal leaflet	Length	quantitative	tape
	Width	quantitative	tape
Median leaflet	Length	quantitative	tape
	Width	quantitative	tape
Apical leaflet	Length	quantitative	tape
	Width	quantitative	tape

¹The distance between the consecutive leaflets was used to calculate the leaflet spacing index (SI) following **IPGRI (2005)**. This index is a standardization of the spacing between two consecutive leaflets that has been successfully used to describe the spacing between leaflets in *Phoenix dactylifera* varieties. The index (SI) was calculated using the following formula:

$$SI = \frac{a + b + c}{d}$$

With SI= spacing index, a= distance between the first and second leaflets, b=distance between the second and the third leaflets, c= distance between the third and fourth leaflets and d= distance between the first and fourth leaflets.

II.3.3.2. Data analyses

We used multivariate statistical techniques to assess both quantitative and qualitative traits, following a multistep approach. We employed a Factor analysis of mixed data (FAMD) to reveal the underlying structure of the data. Factor analysis of mixed data (FAMD) is a method that analyzes a dataset containing both quantitative and qualitative variables (**Pagès, 2004**). More precisely, the continuous variables are scaled to unit variance and the categorical variables are transformed into a disjunctive data table and then scaled using the specific scaling of multiple correspondence Analysis. This ensures to balance the influence of both continuous and categorical variables in the analysis. This method allows one to study the similarities between individuals taking into account mixed variables and to study the relationships between all the variables. Then, the Hierarchical clustering method was then applied on axes for grouping individuals based on their similarities and presented as a dendrogram. The analysis was performed through the package “*FactoMiner*” and “*FactoExtra*” in the R software version 4.0.4 (**R Core Team, 2021**). Finally, we checked cluster quality, in terms of within-cluster and between-cluster variability, using the one-way analysis of variance (ANOVA). Each cluster was described using the quantitative and qualitative variables. For each quantitative character, one measure of central tendency, the mean, and one measures of variability, the range, are given, as well as sample size (number of individuals in the cluster). Each identified cluster was assessed to clarify its similarities with palm species using the scientific description and the currently accepted taxonomy of the *Raphia* genus (**Palisot de Beauvois, 1804; Chevalier, 1908; Otedoh, 1982; Dransfield et al., 2008; Mogue Kamga et al., 2019**).

II.3.4. Species distribution modelling and vulnerability of wild palms

II.3.4.1. Occurrence data

Occurrence data was extensively collected from the fieldwork (taken with a GPS Garmin 64s from 2019 to 2021). Other occurrence data were obtained from the Global Biodiversity

Information Facility (www.gbif.org) and previous fieldworks (**Ouédraogo, 2006; Zon et al., 2020**) resulted in a total of 489 occurrences for five palm species (Table VIII). The data collection was restricted to only Burkina Faso (Figure 10), which is the focus of the study, rather than the whole West-Africa in order to avoid inaccuracy in models' outputs that may be due to the scarcity, and unbalanced occurrence data across regional range of the species (**Salako et al., 2019**). In addition, both local and very general datasets can produce useful predictions (**Konowalik & Nosol, 2021**). *Calamus deerratus* was not retained in this study because of its low occurrence records.

The occurrence data underwent a further filtering procedure to remove clustered data. The filtering procedure was conducted in the *Humboldt* package in R by keeping one occurrence within each of 1km x 1km. After the filtering, we obtained a final dataset of 59 records for *Borassus akeassii*, 175 records for *Elaeis guineensis*, 39 records for *Phoenix reclinata* and 50 records for *Raphia sudanica*, that were used for the modeling process.

Table VIII: Occurrence records of palm species

source	<i>Borassus akeassii</i>	<i>Calamus deerratus*</i>	<i>Elaeis guineensis</i>	<i>Phoenix reclinata</i>	<i>Raphia sudanica</i>	Total
GBIF	13	6	24	18	13	120
Zon (<i>Pers. Obs.</i>)	70	4	72	47	67	248
Zon et al., 2020			110			110
Ouédraogo, 2006	-	-	2	-	9	11
Total	83	10	208	65	89	489

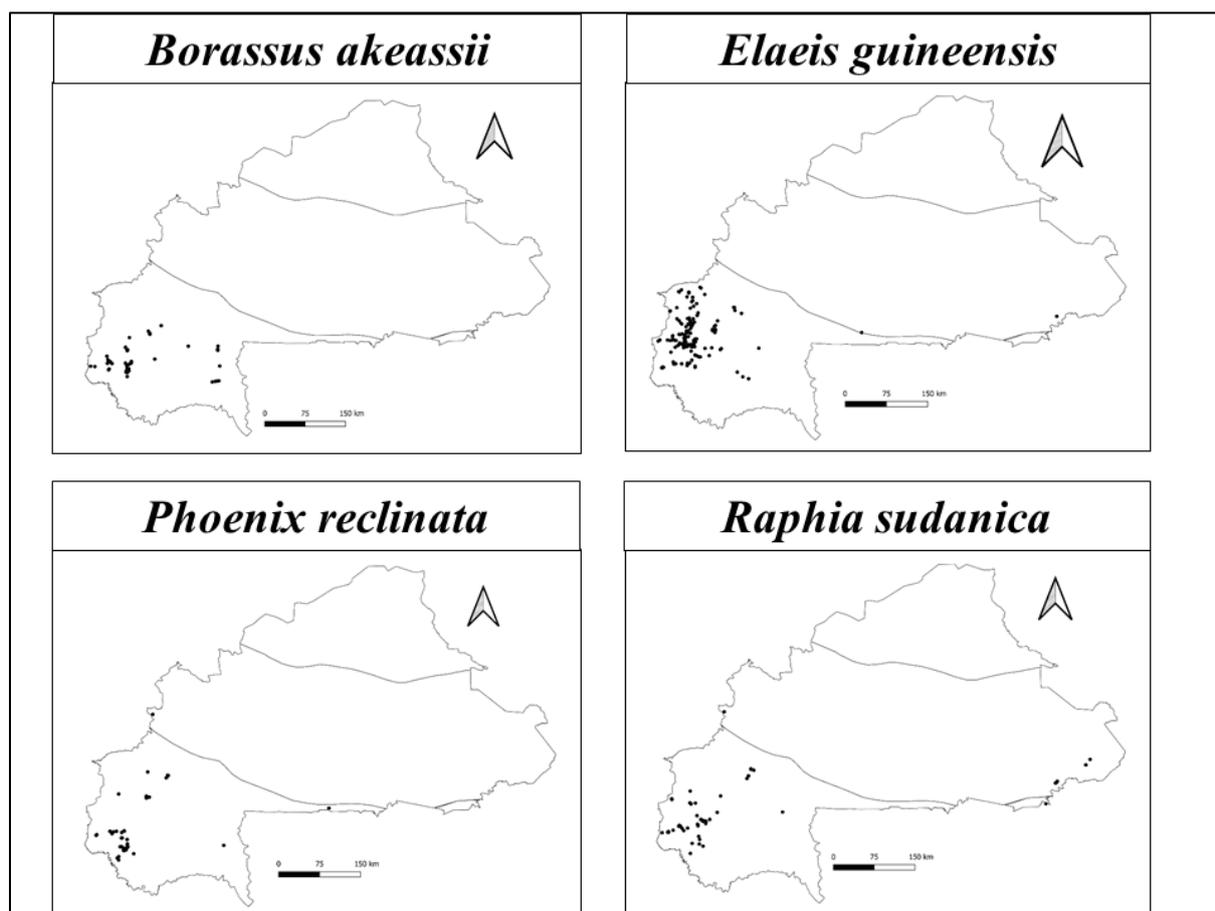


Figure 10: Spatial distribution of wild palms occurrence data collected in Burkina Faso

II.3.4.2. Environmental variables

Historical climate data comprising 19 bioclimatic variables were downloaded from the WorldClim website version 2.0 (www.worldclim.org, Fick & Hijmans, 2017). The 19 bioclimatic variables are derived from temperature and precipitations values of 1970-2000 and represent more meaningful biological variables that are often used in SDM (Dimobé *et al.*, 2020; Lompo *et al.*, 2021; Balima *et al.*, 2022; Manda *et al.*, 2022; Pillet *et al.*, 2022). Future climatic data consisted of two models of the Coupled Model Intercomparison Project phase 6 (CMIP6): the Met Office climate model (HadGEM3-ES) and Max-Planck Institute Earth System Model for high Resolution (MPI-ESM-HR) and two scenarii were used: the middle-of-the way (SSP4.52) and the highway (SSP5.85) scenarii. The selection of the two models and scenarii is justified by the fact that they were among the most used GCM in SDM in West Africa (Fandohan *et al.*, 2013; Dimobé *et al.*, 2020; Balima *et al.*, 2022). The time scale of the predictions is the current and two future periods (the near future: 2041-2060) and the far future: 2081-2100).

Soil data were obtained at 250m resolution from the SoilGrid database (<https://soilgrids.org/>). Eight sets of soil characteristics were downloaded. These include bulk density, soil organic carbon, pH in water, clay content, sand content, silt content, cation exchange capacity and Nitrogen content (Poggio *et al.*, 2017). These soil variables were used in previous studies (e.g., Manda *et al.*, 2022). Considering the fact that the interaction between soil and plants is critical in the first 16 cm depth (Goebes *et al.*, 2019), three soil depth horizons (0-5, 5-15, and 15-30 cm) were used in this study following Manda *et al.* (2022). Thus, a total of 24 soil layers were downloaded and resampled at 1 km resolution to match other environmental layers resolutions. Digital elevation model (DEM) derived from the Shuttle Radar Topography Mission (SRTM) was also downloaded from the WorldClim website version 2.0 (www.worldclim.org) and used to generate the topographic position index (TPI) using QGIS version 3.16. The TPI is defined as the difference between the elevation at the central point and the mean elevation within a defined neighborhood and thus determines the central point's relative topographic location (Weiss, 2001). The TPI is one of several morphometric characteristics based on nearby locations that might be helpful in topographic and DEM analysis. We do not include the elevation because it does not have any biologically meaning information in the species distribution, especially for a flat study area as Burkina Faso. The drainage density was derived by rasterizing the national geodatabase of rivers networks at the spatial resolution of 1 km. Drainage density, that corresponds to the total length of the river network channels per unit area

of the basin, is an important property of a river network (Moglen, 1998). Drainage density was used as a proxy of hydrographic because the distribution of the palms seems dependent on the hydrographic network in the semi-arid climatic context like Burkina Faso (Zon *et al.*, 2020).

II.3.4.3. Species distribution modelling

The SDM of wild palm species were fit with the MaxEnt algorithm implemented in the *dismo* package (Hijmans *et al.*, 2021). The MaxEnt algorithm work by establishing the relationship between species occurrence records in the study area and the environmental variables (Phillips *et al.*, 2006; Elith *et al.*, 2011). MaxEnt is among the many SDM tools that are increasingly used in conservation-oriented studies because of its high predictive accuracy, stability and reliability with presence-only and small data sets (Dimobé *et al.*, 2020; Lompo *et al.*, 2021; Manda *et al.*, 2022; Balima *et al.*, 2022; Pillet *et al.*, 2022). Predictors were further selected by checking for multicollinearity using the Variance Inflation Factor ($VIF \leq 10$), retaining only 20 variables from the 45 initial variables (Appendix 4), that were used for the modeling. Variables that contributed $<1\%$ to each of the model after every run for three successive runs were excluded. Finally, five environmental variables that contributed the most to each of the models were retained for building the final models (Manda *et al.*, 2022).

The models were cross-validated with ten replicates runs and the performance of each model assessed using three metrics, the Area Under the Curve (AUC), the True Skill Statistic (TSS), and the Boyce Continuous index (BCI) (Boyce *et al.*, 2002; Elith *et al.*, 2006; Allouche *et al.*, 2006). The AUC with values ranging from 0 to 1 is a threshold-independent measure of the model's ability to differentiate accurate predictions from random ones (Araujo *et al.*, 2005). Thus, models were considered as having low accuracy when $0.5 \leq AUC < 0.7$, good accuracy if $0.8 \leq AUC < 0.9$ and high accuracy if $AUC \geq 0.9$ (Dimobé *et al.*, 2020). The TSS is a threshold-dependent measure of accuracy that is expressed as the sensitivity + specificity - 1 (Allouche *et al.*, 2006; Balima *et al.*, 2022). Its values range from -1 to $+1$, and values closer to 1 indicate good-performance models (Allouche *et al.*, 2006). Therefore, models were described as poor ($TSS < 0.4$), acceptable ($0.4 \leq TSS < 0.8$), and very good ($TSS > 0.8$) (Manda *et al.*, 2022). The Boyce index is a suitable metric for presence-only models in the sense that it measures how much model predictions deviate from a random distribution of the observed presences across the prediction gradients (Boyce *et al.*, 2002). It fluctuates continuously between -1 and $+1$ and values close to zero indicate that the model is identical to a random model, while negative values indicate counter predictions. Positive values indicate a model

whose present predictions are consistent with the distribution of presences in the evaluation dataset (**Hirzel *et al.*, 2006**).

The continuous output of SDM is usually binarized to delineate suitable and unsuitable habitats used to quantify range changes over time (**Dimobé *et al.*, 2020; Lompo *et al.*, 2021; Balima *et al.*, 2022; Manda *et al.*, 2022**). Binarization makes easier the interpretation of the distribution maps and their usage in subsequent analysis (**Jamwel *et al.*, 2021; Manda *et al.*, 2022**). Thus, the maximum TSS threshold was used to distinguish suitable from unsuitable habitats. **Liu *et al.* (2013)** showed that this threshold is the most appropriate in the conservation study that use presence-only data. The areas of predicted habitat under current and future climate models were calculated using QGIS 3.16 in order to assess the extent of gain or loss in suitable area under the projected climate scenarios.

II.2.5.3. Vulnerability analysis across species

For assessing the climate change vulnerability of wild palms species, sensitivity and exposure were first estimated through the Climate Niche Factor Analysis (CNFA) framework. Sensitivity was quantified by the marginality, which reflects the niche centroid distance between the species habitats and the global range, and the specialization, which is the ratio of size of the global niche to that of the species niche. Exposure was quantified by a dissimilarity measure between historical climatic data and future climatic data within the species habitat. According to the CNFA framework, the sensitivity and exposure are estimated within the current habitat of the species (**Rinnan & Lawler, 2019**). Hence, the current suitable habitat generated by the Maxent model were used to spatially represent such current habitat (**Jamwal *et al.*, 2021**). Specifically, a vulnerability value for each binary map deriving from each scenario, global circulation model and time scale was estimated through the “*CENFA*” R package (**Rinnan & Lawler, 2019**). An ANOVA followed by a TukeyHSD post-hoc test was then applied to compare the vulnerability values among palm species.

CHAPTER III: RESULTS

III.1. Local uses, perceptions of dynamics and conservation practices of wild palms in Western Burkina Faso

III.1.1. Socio-cultural profile of the informants

The informants belonged to five different ethnic groups, with a dominance of Bobo and Turka (Table IX). They were on average 47 ± 15 years old. More than 61% of them were adults, whereas the young were the less represented (Table IX). All the informants were autochthons and most were illiterate (69.77%). Farming is the main activity they practiced.

III.1.2. Diversity of known palms species

The 258 informants cited seven different palm species. The number of palm species cited per informant varied significantly among ethnic groups ($\chi^2= 47.58$, $df= 4$, $p\text{-value} < 0.001$), gender ($\chi^2= 11.78$, $df= 1$, $p\text{-value} < 0.001$) and age categories ($\chi^2= 13.89$, $df= 2$, $p\text{-value} < 0.001$). The Gouin (3.62 ± 0.67), Siamou (3.42 ± 0.66) and Turka (3.31 ± 0.71) mentioned significantly higher number of palm species than Bobo (2.75 ± 0.72) and Senoufo (3.02 ± 1.02) (Figure 11A). Adult (3.20 ± 0.80) and old informants (3.26 ± 0.74) cited more species than younger ones (2.77 ± 0.85 ; Figure 11B). Men cited 3.27 ± 0.79 palm species while women informants mentioned 2.95 ± 0.81 palm species (Figure 11C). The ANOSIM shows that only ethnic groups modulated the palm knowledge among informants (Table X). *Borassus akeassii* and *Elaeis guinneensis* were cited by all the five ethnic groups while *Calamus deerratus* was only reported by Senoufo and Bobo ethnic groups (Figure 12).

Table IX: Socio-cultural profile of the informants

Factors	Modalities	Number of informants	Proportion (%)
Ethnic group	Bobo	91	35.27
	Senoufo	33	12.79
	Siamou	33	12.79
	Gouin	40	15.50
	Turka	61	23.64
Gender	Men	150	58.14
	Women	108	41.86
Age categories	Young (18-30 years)	43	16.66
	Adult (30-60 years)	158	61.24
	Old (> 60 years)	57	22.09

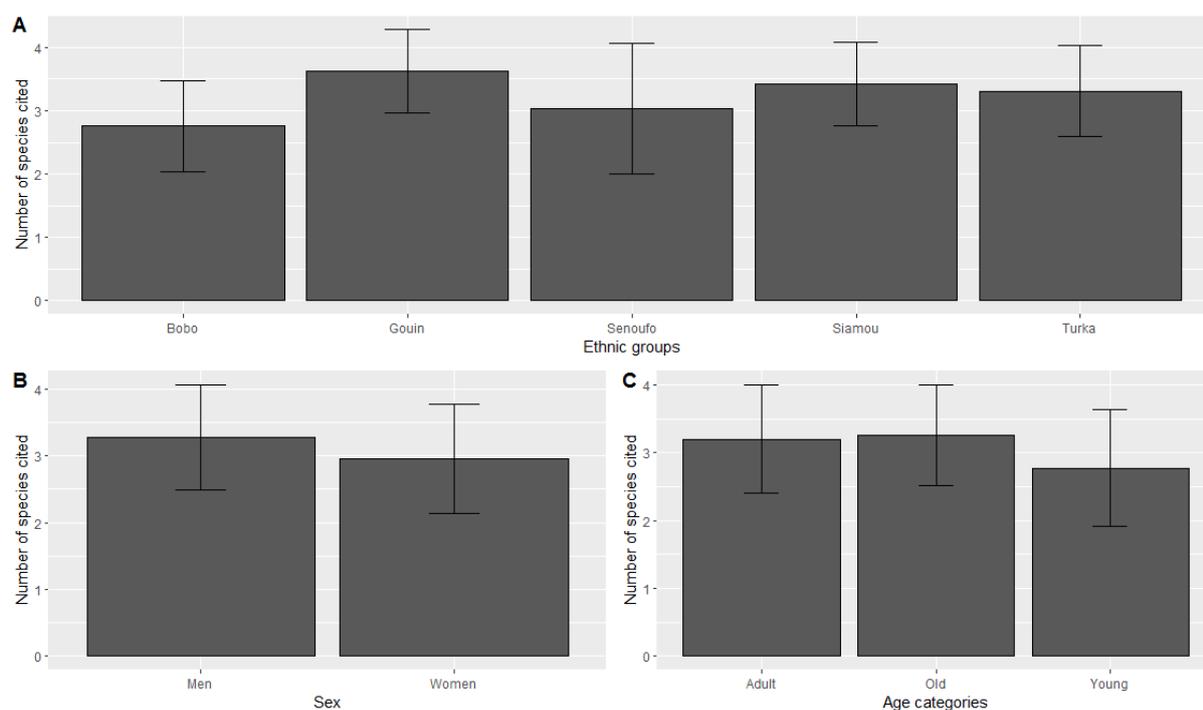


Figure 11: Distribution of the number of palm species cited by local people according to ethnic groups (A), gender (B) and age categories (C)

Each bar represents the mean number of palm species cited in the category and the scatter indicated the standard deviation.

Table X: Results of the analysis of similitude of the palms according to socio-cultural factors

Factors	R	p-value
Ethnic group	0.286	0.001
Gender	0.004	0.299
Age	0.018	0.168

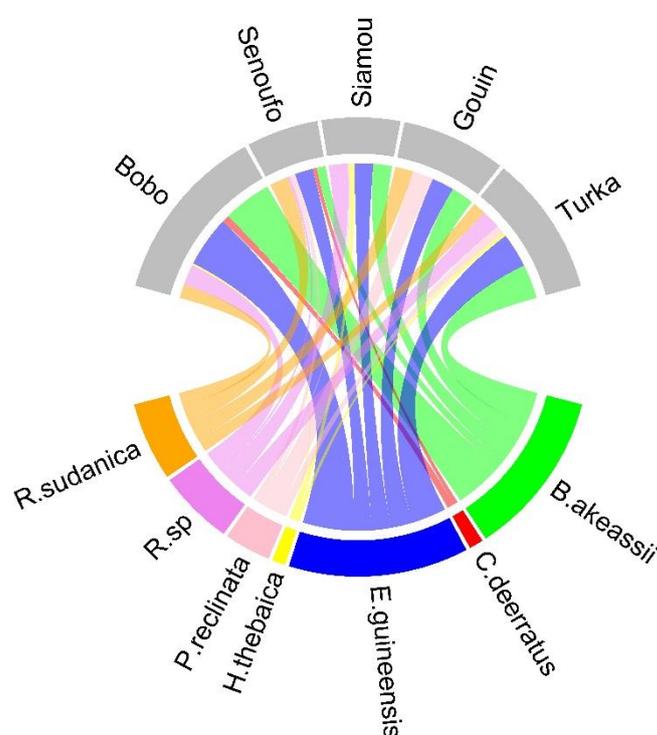


Figure 12: Association between ethnic groups and palm species cited by the informants in Western Burkina Faso

The diagram shows the five socio-linguistic groups (top half) related to each of the seven palms species (bottom half). Each coloured line joining a specific ethnic group and a palm species represents one citation.

III.1.3. Uses diversity of palms

In general, *Elaeis guineensis*, *Borassus akeassii*, *Raphia sudanica* and *Raphia sp.* were the most cited palms while *Calamus deerratus* and *Hyphaene thebaica* were the less cited ones. *Raphia sp.* is a specimen of *Raphia* genus that can be apparently distinguished from *Raphia sudanica* and both are called by different local names (Table XII). Both *Raphia* specimen may represent distinct taxa and thus treated as different species in this thesis. The unknown species is thus referred to as *Raphia sp.* until a taxonomic treatment of the genus in Burkina Faso become available. The use-values varied significantly among species ($p < 0.05$) with *Borassus akeassii* (UV=6.77) and *Elaeis guineensis* (UV=3.90) holding the highest values (Table XI). The use consensus value was low for all species except for *Borassus akeassii* and *Elaeis guineensis* (Table XI). There was a positive correlation between the importance of palms (use value, use diversity value and use consensus value) and the diversity of informants (relative frequency of citation, informant diversity value) (Figure 13). More uses were found for palms that were regarded as important. The influence of socio-cultural factors on the use value depended on the considered palm species (Table XIII). Ethnic group influenced the use-value of *Borassus akeassii*, *Elaeis guineensis*, *Raphia sp.* and *Raphia sudanica*. Age had a significant influence on the use-value of *Borassus akeassii* and *Calamus deeratus* while gender influenced *Phoenix reclinata* and *Raphia sudanica* use values (Table XIII).

The informants reported the usefulness of 10 different palms parts. The fruits (40.65%), leaves (29.32%), sap (11.85%) and stipe (9.95%) were the most cited used parts of palms, while hypocotyl (0.28%) and fiber (0.02%) were the less cited ones (Figure 14B). These parts were used in 10 different use categories. Food (32.46%), handicrafts (14.62%), trade (13.63%) and building (12.30%) were the most reported use category whereas culture, rites (1.16%) and fodder (0.34%) were the less reported one (Figure 14A).

Table XI: Quantitative measures of uses and importance of wild palms

Species	Use-value	Informants diversity value	Use diversity value	Relative frequency of citation	Use consensus value
<i>Borassus akeassii</i>	6.768	201.910	5.495	90.310	0.806
<i>Calamus deerratus</i>	1.105	17.64	1.218	10.465	-0.791
<i>Elaeis guineensis</i>	3.898	212.755	2.902	99.225	0.984
<i>Hyphaene thebaica</i>	1.210	16.030	2.580	4.263	-0.915
<i>Phoenix reclinata</i>	1.6	49.021	3.744	23.256	-0.535
<i>Raphia sp</i>	3.775	58.110	4.565	43.023	-0.139
<i>Raphia sudanica</i>	2.896	98.952	4.933	41.473	-0.171

Table XII: Local names, growth habit and local conservation status of wild palms species cited by informants in Western Burkina Faso

Scientific names	Threats status*	Growth Habit	local names				
			Bobo	Siamou	Turka	Gouin	Senoufo
<i>Borassus akeassii</i>	LC	Tree	<i>Pre</i>	<i>kpefing</i>	<i>Koore</i>	<i>Koun-here</i>	<i>Yatchin</i>
<i>Calamus deerratus</i>	EN	Liana	<i>chiampre</i>	-	-	-	<i>Gosso</i>
<i>Elaeis guineensis</i>	LC	Tree	<i>Tinini</i>	<i>Sinfing</i>	<i>Kanle</i>	<i>kakanle</i>	<i>Siatchin</i>
<i>Hyphaene thebaica</i>	LC	Tree	-	<i>Kankpeni</i>	<i>Dounou kore</i>		
<i>Phoenix reclinata</i>	LC	Tree			<i>Hihiri</i>	<i>namproug</i>	<i>Veguetchin</i>
<i>Raphia sudanica</i>	NE	Tree	<i>Bagolchio</i>	<i>Dje</i>	<i>Kalgora</i>	<i>Kantienga</i>	<i>Bangnan</i>
<i>Raphia sp.</i>	NE	Acaulescent	<i>Binchio</i>	<i>Mel</i>	<i>Kalgora</i>	<i>Kantienga</i>	<i>Yienna</i>

*The threat status was based on *Schmidt et al., (2017)* in Burkina Faso

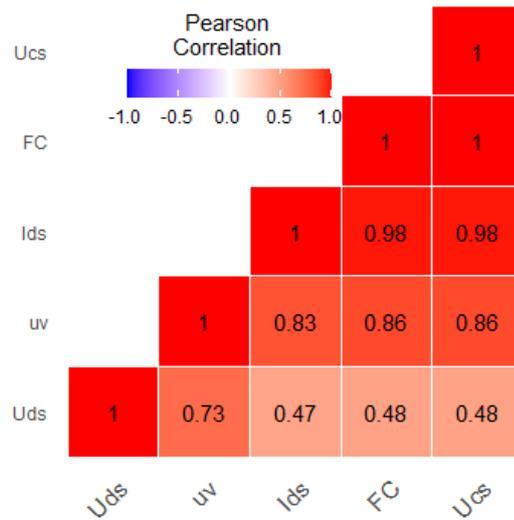


Figure 13: Pearson correlation among ethnobotanical indices

Uds= Use diversity value, uv= Use value, Ids= Informants diversity value, FC= Relative frequency of citation, Ucs= Use consensus value

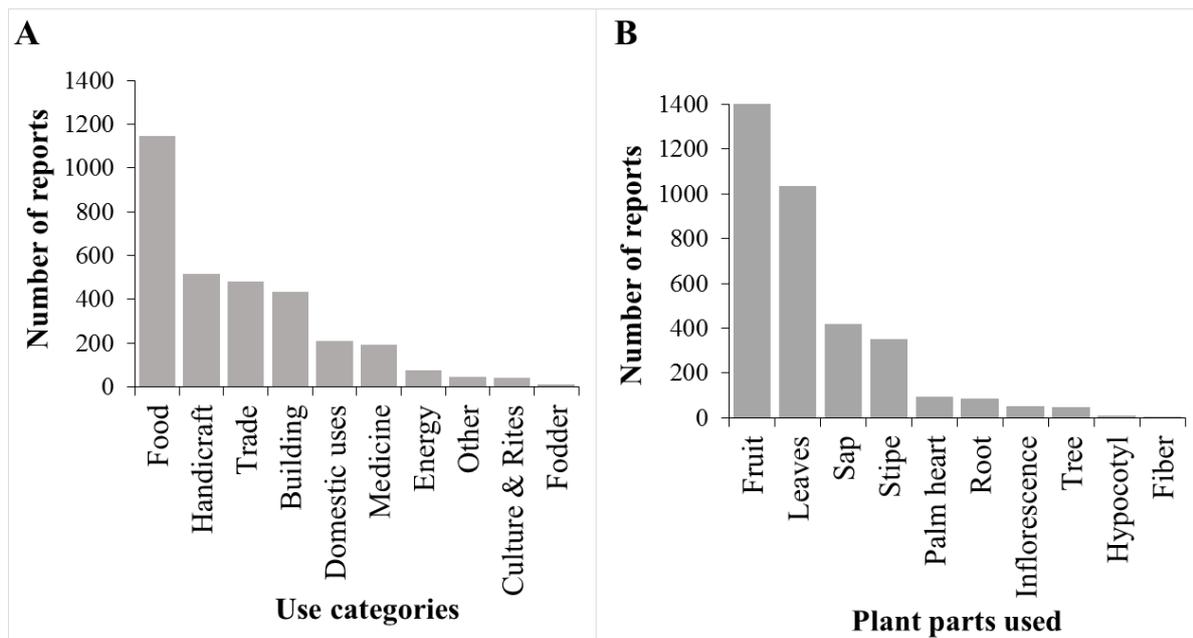


Figure 14: Number of reports of different use categories (A) and different parts used (B) of wild palms in Western Burkina Faso

Table XIII: Variation of the use values of each palm species according to socio-cultural factors

Factors		<i>Borassus akeassii</i>	<i>Calamus deerratus</i>	<i>Elaeis guineensis</i>	<i>Hyphaene thebaica</i>	<i>Phoenix reclinata</i>	<i>Raphia sp.</i>	<i>Raphia sudanica</i>
	Bobo	6.13	1	3.18	1.66		-	2.29
	Senoufo	4.56	1.28	4.46		2	2	4.28
Ethnic groups	Siamou	6.69		4.93	1.11		4.27	-
	Gouin	7.77		3.13		1.61		2.29
	Turka	7.59		4.57	1.14	1.5	3.54	3.95
	p-value	1.595e-05	0.056	2.496e-09	0.564	0.645	0.0237	3.993e-09
Gender	Men	6.76	1.13	3.92	1.37	1.77	3.84	3.28
	Women	6.77	1	3.87	1.09	1.25	3.66	2.44
	p-value	0.9304	0.5286	0.7909	0.3291	0.01414	0.6305	0.004634
Age	Young	6.07	1.33	3.66	1	1	2.5	2.95
	Adult	7.13	1.05	3.87	1.25	1.52	3.8	2.68
	Old	6.25	1.14	4.12	1.33	1.85	4.2	3.62
	p-value	0.02967	0.01317	0.6267	0.5353	0.1966	0.1315	0.0671

p-value in bold are regarded as significant (*p*-value < 0.05)

III.1.4. Perceptions of dynamics of palms

The local perceptions of dynamics depended on the considered palms species (Fisher exact test, p-value= 0.0004998; Figure 15). Indeed, the majority of informants reported the decline of *Hyphaene thebaica*, *Phoenix reclinata*, *Raphia sudanica* and *Raphia sp.* while the majority of informants reported an increase for *Calamus deerratus* in the study area (Figure 15). The declining causes were mainly due to human pressure (harvesting, urbanization and agriculture) and natural one (drought, wind and pests). Agriculture was cited for all palm species except *Calamus deerratus* while animal pressure was revealed only for *Raphia sudanica* and *Elaeis guineensis* (Figure 16).

III.1.5. Local conservation practices of wild palm species

Four palm species (*Borassus akeassii*, *Elaeis guineensis*, *Raphia sudanica* and *Raphia sp.*) benefit for conservation care by local people. *Borassus akeassii* and *Elaeis guineensis* were the species that mostly benefited for conservation care while no conservation action was reported for *Phoenix reclinata* and *Calamus deerratus* (Figure 17). In general, and independently of species, natural assisted regeneration and plantation were the conservation actions adopted by local people to locally conserve the palms species. However, no conservation action was highly reported by the majority of informants (63.79%). The remaining informants adopted plant fencing (7.98%), plantation (22.96%) and natural assisted regeneration (5.27%) as conservation practices.

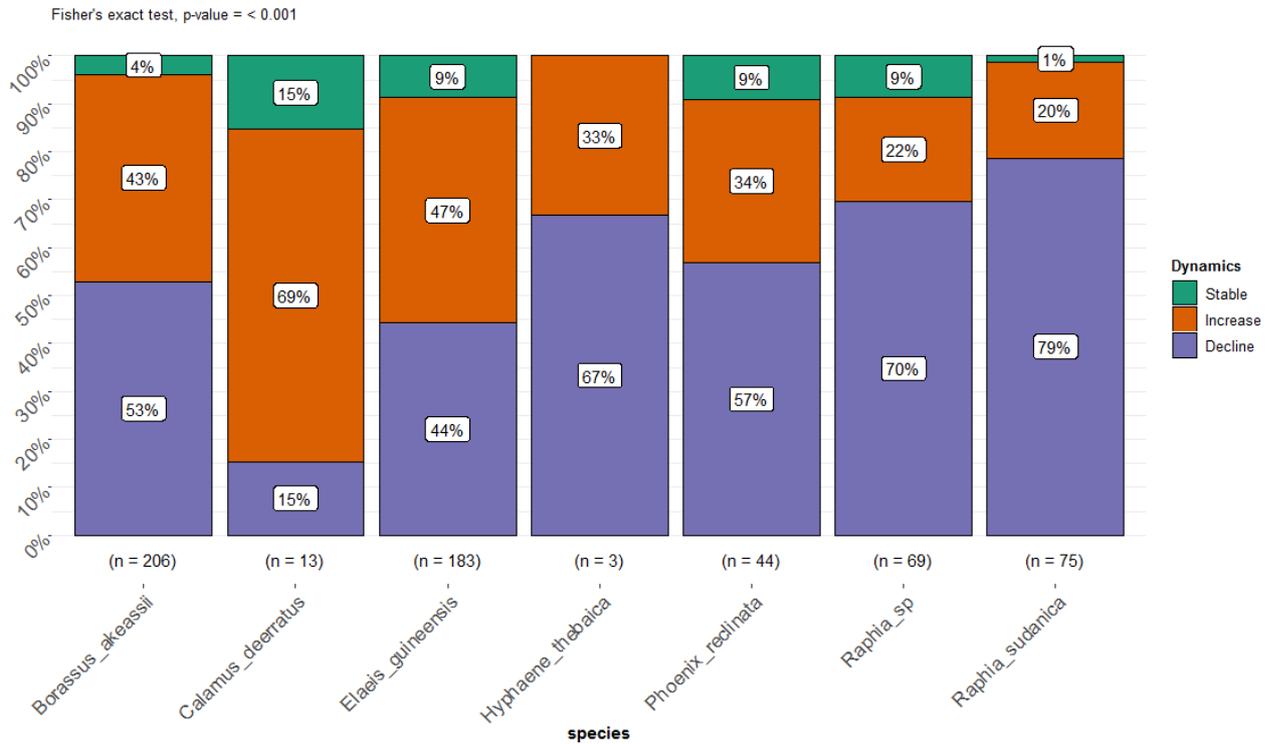


Figure 15: Local perception of the dynamics of wild palms in Western Burkina Faso

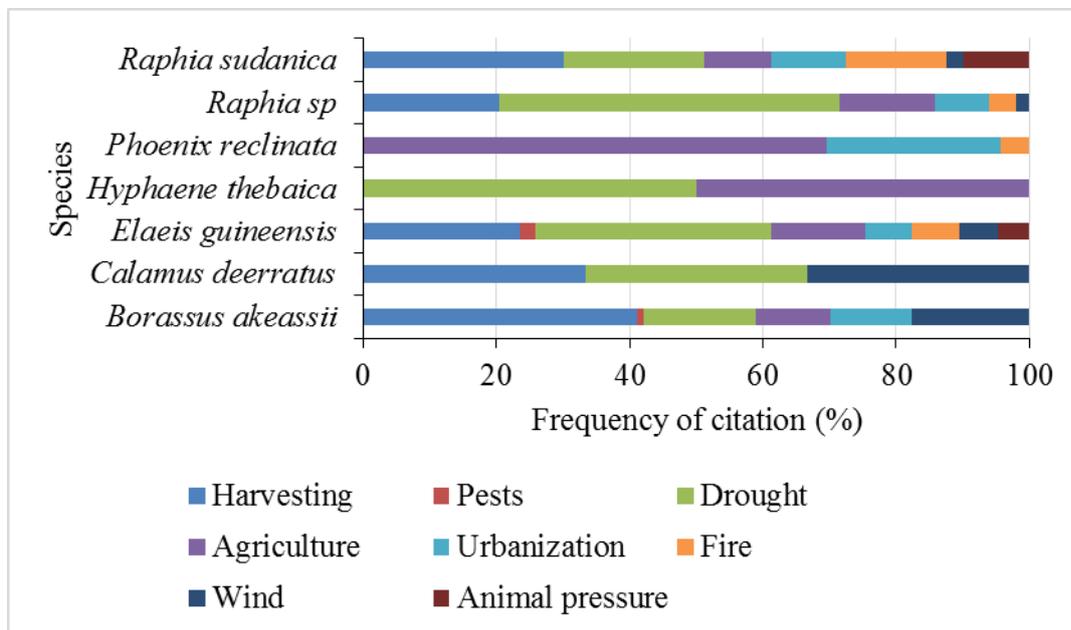


Figure 16: Factors determining the decline of wild palms as reported by local people in Western Burkina Faso

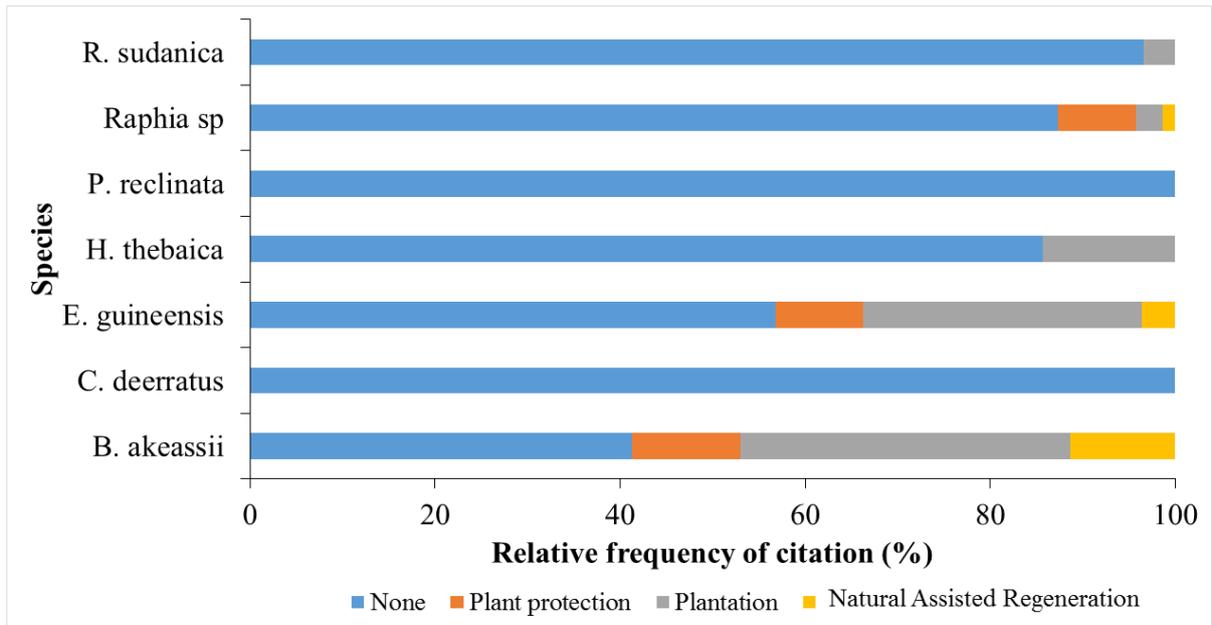


Figure 17: Conservation practices used by local people for wild palms in Western Burkina Faso

III.2. Population structure, habitat diversity and regeneration mechanisms of wild palms

III.2.1. Characterisation of the wild palm's habitats

Data on habitat characteristics showed that the wild palm species established their populations in various environmental conditions depending on the considered species. For instance, *Borassus akeassii* was well established in uplands while *Phoenix reclinata* occurred mostly in lowlands conditions (Table XIV). Concerning the vegetation type, *Borassus akeassii* was found on farmlands and *Elaeis guineensis* and *Raphia spp.* were mostly encountered in gallery forests (Table XIV).

III.2.2. Population structures of wild palms

The densities of populations varied among life stages with a clear predominance of seedlings for *Borassus akeassii* and *Elaeis guineensis* in contrast to *Phoenix reclinata* and *Raphia spp.* populations where the juvenile stage was more dominant (Figure 18). Indeed, the seedlings represented 59.24 % and 85.32% of the *Borassus akeassii* and *Elaeis guineensis* populations respectively.

The rate of exploited trees was high for *Borassus akeassii* (51%) and *Raphia spp.* (77%) while the mortality ratios were low in general for all species (Table XV). The sex ratio of *Borassus akeassii* and *Phoenix reclinata* were male-biased (p -value=0.0005).

Moreover, the Simpson index of dominance (S) was above 0.1 and the permutation index (P) was above zero for all the assessed populations (Table XV). The quotients between consecutive life stages of palms populations examined here were not constant, but fluctuating between consecutive life stages (Figure 19).

Table XIV: Habitat characterization (%) of wild palm species in Western Burkina Faso

Factors	Modalities	<i>Borassus akeassii</i>	<i>Elaeis guineensis</i>	<i>Phoenix reclinata</i>	<i>Raphia spp.</i>
Topography	lowland	0	37.93	93.33	13.79
	Upland	100	58.62	6.67	86.21
Soil	Lateritic	0	6.90	0	3.44
	Loamy	10	79.31	36.67	55.17
	Clayey	13.33	0	56.67	6.90
	Sandy	70	10.34	6.67	20.69
	Gravelly	6.67	0	0	0
Vegetation type	Farmlands	100	3.45	20.00	0
	Galery forests	0	79.31	16.67	86.21
	Savannas	0	13.79	40.00	13.79
	woodlands	0	0	20.00	0

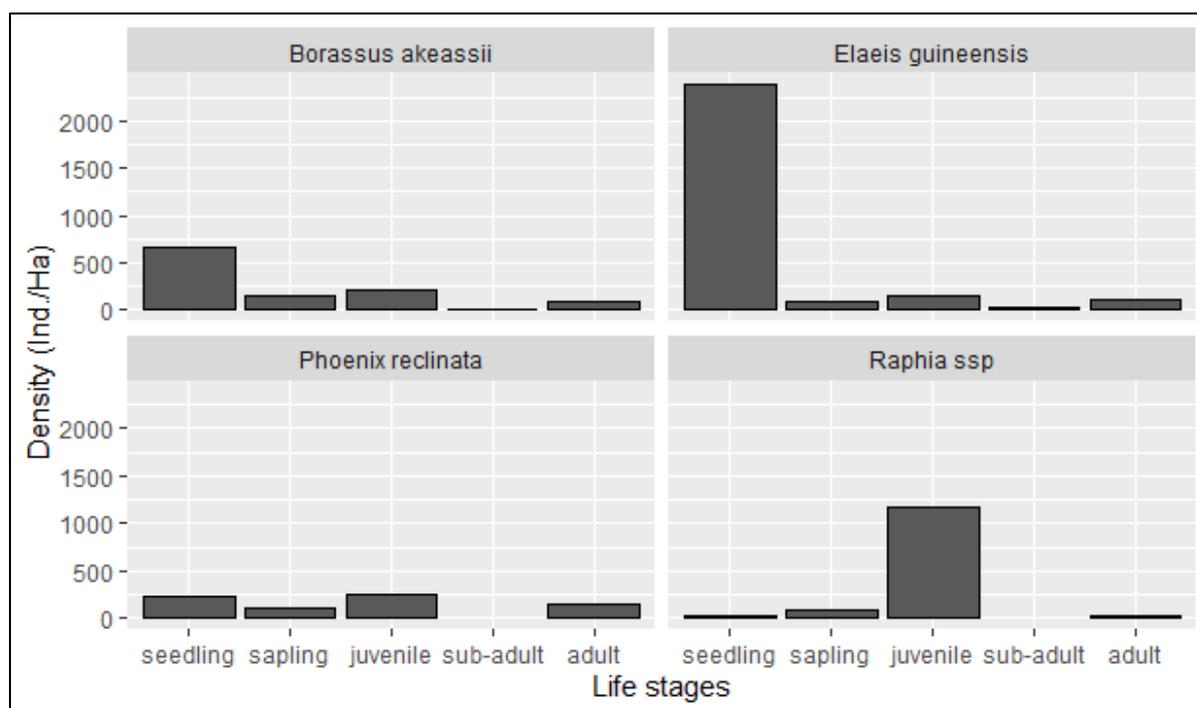


Figure 18: Life stage profiles of palm species in Western Burkina

Table XV: Demographic and structural parameters of wild palm species in Western Burkina Faso

Parameters	<i>Borassus akeassii</i>	<i>Elaeis guineensis</i>	<i>Phoenix reclinata</i>	<i>Raphia spp</i>
Densities (mean±sd)	1105.33 ± 797.41	2786.33±1907.93	720.00±418.21	1301.03±440.42
Sex-ratio	0.42		0.46	
Regeneration ratio	15.95	20.54	2.33	3.48
Mortality ratio	0.13	0.05	0.14	0.01
Simpson index	0.41	0,73	0,27	0,81
Permutation index	4	6	6	6

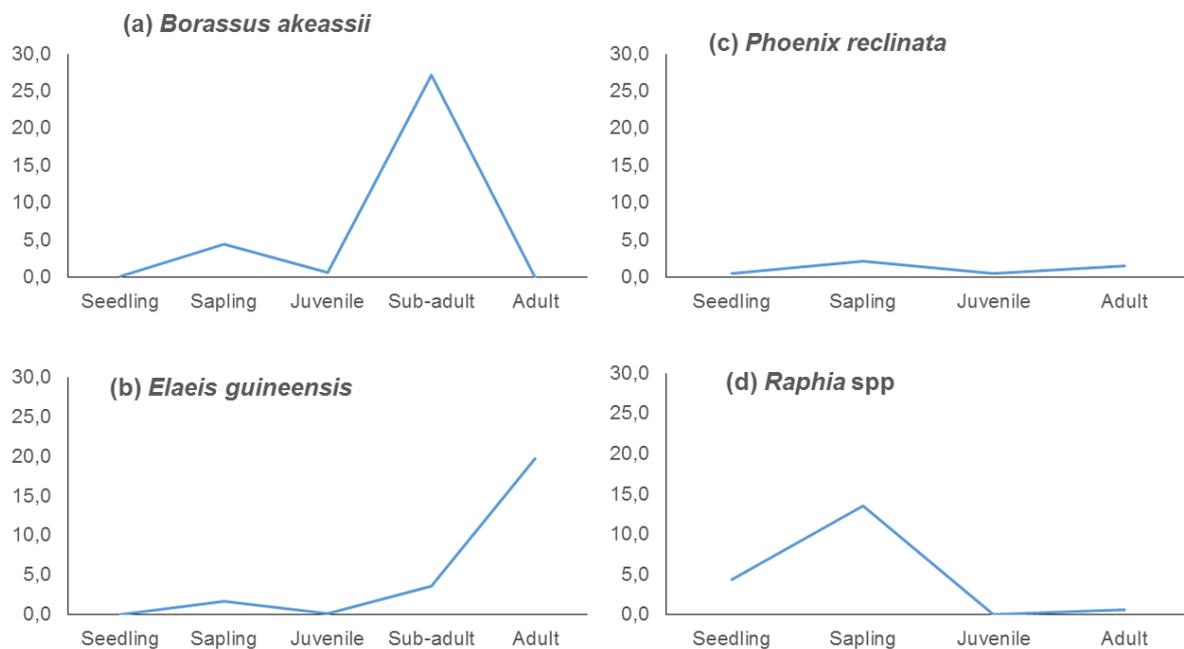


Figure 19: Quotient between successive life stages of wild palms in Western Burkina Faso

III.2.3. Trees co-occurring in wild palms

The habitat of *Borassus akeassii* held 30 woody species belonging to 26 genera and 15 Family. The rank-frequency diagram showed that, *Vitellaria paradoxa* and *Parkia biglobosa* were the dominant woody species (Figure 20). Ninety-seven woody species belonging to 67 genera and 26 families were associated with *Elaeis guineensis*. The rank-frequency diagram showed that *Khaya senegalensis*, *Carapa procera* and *Vitex doniana* were the most frequent woody species in *Elaeis guineensis* stands (Figure 20). Sixty-three woody species belonging to 44 genera and 20 families were found in the habitat of *Phoenix reclinata*. *Lannea velutina*, *Ficus sur*, *Diospyros mespiliformis*, *Terminalia schimperi*, *Mitragyna inermis*, *Sarcocephalus latifolius* and *Vachellia seyal* were the most frequent species in *Phoenix reclinata* stands (Figure 20). Seventy-three woody species belonging to 56 genera and 22 families were associated to *Raphia* spp. *Syzygium guineense*, *Ficus sur*, *Carapa procera* and *Sarcocephalus latifolius* were the most frequent species in *Raphia* spp. stands (Figure 20).

The co-occurring species per plot varied according to the palm stands (Table XVI). Indeed, the diversity values expressed by the species richness and the Shannon index were significantly lower in *Borassus akeassii* stands compared to the other palms stands (Table XVI).

III.2.4. Regeneration mechanisms of wild palms

Wild palms in general regenerated by seeds. All juveniles of *Borassus akeassii*, *Elaeis guineensis* and *Raphia* spp. came from seeds germination. Table XVII showed that vegetative regeneration mechanisms was observed only for *Phoenix reclinata* in Western Burkina Faso. Indeed, 65% of young individuals of *Phoenix reclinata* came from tillering (Table XVII).

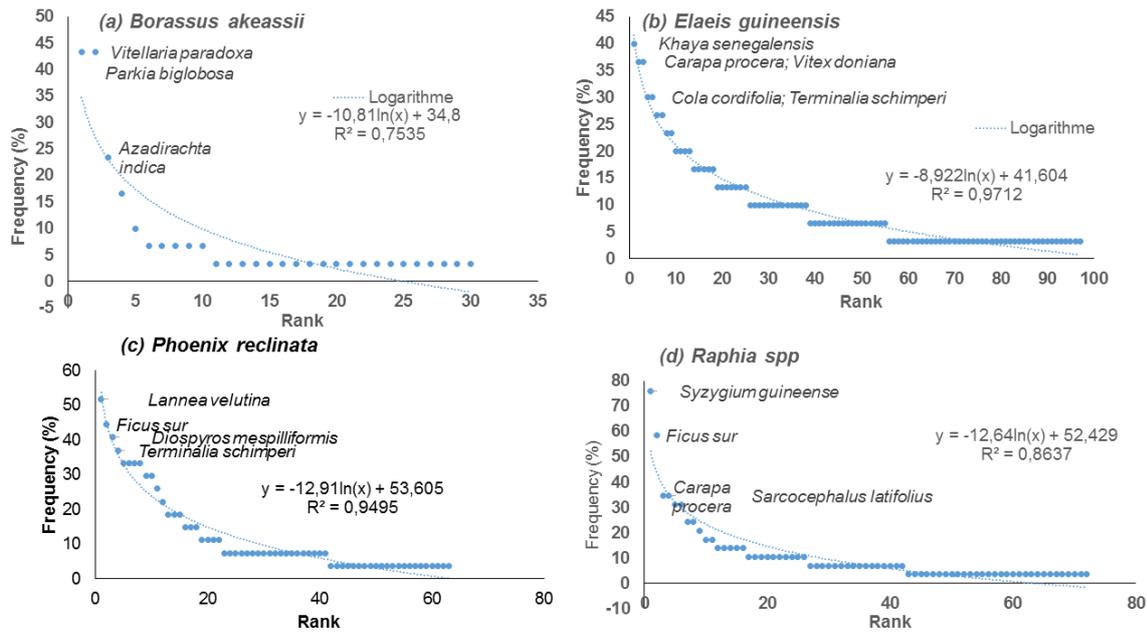


Figure 20: Frequency-rank diagrams of co-occurring species with palms in Western Burkina Faso

Table XVI: Variation of co-occurring trees with palms in Western Burkina Faso

Stands	Number of species	Shannon index	Evenness	Number of individuals	Mean diameter
<i>Borassus akeassii</i>	3.35 ± 1.95 b	0.87 ± 0.56 b	0.82 ± 0.15	9.20 ± 7.03 b	27.22 ± 16.70
<i>Elaeis guineensis</i>	9.45 ± 6.30 a	1.79 ± 0.74 a	0.93 ± 0.34	19.72 ± 13.02 a	23.25 ± 6.69
<i>Phoenix reclinata</i>	7.81 ± 5.40 a	1.62 ± 0.86 a	0.94 ± 0.05	14.04 ± 11.77 a	28.13 ± 20.20
<i>Raphia spp.</i>	7.55 ± 4.33 a	1.65 ± 0.48 a	0.89 ± 0.10	14.83 ± 7.86 a	23.14 ± 7.11
<i>p-value</i>	0.000653	0.0001346	0.06426	0.0001282	0.9922

Table XVII: Variation of co-occurring trees with palms in Western Burkina Faso

Species	True seedlings (%)	Tillers (%)
<i>Borassus akeassii</i>	100	0
<i>Elaeis guineensis</i>	100	0
<i>Phoenix reclinata</i>	33.26	65.87
<i>Raphia spp.</i>	100	0

III.3. Morphological variation in the genus *Raphia* P.Beauv.

III.3.1. Hierarchical clustering

Groups of similar individuals were clustered in three clusters, underlining the power of multivariate analyses with quantitative and qualitative morphological characters in the genus *Raphia* (Figure 21). Multivariate analysis of variance showed significant differences between the groups (p -value < 0.001) sustaining the quality of the clustering. Cluster 1 had 30 individuals, while cluster 2 and cluster 3 had 18 and 12 respectively. Post hoc Tukey test and qualitative variables allow many characters to differentiate cluster 1 from cluster 2 and cluster 3. The application of the morphological species concept suggested that cluster 1 might belong to the same species that is different from the species representing cluster 2 and cluster 3. Indeed, despite the consistency of cluster 2 and cluster 3, few characteristics are exclusive to them (Tables XVIII; XIX).

III.3.2. Taxonomy treatment

Raphia P. Beauv.

Palm tree or acaulescent; monoic, hapaxanthic, pinnate leaves, leaflets reduplicate with spines.

Keys to the species of *Raphia*

1 Stem present, Petiole absent or very short and robust (0.5—1.4 cm long); basal leaflets densely inserted on rachis, spines dense..... *Raphia sudanica* A. Chev.

1' Stemless, Petiole thin and long rounded (up to 200 cm long), basal leaflets sparsely inserted on the rachis, spine sparse..... *Raphia* sp.

***Raphia sudanica* A. Chev**

Synonyms: *Raphia humilis* A. Chev., *Raphia badamensis* A. Chev., *Raphia heberostris* Becc.

Tall and massive palm, Stem up to 5 m, (— rarely acaulescent). Petiole present or absent, if present, 2—32 cm long; and 44 — 101 mm width. Rachis: 388 — 773 cm length, unarmed and rounded abaxially while canaliculated adaxially with four rank of spines. Leaflets: 83 — 169 each side, reduplicate linear-lanceolate, basal leaflets: 21 — 95 cm of length and 0.20 — 1.80 cm width, inserted each 1-3 cm. Median leaflet: 84 — 167 cm length and 2.90 — 6 cm width. Apical leaflet: 13.80 — 55 cm length and 0.40 — 1.30 cm width.

Distribution: —localities visited: Toussiana (Comoé, Cascades Region), Niofila (Léraba, Cascades Region), Kartasso (Kéné Dougou, Hauts Bassins Region).

Habitats: Sudanian savannas, gallery forests, savanna near streams and rivers.

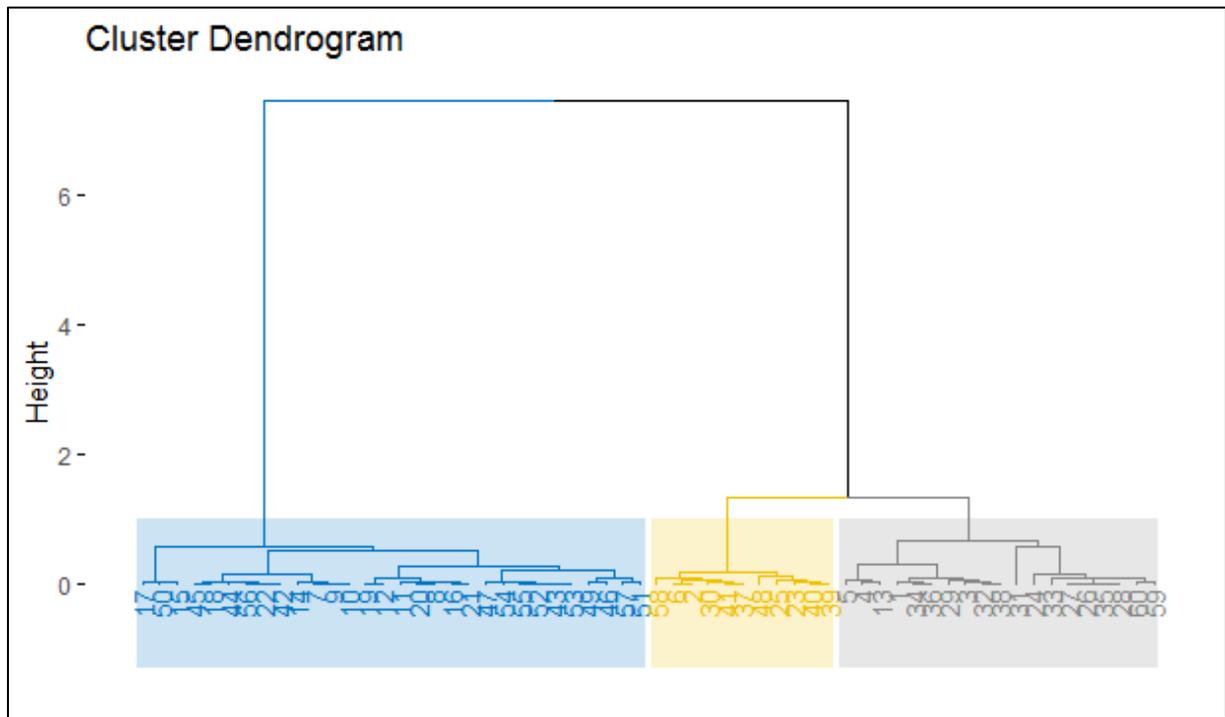


Figure 21: Hierarchical cluster diagram of Raphia individuals

Table XVIII: Comparison of quantitative characters among the identified clusters.

All measurements are in mm (mean \pm SD, with minimum-maximum values in brackets). Means with different superscript letters (a–c) within each variable significantly differ (Tukey's test, p -value < 0.05).

variables	Cluster 1	Cluster 2	Cluster 3	p -value
Stem height	0.03b (0 - 0.5)	2.30a (0 – 4)	2.45a (1.30 – 4.5)	$< 2.2e-16$
Petiole length	86.99a (21 - 242)	12.14b (2 – 32)	-	1.872e-09
Section of the petiole	33.42a (21.30 – 52.30)	72.09b (44.85 – 101)	-	$< 2.2e-16$
Rachis length	469.9 (242 – 620)	541.2 (388 – 773)	530.5 (400 - 730.0)	0.04295
Leaflets space index	0.956a (0.755 - 1.224)	0.557ab (0.175 - 0.871)	0.318b (0.006 - 0.526)	0.03048
Number of leaflets	87.63a (56 – 123)	135.6b (83 – 169)	137.9b (118 – 164)	4.399e-13
Basal leaflet length	61.35a (13 – 165)	56.72a (21 – 95)	58.12a (30.50 - 86.00)	0.8595
Basal leaflet width	0.56a (0.10 – 1)	0.96b (0.20 – 1.80)	0.68ab (0.40 - 1.20)	0.001336
Median leaflet length	107.5a (73 – 161)	123.9b (96 – 167)	134.8b (84.5 – 157)	0.000198
Median leaflet width	3.04a (2 - 4.20)	4.03b (3.10 - 5.00)	4.20b (2.90 - 6.00)	2.234e-09
Apical leaflet length	17.54a (11.40 – 26)	24.42b (13.80 - 44.20)	32.83c (15 – 55)	6.029e-07
Apical leaflet width	0.66a (0.40 - 1.60)	0.76a (0.40 - 1.30)	0.80a (0.40 - 1.30)	0.2765

Table XIX: Comparison of qualitative characters among the clusters

Variable	Cluster 1	Cluster 2	Cluster 3
Presence of stipe	no	yes	yes
Presence of petiole	yes	yes	no
Petiole spinescence	no	yes	
Petiole shape	rounded	canaculated	
Density of spine	sparse	dense	dense



Figure 22: *Raphia sudanica* A. Chev in Western Burkina Faso

A) Habitus notice a stem bearing leaves with very short or no petiole, B) Portion of the leaf showing dense spines; C) Base of Rachis showing the densely inserted leaflets with highly dense spines.

Vernacular names: *Djê* (Siamou), *Bangolchio* (Bobo), *Katchinga* (Gouin), *Bangnan* (Senufo), *Ban* (Dioula).

Conservation: *Raphia sudanica* is classified as Near Threatened according to the IUCN criteria (Cosiaux et al., 2018). However, our observation in the wild populations of the species in Western Burkina Faso indicate that the species is vulnerable due to the overexploitation of its rachis and fruits for diverse usages coupled to the lack of regeneration.

Raphia sp.

Diagnosis: - Distinguished by the stemless habit, long and thin petiole and sparse spines.

Small, stemless (— rarely present, if present < 50 cm). Leaves coming directly from the ground (Figure 3A). Petiole: always present and long, 21 — 242 cm length and 21 — 52 mm width. Rachis: 242 — 620 cm length, unarmed and rounded both abaxially and adaxially. Leaflets: 56 — 123 each side, reduplicate and linear lanceolate; basal leaflet: 13 — 165 cm length and ≤1 cm width, inserted each 5-12 cm (Figure 23C). Median leaflet: 73 — 161 cm length and 2— 4.20 cm width. Apical leaflet: 11.40 — 26 cm length and 0.40 — 1.60 cm width.

Distribution: — the species occurred in the sudanian climatic zone. Localities visited: Toussiana (Comoé, Cascades Region), Niofila (Léraba, Cascades Region), Kartasso (Kéné Dougou, Hauts Bassins Region).

Habitats : Sudanian savannas. *Raphia sp.* is known to grow in open habitats, along streams and most of times in monodominant stands as also observed for *Raphia vinifera* in Cameroun (Mogue Kamga et al., 2019).

Vernacular names: *Mel* (Siamou), *Binchio* (Bobo), *Katchinga* (Gouin), *Yienan* (Senufo), *Ban* (Dioula).

Conservation: *Raphia sp.* is highly exploited for the rachis by local people in Western Burkina Faso. In addition, the lack of regeneration make the species vulnerable at the local scale.

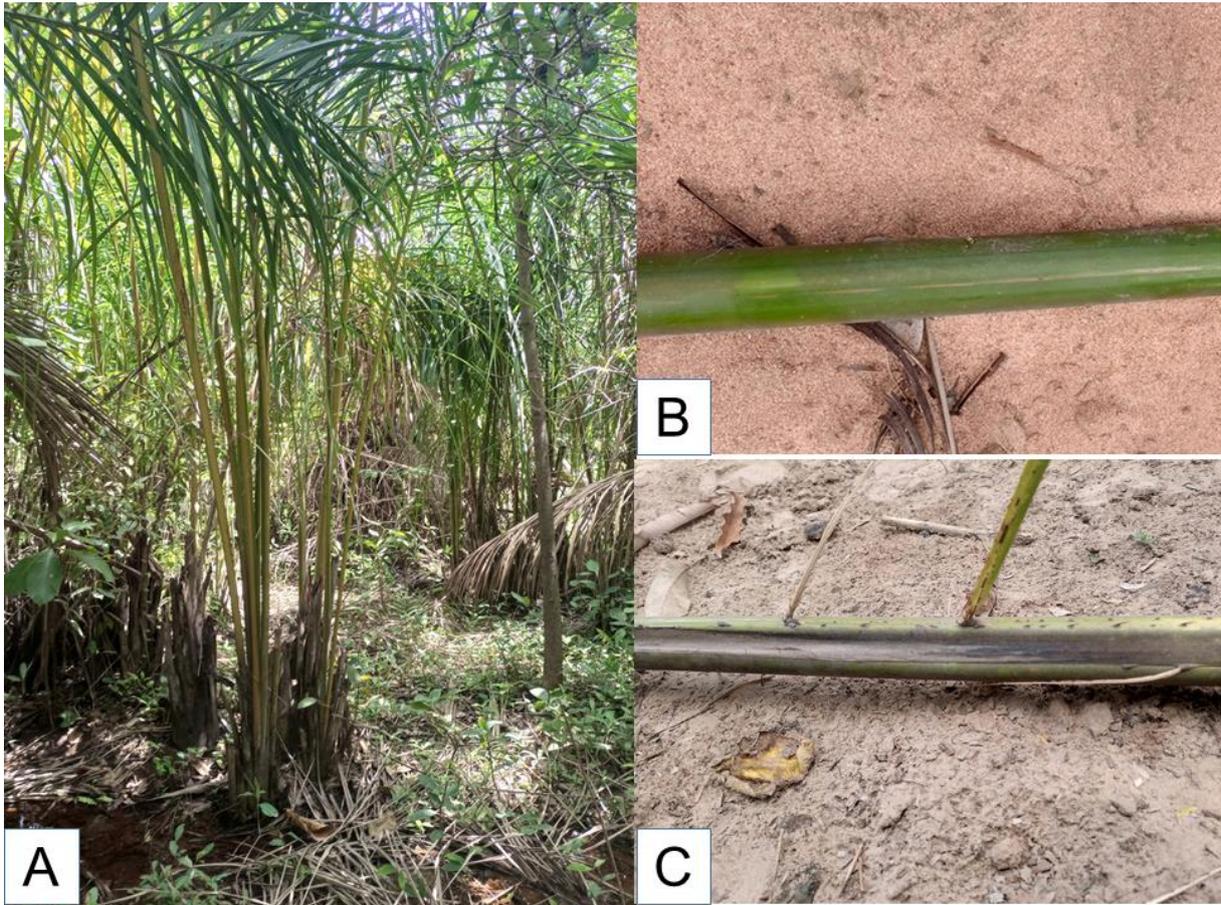


Figure 23: *Raphia sp.* in Western Burkina Faso.

A) Habitus, notice a long petiole of the leaves coming directly from the ground. B) Portion of petiole showing a rounded unarmed. C) basal portion of the leaf showing the spacing between two leaflets.

III.5. Wild palms vulnerability to climate change

III.5.1. Accuracy, performance and key predictors of wild palms models

The evaluation metrics (AUC, TSS and BCI) showed variable accuracy of the individual models of palm species built in Burkina Faso (Table XIX). The TSS and the AUC indicated that all models were highly accurate and the positive BCI showed the good accuracy of all models to predict the occurrence of wild palms in Burkina Faso (Table XIX). Hence, the models were considered accurate to predict the distribution of wild palm species in Burkina Faso.

Eight (8) variables were included in all the models (Table XX). The wild palms models included two variables related to temperature (Bio 3 and Bio 9), four variables related to precipitation (Bio14, Bio17, Bio 18 and Bio 19), one soil variable (silt content at 0-5 cm depth) and one topographic variable (TPI). Bio 3 and Bio14 were determinant in all the models of wild palm species while Bio9 (Mean Temperature of Driest Quarter) was important only for *Elaeis guineensis* and silt content for *Borassus akeassii* (Table XX). The TPI was determinant for *Phoenix reclinata* and *Raphia* models (Table XX). Furthermore, the variable Bio3 (Isothermality) had the highest gain of all variables when fitted in isolation in *Borassus akeassii* model (Figure 24 A), while the Bio19 (Precipitation of Coldest Quarter) had the highest gain in *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica* models (Figure 24 B,C and D). This indicates that the omission of these variables decreased considerably the gain and shows that they possessed the most important information that were not present in other variables.

III.5.2. Suitable habitat distribution of wild palms under current and future climatic conditions in Burkina Faso

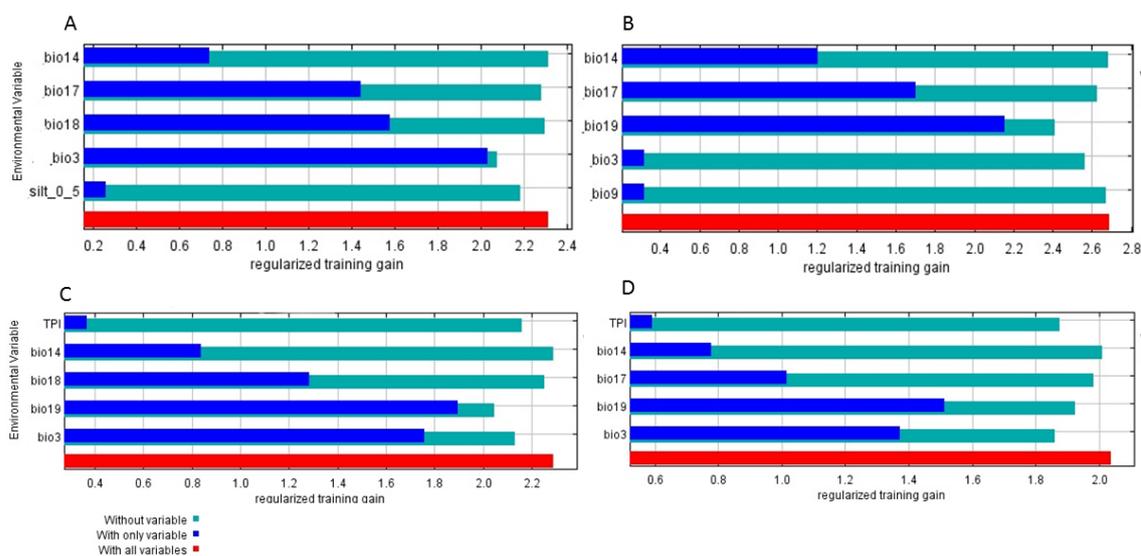
The SDM results varied according to palm species, global climate models (GCM) and scenarios. Currently, the suitable habitats occurred for all the species in the Sudanian climatic zone, especially in Western Burkina Faso (Figures 25, 26, 27 and 28). Under current climatic conditions, almost 85 -88 % of the country was unsuitable for palms species, while the suitable areas covered 11% (accounting for 31137.88 km²), 14% (accounting for 39233.84 km²), 13% (accounting for 36401.95 km²) and 15% (accounting for 41987.78 km²) respectively for *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica*. Thus, *Raphia sudanica* occupied the greatest extent while *Borassus akeassii* occupied the smaller potential distribution.

Table XX: Evaluation metrics of individual model

Species	AUC	TSS	BCI
<i>Borassus akeassii</i>	0.927 ± 0.066	0.811 ± 0.165	0.222 ± 0.083
<i>Elaeis guineensis</i>	0.976±0.009	0.894 ± 0.037	0.677 ± 0.123
<i>Phoenix reclinata</i>	0.946 ± 0.031	0.862± 0.091	0.357 ± 0.093
<i>Raphia sudanica</i>	0.939 ± 0.046	0.842 ± 0.125	0.831 ± 0.062

Table XXI: Variables contribution (%) in the models of wild palms in Burkina Faso

Variables		<i>Borassus akeassii</i>	<i>Elaeis guinnensis</i>	<i>Phoenix reclinata</i>	<i>Raphia sudanica</i>
Temperature variables	Bio 3	72.5	7.7	52.8	46
	Bio9	-	5.1	-	-
Precipitation variables	Bio14	7.6	11.6	12.5	17.7
	Bio17	7.6	10.2	-	2.9
	Bio18	7.3	-	3.6	-
Soil variable	Bio19	-	65.3	27.4	24.7
	Silt_0-5	4.9	-	-	-
Topography variable	TPI	-	-	3.6	8.7

**Figure 24:** Jackknife test of individual palms models in Burkina Faso;A) *Borassus akeassii*, B) *Elaeis guineensis*, C) *Phoenix reclinata* and D) *Raphia sudanica*

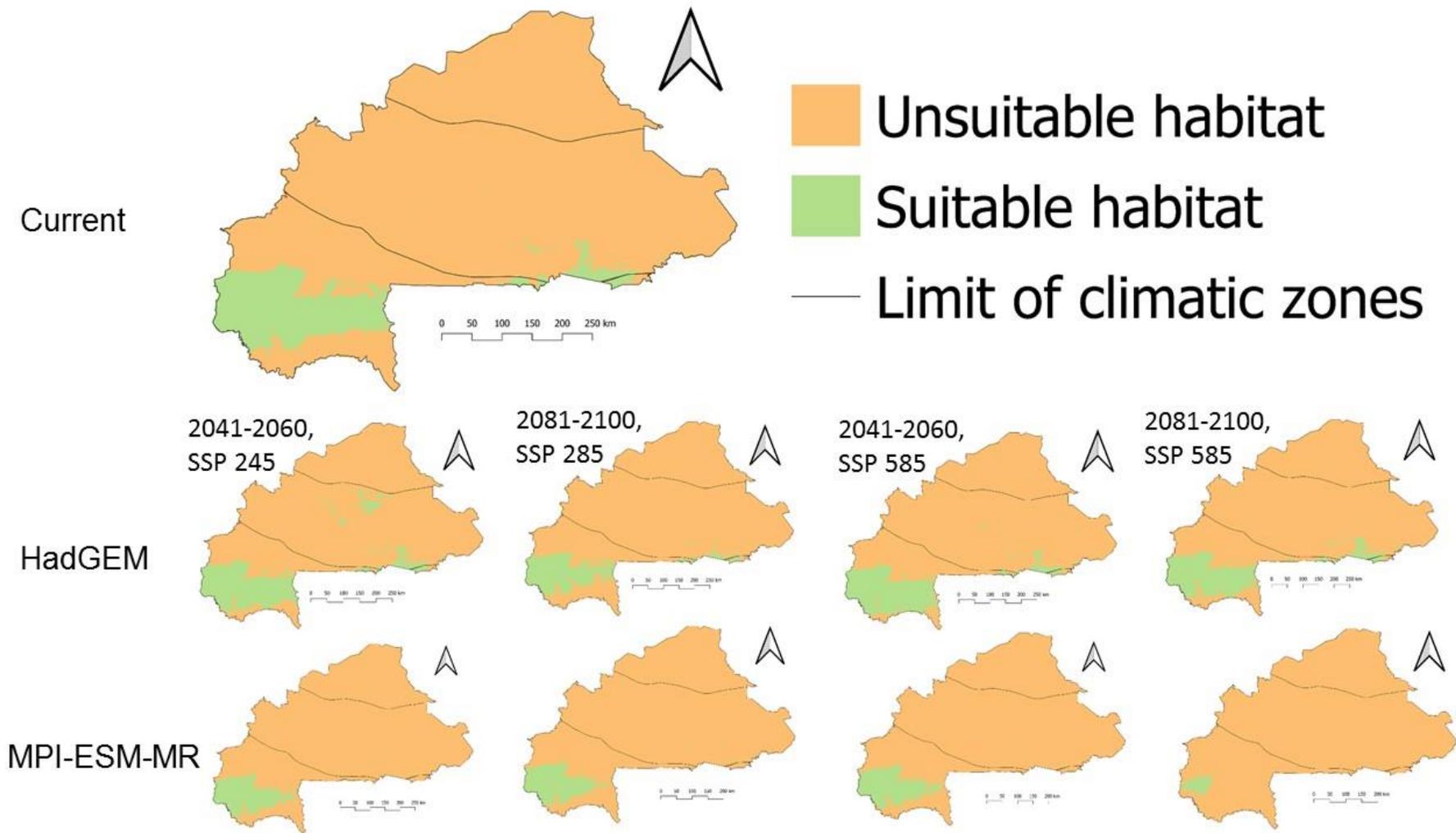


Figure 25: Potential distribution of *Borassus akeassii* under current and future climatic conditions in Burkina Faso

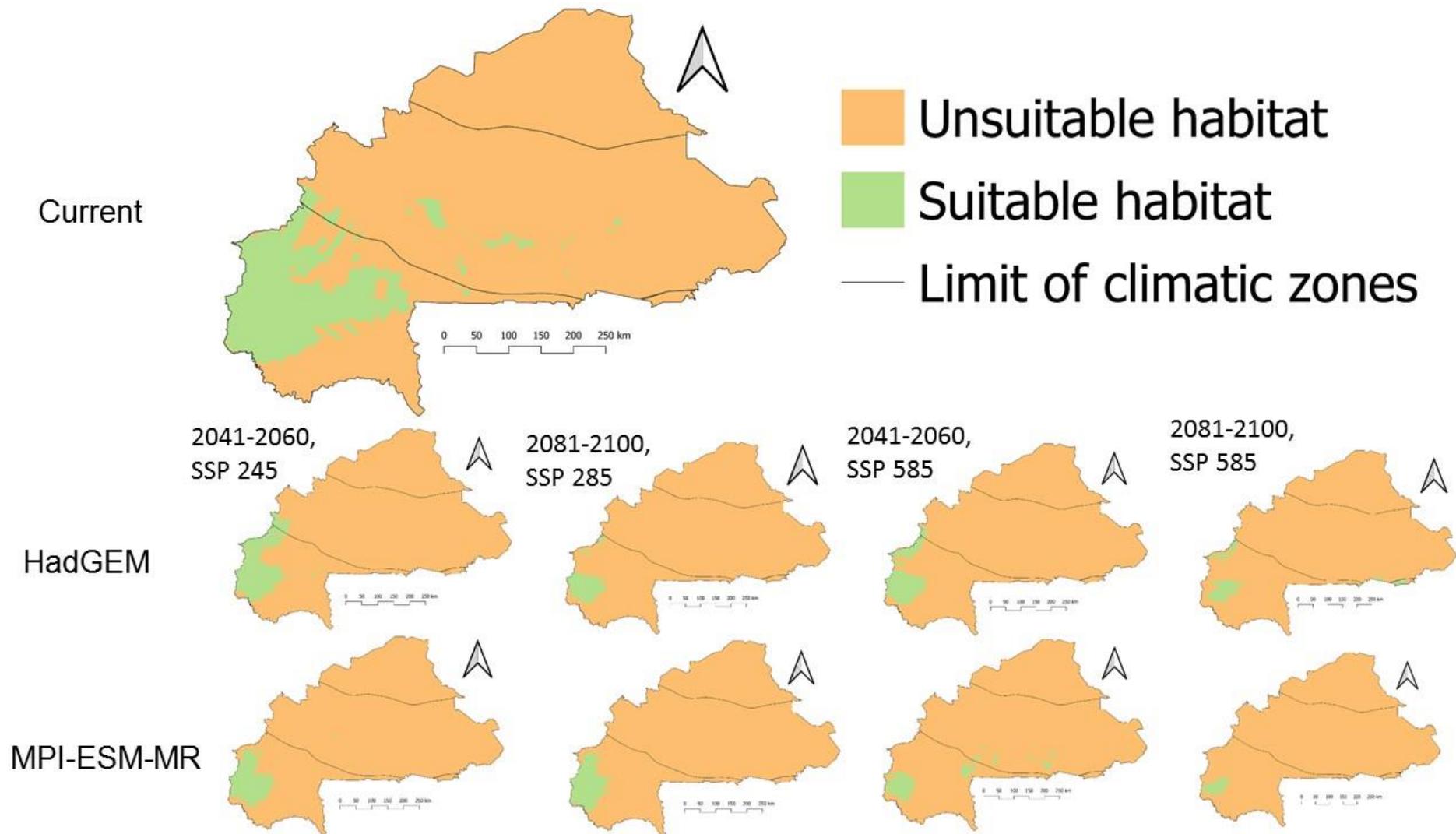


Figure 26: Potential distribution of *Elaeis guineensis* in Burkina Faso under current and future climatic conditions

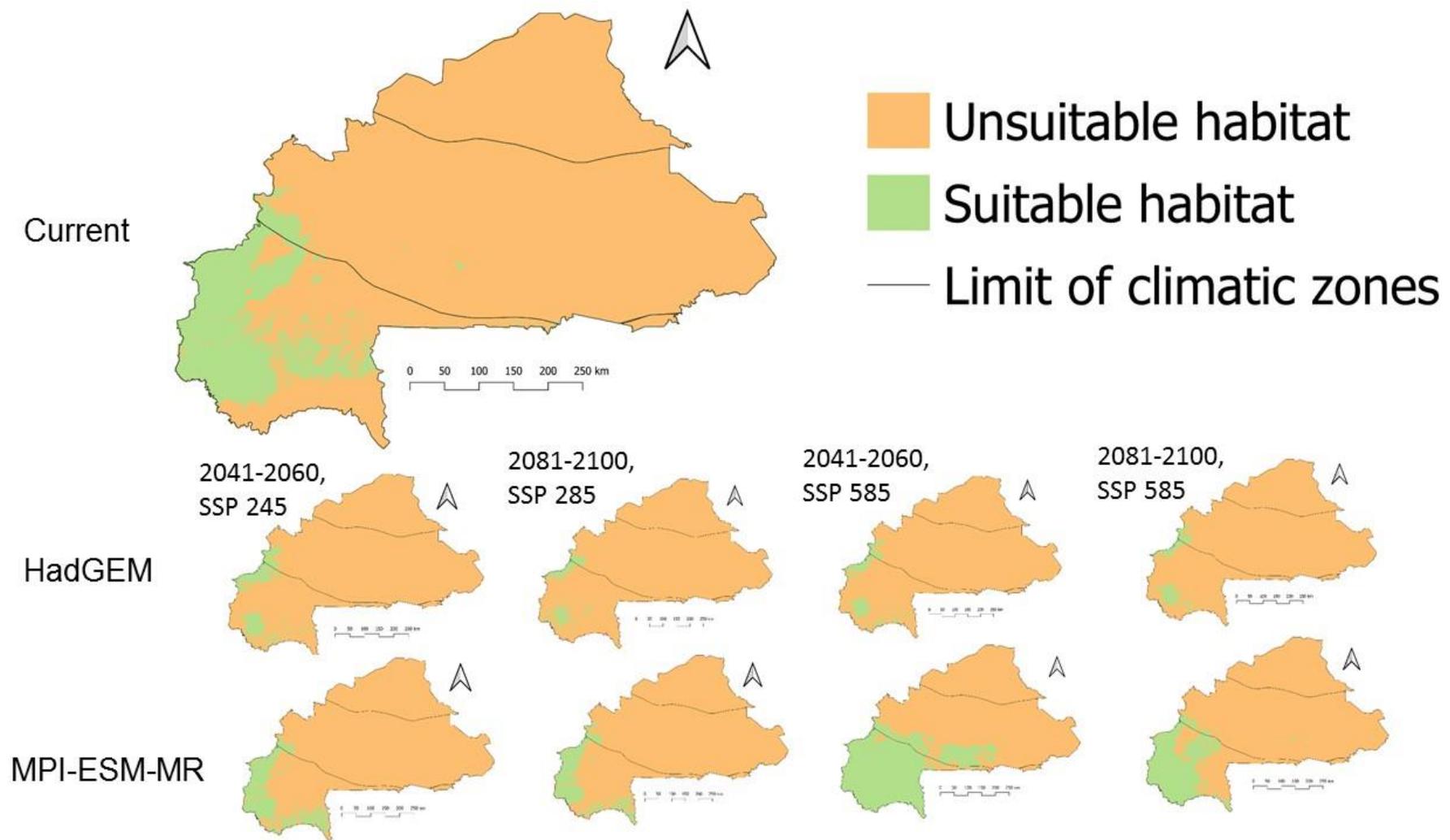


Figure 27: Potential distribution of *Phoenix reclinata* in Burkina Faso under current and future climatic conditions

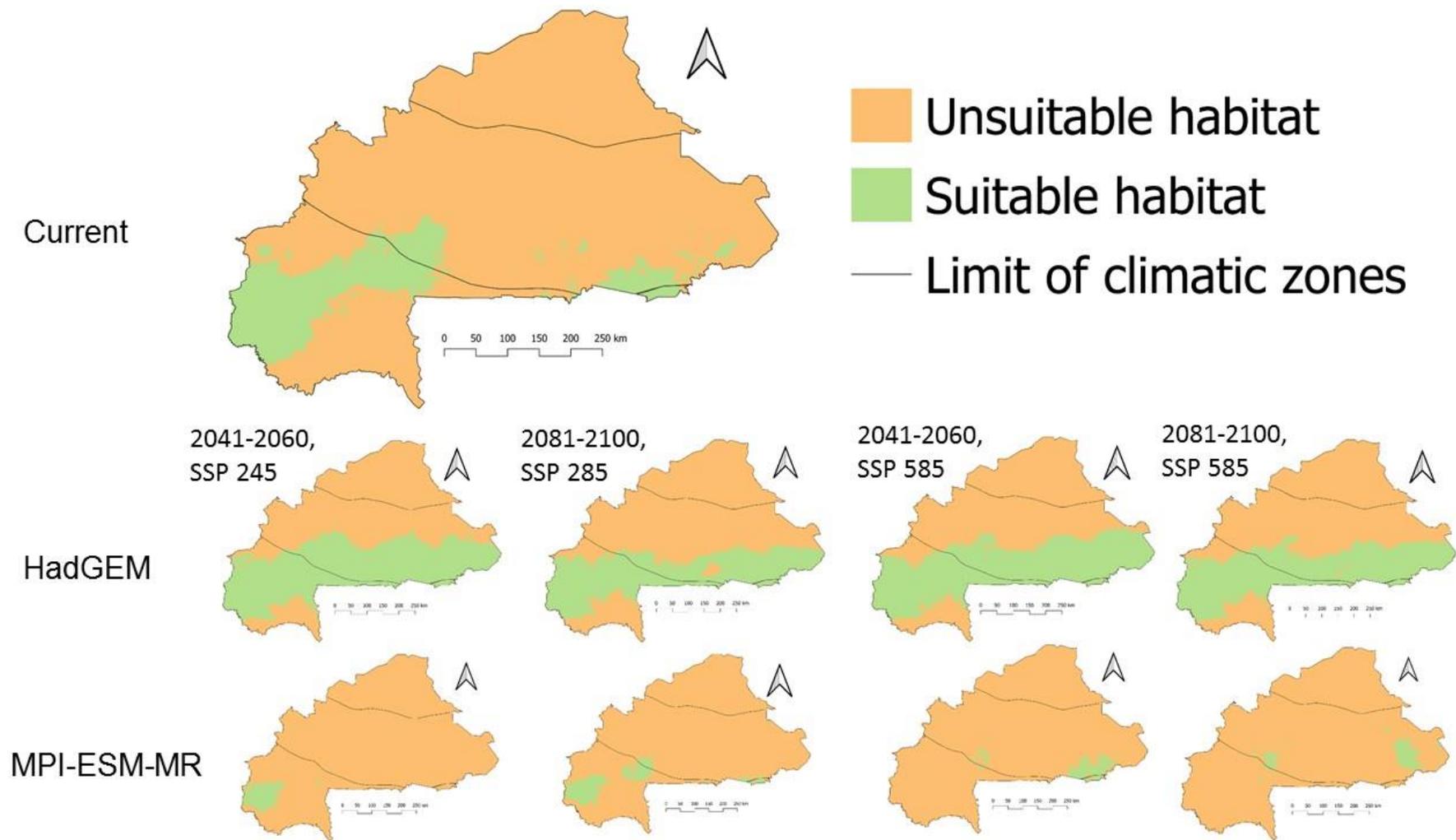


Figure 28: Potential distribution of *Raphia sudanica* in Burkina Faso under current and future climatic conditions

Models indicated that climate change may contracted or expanded the suitable areas of palms depending on the considered species, GCM, scenario and time scale. We noticed that for the same species, the trend was variable according to the scenarios and GCM. For example, under the scenario SSP 245, *Raphia sudanica* was predicted to loose 10.89% and 7.94% respectively in 2041-2060 and 2081-2100 with the model MPI-ESM while the species was predicted to gain 28.51% and 16.70% respectively in 2041-2060 and 2081-2100 with the model HadGEM (Table XXI). For *Borassus akeassii*, even if the trend was variable between scenarios and GCM, all predictions highlighted the contraction of the species range under climate change (Table XXI).

III.5.3. Vulnerability across species

The vulnerability values calculated under climate SDMs were variable according to the considered species (ANOVA result: p-value <0.001). Under all climate change scenarios, *Borassus akeassii* showed lower vulnerability values compared to *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica* (Figure 29). The vulnerability value was not statistically different between *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica* (TukeyHSD p-value > 0.05) even if, *Raphia sudanica* showed higher vulnerability value.

Table XXII: Dynamic of suitable and unsuitable areas for palms conservation in Burkina Faso

Species	suitability	Current		HadGEM				MPI-ESM			
				SSP 2.45		SSP 585		SSP 2.45		SSP 585	
		Extent	%	Extent	Trend* (%)	Extent	Trend* (%)	Extent	Trend* (%)	Extent	Trend*
2041 - 2060											
<i>Borassus akeassii</i>	Suitable	31137.88	11.39	40922.15	+3.58	36401.38	+1.93	22587.12	-3.13	22587.12	-3.13
	Unsuitable	242280.02	88.61	232495.75		237016.52		250843.35		250843.35	
<i>Elaeis guineensis</i>	Suitable	39233.84	14.39	22993.29	-5.96	15144.15	-8.83	15366.60	-8.75	10799.94	-10.43
	Unsuitable	233435.24	85.61	249675.80		257524.94		257302.49		261869.15	
<i>Phoenix reclinata</i>	Suitable	36401.95	13.31	21113.30	-5.59	18430.26	-6.57	27914.89	-3.10	79705.70	15.84
	Unsuitable	237028.68	86.69	252317.17		255000.22		245515.59		273430.48	
<i>Raphia sudanica</i>	Suitable	41987.78	15.36	119951.68	+28.51	114283.71	+26.44	12208.38	-10.89	10681.07	-11.45
	Unsuitable	231442.70	84.64	153478.80		159146.77		261222.09		262749.41	
2081 - 2100											
<i>Borassus akeassii</i>	Suitable	31137.88	11.39	26731.37	-1.61	34215.77	+1.13	20687.26	-3.82	3990.35	-9.93
	Unsuitable	242280.02	88.61	246686.43		239202.14		252743.22		269440.13	
<i>Elaeis guineensis</i>	Suitable	39233.84	14.39	9767.92	-10.81	8822.83	-11.15	14469.55	-9.08	3893.51	-12.96
	Unsuitable	233435.24	85.61	262901.17		263846.26		258199.54		268775.58	
<i>Phoenix reclinata</i>	Suitable	36401.95	13.31	16674.17	-7.22	13428.59	-8.40	25966.43	-3.82	41936.19	2.02
	Unsuitable	237028.68	86.69	256756.31		260001.89		247464.05		231494.29	
<i>Raphia sudanica</i>	Suitable	41987.78	15.36	87662.42	+16.70	101435.38	+21.74	20268.09	-7.94	14285.91	-10.13
	Unsuitable	231442.70	84.64	185768.06		171995.10		253162.39		259144.57	

*Trend (%) correspond to change in the potential suitable habitats, Negative value indicates a decrease while a positive value indicates an increase

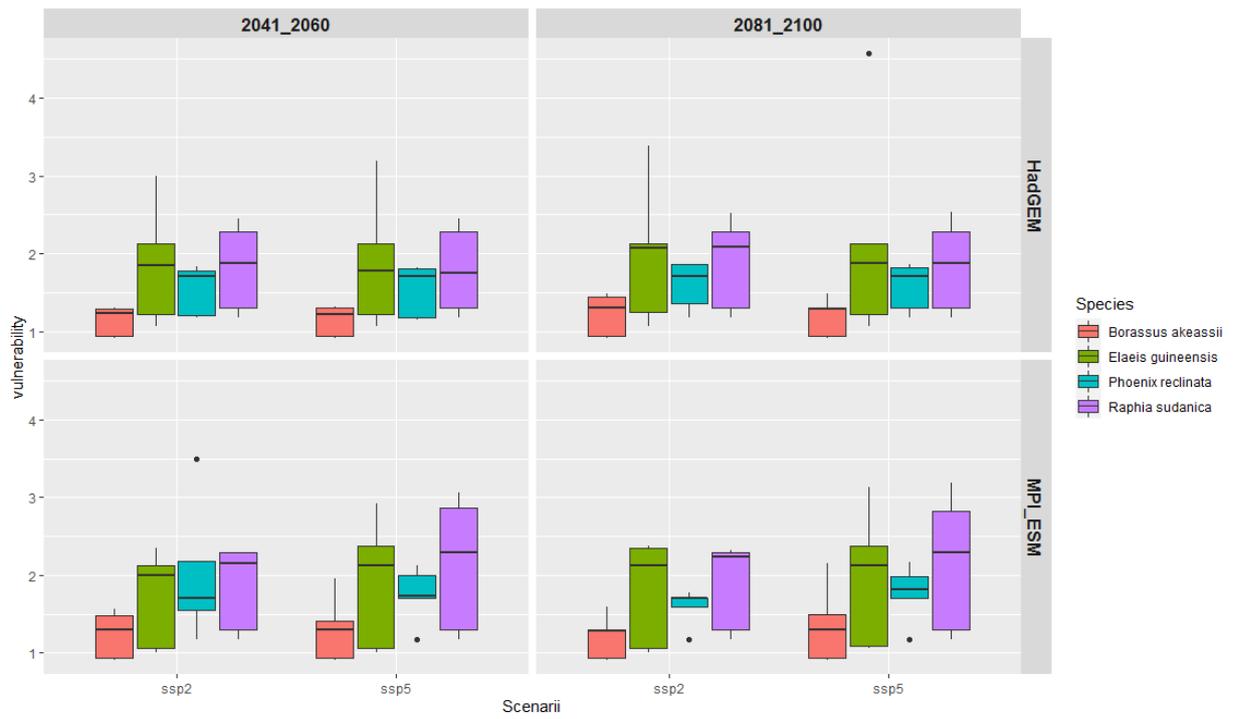


Figure 29: Vulnerability values of wild palms to climate change according to GCM, scenario and time scale

CHAPTER IV: DISCUSSION

The palm knowledge presented as a number of species varied among ethnic groups, gender and age while only ethnic groups modulated the cited palm species. The influence of ethnic group, gender and age on the species knowledge was described in previous studies in Burkina Faso (Ouédraogo *et al.*, 2013; Tiétiambou *et al.*, 2016; Ouédraogo *et al.*, 2019). The species diversity in natural environment has been ascribed to the main reason for the diversity of plants used (Ouédraogo *et al.*, 2013; Camara-Leret *et al.*, 2014). Despite the low diversity of wild palms in Burkina Faso, all the palm species were cited by local people for their usefulness. *Elaeis guineensis* and *Borassus akeassii* were cited by all ethnic groups because of their socio-economic importance and local abundance. For instance, the oil potentials of *Elaeis guineensis* make it a well-known palm species in Western Burkina Faso (Ouédraogo *et al.*, 2013; Tiétiambou *et al.*, 2016). *Borassus akeassii* is among the most frequent and abundant palm species in Burkina Faso (Bayton & Ouédraogo, 2009; Ouédraogo, 2010), and socio-economically important palm whose products are trade in local markets (Yaméogo *et al.*, 2008). To date, *Raphia sudanica* is the only species of the *Raphia* genus known to occur in Burkina Faso (Thiombiano *et al.*, 2012). Nevertheless, local people distinguished two different types of *Raphia* specimens they called by different local names. The taxonomy of *Raphia* genus has been problematic (Otedoh, 1982; Mogue Kamga *et al.*, 2019; Helmstetter *et al.*, 2020), and there is a doubt concerning the occurrence of only *Raphia sudanica* species in Burkina Faso. However, *Raphia sudanica* is known to exhibit a high morphological variation (Chevalier, 1932; Ouattara *et al.*, 2014) that suggests future investigations to look into that variation among *Raphia* individuals in Burkina Faso.

As previously documented, species-specific traits explained how much a palm is used and esteemed by local populations (Byg & Balslev, 2001; Byg & Balslev, 2004). This is evidenced by the fact that the various indices of palm importance varied among species. The physical and anatomical traits of the species, together with the cultural preferences, are factors that affect their usefulness and desirability for various uses (Camara-Leret *et al.*, 2017). Use consensus values showed that few species were used by most informants, suggesting that informants did not agree very much on which species were important (Paniagua-Zambrana *et al.*, 2007). Our analyses revealed the intense exploitation of four species (*Borassus akeassii*, *Elaeis guineensis*, *Raphia sudanica* and *Raphia sp.*), revealing potential human influences on these species' population dynamics, which should be assessed and addressed (Araujo & Lopes, 2012). In addition to the number of uses, the cultural factors also determine the importance of a given resource (Araujo & Lopes, 2012; Mogue Kamga *et al.*, 2020). For example, the sap extracted

from *Borassus akeassii* is culturally used in different ceremonies including weddings and funerals in the Gouin and Turka communities. Loss of diversity and a focus on a few distinct applications might be perceived as loss of knowledge, which could then be connected to missed learning opportunities, such as with the extinction of some species (Anyinam, 1995; Salako *et al.*, 2018a). Although, *Calamus deerratus* is rare and possesses a lower use value in Burkina Faso, it holds interesting uses that are also disappearing. For example, the cane of *C. deerratus* was formerly used to make a utensil culturally used by the bride to carry commodities within the Bobo communities.

Food and construction were the most important use categories and fruits, leaves, sap and stipe were the most reported used parts in our study, as revealed in others studies on palms (Byg & Balslev, 2006; Paniagua-Zambrana *et al.*, 2007; Macia *et al.*, 2011; Araujo & Lopes, 2012). That could be explained by the existing link between the parts used and the use categories in palms. For instance, flowers and roots were mainly used in traditional medicine, while fruit, sap and hypocotyl were used in food and rites categories (Zon *et al.*, 2021). Leaves and stipe were mainly used as materials for building and handicraft (Byg & Balslev, 2001; Salako *et al.*, 2018a).

Our findings confirm the overall pattern that socio-cultural variables have an impact on how various wild palm species are used. Consequently, differences of ethnicity on plant uses have been widely reported in Burkina Faso (Ouédraogo *et al.*, 2013; Balima *et al.*, 2018; Ouédraogo *et al.*, 2019; Tiétiambou *et al.*, 2020). That difference among ethnic groups was mainly due to the cultural heritage and knowledge being transmitted from generation to generation within the same ethnic group (Ouédraogo *et al.*, 2019). However, the knowledge may also be transmitted between different ethnic groups in a same locality, which may result in the homogenization of some species uses like for *Borassus akeassii* in Western Burkina Faso (Béné & Fournier, 2021). Knowledge differs also between genders as far as uses are concerned, with women holding higher knowledge especially on medicinal and food uses (Gaoue *et al.*, 2017). Women are more specialized in the collection of non-timber forest products (Tiétiambou *et al.*, 2020). The influence of age on plant uses is also accepted and explained by the fact that older people experienced more uses than the younger ones and secondly by the fact of the transmission of knowledge across generations (Salako *et al.*, 2018a).

The species-dependent influence of socio-cultural factors on the use values we observed concurs with previous studies (Donou Hounsodé *et al.*, 2016; Tiétiambou *et al.*, 2020). Salako *et al.* (2018a) reported that the pattern of knowledge distribution across age categories depends on local and regional availability of the studied resources. The most common a species

is the most likely knowledge on its utilization is similar across age categories (**Salako et al., 2018a**). The influence of the local resource abundance on the use has been reported in the literature for palm species (**Byg & Baslev, 2004; Byg & Baslev, 2006; Camara-Leret et al., 2014**). Nevertheless, since human decision processes are complex, the selection and exploitation of a plant are influenced by ecological or economic factors as well as social and cultural ones (**Gbesso et al., 2017; Salako et al., 2018a**).

Understanding local people's perceptions on natural resource availability and dynamics is important to implement well-adapted conservation actions. Indeed, capitalizing various social perceptions of a particular endangered species can contribute to its conservation (**Cortés-Avizanda et al., 2018**). Our study revealed that local communities report a decline for most palm species. However, the high proportion of informants who reported an increasing trend for the populations of *Borassus akeassii*, *Elaeis guineensis* and *Calamus deerratus* are in line with previous studies on *Borassus aethiopicum* in Benin (**Salako, 2015**). The relatively higher proportion of informants reporting the increasing trend in *Borassus akeassii* and *Elaeis guineensis* populations suggests that in their localities, the decline may not be as severe as for other useful species or that the abundance is so high that the decline is not perceptible (**Salako, 2015**). In general, local people perceived a current decline of plants species in sub-Saharan regions (**Lykke et al., 2000; Tiétiambou et al., 2020; Lokonon et al., 2021**).

The main causes of regression reported by local people are consistent with other findings, where anthropogenic threats, particularly overexploitation and agricultural pressure were major causes of many plant species decline, including palms in the sub-Saharan Africa regions (**Ngom et al., 2018; Zon et al., 2020**). Repeated harvesting of leaves may severely limit the growth of palms and excessive harvesting of unripe fruits impedes the regeneration potential of *Borassus spp.* (**Thione, 2000; Ahissou et al., 2017**). As far as sap extraction is concerned, the populations' structures of palms are dangerously affected in Côte d'Ivoire because palm trees are felled for sap extraction (**Mollet et al., 2000**). In Burkina Faso, despite intense tapping of the adult palms, the mortality appears low because of a certain sustainability of this exploitation (**Guinko & Ouédraogo, 2005**). Indeed, the tapping method used in Burkina Faso maintained the tree alive and exploitable for many years. In addition to anthropogenic pressures, natural factors also threatened the natural population of *Borassus akeassii*. Among them, local people cited drought, wind, and parasites. The major natural factor threatening populations of *Borassus akeassii* is probably drought, which causes high mortality among older palm trees that are sensitive to fluctuations in the groundwater level (**Sambou et al., 1992**). Climate is the main

factor that influences palm populations' structure and diversity, especially water-related variables (Kreft *et al.*, 2006; Salako *et al.*, 2019a).

Management decisions can benefit from local conservation practices and enhance them for better delivery (Tiétiambou *et al.*, 2020). Despite the minor acknowledgments of local practices of conservation by the official conservation policies, local people have used these practices to conserve a variety of plant species for centuries. The adoption of local practices of conservation could be encouraged by species' spiritual, economic, and ecological values (Millogo-Rasolodimby, 1993; Balima *et al.*, 2018; Tiétiambou *et al.*, 2020). The conservation practices cited by local population include natural assisted regeneration and plantation of *Borassus akeassii* and *Elaeis guineensis*. Such practices were previously reported in Burkina Faso (Yaméogo *et al.*, 2016; Zon *et al.*, 2020; Béné & Fournier, 2021). Our finding showed that *Borassus akeassii* and *Elaeis guineensis* possessed the highest use values, the most cited palms and the ones that also benefit much for conservation care. This suggests that the conservation practices were motivated by the importance of the species and corroborates the correlation between use values and the adoption of conservation practices for the benefit of species (Tiétiambou *et al.*, 2020). Compared to *Borassus akeassii* and *Elaeis guineensis*, which benefit from particular conservation care within the farmlands, *Raphia* species seemed to be neglected despite their high use values for local people. This might be due to the swamplands conditions where they occur (Stauffer *et al.*, 2014). Indeed, the swamplands are used for rice and vegetable cultivation in Burkina Faso and the massive growth habit, together with the spinescence of the plant may discourage the adoption of particular conservation measures of *Raphia*. The destruction of *Raphia* species habitat for agriculture constitutes big challenges towards its domestication and sustainable conservation in agroecosystems. Nevertheless, *Raphia hookerii* and *Raphia vinifera* were cultivated in Benin and Cameroun for exploitation (Donou Hounsodé *et al.*, 2016; Cosiaux & Couvreur, 2020), showing that the conservation and the domestication of *Raphia* species are possible.

This study on local uses, perceptions and conservation practices revealed the importance of seven wild palm species in Western Burkina Faso. The palms' knowledge was modulated by ethnic group, gender and age category. The influence of the socio-cultural factors on palm uses was species-dependent. This study also provides evidence that fruit, leaves and sap were the most exploited parts and food and construction were the most important use categories of palms in Western Burkina Faso. In addition, the most important palm species (*Borassus akeassii* and *Elaeis guineensis*) were the ones that benefit more for conservation care. However, the local conservation practices adopted by local communities in Western Burkina Faso do not guarantee

the effective conservation of wild palms under the combined effect of human and climate change pressures. The decreasing of the palm species could erode the local knowledge and become a missed-learning opportunities for current and future generations. This calls for more effective conservation actions of palms populations and local knowledge. Promoting palm products, sustainable exploitation and local conservation practices through a specific approach and context could both improve the livelihoods of local communities and contribute to efficient conservation of wild palms.

The densities of *Borassus akeassii* population reported in our study confirm the abundance of the species in Western Burkina Faso. It is among the most abundant and common palm species in Burkina Faso (**Bayton et al., 2006; Ouédraogo, 2010**). The population density of *Borassus akeassii* is comparable to those of *Borassus aethiopum* in some West Africa areas (**Ouisavi et al., 2011; Sow & Thiam, 2013**). The population of *Borassus akeassii* had a male-biased sex ratio. A biased sex ratio is more linked to environmental conditions, with females being more numerous in favourable conditions. Male-biased populations are reported to be more frequent in long-living dioecious species that produce large fleshy fruits (**Sinclair et al., 2012**) like *Borassus akeassii*. Most previous studies in West Africa reported a female-biased sex ratio or an equal sex-ratio in *Borassus* populations (**Barot et al., 1999a; Ouisavi et al., 2011; Salako, 2015; Atakpama et al., 2022**), and this is, in general, linked to the pattern of exploitation. In Burkina Faso, *Borassus akeassii* is mainly exploited for sap and leaves (**Guinko & Ouédraogo, 2005; Yaméogo et al., 2008**), and this exploitation is not sex-oriented. Thus, the male-biased sex ratio observed in this study could be link to the aridity of climate. Indeed, previous studies showed that plants growing under water restriction displayed a male-biased sex-ratio while plants raised under sufficient water conditions displayed a more or even female-biased sex-ratio (**Field et al., 2012; Sinclair et al., 2012**). The western part of Burkina Faso has a dry tropical climate that is prone to strong seasonal and annual climatic variations.

The results indicate that *Elaeis guineensis* is more abundant than *Phoenix reclinata* in Western Burkina Faso. The density of *Elaeis guineensis* measured in this study was higher than those found by others scientists in West Africa (**Madelaine et al., 2008; Camara et al., 2019**). Indeed, **Sagna et al. (2019)** reported a density of 775 individuals/ha in agroforestry systems in Guinea Bissau. However, despite its lowest densities compared to other wild palms in Burkina Faso, the density of *Phoenix reclinata* reported here was higher than those obtained by **Kinnaird (1992)** in Kenya, **Mjoli & Shackleton (2015)** in South Africa, and **Martins & Shackleton (2017)** in Mozambique. Differences in the densities across the studies are likely to be related to differences in soils, climate and disturbance specific to each locality (**Martins &**

Shackleton, 2017). For instance, local environmental heterogeneity mediates palm relative abundance (**Muscaralla et al., 2020**). Anthropogenic causes such as exploitation of different palm products, extraction techniques, and intensity of the exploitation are also likely to affect densities across studies (**Mollet et al., 2000; Ahissou et al., 2017**). Indeed, while *Borassus aethiopum*, *Elaeis guineensis* and *Phoenix reclinata* were highly exploited for sap in the neighboring countries by feeling down the trees, this exploitation was not a common pattern in Western Burkina Faso. Microtopographic variation affects the distribution and abundance of palms within swamps and floodplains, many of these patterns probably reflecting differing degrees of tolerance of flooding, waterlogging, or drought (**Svenning, 1999**). Distance to market, distance to waterline and soil fertility were also important factors that shape the abundance of wild palms (**Martins & Shackleton, 2017**). The abundance of *Elaeis guineensis* could be due to the local conservation practices adopted by local people to ensure the sustainability of the species. Indeed, in line with the high economic value of *Elaeis guineensis*, local people conserve locally the species by natural assisted regeneration, seedlings fencing among different communities of Burkina Faso (**Zon et al., 2020**). The seedlings were more abundant for *Elaeis guineensis* comparatively to *Phoenix reclinata*. The low abundance of *Phoenix reclinata* could be due to its mechanisms of regeneration.

The seedlings were more abundant for *Borassus akeassii* and *Elaeis guineensis* comparatively to *Raphia spp.* and *Phoenix reclinata*. The abundance of seedlings in *Borassus akeassii* and *Elaeis guineensis* stands could be due to the local conservation practices adopted by local people to ensure the sustainability of the species. Indeed, in line with the high economic value of *Borassus akeassii* and *Elaeis guineensis*, local people conserve locally the species by natural assisted regeneration, plant fencing and plantation among different communities of Burkina Faso (**Zon et al., 2020**). For, *Raphia spp.*, the overexploitation of the rachis and the fruits coupled with the hapaxanthic behaviours of the species could hamper the regeneration in Western Burkina Faso. In general, seed production, seed fertility and germination, seedling survivorship and growth were determinants factors of the recruitment and establishment of juveniles, particularly in semi-arid environments (**Ouédraogo et al., 2006; Ouédraogo, 2006; Martins & Shackleton, 2017**).

The Simpson index of dominance above 0.1, the permutation index above zero and the fluctuating quotients between the consecutive life stages for all the studied palms stands indicated unstable populations. For *Borassus akeassii*, the unstable population structure could be linked to a selective human effect on *Borassus akeassii* individuals. Indeed, farmers act on the life stage succession by their selective preference of individuals for exploitation. The

selective effect of farmers in farmlands may explained the observed unstable population structure in agroforestry systems (**Madelaine et al., 2008; Idohou et al., 2016a**). As the structure of semi-wild palm groves is partly explained by agricultural practices, it could be used as an ecological indicator of changes in practices in relation to socio-economic conditions of local populations (**Madelaine et al., 2008**). The factors that hamper the structure of *Elaeis guineensis* were mainly rainfall weakness (**Zon et al., 2020**) and probably the light limitation due to the gallery forest conditions in which *Elaeis guineensis* occurs in Burkina Faso. Indeed, the shady conditions of the gallery forests do not prevent the germination of *Elaeis guineensis* but restraint the seedlings growth (**Rees, 1963**). The unstable population of *Phoenix reclinata* could be explained by its habitat transformation for rice cultivation.

However, the good recruitment of *Borassus akeassii* is a potential source to ensure the successful regeneration of the palm groves whether this scenario could be a constant recruitment over the years (**Sinclair et al., 2012**).

The findings showed that whereas palms were dominant in their habitats regarding their density, stands display important species and families that were represented. Agroforestry trees such as *Vitellaria paradoxa* and *Parkia biglobosa* mainly co-occurred with *Borassus akeassii* because of the occurrence of this palm on farmlands in Western Burkina Faso. The predominance of woody species such as *Khaya senegalensis*, *Carapa procera* and *Vitex doniana* in *Elaeis guineensis* stands could be explained by the fact that these species together with *Elaeis guineensis* constitutes a predominant species in gallery forests in the sudanian zone of Burkina Faso (**Sambaré et al., 2011; Thiombiano et al., 2012; Sambaré et al., 2020**). The predominance of *Lannea velutina*, *Ficus sur*, *Diospyros mespiliformis*, *Terminalia schimperi*, *Mitragyna inermis*, *Sarcocephalus latifolius* and *Vachellia seyal* in *Phoenix reclinata* stands could be explained by their ecological requirements, or plasticity. Indeed, these species were adapted to the temporal flooded conditions and thus mainly occur in lowlands and swamplands like *Phoenix reclinata*.

The majority of co-occurring tree species recorded with the palms are classified as least concern in the global assessment of UICN red list (Appendix 3). However, some species such as *Khaya senegalensis* encountered in the habitat of *Elaeis guineensis*, and *Vitellaria paradoxa* co-occurring with *Borassus akeassii* are listed as vulnerable globally and locally in Burkina Faso (**Nabaloum et al., 2022; Appendix 3**). In addition, these species are among the useful ones in the flora of Burkina Faso that provide food, oil products, medicine, and contribute to generate income to local people. For instance, *Khaya senegalensis* and *Diopyros mespiliformis* were ranked among the top useful plants in Burkina Faso (**Zizka et al., 2015; Nabaloum et al.,**

2022). Thus, the conservation of the habitats of wild palm species may contribute to conserve particularly both vulnerable and useful species in the sudanian climatic conditions of Western Burkina Faso.

Any vegetative regeneration mechanism was not observed for *Borassus akeassii*, *Elaeis guineensis* and *Raphia spp.* **Russell (1965)** reported that *Raphia spp.* are able of vegetative reproduction by suckering. Vegetative reproduction through suckering reported by previous researchers may be true seedlings coming from seeds that germinate under a mature individual of *Raphia*, and subsequently welded to this tree (**Chevalier, 1932**). Our observation is consistent with **Donou Hounsodé (2017)** who reported that *Raphia spp.* are not able of suckering.

More than half of *Phoenix reclinata* seedlings come from tillering. This vegetative mechanism of regeneration has been reported for the cultivated date palm *Phoenix dactylifera*. This indicates some limitation in the recruitment levels of *Phoenix reclinata* populations due to its mechanisms of regeneration. Indeed, **Faruquei et al. (2020)** reminded that offshoots of *Phoenix dactylifera* are mainly produced in a limited number (20–30 per palm) during the early life of the plant (10–15 years from the planting).

This study investigates the population structure and stability, the diversity of co-occurring trees and the mechanisms of regeneration of four palms populations, *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* and *Raphia spp.* in Western Burkina Faso. The populations of the investigated palms are unstable. *Borassus akeassii* and *Elaeis guineensis* presented high seedlings compared to *Phoenix reclinata* and *Raphia spp.* The diversity of co-occurring trees in palms habitats varied according to the considered palms species. Socio-economic important and vulnerable tree species co-occurred with palms in Western Burkina Faso. Therefore, this situation calls for inclusive approaches to better conserve these useful plant resources. An important contribution will be to track the vulnerability to these species to global climate change.

Multivariate analysis of morphological data from *Raphia* in Western Burkina Faso delimits 3 clusters of individuals. Application of the morphological species concept and the current taxonomic treatment to these clusters gives potentially two species in the genus *Raphia* in Burkina Faso. These potential species of the genus *Raphia* could be distinguished by the growth habit, the characteristics of petiole and leaflets, and the density of spines. Indeed, these characters are for high importance in distinguishing the *Raphia* in addition to the shape of inflorescence (**Otedoh, 1982; Helmstetter et al., 2020**). The first and obvious trait

distinguishing these two “morpho-species” is the growth habit. Indeed, the cluster 2 and 3, possess an aboveground stem to 5 m with leaves possessing a short petiole and leaflets densely armed with small spines. These clusters could be identified as *Raphia sudanica* (**Chevalier, 1908; Ouattara et al., 2014**). However, individual in cluster 1 are stemless, with thin and long petiole directly coming from the ground with sparse spines on the rachis and leaflets, and thus are referred to as *Raphia sp.* The great diversity in growth habits discussed above is of immense taxonomic value in distinguishing between *Raphia* species (**Otedoh, 1976**). Currently, only three species of *Raphia* are known to be stemless namely *Raphia vinifera*, *Raphia regalis* and *Raphia palma-pinus* (**Stauffer et al., 2014; Mogue Kamga et al., 2020**). *Raphia regalis* can be easily recognised by its greatest leaves. *Raphia palma-pinus* is known to occur in humid forest and exhibit a huge inflorescence (**Stauffer et al., 2014**). *Raphia vinifera*, known to occur in open vegetation (**Mogue Kamga et al., 2019; Cosiaux & Couvreur, 2020**), may be occurred in Sudanian conditions. Indeed, **Chevalier (1932)** think of the occurrence of *Raphia vinifera* around Sikasso and Bobo-Dioulasso. Is *Raphia sp.* a representative of *Raphia vinifera*? (**Palisot de Beauvois, 1804; Mogue Kamga et al., 2019**). In the absence of diagnose characteristics of *Raphia vinifera*, that could allow us to make a comparison, we cannot be sure that *Raphia sp.* is a representative of *Raphia vinifera*.

The leaf is also one of the distinguishing characters of the palms (**Dransfield et al., 2008**) and could easily be used to distinguish *Raphia sudanica* from other species of *Raphia* (**Ouattara et al., 2014**). Indeed, the leaflets of *R. sudanica* are smaller, with dense and small spines, which is very characteristic of the species and is not seen in any other species of the genus (**Ouattara et al., 2014**). In addition to the density of the spines on leaflets, the spacing of the leaflets could be used to differentiate *Raphia* species. Indeed, *Raphia sudanica* is characterised by highly dense spines, with leaflets densely inserted while *Raphia sp.* has fewer spines, with leaflets sparsely inserted. One important and distinctive character is the petiole. If the petiole is absent (Cluster 2) or short and robust with four ranks of spines (Cluster 3) in *Raphia sudanica*, this characters is always present, very long and thin and unarmed in *Raphia sp.* The leaflets number appears to vary a lot in our data, and may not be suitable to be used as distinctive characters to differentiate the species of *Raphia*. The two recognized species of *Raphia* co-occurred in Western Burkina Faso. The co-occurrence of many delimited *Raphia* species or adjacent to one another has been also previously reported in Cameroun (**Otedoh, 1976**) and Benin (**Donou Hounsodé, 2017**).

In our data, individuals of *Raphia sudanica* have been split into two different groups. This was also reported for molecular data (**Helmetter et al., 2020; Jimenez et al., 2021**). However, many

characters were distributed between these two groups belonging to a single species *Raphia sudanica*. In addition, the high morphological variation of *Raphia sudanica* has been reported by authors such as **Ouattara et al. (2014)** and suggests that the two groups belong to *Raphia sudanica*. Nevertheless, it is necessary to determine whether these groups may actually represent two infraspecific taxa of *Raphia sudanica*.

The observation and data collected through this study showed that the individuals of *Raphia* occurring in Western Burkina Faso belong to two morphologically distinct species: *Raphia sudanica* A. Chev. and *Raphia sp.* These two species co-occurred and could be easily be differentiated in the field by their habit, petiole and rachis. Despite the morphological distinctiveness of *Raphia sp.* presented here, morphological data related to reproductive features (fruits and flowers) and molecular data are needed to confirm its similarities with *Raphia vinifera* P.Beauv. However, we need to treat these result with caution because *Raphia sudanica* is known to exhibit a high morphological variation and present a dwarf form in some populations (**Ouattara et al., 2014**). The morphological data constitute an important step towards the application of molecular tools to assess the specific diversity of *Raphia* in Burkina Faso. Furthermore, future research must address the genetics, distribution and reproduction of all recognised species of *Raphia* to better conserve the diversity associated to palms in general and to the *Raphia* genus in particular in Burkina Faso.

In general, the distribution of palms is influenced by the effect of climatic and non-climatic variables such as soil and topography. This result aligned with previous works that reported the limiting effect of climatic and other environmental conditions in the distribution of African palms (**Blach-Overgaard et al., 2010; Idohou et al., 2016b; Idohou et al., 2016c**), and other plant species (**Balima et al., 2022; Manda et al., 2022**). In terms of climate, our result is consistent with previous studies that reported that palms were more dependent on water-related variables than temperature (**Kreft et al., 2006; Blach-Overgaard et al., 2010**). The relevance of the precipitation of driest month (Bio14), which is included in all individual models is likely linked to its effects on hydrological regimes and rivers characteristics, which in turn affect the habitat suitability (**Jamwal et al., 2021**), especially for species that grow closer to streams and rivers such as *Elaeis guineensis* and *Raphia sudanica*.

The Temperature is found to be determinant of the distribution of *Borassus akeassii*. This result is consistent with the one reported for *Borassus aethiopum* by **Idohou et al. (2016c)**. The influence of temperature in palms distribution is clear and determinant at global scale, as palms could not stand into freeze and cold temperature due to their inability to undergo vegetative dormancy (**Tomlinson, 2006; Dransfield et al., 2008; Reichgelt et al., 2018**). The strong

sensitivity of palm family to temperature suggests that the expansion of individual species at the distributional limits of the palm family constitutes a good indicator for the current climate change (Walther *et al.*, 2007; Eiserhardt *et al.*, 2011; Reichgelt *et al.*, 2018).

The influence of topography on palm distributions should be linked to the possible effects of hydrology as reported by Eiserhardt *et al.* (2011). Indeed, TPI was found to be an important predictor for *Phoenix reclinata* and *Raphia sudanica* models. This is consistent with field observations that showed that those palms species occurred more in lowlands, swamplands and ooze habitats (Profizi, 1988; Stauffer *et al.*, 2014).

Despite the high consistency and the good predictive ability of the SDM, the results should be treated with caution, because the current potential distribution of the species represents the suitability based on the predictors included in the models (Dawson *et al.*, 2011; Dimobé *et al.*, 2020; Macedo-Santana *et al.*, 2021). Pearson & Dawson (2003) reminded that the importance of the variables used in SDM is dependent on the scale of the study with climate acting in global and continental scales and soil and biotic interactions stronger at local and landscape scales. Thus, the presence of the species may change when considering additional factors such as biotic interactions and their dispersal capacity (Dawson *et al.*, 2011; Macedo-Santana *et al.*, 2021). The lower predicted extend for wild palms species under current climatic conditions in Burkina Faso highlighted the under-representation of palms in semi-arid climatic conditions. Indeed, Muscaralla *et al.* (2020) reported that the local abundance of palms is driven by local annual precipitation, with the good representation in humid tropical forests (Couvreur *et al.*, 2011). Such outcomes agreed with the well-known preference of *Elaeis guineensis*, *Raphia spp.* and *Phoenix reclinata*, for the most humid part of Burkina Faso located in the South-Western part of the country.

The variable trends between different climatic scenarios reported here, agreed with several authors in West Africa (Fandohan *et al.*, 2013; Idohou *et al.*, 2016; Dimobé *et al.*, 2020; Balima *et al.*, 2022; Issoufou *et al.*, 2022). This variability could be linked to the uncertainty that comes from the GCM to accurately predict the particular regional climate phenomena, for example the monsoon conditions or droughts (Harris *et al.*, 2014; Baker *et al.*, 2017). Because some of these processes may be simulated by different GCMs, all GCMs are not equally credible depictions of the local climate conditions for all sites (Baker *et al.*, 2017; Diawara & Lobanov, 2019). Indeed, a wider range of precipitation uncertainty (roughly between -30 and 30 %) is predicted in the Sahel under future climate change (Sylla *et al.*, 2015). In addition, Diawara & Lobanov (2019) by assessing the accuracy of 20 GCM (including the HadGEM and MPI-ESM) to simulate temperature and precipitation across Mali (West Africa Sahel),

concluded that all the standard deviation of the simulated precipitations by all the GCM were above 10% of the mean of the precipitation of the country, highlighting the less approximation of the precipitations by all the models. Thus, if the uncertainty remains concerning the range contraction or expansion in the face of climate change (**Fandohan et al., 2013; Balima et al., 2022**), it is clear that some species will be more vulnerable than others.

The vulnerability assessment shows that *Borassus akeassii* is less vulnerable to climate change than *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica*. Indeed, specialist species showed the highest vulnerability when compared to generalist ones (**Rinnan & Lawler, 2019; Jamwal et al., 2021**). That is consistent with field data indicating that *Borassus akeassii* is a typical species of the sudanian savannas (**Bayton et al., 2006; Bayton, 2007**) while, *Elaeis guineensis* and *Raphia sudanica* found refuge in riparian vegetation in Sudanian climatic conditions like Western Burkina Faso (**Arbonnier, 2009**). **Stauffer et al. (2014)** described *Elaeis guineensis*, *Raphia sudanica* and *Phoenix reclinata* as lowlands palm species. Thus, the integration of SDM into CNFA analysis highlighted that the vulnerability of species is a combination of its sensitivity and exposure to climate and that considering only the exposure as assessed by classical correlatives models may fail to assess the real vulnerability of species to climate change. By the way, **Jamwal et al. (2021)** concluded that the vulnerability is more determine by the sensitivity than the habitat exposure, usually assess by classical correlative models.

Nevertheless, the vulnerability assessment is limited by the non-inclusion of the adaptative capacity and the dispersion potential of the species (**Rinnan & Lawler, 2019**). Indeed, the lack of information make the adaptative capacity the most challenging component to be included in the CCVA, which is usually neglected (**Jamwal et al., 2021**). Moreover, species may adapt differently to climate change, and the inclusion of adaptative capacity is crucial to depict the real vulnerability of species in order to think suitable actions towards biodiversity conservation. Recently, **Jinga et al. (2021)** showed that the non-consideration of local adaptation through intraspecific-level leads to the under- or overestimation of the impacts of climate change on biological resources. Although, human pressures through land use changes and overexploitation may have an important impact on wild palms vulnerability, and thus may be considered in any conservation strategies (**Mollet et al., 2000; Thione, 2000; Ouattara et al., 2015; Idohou et al., 2016c; Salako et al., 2019**), it is out of the scope of this study.

This study identified potential areas for palms conservation in Burkina Faso under climate change for *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica*. It is demonstrated that water-related variables, topography and temperature drive the distribution of

wild palms in Burkina Faso. Likewise, the current potential areas are located in Western Burkina Faso and covered less than 15% of the country. Although it is unclear if palms may contract or expand their suitable areas in the face of climate change, their vulnerability is quite obvious due to their dependency on water-related variables. Indeed, the CCVA acknowledges *Borassus akeassii* as less vulnerable compared to *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica*. These results provide an important step towards the prioritization of conservation efforts of palms species in semi-arid areas. However, given the human pressures on wild palms populations, future research should focus on the propagation and the resilience of wild palm species to these pressures through traits-based experiments.

CONCLUSION AND PERSPECTIVES

This study has been carried out in Western Burkina Faso to investigate the ecological and conservation patterns of wild palm species through interviews, inventories, direct observation and species distribution modelling. The results suggest that wild palms constitute keystone species that contribute to the local people livelihoods and well-being in semi-arid climatic conditions in Western Burkina Faso. Thus, some efforts must be undertaken to better conserve their resource and to increase their availability for current and future generations. Yet, palms are understudied and under-represented in semi-arid and arid areas in West Africa, but their importance in providing food, medical resources, building materials, handicrafts, and cultural rites is undisputed. This study brings evidence that palms growing in arid and semi-arid areas such as *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata*, *Raphia sudanica* and *Raphia sp.* are among the most useful palm species in West Africa and particularly in Western Burkina Faso. *Raphia sp.* is a species of the genus *Raphia* that co-occurred with *Raphia sudanica* in Western Burkina Faso, and that local people differentiate from the latter. Nevertheless, the socio-cultural factors including ethnic group, age category and gender were determinant for the importance of palms, even if their impacts depend on the considered palm species. In addition, local people noticed a decline for most of the palm species. However, they adopt natural assisted regeneration, plantation and plant fencing to conserve only the most useful for them like *Borassus akeasii*, *Elaeis guineensis* and *Raphia spp.* This result highlighted that promoting palms products is determinant in effective conservative programmes. In addition, the conservation may be based on the local practices that should be improved for an effective conservation of these important resources.

The field inventories highlighted the unstable populations for *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* and *Raphia spp.* in Western Burkina Faso. *Borassus akeassii* and *Elaeis guineensis* showed a good potential of regeneration while the seedlings and saplings were less represented in the populations of *Phoenix reclinata* and *Raphia spp.* Only *Phoenix reclinata* displayed a potentiality for regenerating by tillering. The co-occurring species with palms depend on the considered palm species, with significant less species in the habitat of *Borassus akeasii* compared to *Elaeis guineensis*, *Phoenix reclinata* and *Raphia spp.* Indeed, *Borassus akeassii* occurred mainly in farmlands, while *Raphia spp.* and *Elaeis guineensis* grow in riparian vegetations. Despite their less representation, the co-occurring species are important species that may be conserved when actions are undertaking to conserve palms *in situ*.

The morphological assesement identified a potential new species of *Raphia* for the palm flora of Burkina Faso, *Raphia sp.* that co-occurred with *Raphia sudanica* in Western Burkina Faso. *Raphia sp.* could easily be differentiated from *Raphia sudanica* by its stemless habit, the long

and thin petiole and sparse spines. However, a huge morphological variation of *Raphia sudanica* highlighted the need for more data on the difference between the two type of *Raphia* identified in this study. This calls for more research on genetic diversity of *Raphia spp.* in Burkina Faso to completely resolve the real diversity of this important taxa. Thus, future research may collect fertile specimen of both type of *Raphia* that may be sent to palm herbaria for confirmation. It could result in the increase of the current diversity of wild palms in Burkina Faso to eight with two species of *Raphia*.

The species distribution models indicated that wild palms species may contract or expand their suitable areas under climate change according to the climatic models and scenarios. However, their vulnerability to climate change is evident because of their dependency on water availability. The CCVA showed that *Borassus akeassii* is less vulnerable to climate change compared to *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica*. This information is important for implementing effective conservation actions and priorities to improve the adaptations of local populations and reduce their vulnerability to climate change.

Despite the importance of these results, several aspects need to be investigated in detail in order to provide sound information for the conservation of palms in semi-arid context under human and climate change pressures. These include:

- (i) The resilience of wild palm species to the exploitation of their products. Such investigations could for instance document the impact of sap tapping for palm wine on *Borassus akeassii* and the impact of exploitation of the leaves on *Raphia spp.* in Burkina Faso.
- (ii) The genetic diversity of the *Raphia spp.* in Burkina Faso. That could improve our understanding of the diversity of these important taxa and therefore contribute to better conserve the diversity of palms regarding that *Raphia sudanica* is among the most vulnerable species to climate change.
- (iii) A trait-based assessment of the adaptative capacity of wild palms to climate change by following the growth of different species under different climatic conditions.
- (iv) For the biodiversity modelling, further studies may include additional factors such as extremes climatic factors, biotic interactions, landuse and scale effects in order to provides insights and additional interpretive information when modelling the distribution of palms.
- (v) Some palm species such as *Borassus aethiopum*, *Hyphaene thebaica* and *Calamus deerratus* need attention in future research in documenting their demography, and distribution in order to understand their conservation status in Burkina Faso.

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APPENDIX

Appendix 1: List of publication

Scientific articles

1. **Zon A. O.**, Kouassi K.E. and Ouédraogo A. (2021) Current knowledge and future directions on West African wild palms: an analytical review for its conservation and domestication in the context of climate change and human pressures. *Genetic Resources and Crop Evolution*, 68: 1731-1745. <https://doi.org/10.1007/s10722-021-01158-9>
2. **Zon A.O.**, Tiétiambou F.R.S., Kabré B., Kouassi K.E. and Ouédraogo A. (2022) Assessment of the conservation status of *Borassus akeassii* Bayt., Ouédr. & Guinko in Western Burkina Faso through local communities perceptions and the species stands structure. *Global Ecology and Conservation*. <https://doi.org/10.1016/j.gecco.2022.e02284>

Communications

1. **Zon A.O.**, Kouassi K.E., and Ouédraogo A. (2022). Disentangling the effects of socio-cultural factors on the uses and conservation of wild palms (Arecaceae) in Western Burkina Faso. Premières journées scientifiques de l'Université de Dédougou, Dédougou, Burkina Faso, du 12 au 15 Janvier 2022. (Oral Presentation)
2. **Zon A.O.** and Ouédraogo A. (2019). An analytical review on West African palms diversity and uses. Journées scientifiques et Portes ouvertes de l'Université Joseph Ki-Zerbo, Ouagadougou, Burkina Faso, du 28 au 30 Novembre 2019. (Poster)

Appendix 2: Questionnaire for ethnobotanical data collection

Fiche N°:..... Localité (Village) :..... ; Zone climatique :..... Date :.....
 Coordonnées géographiques:.....

A/ identification de l'enquêté : Sexe :..... Age :..... Ethnie :..... Profession :..... Niveau académique :
 Néant Alphabétisée Primaire Secondaire Universitaire Statut de résidence : résident non résident Statut matrimoniale : Célibataire marié(e)
 veuf(ve)

Culture : Langues parlées : Ethnic Dioula Français Autres :..... Relation parental : deux parents de l'ethnie Un seul parent

B/ connaissance et usages des palmiers : quels sont les palmiers que vous connaissez et dans quels domaines les utilisez-vous ?

Connaissance, utilisation et Usages : **Alim. Hum.** (Alimentation humaine) / **Art.** (Artisanat) / **Méd.** (Médecine traditionnelle) / **Cons.**(Construction) / **Energ.** (Énergie) /
Agro (Agroécologie) / **Alim. anim.** (Alimentation animale) / **Com.** (Commercialisation) / **Cult.&Rit** (culture & Rites)

Remplir le tableau avec les organes concernés

Espèces	Nom local	Connaissanc e (1/0)	Utilisation (1/0)	Usages										
				Alim. Hum.	Art.	Méd.	Const.	Energ.	Agro.	Alim. Anim.	Com.	Cult. &Rit	Autres	
<i>Borassus aethiopum</i>														
<i>Borassus akeassii</i>														
<i>Calamus deeratus</i>														
<i>Elaeis guineensis</i>														
<i>Hyphaene thebaica</i>														
<i>Phoenix reclinata</i>														
<i>Raphia sudanica</i>														
Autres														

Ra=racine ; st=stipe ; se=sève ; hy=hypocotyle ; pe=pétiole ; li=limbe ; inf=inflorescence ; bt=bourgeon terminal ; pu=pulpe ; gr=graine ; hu=huile ; autres=à préciser
 Notes :.....

B/ Perceptions locales des palmiers

Scores d'importance : 0 : non utilisé ; 1 : faiblement utilisé ; 2 : moyennement utilisé ; 3 : fortement utilisé

espèces	Nom local	Signification	Importance									disponibilité.	évolution	Raisons	CONS.	
			Alim. Hum	Art.	Méd.	Const.	Energ.	Agro.	Alim. Anim	Com.	Cul& Rit					
<i>Borassus aethiopum</i>																
<i>Borassus akeassii</i>																
<i>Calamus deeratus</i>																
<i>Elaeis guineensis</i>																
<i>Hyphaene thebaica</i>																
<i>Phoenix reclinata</i>																
<i>Raphia sudanica</i>																
<i>Autres :.....</i>																

Code de Disponibilité : 0 absent dans la localité ; 1 : rare ; 2 : peu abondant ; 3 abondant

Evolution : 0 : stable, 1 : Régression ; 2 : progression

Raisons : exp=exploitation intensive ; agr=agriculture ; pa=parasites, sèch=sècheresse ; autre=à préciser

Stratégies de conservation (CONS.) : 0 = aucun 1 = protection des plantules, 2 = Reboisement/ plantation 3=RNA

Notes :

.....

.....

.....

Appendix 3: Co-occurring trees species with wild palms in Western Burkina Faso

Table S1: Co-occurring trees species with *Borassus akeassii* in Western Burkina Faso

Species	Family	UICN redlist categories
<i>Adansonia digitata</i> L.	Malvaceae	
<i>Anacardium occidentale</i> L.	Anacardiaceae	LC
<i>Annona senegalensis</i> Pers.	Annonaceae	LC
<i>Anthocleista djalonensis</i> A.Chev.	Loganiaceae	LC
<i>Azadirachta indica</i> A.Juss.	Meliaceae	LC
<i>Blighia sapida</i> K.D.Koenig	Sapindaceae	LC
<i>Cassia sieberiana</i> DC.	Fabaceae	LC
<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalziel	Fabaceae	LC
<i>Detarium microcarpum</i> Guill. & Perr.	Fabaceae	LC
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	Fabaceae	LC
<i>Diospyros mespiliformis</i> Hochst. ex A.DC.	Ebenaceae	LC
<i>Faidherbia albida</i> (Delile) A.Chev.	Fabaceae	LC
<i>Gmelina arborea</i> Roxb.	Lamiaceae	LC
<i>Jatropha curcas</i> L.	Euphorbiaceae	LC
<i>Khaya senegalensis</i> (Desv.) A.Juss.	Meliaceae	VU
<i>Lannea acida</i> A.Rich.	Anacardiaceae	LC
<i>Lannea microcarpa</i> Engl. & K.Krause	Anacardiaceae	LC
<i>Lannea velutina</i> A.Rich.	Anacardiaceae	LC
<i>Mangifera indica</i> L.	Anacardiaceae	DD
<i>Mitragyna inermis</i> (Willd.) Kuntze	Rubiaceae	LC
<i>Parkia biglobosa</i> (Jacq.) G.Don	Fabaceae	LC
<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	Fabaceae	
<i>Prosopis africana</i> (Guill. & Perr.) Taub.	Fabaceae	LC
<i>Securidaca longipedunculata</i> Fresen.	Polygalaceae	LC
<i>Terminalia avicennioides</i> Guill. & Perr.	Combretaceae	LC
<i>Terminalia engleri</i> Gere & Boatwr.	Combretaceae	LC
<i>Terminalia macroptera</i> Guill. & Perr.	Combretaceae	LC
<i>Vitellaria paradoxa</i> C.F.Gaertn.	Sapotaceae	VU
<i>Vitex doniana</i> Sweet	Lamiaceae	LC

<i>Zanthoxylum zanthoxyloides</i> (Lam.) Zepern. & Timler	Rutaceae	LC
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Table S2: Co-occurring tree species with *Elaeis guineensis* in Western Burkina Faso

Species	Family	UICN redlist categories
<i>Azelia africana</i> Sm. ex Pers.	Fabaceae	VU
<i>Alchornea cordifolia</i> (Schumach. & Thonn.) Müll.Arg.	Euphorbiaceae	LC
<i>Anacardium occidentale</i> L.	Anacardiaceae	LC
<i>Anthocleista djalonensis</i> A.Chev.	Gentianaceae	LC
<i>Berlinia grandiflora</i> (Vahl) Hutch. & Dalziel	Fabaceae	LC
<i>Bridelia scleroneura</i> Müll.Arg.	Euphorbiaceae	LC
<i>Carapa procera</i> DC.	Meliaceae	LC
<i>Cassia sieberiana</i> DC.	Fabaceae	LC
<i>Ceiba pentandra</i> (L.) Gaertn.	Malvaceae	LC
<i>Cola cordifolia</i> (Cav.) R.Br.	Malvaceae	LC
<i>Cola laurifolia</i> Mast.	Malvaceae	LC
<i>Combretum adenogonium</i> Steud. ex A.Rich.	Combretaceae	LC
<i>Combretum collinum</i> Fresen.	Combretaceae	LC
<i>Combretum glutinosum</i> Perr. ex DC.	Combretaceae	LC
<i>Combretum molle</i> R.Br. ex G.Don	Combretaceae	LC
<i>Combretum nigricans</i> Lepr. ex Guill. & Perr.	Combretaceae	LC
<i>Cordia myxa</i> L.	Boraginaceae	LC
<i>Crateva adansonii</i> DC.	Capparaceae	LC
<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalziel	Fabaceae	LC
<i>Detarium microcarpum</i> Guill. & Perr.	Fabaceae	LC
<i>Dialium guineense</i> Willd.	Fabaceae	
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	Fabaceae	LC
<i>Diospyros mespiliformis</i> Hochst. ex A.DC.	Ebenaceae	
<i>Erythrophleum suaveolens</i> (Guill. & Perr.) Brenan	Fabaceae	LC
<i>Faidherbia albida</i> A.Chev.	Fabaceae	LC
<i>Feretia apodanthera</i> Delile	Rubiaceae	
<i>Ficus asperifolia</i> Miq.	Moraceae	LC

<i>Ficus natalensis</i> Hochst.	Moraceae	LC
<i>Ficus platyphylla</i> Delile	Moraceae	LC
<i>Ficus sur</i> Forssk.	Moraceae	LC
<i>Ficus sycomorus</i> L.	Moraceae	LC
<i>Garcinia ovalifolia</i> Oliv.	Clusiaceae	LC
<i>Gmelina arborea</i> Roxb.	Lamiaceae	LC
<i>Grewia flavescens</i> Juss.	Tiliaceae	LC
<i>Guiera senegalensis</i> J.F.Gmel.	Combretaceae	LC
<i>Gymnosporia senegalensis</i> (Lam.) Loes.	Celastraceae	LC
<i>Haematostaphis barteri</i> Hook.f.	Anacardiaceae	
<i>Holarrhena floribunda</i> (G.Don) T.Durand & Schinz	Apocynaceae	LC
<i>Isoberlinia doka</i> Craib & Stapf	Fabaceae	LC
<i>Keetia multiflora</i> (Schumach. & Thonn.) Bridson	Rubiaceae	LC
<i>Khaya senegalensis</i> (Desr.) A.Juss.	Meliaceae	VU
<i>Lannea acida</i> A.Rich.	Anacardiaceae	LC
<i>Lannea barteri</i> (Oliv.) Engl.	Anacardiaceae	LC
<i>Lannea velutina</i> A.Rich.	Anacardiaceae	LC
<i>Loeseneriella africana</i> (Willd.) N.Hallé	Celastraceae	
<i>Macrosphyra longistyla</i> (DC.) Hiern	Rubiaceae	
<i>Mangifera indica</i> L.	Anacardiaceae	DD
<i>Manilkara multinervis</i> (Baker) Dubard	Sapotaceae	
<i>Maranthes polyandra</i> (Benth.) Prance	Chrysobalanaceae	LC
<i>Mitragyna inermis</i> (Willd.) Kuntze	Rubiaceae	LC
<i>Morelia senegalensis</i> A.Rich.	Rubiaceae	LC
<i>Myrianthus serratus</i> (Trécul) Benth. & Hook.	Moraceae	LC
<i>Oncoba spinosa</i> Forssk.	Salicaceae	LC
<i>Opilia amentacea</i> Roxb.	Opiliaceae	
<i>Parinari curatellifolia</i> Planch. ex Benth.	Chrysobalanaceae	LC
<i>Parinari curatellifolia</i> Planch. ex Benth.	Chrysobalanaceae	LC
<i>Parkia biglobosa</i> (Jacq.) R.Br. ex G.Don	Fabaceae	LC
<i>Paullinia pinnata</i> L.	Sapindaceae	
<i>Pentadesma butyracea</i> Sabine	Clusiaceae	LC
<i>Pericopsis laxiflora</i> (Benth.) Meeuwen	Fabaceae	LC

<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	Fabaceae	
<i>Pouteria alnifolia</i> (Baker) Roberty	Sapotaceae	LC
<i>Prosopis africana</i> (Guill. & Perr.) Taub.	Fabaceae	LC
<i>Pterocarpus erinaceus</i> Poir.	Fabaceae	EN
<i>Pterocarpus santalinoides</i> DC.	Fabaceae	LC
<i>Raphia sudanica</i> A. Chev.	Arecaceae	NT
<i>Saba comorensis</i> (Bojer ex A.DC.) Pichon	Apocynaceae	
<i>Saba senegalensis</i> (A.DC.) Pichon	Apocynaceae	
<i>Salacia pyriformis</i> (Sabine) Steud.	Celastraceae	LC
<i>Sarcocephalus latifolius</i> (Sm.) E.A.Bruce	Rubiaceae	
<i>Synsepalum pobeguianum</i> (Pierre ex Lecomte) Aké Assi & L.Gaut.	Sapotaceae	LC
<i>Syzygium guineense</i> (Willd.) DC.	Myrtaceae	LC
<i>Tacazzea apiculata</i> Oliv.	Asclepiadaceae	
<i>Terminalia avicennioides</i> Guill. & Perr.	Combretaceae	LC
<i>Terminalia leiocarpa</i> (DC.) Guill. & Perr.	Combretaceae	LC
<i>Terminalia macroptera</i> Guill. & Perr.	Combretaceae	LC
<i>Uvaria chamae</i> P.Beauv.	Annonaceae	LC
<i>Vachellia seyal</i> Delile	Fabaceae	LC
<i>Vachellia sieberiana</i> DC.	Fabaceae	LC
<i>Vernonia colorata</i> (Willd.) Drake	Asteraceae	LC
<i>Vitellaria paradoxa</i> C.F.Gaertn.	Sapotaceae	VU
<i>Vitex doniana</i> Sweet	Lamiaceae	LC
<i>Vitex madiensis</i> Oliv.	Lamiaceae	LC
<i>Xylopia aethiopica</i> (Dunal) A.Rich.	Annonaceae	LC
<i>Zanthoxylum zanthoxyloides</i> (Lam.) Zepern. & Timler	Rutaceae	LC

Table S3: Co-occurring tree species with *Phoenix reclinata*

Scientific names	Family	UICN redlist
<i>Azzeria africana</i> Sm. ex Pers.	Leguminosae	VU
<i>Antidesma venosum</i> E.Mey. ex Tul.	Euphorbiaceae	LC
<i>Azadirachta indica</i> A.Juss.	Meliaceae	LC
<i>Berlinia grandiflora</i> Hutch. & Dalziel	Leguminosae	LC

<i>Bombax costatum</i> Pellegr. & Vuillet	Malvaceae	LC
<i>Carissa edulis</i> Vahl	Apocynaceae	
<i>Cassia sieberiana</i> DC.	Fabaceae	LC
<i>Cola cordifolia</i> [R.Br.]	Malvaceae	LC
<i>Cola laurifolia</i> Mast.	Malvaceae	LC
<i>Combretum collinum</i> Fresen.	Combretaceae	LC
<i>Combretum fragrans</i> F.Hoffm.	Combretaceae	
<i>Combretum molle</i> R.Br. ex G.Don	Combretaceae	LC
<i>Combretum nigricans</i> Leprieur ex Guill. & Perr.	Combretaceae	LC
<i>Cordia myxa</i> Forssk.	Boraginaceae	LC
<i>Crateva adansonii</i> DC.	Capparaceae	LC
<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalziel	Fabaceae	LC
<i>Diospyros mespiliformis</i> Hochst. ex A.DC.	Ebenaceae	LC
<i>Elaeis guineensis</i> Jacq.	Arecaceae	LC
<i>Feretia apodanthera</i> Delile	Rubiaceae	
<i>Ficus asperifolia</i> Miq.	Moraceae	LC
<i>Ficus capreifolia</i> Delile	Moraceae	LC
<i>Ficus platyphylla</i> Delile	Moraceae	LC
<i>Ficus sur</i> Forssk.	Moraceae	LC
<i>Ficus sycomorus</i> L.	Moraceae	LC
<i>Gardenia aqualla</i> Stapf & Hutch.	Rubiaceae	
<i>Gmelina arborea</i> Roxb. ex Sm.	Lamiaceae	LC
<i>Holarrhena floribunda</i> T.Durand & Schinz	Apocynaceae	LC
<i>Isoberlinia doka</i> Craib & Stapf	Leguminosae	LC
<i>Khaya senegalensis</i> A.Juss.	Meliaceae	VU
<i>Lannea acida</i> A.Rich.	Anacardiaceae	LC
<i>Lannea microcarpa</i> Engl. & K.Krause	Anacardiaceae	LC
<i>Lannea velutina</i> A.Rich.	Anacardiaceae	LC
<i>Lonchocarpus cyanescens</i> Benth.	Leguminosae	
<i>Mitragyna inermis</i> (Willd.) Kuntze	Rubiaceae	LC
<i>Oncoba spinosa</i> Forssk.	Flacourtiaceae	
<i>Parkia biglobosa</i> (Jacq.) R.Br. ex G.Don	Leguminosae	LC
<i>Paullinia pinnata</i> L.	Sapindaceae	

<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	Leguminosae	
<i>Pouteria alnifolia</i> (Baker) Roberty	Sapotaceae	LC
<i>Prosopis africana</i> Taub.	Leguminosae	LC
<i>Pterocarpus erinaceus</i> Poir.	Fabaceae	EN
<i>Pterocarpus santalinoides</i> L'Hér. ex DC.	Leguminosae	LC
<i>Saba senegalensis</i> (A.DC.) Pichon	Apocynaceae	
<i>Sarcocephalus latifolius</i> (Sm.) E.A.Bruce	Rubiaceae	
<i>Syzygium guineense</i> DC.	Myrtaceae	LC
<i>Tacazzea apiculata</i> Oliv.	Apocynaceae	
<i>Tamarindus indica</i> L.	Leguminosae	LC
<i>Tectona grandis</i> L.f.	Lamiaceae	
<i>Terminalia avicennioides</i> Guill. & Perr.	Combretaceae	LC
<i>Terminalia laxiflora</i> Engl.	Combretaceae	LC
<i>Terminalia macroptera</i> Guill. & Perr.	Combretaceae	LC
<i>Terminalia schimperi</i> (Hochst. Ex Hutch. & Dalziel) Gere & Boatwr.	Combretaceae	LC
<i>Vachellia seyal</i> (Delile) P.J.H.Hurter	Leguminosae	LC
<i>Vachellia sieberiana</i> (DC.) Kyal. & Boatwr.	Leguminosae	LC
<i>Vernonia colorata</i> Drake	Asteraceae	LC
<i>Vitellaria paradoxa</i> C.F.Gaertn.	Sapotaceae	VU
<i>Vitex doniana</i> Sweet	Lamiaceae	LC
<i>Zanthoxylum zanthoxyloides</i> (Lam.) Zepern. & Timler	Rutaceae	LC

Table S3: Co-occurring tree species with *Raphia ssp* in Western Burkina Faso

Species	Family	UICN redlist
<i>Afzelia africana</i> Sm. ex Pers.	Fabaceae	VU
<i>Alchornea cordifolia</i> (Schumach. & Thonn.)	Euphorbiaceae	LC
<i>Anonna senegalensis</i> Pers.	Anonnaceae	LC
<i>Anthocleista djalonensis</i> A.Chev.	Loganiaceae	LC
<i>Azadirachta indica</i> A. Juss	Meliaceae	LC
<i>Berlinia grandiflora</i> (Vahl) Hutch. & Dalziel	Fabaceae	
<i>Breonadia salicina</i> (Vahl) Hepper & J.R.I.Wood	Rubiaceae	LC
<i>Bridelia ferruginea</i> Benth	Phyllantaceae	LC

<i>Carapa procera</i> DC.	Meliaceae	LC
<i>Cassia sieberiana</i> DC.	Fabaceae	LC
<i>Ceiba pentandra</i> (L.) Gaertn.	Malvaceae	LC
<i>Cola cordifolia</i> (Cav.) R.Br.	Malvaceae	LC
<i>Cola laurifolia</i> Mast.	Malvaceae	LC
<i>Combretum collinum</i> Fresn.	Combretaceae	LC
<i>Cordia myxa</i> L.	Boraginaceae	LC
<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalziel	Fabaceae	LC
<i>Detarium microcarpum</i> Guill. & Perr.	Fabaceae	LC
<i>Dialium guinnense</i> Willd.	Fabaceae	LC
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	Fabaceae	LC
<i>Diospyros mespiliformis</i> Hochst. ex A.DC.	Ebenaceae	LC
<i>Elaeis guineensis</i> Jacq.	Arecaceae	LC
<i>Eucalyptus camaldulensis</i> Dehnh.	Myrtaceae	NT
<i>Faidherbia albida</i> (Delile) A.Chev.	Fabaceae	LC
<i>Ficus sur</i> Forssk.	Moraceae	LC
<i>Gmelina arborea</i> Roxb.	Lamiaceae	LC
<i>Haematotaphis barteri</i> Hook.f.	Anacardiaceae	
<i>Holarrhena floribunda</i> (G.Don) T.Durand & Schinz	Apocynceae	
<i>Isoberlinia doka</i> Craib & Stapf	Fabaceae	LC
<i>Isoberlinia tomentosa</i> (Harms) Craib & Stapf	Fabaceae	LC
<i>Khaya senegalensis</i> (Desr.) A.Juss.	Meliaceae	VU
<i>Lannea acida</i> A. Rich	Anacardiaceae	LC
<i>Lannea barteri</i> (Oliv.) Engl.	Anacardiaceae	LC
<i>Lannea microcarpa</i> Engl. & K.Krause	Anacardiaceae	LC
<i>Lannea velutina</i> A. Rich	Anacardiaceae	LC
<i>Lophira lanceolata</i> Tiegh. ex Keay	Ochnaceae	LC
<i>Macrosphyra longistyla</i> (DC.) Hiern	Rubiaceae	
<i>Mangifera indica</i> L.	Anacardiaceae	DD
<i>Manilkara multinervis</i> (Baker) Dubard (Baker) Dubard	Sapotaceae	
<i>Maranthes polyandra</i> (Benth.) Prance	Chrysobalanaceae	LC
<i>Mitragyna inermis</i> (Willd.) Kuntze	Rubiaceae	LC
<i>Parinari curatellifolia</i> Planch. ex Benth.	Chrysobalanaceae	LC

<i>Parkia biglobosa</i> (Jacq.) G.Don	Fabaceae	LC
<i>Pentadesma butyracea</i> Sabine	Clusiaceae	LC
<i>Pericopsis laxiflora</i> (Benth.) Meeuwen	Fabaceae	LC
<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	Fabaceae	
<i>Prosopis africana</i> (Guill. & Perr.) Taub.	Fabaceae	LC
<i>Psidium guajava</i> L.	Myrtaceae	LC
<i>Pterocarpus lucens</i> Lepr. ex Guill. & Perr.	Fabaceae	LC
<i>Saba senegalensis</i> (A.DC.) Pichon	Apocynaceae	
<i>Sarcocephalus latifolius</i> (Sm.) E.A.Bruce	Rubiaceae	LC
<i>Strychnos usambarensis</i> Gilg	Loganiaceae	
<i>Syzygium guineense</i> (Willd.) DC.	Myrtaceae	LC
<i>Tacazzea apiculata</i> Oliv.	Apocynceae	
<i>Tectona grandis</i> L.f.	Lamiaceae	
<i>Terminalia avicennioides</i> Guill. & Perr.	Combretaceae	
<i>Terminalia engleri</i> Gere & Boatwr.	Combretaceae	LC
<i>Terminalia laxiflora</i> Engl. & Diels	Combretaceae	LC
<i>Terminalia macroptera</i> Guill. & Perr	Combretaceae	LC
<i>Terminalia schimperi</i> (Hochst. ex Hutch. & Dalziel)	Combretaceae	LC
Gere & Boatwr		
<i>Uvaria chamae</i> P.Beauv.	Annonaceae	LC
<i>Vernonia colorata</i> (Willd.) Drake	Asteraceae	LC
<i>Vitellaria paradoxa</i> C.F.Gaertn.	Sapotaceae	VU
<i>Vitex doniana</i> Sweet	Lamiaceae	LC
<i>Xylopi aethiopica</i> (Dunal) A.Rich.	Annonaceae	LC
<i>Zanthoxylum zanthoxyloides</i> (Lam.) Zepern. & Timler	Rutaceae	LC

Appendix 4: VIF of variables used in the MaxEnt models

	Variables	VIF
Factor	layers	
Hydrography	Drainage density	1.022065
	bio11	5.103264
	bio14	5.267787
	bio17	9.187422
bioclimatic	bio18	2.347915
	bio19	4.765914
	bio3	4.117239
	bio8	4.398769
	bio9	8.409851
	Bulk_15_30	6.767422
	CEC_15_30	1.801224
	Clay_0_5	4.034108
	clay_15_30	4.347648
Soil	Nitrogen_0_5	4.822792
	nitrogen_5_15	6.220039
	pH_15_30	6.811716
	silt_0_5	3.381462
	SOC_0_5	5.684843
	SOC_15_30	3.138427
Topography	TPI	1.052116

PUBLICATIONS

PUBLICATION I



REVIEW

Current knowledge and future directions on West African wild palms: an analytical review for its conservation and domestication in the context of climate change and human pressures

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Abstract Palms constitute vital species for local people's well-being, especially in West Africa. This analytic review aims at providing an overview of West African palms flora diversity, uses, ecology, and conservation. Scientific papers related to palms in West Africa were searched on electronic databases *Google Scholar*, *Web of Science*, and general web search on *Google* using the names of palms occurring in West Africa. From 108 scientific articles, we extracted relevant information after a critical reading. Papers were published between 1930 and 2019 and most of the studies focused on biochemistry, ethnobotany, and population structure. We identify in the literature 25 species belonging to 12 genera, 32% of them growing in dry areas. Five growth forms were identified among West African palms species. Erect

and solitary stem forms were the most representative. Concerning leaf forms, most west African palms (84%) have pinnate leaves. Sexual systems of palms were represented by monoecy, dioecy, and hermaphroditism, with the predominance of monoecy (44%). The pleioanthic species are the most represented reproductive feature (76%) and only *Raphia* palms are hapaxanthic. As far as uses are concerned, there is a link between used parts and uses categories. According to the relative importance index, the four first palm species in West Africa, namely *Borassus aethiopum* Mart., *Elaeis guineensis* Jacq., *Borassus akeassii* Bayton, Ouedr. & Guinko, and *Hyphaene thebaica* Mart. grow in dry areas. Rattans have a low relative index value due to their non-consumed organs. Critical analysis was presented in the focus of population structure, distribution, and propagation aspects. The review highlights a research gap in carbon sequestration, phenology, and called for more research effort in semi-arid and arid areas. Such investigations would help in planning better sustainable management and conservation of palm in West Africa.

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Keywords Diversity · Ethnobotany · Population structure · Distribution · Arecaceae · Arid areas

Introduction

The palms (*Arecaceae*) comprise 181 genera and approximately 2600 species belonging to five sub-families namely *Calamoideae*, *Nypoideae*, *Coryphoideae*, *Ceroxyloideae* and *Arecoideae* (Baker and Dransfield 2016) occurring in tropical and subtropical regions of the world (Eiserhardt et al. 2011). In Africa, palms are less diversified compared to other large regions (Stauffer et al. 2017; Baker and Couvreur 2013; Couvreur 2015) and its risks of extinction are low at a continental scale (Cosiaux et al. 2018). In the contrary, at a local scale, they are threatened by overexploitation of their products (Mollet et al. 2000; Ahissou et al. 2017) and climate variability (Blach-Overgaard et al. 2015). For instance, West African palm species are exposed to multifactorial threats including climate change and 90% are not cultivated (Stauffer et al. 2017).

In West Africa, palm resources rank among the most appreciated Non-Timber Forest Products and contribute significantly to household incomes, particularly in the rural areas (Stauffer et al. 2017). Indeed, palms are important multipurpose trees in rural communities (Camara et al. 2017; Guinko and Ouédraogo 2005; Yaméogo et al. 2008), with all the parts being used for several purposes including food, traditional medicine, construction and trade (Ouattara et al. 2015). Besides, palms populations produce high amount of biomass in the frond and the stem which could allow them to contribute to climate change mitigation through carbon sequestration (Aholoukpè et al. 2013, 2018). Although the importance of palms for west African populations is undisputed, we still lack fundamental baseline information for the development of more responsible management practices. This includes a basic understanding of biology, taxonomy, genetic diversity, ecology, ethnobotany, applied harvesting practices and management techniques of palms. Regarding the substantial body of knowledge published on palms in West Africa, there is a need for capitalizing the available information to identify knowledge gaps and direct further research. Previous reviews of west African palms focused on the genus *Raphia* (Obahiagbon 2009; Russell 1965). Recently, Mogue Kamga et al. (2020) reviewed the uses and cultural importance of the *Raphia*'s species in their distributional range. Stauffer et al. (2017) presented a floristic update of African palms and

concluded to the presence of 39 species belonging to 14 genera in West Africa (Stauffer et al. 2017).

Here we carried out an analytical review to present an up-to-date overview of studies on diversity, uses, ecology and conservation of palms in West Africa. Specifically, this review aimed at (1) exploring the diversity and importance of palms species studied in West Africa; (2) summarizing the scope of the available literature; and (3) presenting key findings, knowledge gaps and prospects. We expect to provide synthesized information that would guide palms' domestication and conservation actions in West Africa.

Material and methods

Literature survey

We gathered scientific papers on electronic databases *Google Scholar*, *Web Of Science*, and general search web on *Google* by using a combination of generic and scientific names of palm trees occurring in West Africa (Stauffer et al. 2017). The checklist of palm species occurring in West Africa (following Stauffer et al. 2017) has been used to search literature on the different databases with a species-specific approach. Any article published in a peer-reviewed journal and having its title or keywords list, the name of a palm is included in this review. The articles that do not clearly specify the palm's name or the detailed description of the species are excluded from this study (e.g. Bi and Kouakou 2004; Idohou et al. 2015a). We extracted information from 108 articles, which carried out a study on palms published since 1930 and focused on many research fields to make a database. Besides, the reviews of literature and the studies on a global scale on palms (ex. Whole Africa) were considered to complete the information presented here (n = 8). All included articles were critically read.

Data extraction and analysis

Each species' scientific name, the publication date, the country, the study category of each article, and the different reported uses are extracted in each selected article. Some important biological traits of each palm species (leaf form, reproductive strategy, growth form) and their presence in dry areas are reported

based on literature (Arbonnier 2009; Stauffer et al. 2014) and our fieldwork experience. The biological diversity of the palm species is estimated by the number of species, the number of genera, and the proportion of species belonging to every subfamily or having a particular biological trait.

The uses' information is extracted only from articles focusing on an ethnobotanical survey to report palms' uses in different communities. The data extracted concerned the palm part used and the uses category for each reported palm. The frequencies of the plant parts according to the used categories are calculated. Besides, the relative importance index (RI) of each palm species is calculated according to the formula of Tardio and Pardo-De-Santayan (2008) adapted by Zizka et al. (2015):

$$RI = \frac{[\max(FRC) + \max(RNU)]}{2}$$

With: RFC = relative frequency of citation (Frequency of citation/Number of References), RNU = Relative number of use-categories (Number of uses/Maximum number of uses of a species). The relative index of importance (RI) is calculated to rank the palm species according to their importance.

Correspondence analysis was computed to appreciate the link between plant parts and use categories of palms through the package 'FactorMiner' in R program 3.6.1 (R Core Team 2019).

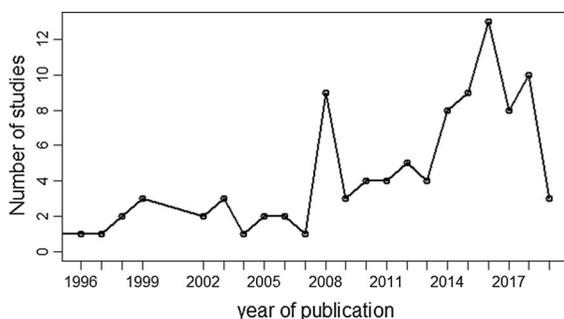


Fig. 1 Temporal trends of publication on palms in West Africa from 1996 to 2019

Results

Temporal and spatial trends and focus of the studies

The number of papers on palms in West Africa increased generally, but with some fluctuations (Fig. 1). About 73.83% of the papers included in our review were published from 2008 to 2019. The highest number of papers ($n = 13$) was recorded in 2016 while the lowest ($n = 1$) in many years before 2007.

In west Africa, the articles on palms come mostly from coastal countries as Nigeria, Benin, Ghana, and Cote d'Ivoire (Fig. 2a). The Sahel is relatively less investigated, with Burkina Faso holding the high number of publications in that region with 16 papers. In contrast, no publication has been reported in Mali and Mauritania, and only four publications from Niger (Fig. 2a). Moreover, the number of species reported is few in the Sahel than in the coastal countries (Fig. 2b). For instance, only two species are studied in Burkina Faso and Niger, while Stauffer et al. (2017) reported 8 and 7 species in these countries, respectively.

Most publications focused on ethnobotany, and to some extent, on biochemistry and population structure (Fig. 3). As compared to ethnobotany, there were fewer studies on distribution, and other fields as Biomass estimation, phenology and genetics (Fig. 3).

Biological diversity of palms in West Africa

From this literature survey, 25 species belonging to 12 genera and four subfamilies of palms were reported in West Africa (Table 1). Amongst the identified palm species, 32% grow in dry areas (Table 1), and 76% are pleonanthic (Fig. 4d). The hapaxanthic are made up of *Raphia*. Five growth forms and three leaf forms were identified with the dominance of erect and solitary stem (Fig. 4c) and pinnate leaves (Fig. 4a). The sexual pattern is dominated by monoecy (Fig. 4b).

Relative Importance of palms

Our findings highlighted the importance of 20 palm species over 25 identified in this review (Table 2). The relative importance index (RI) of each palm species, comprising between 0.09 and 0.80, was used to rank the species according to their usefulness in West Africa (Table 2). We do not report the RI of *R. regalis*

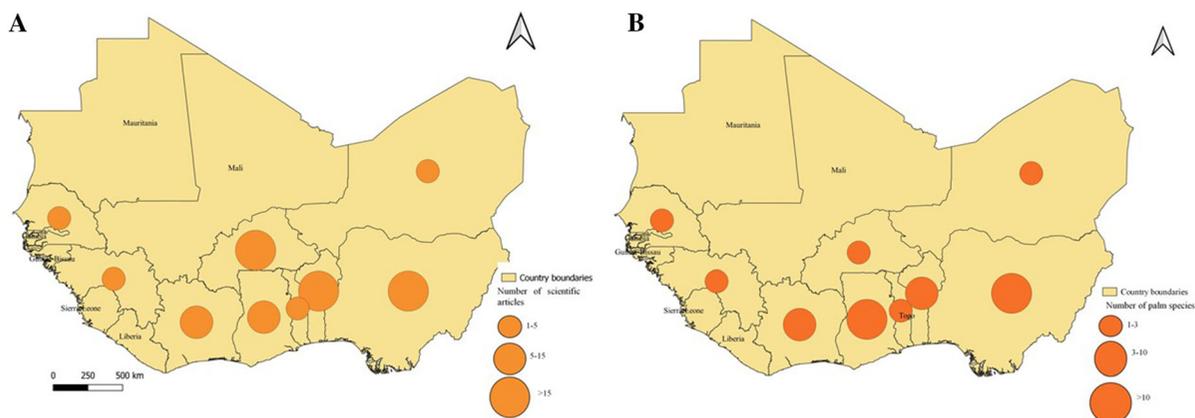


Fig. 2 a Spatial distribution of number of publications per country, b Spatial distribution of species recorded

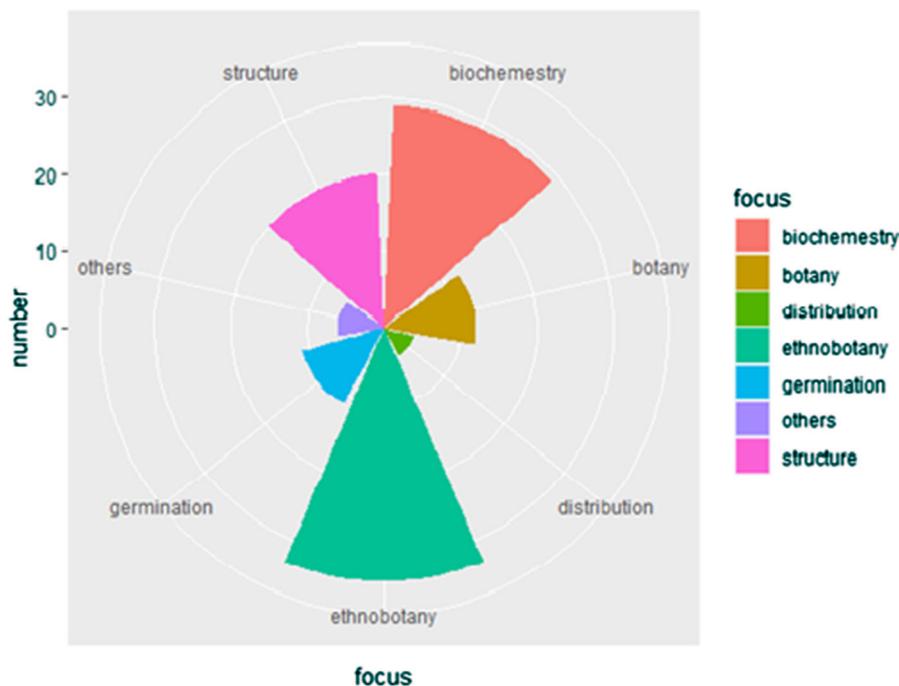


Fig. 3 Number of studies on palms following focus in West Africa

Becc., *Raphia farinifera* (Gaertn.) Hyl., *Raphia vinifera* P. Beauv. and *Phoenix dactylifera* L. because few articles reported their uses in the west African palms' literature. Hence, *R. vinifera* was confused for a long time to *Raphia mannii* (Mogue Kamga et al. 2019). *Borassus aethiopum* Mart., *Elaeis guineensis* Jacq., *Hyphaene thebaica* Mart. and *Calamus deeratus* G. Mann & H. Wendl. were the most important palms in West Africa. At the same time, the rattans (*Eremospatha dransfieldii* Sunderl., *Eremospatha*

hookerii (G. Mann & H. Wendl.) H. Wendl. and *Laccosperma opacum* Drude), *Phoenix reclinata* Jacq. and *Sclerosperma profizianum* Valk. & Sunderl. possessed low RI (Table 2).

Usefulness of palm parts in different categories

The cumulative percentage of variances derived from the correspondence analysis (CA) revealed that the first two dimensions explain 57.41% and 30.48% of

Table 1 Diversity of palms and their occurrence in dry areas in West Africa based on literature review

Species	Tribes	Subfamily	Occurrence in dry regions
<i>Borassus aethiopum</i> Mart	Borasseae	Coryphoideae	Yes
<i>Borassus akeassii</i> Bayton, Ouedr. & Guinko	Borasseae	Coryphoideae	Yes
<i>Calamus deerratus</i> G. Mann & H. Wendl	Calameae	Calamoideae	
<i>Cocos nucifera</i> L	Cocoseae	Arecoideae	Yes
<i>Elaeis guineensis</i> Jacq	Cocoseae	Arecoideae	Yes
<i>Eremospatha dransfieldii</i> Sunderl	Lepidocaryeae	Calamoideae	
<i>Eremospatha hookeri</i> (G. Mann & H. Wendl.) H. Wendl	Lepidocaryeae	Calamoideae	
<i>Eremospatha macrocarpa</i> H. Wendl	Lepidocaryeae	Calamoideae	
<i>Hyphaene guineensis</i> Schumach. & Thonn	Borasseae	Coryphoideae	
<i>Hyphaene thebaica</i> (L.) Mart	Borasseae	Coryphoideae	Yes
<i>Laccosperma acutiflorum</i> (Becc.) J. Dransf	Lepidocaryeae	Calamoideae	
<i>Laccosperma leave</i> (G. Mann & H. Wendl.) Kuntze	Lepidocaryeae	Calamoideae	
<i>Laccosperma opacum</i> Drude	Lepidocaryeae	Calamoideae	
<i>Laccosperma secundiflorum</i> (P. Beauv.) Kuntze	Lepidocaryeae	Calamoideae	
<i>Nypa fructicans</i> Wurmb		Nypoideae	
<i>Oncocalamus mannii</i> (H. Wendl.) H. wendl	Lepidocaryeae	Calamoideae	
<i>Phoenix dactylifera</i> L	Phoeniceae	Coryphoideae	Yes
<i>Phoenix reclinata</i> Jacq	Phoeniceae	Coryphoideae	Yes
<i>Raphia hookeri</i> G. Mann. & H. Wendl	Lepidocaryeae	Calamoideae	
<i>Raphia palma-pinus</i> (Gaertn.) Hutch	Lepidocaryeae	Calamoideae	
<i>Raphia sudanica</i> A. Chev	Lepidocaryeae	Calamoideae	Yes
<i>Raphia vinifera</i> P. Beauv	Lepidocaryeae	Calamoideae	
<i>Raphia farinifera</i> (Gaertn.) Hyl	Lepidocaryeae	Calamoideae	
<i>Raphia regalis</i> Becc	Lepidocaryeae	Calamoideae	
<i>Sclerosperma profizianum</i> Valk. & Sunderl	Sclerospermeae	Arecoideae	

the total variation (Fig. 5). Therefore, these axes explaining 87.89% of the total variation were used to describe the link between palms' parts and the uses categories. The correspondence analysis sustains that flowers, resin, and roots are mainly used in traditional medicine. In contrast, fruit, sap and hypocotyl are used in food and rites categories, and leaves and stipe are used as materials for building and handicrafts (Fig. 4).

Discussion

Biological diversity of palms

The number of species reported in this review is lower than that reported in previous studies (Stauffer et al. 2017). According to Stauffer et al. (2017), 39 species

belonging to 13 genera of palms are present in West Africa, confirming that palms are under-investigated in this region. However, *E. dransfieldii*, *Hyphaene macrosperma* and *Oncocalamus wrightianus* were reported as endemic palm species in West Africa (Stauffer et al. 2017). No study was interested in the two last cited palm species. *H. macrosperma* is one of the eight recognised species of *Hyphaene*, extremely poorly known and for which type material is either very scant or completely lacking (Stauffer et al. 2018). *E. dransfieldii* grows only in the tropical rain forest in Ghana, Ivory Coast, and Sierra Leone (Cosiaux et al. 2018; Ouattara et al. 2015). It is an endangered rattan palm because of habitat loss and over-exploitation of stems (Cosiaux et al. 2018). It is crucial to assess the conservation state of these species due to their endemism in West Africa. Also, the genus *Podococcus*

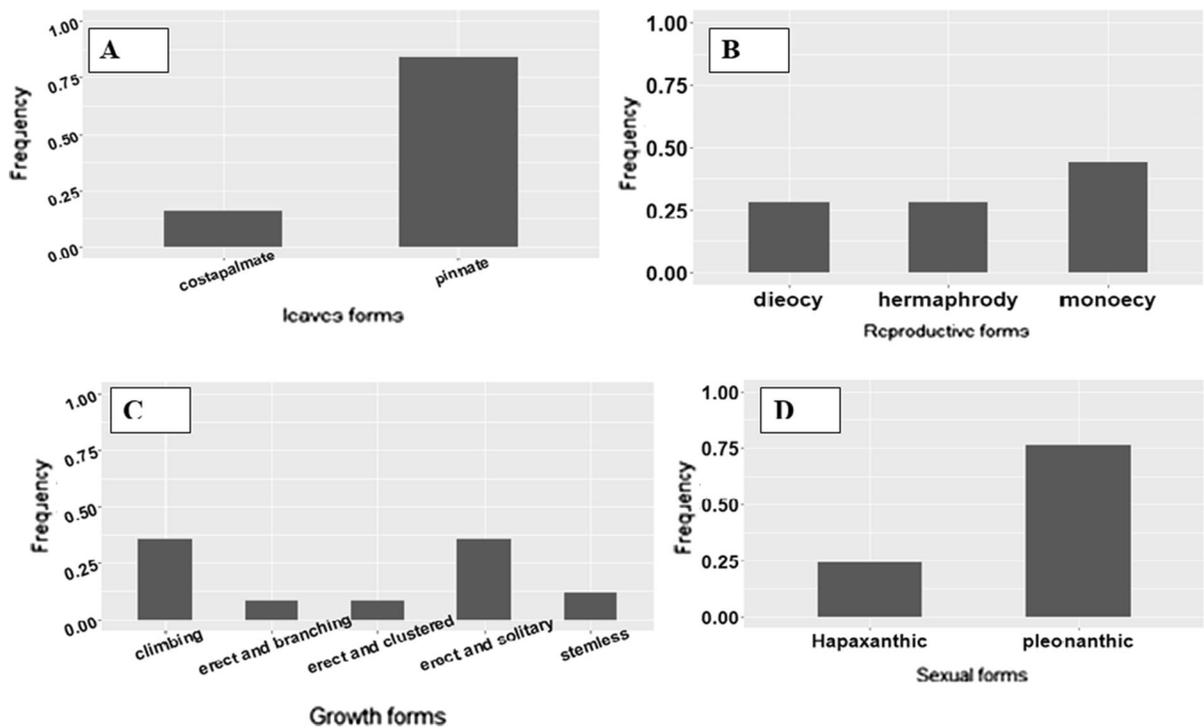


Fig. 4 Biological diversity of palms in West Africa: **a** Leaves forms, **b** Reproductive types, **c** Growth forms and **d** Sexual patterns

Table 2 Palm species in West Africa ranked using the Relative importance index

Species	RNU	RFC	RI	Rank
<i>Borassus aethiopum</i> Mart	6	0.375	0.80357143	1
<i>Elaeis guineensis</i> Jacq	7	0.05	0.55	2
<i>Borassus akeassii</i> Bayton, Ouedr. & Guinko	5	0.05	0.40714286	3
<i>Hyphaene thebaica</i> Mart	5	0.05	0.40714286	4
<i>Calamus deeratus</i> G. Mann & H. Wendl	4	0.05	0.26428571	5
<i>Eremospatha macrocarpa</i> H. Wendl	3	0.05	0.26428571	6
<i>Laccosperma secundiflorum</i> (P. Beauv.) Kuntze	3	0.05	0.26428571	7
<i>Nypa fruticans</i> Wurm	3	0.05	0.23928571	8
<i>Laccosperma acutiflorum</i> (Becc.) J. Dransf	3	0.025	0.23928571	9
<i>Raphia hookeri</i> G. Mann. & H. Wendl	3	0.025	0.23928571	10
<i>Raphia sudanica</i> A. chev	2	0.05	0.19285714	11
<i>Cocos nucifera</i> L	2	0.025	0.16785714	12
<i>Hyphaene guineensis</i> Schumach. & Thonn.	2	0.025	0.16785714	13
<i>Oncocalamus manni</i> (H. Wendl.) H. wendl	2	0.025	0.16785714	14
<i>Raphia palma-pinus</i> (Gaertn.) Hutch	2	0.025	0.16785714	15
<i>Eremospatha dransfieldii</i> Sunderl	1	0.025	0.09642857	16
<i>Eremospatha hookerii</i> (G. Mann & H. Wendl.) H. Wendl	1	0.025	0.09642857	17
<i>Laccosperma opacum</i> Drude	1	0.025	0.09642857	18
<i>Phoenix reclinata</i> Jacq	1	0.025	0.09642857	19
<i>Sclerosperma profizianum</i> Valk. & Sunderl	1	0.025	0.09642857	20

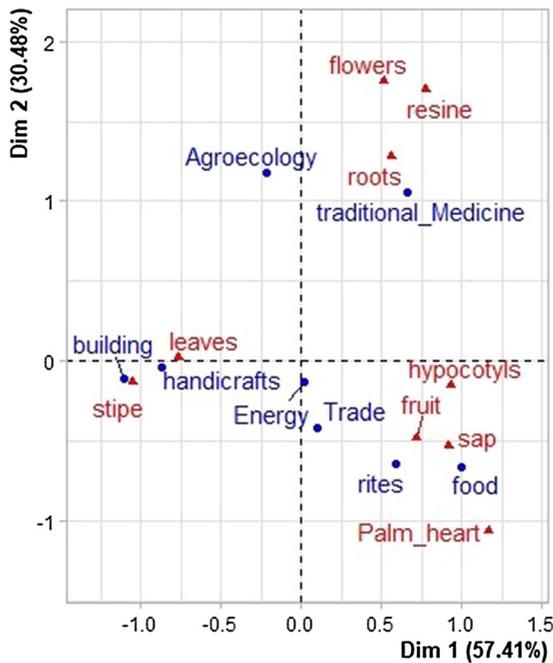


Fig. 5 Relationship between used parts and uses categories of west African palm species

was not reported from our literature survey, even if *Podococcus barteri* barely reach West Africa.

The palm family presents one of the most important growth form varieties in the plant kingdom. We identified five growth forms in West African palms in which erect, and solitary stem are the most frequent (Fig. 4). All species occurring in dry areas (32%) have an erect stem that makes this growth form the most adapted growth form in a dry area. One species, namely *H. thebaica* represented the erect and branching stem. The other growth forms constitute palms that grow exclusively in wet areas. Regarding leaves forms, only the genera *Borassus* and *Hyphaene* representing 16% of species, have costa-palmate leaves. The reproduction strategies are dominated by monoecy, while hermaphroditism and dioecy are less represented. These results corroborate the findings of Stauffer et al. (2017), who demonstrated the dominance of pinnate leaves and monoecy in African palm flora. The morphological diversity of palm was assessed for *B. aethiopicum* in Benin (Salako et al. 2019a) and *H. thebaica* in Benin (Idohou et al. 2015b). Salako et al. (2019a) identified five morphotypes of *B. aethiopicum* based on fruits. They concluded that

environmental factors are not the major drivers of morphological diversity while Idohou et al. (2015b) found three morphotypes for *H. thebaica* in Benin based on fruit characteristics.

Relative importance of palm species

The four first palm species ranked by RI in West Africa, namely *B. aethiopicum*, *E. guineensis*, *B. akeassii*, and *H. thebaica*, naturally grow in a dry area. The socio-economic importance of these species has already been shown by many ethnobotanical surveys in West African countries (Camara et al. 2017; Salako et al. 2018a; Yaméogo et al. 2008). Before its description in 2006 (Bayton et al. 2006), *B. akeassii* has been confused to *B. aethiopicum* or *Borassus flabellifer* (Ake Assi and Guinko 1996; Ouédraogo et al. 2002). However, these two species have been almost used in the same way by local people in West Africa, and their RI should be treated with caution.

No RI was reported for *P. dactylifera*, *R. vinifera*, *R. farinifera* and *R. regalis* suggesting lower importance of these species in West African palm literature. The RI calculated is dependent to the number of studies and the number of uses reported. While a high number of studies mentioning use of a species and a large number of different use categories can be interpreted as indicator of species importance, a low number of uses or references does not necessarily mean that a species is not of high value for specific purposes or on a local scale (Zizka et al. 2015). The date palm *P. dactylifera* is a cultivated palm in west Africa, and its uses are not documented in West Africa (Ouattara et al. 2015). The date palm is believed to have been domesticated in the Mesopotamian region more than 6,000 years ago, and is among the oldest cultivated tree crops. In desert oases of small-scale agriculture, where woody material is scarce, the date palm provides leaves for shading, thatching and weaving into baskets, mats, rope, hats etc. (Johnson 1998). Midribs and petioles have utility in construction and fencing. The entire date palm and date palm leaves have symbolic and ritual significance in major religions.

The non-report of the uses of *R. vinifera* in the literature could be explained by its long misidentification (Mogue Kamga et al. 2019). It has been recently reported that *R. hookeri* and *R. vinifera* are among the most exploited *Raphia* in Africa (Mogue Kamga et al.

2020). The leaves of *R. vinifera* and *R. regalis* are used in construction, and their fruits are eaten (Mogue Kamga et al. 2020). The epidermis of young leaflets yields raffia fibre, which is locally used for making baskets, mats, hats, bags, ropes, hammocks and ceremonial costumes. The Kuba people in DR Congo are well known for weaving beautiful raffia cloth used, such as ceremonial dance skirts and embroidered cloth panels for court rituals. In Europe, raffia fibre is used as tying material for horticulture and handicrafts. The leaves are highly valued for thatching. The petiole and rachis of the leaves of *Raphia vinifera* are often used as poles and rafters and for making furniture items such as stools, bedsteads and benches. Split midribs are woven into floor-mats.

In addition, rattans have low relative index value due to the absence of consumed organs. Almost half of species in the rattan palm genus *Eremospatha* are poorly known and require further collecting efforts (Stauffer et al. 2017), which could also justify their low RI reported in our study. Rattan provides canes for flogging, ropes for tying hides to drum frames, fish traps, and loop for climbing palm trees (Babajide and Bamidele 2004; Ouattara et al. 2015).

The usefulness of palm parts

Hypocotyls

Hypocotyls are a palm part mostly used in human food, in traditional medicine, and trade. Indeed, hypocotyls of *B. aethiopum* are boiled and consumed in many parts of West African regions (Guinko and Ouédraogo 2005; Salako et al. 2018a; Zongo et al. 2018). In traditional medicine, they are used to treat sexual weakness (Gbesso et al. 2016). In the east of Burkina Faso, the boiled hypocotyls are sold for 25FCFA (0.04USD) each (Kansole 2016). In contrast, it ranges between 50–150 FCFA (0.07–0.25 €) in Benin (Michon et al. 2018), contributing enormously to local people's income.

Fruit

The fruit is used in six categories: food, handicraft, traditional medicine, energy, trade and rites & ceremonies. The pulp of many palms as *B. aethiopum*, *B. akeassii*, *H. thebaica*, *E. guineensis* and *R. sudanica* are consumed raw or cooked (Camara et al. 2017;

Salako et al. 2018a; Yaméogo et al. 2008). The flours of *B. aethiopum* had a high amount of crude fibre, carbohydrates, energy, relatively high water absorption capacity, swelling power, oil absorption capacity, and good flowability (Abe-Inge et al. 2018). In craft, the fruit hull was used as a substitute for the corrozo and employed to manufacture the buttons (Bellouard 1950). In Energy, *E. guineensis* pulp was used to produce fire (Camara et al. 2017). *Elaeis guineensis* seeds were used as sacred objects in rituals involved in oracles, which helped to discover the cause of disease or other calamities, for example, the Afan oracle of the Ewe in Togo, or the Ifa oracle of the Yorubas and Fa oracle of the Fon in Benin (Gruca et al. 2014).

Sap

The sap is one of the most important products from palms (Mogue Kamga et al. 2020; Obahiagbon 2009). In general, the sap is extracted from several palm species in West Africa as *Borassus aethiopum*, *B. akeassii*, *E. guineensis*, *Phoenix reclinata*, *Raphia sudanica*, *R. hookeri* and *R. vinifera* (Chevalier 1930; Mollet et al. 2000; Ouattara et al. 2015; Mogue Kamga et al. 2020). For Bellouard (1950), *Borassus*' sap is the best one, and this palm produces on average 100 L of sap per year. The sap was used for beverages, medicine, ritual, and trading. The sap/palm wine is useful in curing jaundice, measles, and flow of mammalian glands in nursing mothers (Obahiagbon 2009). The fresh sap of *B. aethiopum* contains less alcohol and some sugar (e.g. Sucrose, glucose and fructose), vitamin C, and minerals such as calcium, potassium, magnesium, and ammonium (Zongo et al. 2019). Thus, this sap presents a good nutritional value, and its consumption can improve the daily food intake of the rural population. The drinking of palm wine signals the start and end of all social activities undertaken by 50 million southern Nigeria people (Obahiagbon 2009). Sap can be use as vehicle for other medicines. In the trading, even if sap price varies according to the season, sap extraction seems to be the most remunerative activity compared to crafts (Yaméogo et al. 2008).

Leaves and stem

Palm leaves are widely used in handicrafts and construction (Guinko and Ouédraogo 2005; Michon

et al. 2018; Salako et al. 2018a; Yaméogo et al. 2008; Zongo et al. 2018). For example, in Ghana, the petioles of *Raphia* are used to establish the dwelling's wall as well as the framework to the roof (Ouattara et al. 2015). In Cote d'Ivoire, the petioles of *B. aethiopum* are employed to build fences of fields (Portères 1964). In Agroforestry, leaves of *E. guineensis* are burnt and used as fertilizer (Camara et al. 2017). In medicine, young leaves of *B. akeassii* are used to treat earaches beginning of deafness (Yaméogo et al. 2008).

Palm stem are mostly used as material for construction and crafts. In construction, erect stems of males *Borassus* were mostly used to build house (Salako et al. 2018a; Yaméogo et al. 2008). Male individuals' preference was justified by the fullness and resistance of trunk non-attacked by pests (Chevalier 1930).

Flowers, resin, roots and palm heart

Palms flowers, resin and roots are used specifically in traditional medicine. The flower-bearing branches or rachillae of the staminate inflorescences of *B. aethiopum* are used to treat venereal diseases (Sambou et al. 1992). In Ghana, the Akan burn inflorescences from *Elaeis guineensis*, so the smoke drives away evil spirits (Gruca et al. 2014). Uses of resin are reported by few studies (Gschladt 1972; Yaméogo et al. 2008). The resin of *B. aethiopum* is used to delay children's dental thrust (Gschladt 1972; Yaméogo et al. 2008). *B. aethiopum* roots uses in medicine to treat malaria are reported by several ethnobotany survey (Salako et al. 2018a; Zongo et al. 2018) and confirmed by a pharmacological approach (Gruca et al. 2015). They are also used to treat sexual weakness (Gbesso et al. 2016).

Palm heart is used only in food. Indeed, palm heart of *B. aethiopum* and *H. thebaica* were rarely consumed by local people (Giffard 1966; Gschladt 1972).

Population structure of palm in West Africa

Palms stand structure is driven by natural and anthropogenic pressures which contribute to threaten palm populations in West Africa. It is evident that the extraction of non-timber forest products affects the palms' conservation. Indeed, the exploitation of palm heart, stem, roots, and hypocotyls can effectively lead to the palm's death. However, the overexploitation of

organs that can immediately lead to palm death can affect the palm population's conservation. Indeed, it is proved that the fruit exploitation influences the stand structure and regeneration potential of *B. aethiopum* (Ahissou et al. 2017). Sap extraction harms the structure of *E. guineensis*, *B. aethiopum* and *R. sudanica* in Cote d'Ivoire (Mollet et al. 2000). Nevertheless, sap extraction of *B. akeassii* in Burkina Faso is done by a sustainable practice that maintains the tree alive and exploitable for long years (Guinko and Ouédraogo 2005). It is important to document this practice to promote sustainable exploitation of sap in the palm population.

Other scientists were interested in the environmental patterns of the palm population's structure. Most of them studied the spatial pattern of palms (Barot et al. 1999a; Idohou et al. 2016a; Salako et al. 2018b). They mostly found that palms have an aggregative spatiality (Barot et al. 1999b; Salako et al. 2018b) with intraspecific competition between stages (Barot and Gignoux 2003) for *B. aethiopum*. However, there is no association between doum palm and other species (Idohou et al. 2016a), suggesting that heterospecific tree density may negatively influence palm structure. Salako et al. (2015; 2017) showed that elephants' influence on *B. aethiopum* structure in Benin causes a critical issue of conservation in protected areas. Besides, land use types and agricultural systems influence palms structure (Idohou et al. 2016a, b, c; Madelaine et al. 2008). For instance, the density of *B. aethiopum* was higher in protected areas than in agrosystems in Benin (Salako et al. 2019b). The influence of climate on palms structure has been sustained by many publications (Idohou et al. 2016a; Salako et al. 2018b). However, soil moisture and soil temperature affect the spatial abundance of *B. aethiopum* at Lamto Forest in Cote d'Ivoire (Douffi et al. 2018). In opposite, Kouassi et al. (2008) found no influence of soil moisture on rattans densities. That may be explained by the different ecology of those palm species. *B. aethiopum* with palmate leaves and erect solitary stem occurs in dry area although rattans with pinnate leaves and climbing growth form are mostly confined in swampy areas and occur in rivers border.

Impact of climate change on the distribution of palms

At the continental scale, climate constitutes the only strong environmental control of palm species distributions in Africa (Blach-Overgaard et al. 2010). Concerning the most important climatic predictors of African palm distributions, water-related factors were most important for 25 of the 29 species analysed (Blach-Overgaard et al. 2010). Thus, climate change could influence the future distribution of palms. Indeed, on average, African palm species may experience a decline in climatic suitability in > 70% of their current ranges by 2080 (Blach-Overgaard et al. 2015). In West Africa, palms distributions are governed by a combination of effects of climate (temperature and precipitation) and substrates (soils) and others ecological factor as Vegetation indices and gross primary productivity (Idohou et al. 2016b, c). The impact of climate variables on palms distribution suggests that climate change will probably influence palms distributions. Unfortunately, Idohou et al. (2016b) concluded that palm species distributions would remain largely stable under future climate forecasts in West Africa. However, some species are expected to experience some retraction of present-day distributional areas. In Benin, Idohou et al. (2016c) showed that wild palms responded differentially to different suites of environmental factors. Indeed, some species showed best model performance with Vegetation indices, Gross Primary Productivity and Soil (*B. aethiopum*), others with Gross Primary Productivity and Soil (*H. thebaica*, *R. sudanica*) or Vegetation indices and Gross Primary Productivity (*P. reclinata*), or with only soil factor (*E. macrocarpa*, *L. opacum*, *Raphia hookeri* and *R. vinifera*) (Idohou et al. 2016c). In West Africa, most palm species' highest-priority areas are located along the coast (from Guinea to Nigeria) (Idohou et al. 2016b). The decrease in habitat suitability of *B. aethiopum* was pronounced in the semi-arid zone where the species is currently widely distributed (Salako et al. 2019b).

Local Perceptions and conservation practices of palm trees

Understanding local people's perceptions are important to make well-planned conservation actions. However, they inform about people's ecological

knowledge. Indeed, many studies have been carried out to describe the techniques of sap extraction (Onuche et al. 2012; Sambou et al. 2002) and the pattern of exploitations or transformation (Gbesso et al. 2017, 2013). Some other studies were interested in local ecological knowledge as interactions implying palms (Houndonougbo et al. 2017; Yameogo et al. 2016).

Concerning palm tapping, Onuche et al. (2012) identified three methods: the inflorescent flower, the terminal budding, and the tree felling methods. Ikegwu (2014) described these methods focusing on oil palm and *Raphia* tapping. The tree felling and the final budding methods are destructive because they lead to the death of the tapped trees (Onuche et al. 2012). The terminal budding method allowed obtaining at average 10 l per day per tree, but it leads to the death of the exploited trees after 35–40 days (Sambou et al. 2002).

There is no particular restriction for the exploitation of palm tree *B. aethiopum*, and only cutting down needs village chief or ranger authorization in Benin (Gbesso et al. 2017). There is contradictory interest in palm resource management between actors (Gbesso et al. 2017), making well conservation practice more difficult. In the contrary, *Borassus* species are protected in Burkina Faso.

People perceived interactions that imply palms. For local people in Burkina Faso, *B. akeassii* affects soil fertility by falling and decomposing fruit and leaves, which allowed the best development of the culture around palm trees (Yameogo et al. 2016). Besides, good coexistence between *B. akeassii* roots and culture ones and agricultural practices allowed the best development of palm (Yameogo et al. 2016).

Propagation of palms tree in West Africa

It is known that palm propagate mostly by seed germination. However, palm seeds germination was confronted to dormancy, embryo immaturity, seed coat impermeability, and physiological events during seed storage (Idohou et al. 2015b; Moussa et al. 1998). It is reported that high temperature pretreatment was essential for the germination of *E. guineensis* seeds (Labro et al. 1964; Rees 1961, 1962). The excellent germination rate of *E. guineensis* seeds was obtained by dry hot pretreatment at 40 °C for 80 days afterward cooled at the optimum seed moisture content (Rees

1961, 1962). Rabéchaud (1962) described five stages in *E. guineensis* seed germination. Currently, germination of *E. guineensis* has been mastered, and this palm has successfully grown and introduced in many areas for cultivation. Concerning savanna palms, namely *B. aethiopum*, *H. thebaica*, *P. reclinata* and *R. sudanica*, their germination is cryptogean and occurs in two stages (Tahir et al. 2007). Among these savanna palms, *H. thebaica* attracts more attention. Indeed, Moussa et al. (1998) carried out the dormancy of doum palm seed and obtained good results for seed soaking pretreatments. Based on fruit characteristics, Idohou et al. (2015b) identified three morphotypes related to phytodistricts in Benin and their influence on germination rate and seedlings growth of *H. thebaica*.

Knowledge gaps and future perspectives

Despite a lot of contributions to assess the diversity of west Africa palm flora (Ake Assi 1995; Ake Assi and Guinko 1996; Russell 1965; Tuley 1995; Stauffer et al. 2017), this diversity remains less known in West Africa, especially in arid and semi-arid regions, due to some taxonomic confusion among species (Ake Assi and Guinko 1996; Mogue Kamga et al. 2019). For instance, Mogue Kamga et al. (2019) concluded recently to a misidentification of *R. vinifera* and think of this species' presence in Burkina Faso, which is not yet confirmed so far. Therefore, we need to make an effort in collecting palms specimen in West Africa, which will contribute to the diversity knowledge in that region. To better understand the palm flora diversity, there is a need to embark in some taxonomic revision (e.g. genus *Raphia*) to clarify some species' position (Helmstetter et al. 2020). Taxonomic revision is necessary for identifying the species and implementing strategies of conservation of the diversity of the palm flora.

Previous studies identify morphotypes within palm species (Idohou et al. 2015b; Salako et al. 2019a) with no environmental drivers. Therefore, there is a need to assess the genetic diversity of palm species to understand the basis of this morphological variation. However, the identification of morphotypes focused on fruit morphology; there is also a need to assess the functional traits following the Leaf Height Seed scheme to highlight the variation pattern of traits.

The uses of palms have been extensively explored in West Africa (Camara et al. 2017; Guinko and Ouédraogo 2005; Michon et al. 2018; Ouattara et al. 2015; Salako et al. 2018a; Yaméogo et al. 2008), but some ethnobotanical data are still needed to understand the perceptions of the importance and the dynamic of palms. However, the uses of some taxa (e.g. rattans and *Raphia*) need to be documented in West African communities. All these ethnobotanical data are necessary to direct sustainable management and conservation of palms in West Africa by identifying the threats these species are undergoing and highlighting the traditional conservation strategies undertaken by local people. Future studies must also address the species' resilience capacities to promote a better conservation plan of palms in West Africa. This could be assessed through population structure, functional traits, and ecological niche modelling approaches. The population structure should assess the resilience capacities at the population level while the functional traits approach helps identify these capacities at the individual level. The palm distribution needs further investigation to understand the pattern of palms distribution in the Sahel and identify the priority area of conservation at the local scale. Indeed, the current distribution study of palms focused on the coastal areas as Benin (Idohou et al. 2016c) or to regional scale as West Africa (Idohou et al. 2016b). In general, the plants in dry and humid regions of the tropics might respond differently to climate and land-use changes. It is urgent to carry out the distribution of palms in dry area and identify priority area for its conservation in the context of climate and anthropogenic changes.

Conclusion

This analytical review provides evidence that palms are under-investigated in West Africa. From the 108 research articles published between 1930 and 2019, we identified 25 palm species belonging to 12 genera and five growth forms, three sexual patterns, and two leaves forms. The growth forms are dominated by erect and solitary palm, and the pinnate leaves are the most dominant among leaves forms. Only *Raphia* are hapaxanthic, and monoecy is dominant. Most of the reported studies focused on ethnobotany, population structure, and biochemical aspects. There is clear

evidence of a link between used parts and uses categories and species growing in dry areas are among the most important in West African palm literature (*Borassus aethiopum*, *Elaeis guineensis*, *Borassus akeassii* and *Hyphaene thebaica*). The population structure of palms is driven by environmental factors (climate and land use) and anthropogenic pressure (sap tapping and fruit exploitation). Despite these studies, there are knowledge gaps regarding genetic drivers of morphotypes, capacities resilience of these species to manifold pressure, including climate change and carbon stock estimation. The latter is essential to highlight the contribution of these species to climate change mitigation. Future studies should also focus on arid and semi-arid areas to contribute to the specimen collection in West Africa.

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Declarations

Conflict of interests Authors declare that they have no conflict of interest.

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PUBLICATION II



Assessment of the conservation status of *Borassus akeassii* Bayt., Ouédr. & Guinko in Western Burkina Faso through local communities perceptions and the species stands structure

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ABSTRACT

Borassus akeassii is one of the most common fan palms in West and Central Africa. In Burkina Faso, the species regenerates in the wild and is kept on farms by local people because of its high usefulness. It is used mainly by local communities for palm wine production and basket-making. We investigated the population dynamics and the local conservation status of *Borassus akeassii* in order to provide tools for the sustainable management of the species. People ($n = 233$) from five different ethnic groups were interviewed and their perceptions and conservation practices of the species were determined and compared between socio-demographic groups. For field measurement of the species populations, 30 inventory plots of 50×50 m size were used to collect data on individual life stage, sex, and exploitation state. Data were used to estimate the densities, the sex ratio, the regeneration and mortality rates and to calculate the permutation index (P), the Simpson's dominance index (S), and the quotient (Q) between consecutive life stages of populations. This information provides highly condensed indices of population dynamics acting over many years. The results showed that 53% of informants report a declining trend for *Borassus akeassii*. However, perceptions of the species dynamics varied among ethnic groups. Harvesting was the main reported cause of the species' decline. Population densities varied among life stages, with a dominance of seedlings. The permutation index, the Simpson's dominance index, and the quotient between consecutive life stages revealed an unstable population structure of *Borassus akeassii*. However, the high intensity of exploitation of individuals versus the low mortality rate suggests *Borassus akeassii* is being used sustainably by local people. People are aware of the species' vulnerability and adopt practices for its conservation (e.g. planting and natural assisted regeneration). Encouraging good local practices of conservation together with the high potential of regeneration could ensure sustainable use of the species in Burkina Faso. Future research should thus focus on documenting the expert knowledge on sustainable exploitation of the species as an example to be reinforced and implemented in other areas.

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1. Introduction

Palm species are less represented and vulnerable in semi-arid and arid areas because of their incapacity to enter physiological dormancy and their high demand for water (Tomlinson, 2006; Kreft et al., 2006). For example, only 34% of West African palm species occur in dry areas (Zon et al., 2021). Despite their low presence in semi-arid areas, palms provide a wide array of food, drink, and medical products, building, and weaving materials to local people (Ouattara et al., 2015; Yaméogo et al., 2008). However, human pressure and climate change increase the threats and vulnerability of palms (Cosiaux et al., 2018; Stauffer et al., 2017; Zon et al., 2020). To prevent the ongoing decline of palms, in-situ and ex-situ conservation strategies are urgently needed, taking into account local knowledge on resource management. Ethnoecological studies advocate integrating local knowledge with ecological investigations to improve ecological impact assessment and develop better plans for sustainable management of resources (Camara et al., 2019; Elias, 2013; Lykke, 2000).

Borassus akeassii is a native palm that comes after *Borassus aethiopicum* in terms of occurrence in West and Central Africa (Atakpama et al., 2022). The species naturally grows in sudanian and sudano-guinean savannas (Bayton et al., 2006), usually with crops planted beneath (Bayton et al., 2006; Bayton and Ouédraogo, 2009; Chevalier, 1930), making it an important component of agroforestry systems (Atakpama et al., 2022; Yaméogo et al., 2008). The species is mainly dispersed by barochory (Barot et al., 1999), but humans are also known to contribute to its dissemination (Guinko and Ouédraogo, 2005). It is a multipurpose palm species which provides local people with several ecosystem services including food, medicine, stipe for construction, shelter and material for craft (Yaméogo et al., 2008). *Borassus akeassii* is exploited in Burkina Faso, mainly for sap extraction and leaves cutting (Guinko and Ouédraogo, 2005; Yaméogo et al., 2008). The sap is used for palm wine and the leaves for basket-making. The overexploitation of its products combined with inadequate land use strategies, jeopardizes the conservation of the *Borassus* species in West Africa (Mollet et al., 2000; Salako et al., 2015). However, sap extraction from *Borassus akeassii* in Burkina Faso is harvest sustainably, using practices that ensures the tree remains alive and can be exploited for many years (Guinko and Ouédraogo, 2005).

The livelihood of local communities in Western Burkina Faso is associated with *Borassus akeassii* and this gives them a deep knowledge of this resource. In addition, *Borassus akeassii* exists close to human settlements (Bayton et al., 2006; Bellouard, 1950; Yaméogo et al., 2016). Local knowledge is a quick, reliable and easy-to-get source of information about local vegetation dynamics (Lykke, 2000; Lokonon et al., 2021; Zon et al., 2020). Local-knowledge based management strategies ensure a focus on traditional actions that contribute to conserve many useful plants. Actions are usually undertaken by local communities that significantly influence the densities of many species (Elias, 2013). Traditional conservation and management actions are diverse and may range from plantations where a species is deliberately planted, to assisted natural regeneration (Tiétiambou et al., 2020; Yaméogo et al., 2016). The conservation practices of species are, however, species-specific and depend on several factors including the socio-demographic profiles (gender, age, education, ethnicity, etc.) of local people (Tiétiambou et al., 2020). Thus identifying the different conservation actions and different factors that may influence the adoption of these actions can be used as a baseline to direct sustainable management and conservation of biodiversity in general and useful plants such as palms in particular. Although local people can describe vegetation dynamics well (Lykke, 2000), it is important to assess the reliability of their perceptions about population dynamics of some useful and common species such as *Borassus akeassii*. Consequently, field data on stand structure are needed.

Assessing the population dynamics of palm species is crucial to identify possible threats and understand their ecological pattern to design a well-informed management plan (Salako et al., 2015, 2018a). A description of the profile and population structure of life stages can provide information on recruitment, growth and mortality that have acted over many years, thereby giving information on the health of the population (Wiegand et al., 2000). Previous studies on palms populations structure in West Africa had been influenced by exploitation (Ahissou et al., 2017; Mollet et al., 2000), climatic regions and land use types (Idohou et al., 2016; Salako et al., 2018a), plant-animal interactions (Salako et al., 2015, 2017), and plant-plant interactions (Barot and Gignoux, 2003). Land use types and agricultural systems are recognized as one of the most important drivers of changes in ecosystems' structure, particularly the population structure of palms (Idohou et al., 2016; Madelaine et al., 2008; Salako et al., 2018a). For example, palms densities were reported significantly higher in protected areas than in farmlands (Idohou et al., 2016; Salako et al., 2018a). Recently, Muscarella et al. (2020) showed that the global abundance of palms is related to local conditions. Thus, the structure and distribution of the species populations are closely linked to human activities, particularly to specific practices (Elias, 2013). Monitoring the populations based on a snapshot information is thus required to determine whether the population of *Borassus akeassii* is declining.

This study investigates the conservation status of the palm species, *Borassus akeassii*, in Burkina Faso in order to guide its sustainable management. Investigations aimed to (1) assess the local communities' perceptions on the dynamics of *Borassus akeassii*'s population, (2) identify the local practices for species conservation, and (3) assess the population structure of *Borassus akeassii*.

2. Material and methods

2.1. The study area

The study was carried out in the Cascades and Hauts-Bassins regions to the West of Burkina Faso (Fig. 1), which contains the country's major stands of *Borassus akeassii* (Bayton and Ouédraogo, 2009; Bayton et al., 2006; Ouédraogo, 1999). This area belongs to the Sudan climatic zone characterized by a mean annual rainfall ranging between 900 and 1100 mm, with two contrasting seasons (Dipama, 2010; Fontès and Guinko, 1995). The rainy season lasts 6–7 months on average, from May or June to November, with 90 rainy days (Ouédraogo et al., 2013). The vegetation is dominated by savannas, dry forests and patches of gallery forests. Inhabitants

were estimated to be 812 062 and 2 238 375 people, respectively in the Cascades and Hauts-Bassins regions (INSD, 2020) and are distributed among 15 ethnic groups. The dominant ethnic groups are Gouin, Senoufo and Bobo. The main economic activity is farming, but local people harvest forest products for their livelihood.

Borassus akeassii is a common palm species in the study area (Guinko and Ouédraogo, 2005; Bayton and Ouédraogo, 2009). Stands of the species are spread thanks to humans' actions (Ouédraogo, 1999). It is kept and exploited by local people on farmlands. The main exploitations of *Borassus akeassii* are sap tapping for palm wine and leaves harvesting for handicrafts (Yaméogo et al., 2008).

2.2. The study species

Borassus akeassii is one of the most common fan palm in West and Central Africa. It was described as a new species in 2006 and occurred in West and Central Africa (Aké Assi and Guinko, 1996; Bayton, 2007; Bayton et al., 2006). *Borassus akeassii* is a pleonanthic dioecious palm with a ventricose stem. The leaves are costapalmate with up to 130 induplicate leaflets and green weakly armed petiole. The fruits have a pointed apex and are greenish when ripe, and the flowers of the pistillate inflorescence are arranged in three spirals (Bayton et al., 2006; Ouédraogo et al., 2002). *Borassus akeassii* shows a preference for well-drained soils and is fire-resistant (Arbonnier, 2009). The habitat of the species is the Sudan savannas with 800 – 1100 mm annual rainfall. In Burkina Faso, most of the species populations are semi-naturally managed for palm wine production.

2.3. Sampling and data collection

2.3.1. Ethnobotanical survey

The informants were selected based only on their knowledge of the palm, *Borassus akeassii*. Any other criteria was not used for selecting informants in order to get a more general way of the population representation. Prior to the interview in each locality, the local names of the species were recorded through a walk in the field with some informants and the local field guide. Thus, 233 informants were interviewed. All the interviews were conducted with the consent of informants. The interviews were conducted entirely in the informants' local languages with translation when necessary using a semi-structured questionnaire (Appendix). The questionnaire included three sections: (i) the socio-cultural information of the informants; (ii) the informant's perceptions of the dynamics

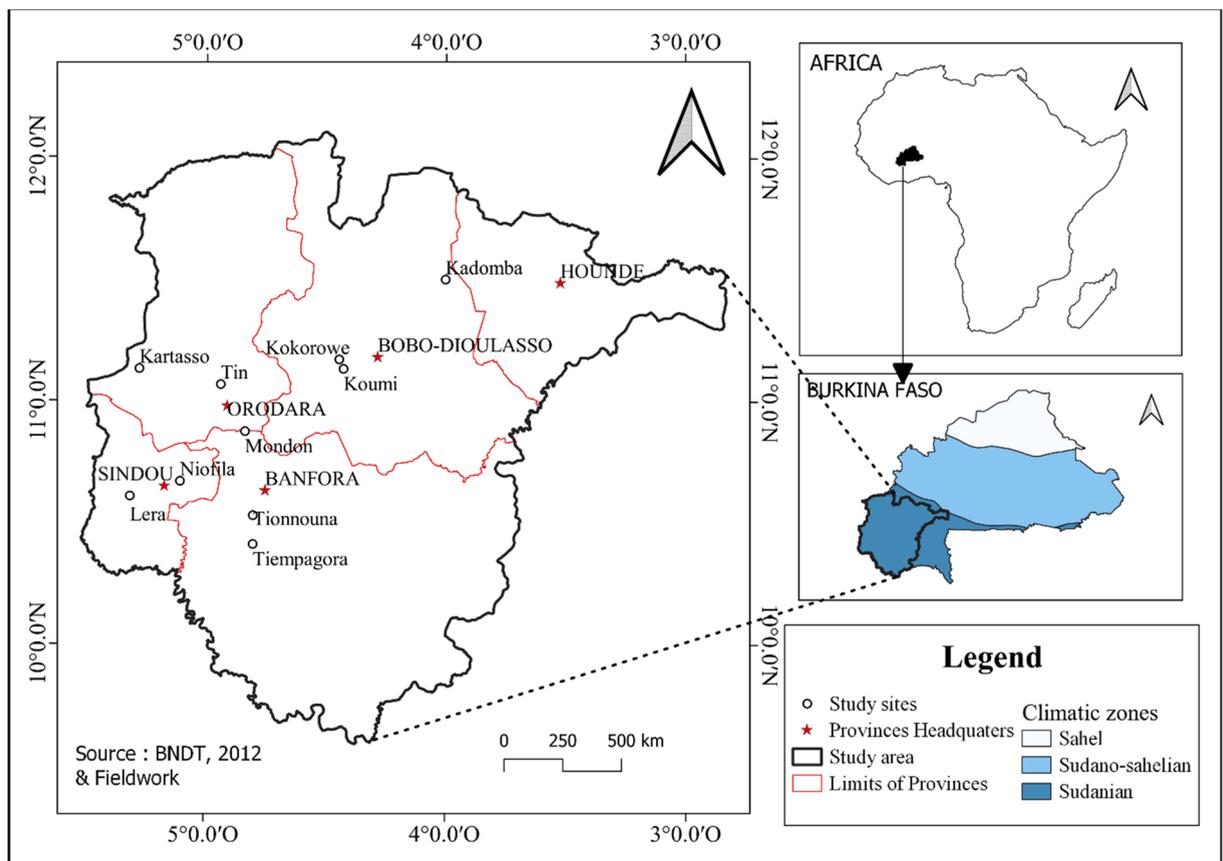


Fig. 1. Location of the study area in Western Burkina Faso showing the sampled villages. The study area belongs to the Sudanian climatic zone of Burkina Faso. The sampled villages are mentioned in lowercases and the Provinces' headquarters in uppercases.

of *Borassus akeassii* and the reasons that underpin the species' decline and (iii) the conservation practices used to conserve *Borassus akeassii* (see Appendix for the structure and content of the questionnaire).

2.3.2. Palm stands inventory

An oriented sampling scheme was applied, based on the occurrence of *Borassus akeassii*. A total of 30 vegetation inventory plots (10 in the Hauts-Bassins and 20 in the Cascades regions) distant from each other by at least 100 m, were set in farmlands where the species occurred. Each inventory plot size was 50 m × 50 m, a size that is often used for palm parklands (Camara et al., 2019; Elias, 2013; Madelaine et al., 2008). All individuals of *Borassus akeassii* in the plot were recorded. For each palm tree in plots, the life stage, sex, and exploitation state were recorded. Life stages were described in Table 1 following Barot et al. (1999). Sex was based on direct observation of flowering and fruiting individuals. A palm is considered exploited when a recent cut in the apical bud is visible and most of the leaves were cut.

2.4. Data analysis

2.4.1. Perceptions of the dynamics and local practices of *Borassus akeassii* conservation

The ethnobotanical data were reorganized according to socio-cultural factors such as ethnic group, gender, age categories, academic level, and region. Informants were classified according to age categories as young (18–30 years), adult (30–60 years), and old (>60 years) following Assogbadjo et al. (2008). Then, the relative frequencies of citation (FC) of each given perception on *Borassus akeassii* population temporal dynamics, cause of the decline, and conservation practice were calculated (Table 2). The association between socio-cultural factors and the perception of *Borassus akeassii* dynamics was examined through a Fisher exact test to account for frequency less than 5 (Crawley, 2007). A pairwise Fisher's exact test was then used to assess the significant difference between ethnic groups' perceptions. The causes of the decline were ranked using the relative frequency of citation and graphically presented. The conservation practices were coded as binary data and analyzed using a Generalized Linear Model (GLM) with a binomial error to assess the effect of socio-demographic factors on the adoption of conservation practices.

2.4.2. Population structure of *Borassus akeassii* in the field

To analyze the population structure of *Borassus akeassii*, demographic parameters namely densities per life stage, regeneration and mortality ratios, and the sex ratio were calculated in addition to structural indices that describe the stability of the population (Table 2). The densities of the different life stages were compared using a Kruskal-Wallis test followed by a Dunn test when the difference was significant (Dunn, 1964). The sex ratio is calculated and deviation from evenness (i.e. 50:50) was tested using the exact binomial test.

The stability of the population was measured using three quantitative indices that were the permutation index (P), the Simpson's dominance index (S), and the quotient (Q) between consecutive life stages (Shen et al., 2013) (Table 1). These indices provided a useful suite of measures sensitive to different aspects of life stages profiles and their interpretation (Shackleton et al., 2005) to assess the departure from a uniform decline that is characteristic of an undisturbed population (Martins and Shackleton, 2017; Wiegand et al., 2000). An undisturbed population will have a permutation index approaching zero, while a disturbed population will have a permutation index above zero (Wiegand et al., 2000; Botha et al., 2002). The Simpson's dominance index was compared to 0.1 (Botha et al., 2002). Quotients between consecutive life stages were presented graphically and the shape of fluctuations was analyzed. All the statistical analyses were performed in R version 4.0.4 (R Core Team, 2021).

3. Results

3.1. Characteristics of surveyed people

Informants' samples included five ethnic groups divided into males and females, young, adult, and old (Table 3). All the informants were at least 18 years old and 62% of them belonged to the adult category. More than half of the informants had no academic level and farming was the professional occupation for 98% of them. The sample was dominated by the Bobo, Gouin, and Turka ethnic groups (Table 3).

Table 1
Description of life stages of *Borassus akeassii* (adapted from *Borassus aethiopicum* by Barot et al., 1999).

Life stages	Description
Seedlings	Individual without an apparent trunk, presence of young leaves (rachis not segmented)
Saplings	Individual without an apparent trunk but leaves slitted.
Juvenile	Individual with a trunk covered with remnant leaves, no reproductive
Sub-adult	Individual with a trunk covered with remnant leaves, reproductive
Adult	Individual with a nude trunk, reproductive.

Table 2

Description of the demographic parameters and the stability index for population structure. The relative frequency of citation was calculated from the ethnobotanical data. The density, the regeneration ratio, the mortality ratio and the sex ratio are demographic parameters that depict the population trend of *Borassus akeassii*. The Simpson index of dominance, the permutation index and the quotient between successive life stages are the stability indices used to assess the population structure of *Borassus akeassii*.

Parameters	Formula	Definition/Expression	References
Relative frequency of citation (RFC)	$RFC = \frac{N_{ui}}{N} \times 100$	RFC is the ratio of the informants' number related to a specific perception or practice (N _{ui}) to the total number of informants (N), expressed as a percentage	–
Density (D)	$D = \frac{n}{s}$	n is the number of individuals s is the size of the plot	–
Regeneration ratio (R)	$R = \frac{\text{seedlings} + \text{saplings}}{\text{adults}}$	R is an indication of palm fecundity	Camara et al. (2019)
Mortality ratio (M)	$M = \frac{\text{dead stems}}{\text{living stems}}$	M is an indication of human pressure	Camara et al. (2019)
Sex-ratio	$\text{sex-ratio} = \frac{\text{females}}{\text{males} + \text{females}}$	–	–
Simpson index of dominance (S)	$S = \frac{1}{n(n-1) \sum_{i=1}^5 n_i(n_i-1)}$	S is a measure of a life stage dominance, with n total of tree and n _i the number of the tree in life stage i	Botha et al. (2002)
Permutation index (P)	$P = \sum_{i=1}^5 j_i - i j_i$	P is the aggregation of the absolute distances between the predicted and the actual ranking of all life stages J _i rank of life stage i (i = 1 for seedling), and the first rank (J _i = 1) attributed to the mostly frequent life stage	Wiegand et al. (2000) Martins and Shackleton (2017)
Quotient between successive life stages (Q)	$Q = n_{i-1}/n_i$	n _i : number of individuals in life stage i n _{i-1} : number of individuals in preceding life stage	Shackleton et al. (2005)

3.2. Local perceptions of the temporal dynamics of *Borassus akeassii* population

Local people perceptions about the temporal dynamics of *Borassus akeassii* population were variable. More than half of informants (53%) noticed a declining trend of palm parklands while a good proportion of people (43%) reported an increasing trend (Table 4). Fewer people (4%) reported that the species' population was stable (Table 4). The perceptions of the dynamic of the species 'population varied significantly according to ethnic groups (Fisher exact test *p*-value= 0.0004). The pairwise Fisher's exact test indicated that the perceptions of Siamou were significantly different from the ones of Bobo, Senoufo, Gouin, and Turka. Indeed, the Siamou mainly report a declining trend while the Bobo and the Gouin reported an increasing trend (pairwise Fisher exact test: *p*-value< 0.05). The proportions of Bobo, Senoufo, Gouin, and Turka reporting an increase and a declining trend were not statistically different (pairwise Fisher exact test: *p*-value>0.05).

As far as the gender, age categories, and geographic location are considered, no significant variations were observed in the perceptions of the species population dynamics (Table 4).

The declining causes of *B. akeassii* populations cited by informants were mainly human exploitation and pressure (harvesting, urbanization, and agriculture) and natural disturbances (drought, wind, and pests). Harvesting was the main cited factor (43%) (Fig. 2).

Table 3

Distribution of informants according to socio-demographic parameters indicating the number and the proportion of informants according to the factors used in the study.

Factors	Modalities	Number of informants	Proportion (%)
Ethnic group	Bobo	83	35.62
	Senoufo	16	6.87
	Siamou	33	14.16
	Gouin	40	17.17
	Turka	61	26.18
Gender	Men	137	58.80
	Women	97	41.63
Age	Young (18–30 years)	40	17.17
	Adult (30–60 years)	145	62.23
	Old (>60 years)	48	20.60
Academic level	None	158	67.81
	Primary	51	21.89
	Secondary	24	10.30

Table 4

Influence of socio-cultural factors on informants' perception of *Borassus akeassii* populations' dynamics in Western Burkina Faso. **p*-value was obtained through a Fisher exact test and *p*-value<0.05 is regarded as significant.

	Perceptions of dynamics of <i>B. akeassii</i> populations			<i>p</i> -value
	Increase (%)	Decline (%)	Stable (%)	
Ethnic group				
Bobo	54	41	5	0.0004 *
Senoufo	43	43	14	
Siamou	0	94	6	
Gouin	63	34	3	
Turka	44	56	0	
Gender				
Men	44	53	3	1
Women	43	53	4	
Age				
Young (18–30 years)	50	44	6	0.2584
Adult (30–60 years)	42	54	4	
Old (> 60 years)	40	58	2	
Academic level				
None	24	35	2	0.3094
Primary	8	7	1	
Secondary	5	4	0	
Geographic location				
Cascades region	24	22	1	0.0896
Hauts-Bassins region	15	24	2	
Total	43	53	4	

3.3. Local practices of *Borassus akeassii* conservation

A small majority of informants (56%) reported having adopted at least one conservation practice while the remaining informants did not. The conservation practices used include creation of plantation (35%), plant fencing (12%) and natural assisted regeneration (12%). Table 5 shows the results of the influence of socio-cultural factors on the conservation practices of *Borassus akeassii*. Among the factors tested, only the ethnic groups significantly influenced the conservation practices (Table 5). Bobo, Gouin, and Turka showed similar and better conservation attitudes than Siamou (Estimates = -1.18 , $p = 0.011$). The gender, age categories, academic level, and geographic location did not influence the adoption of conservation practices (Table 5).

3.4. Population structure of *Borassus akeassii* in the field

The densities of populations varied among life stages with a clear predominance of seedlings (Kruskal-Wallis statistics: $\chi^2 = 73.445$, $df = 4$, $p\text{-value} = 4.249\text{e-}15$) (Fig. 3A). Indeed, the seedlings represented 59.24% of the population. The rate of exploited trees (51%) and the regeneration ratio (15.95) were high while the mortality ratio was low (0.13). The sex-ratio was significantly male-biased (0.42; $p\text{-value} = 0.0005$). Moreover, the Simpson index of dominance (S) was 0.41 and the permutation index (P) was 4. The quotient between consecutive life stages of *Borassus akeassii* population examined here was not constant, fluctuating between consecutive life stages (Fig. 3B).

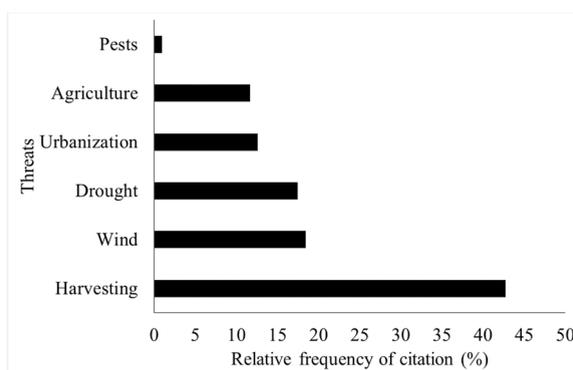


Fig. 2. Causes of population decline of *Borassus akeassii* ranked according to the relative frequency of citation reported by local communities. The barplots show the contribution of the particular threats listed by all informants to all the threats mentioned by all informants.

Table 5

Socio-cultural factors associated with the conservation practices of *Borassus akeassii*: Summary of the binomial generalized linear model. Reference levels: Bobo for Ethnicity, Men for Gender, Adult for Age, None for Academic level and Cascades region for geographic location. * $p < 0.05$ is regarded as significant. Negative estimates indicate lower value compare to the reference level.

	Estimates	Std. Error	Z value	Pr (> z)
Intercept	14.76113	1009.60299	0.015	0.9883
Ethnicity Senoufo	-15.71703	1009.60274	-0.016	0.9876
Ethnicity Siamou	-1.18237	0.46562	-2.539	0.0111 *
Ethnicity Gouin	-14.66504	1009.60301	-0.015	0.9884
Ethnicity Turka	-14.45447	1009.60298	-0.014	0.9886
Gender Women	-0.10956	0.29479	-0.372	0.7101
Age Young	-0.07303	0.43317	-0.169	0.8661
Age Old	-0.52880	0.36316	-1.456	0.1454
Academic level Primary	-0.47118	0.36777	-1.281	0.2001
Academic level Secondary	-0.69322	0.55509	-1.249	0.2117
Location Haut-Bassins region	-14.30278	1009.60292	-0.014	0.9887

4. Discussion

4.1. Local perceptions of the population dynamics of *Borassus akeassii*

Understanding local people's perceptions on natural resource availability is important for implementing appropriate conservation actions. Indeed capitalizing on various social perceptions of a particular endangered species can contribute to its conservation (Cortés-Avizanda et al., 2018). Our study revealed that half of the informants reported a declining trend of *Borassus akeassii* populations in concordance with the field-based statement of the population structure. However, the majority of Bobo and Gouin informants reported an increasing trend for the species population in line with previous studies on *Borassus aethiopus* in Benin (Salako, 2015). The relatively higher proportion of informants of Bobo and Gouin reporting the increasing trend in *Borassus akeassii* population suggests that in their localities, the decline may not be as severe as for other useful species or that the abundance is so high that the decline is not perceptible (Salako, 2015). In general, local people perceived a current decline of plants species in sub-Saharan regions (Lokonon et al., 2021; Lykke et al., 2000; Tiétiambou et al., 2020).

The main causes of decline reported by local people are consistent with other findings, where anthropogenic threats, particularly overexploitation and agricultural pressure were major causes of many plant species decline, including palms in the sub-Saharan Africa regions (Ngom et al., 2018; Zon et al., 2020). Repeated harvesting of leaves may severely limit the growth of palms and excessive harvesting of unripe fruits impedes the regeneration potential of *Borassus* species (Ahissou et al., 2017; Thione, 2000). As far as sap extraction is concerned, the population structure of palms are dangerously affected in Cote d'Ivoire because palm trees are felled for sap extraction (Mollet et al., 2000). In Burkina Faso, despite intense tapping of the adult palms, the mortality appears low because of a sustainability of this exploitation (Guinko and Ouédraogo, 2005). In addition to anthropogenic pressures, natural factors also

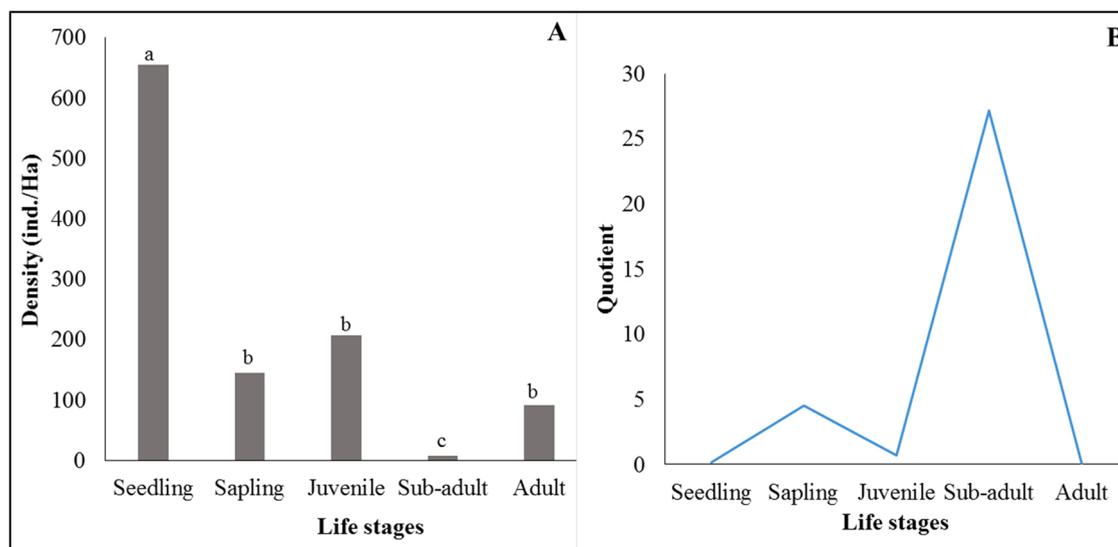


Fig. 3. Life stages profile description of *Borassus akeassii* in Burkina Faso showing (A) Life stages densities, and (B) Quotients between consecutive life stages. The barplots in (A) indicate mean densities of individuals per area unit. $Ind./Ha = individuals/Ha$; different letter indicates significant variation using the Dunn test. The graphic line in (B) showed fluctuating quotient between successive life stages.

threatened the natural population of *Borassus akeassii*. Among them, local people cited drought, wind, and parasites. The major natural factor threatening populations of *Borassus akeassii* is probably drought which causes high mortality among older palm trees that are sensitive to fluctuations in the groundwater level (Sambou et al., 1992). Climate is the main factor that influences palm population and diversity, especially water-related variables (Kreft et al., 2006; Salako et al., 2018a).

4.2. Local conservation practices of *Borassus akeassii*

Delivery of practical management actions should consider the current management practices of farmers (Salako, 2015). Plantation and natural assisted regeneration are common practices of conservation adopted by local people as for other high value agroforestry species like *Vitellaria paradoxa* and *Parkia biglobosa* (Okiror et al., 2012; Teklehaimanot, 2004). Our results revealed that socio-demographic factors, especially ethnicity, influence the adoption of conservation practices of *Borassus akeassii* in Western Burkina Faso and are in line with the conclusion of previous studies (Tiétiambou et al., 2020). According to Yaméogo et al. (2016), the farmers relied much more on natural assisted regeneration than on other methods to regenerate *Borassus akeassii* in the Central-Western region of Burkina Faso. Management actions can take advantage of existing practices and improve them for better delivery (Tiétiambou et al., 2020). Despite the minimal recognition rendered to traditional management practices by official conservation policies, local communities have employed these practices for centuries to ensure the conservation of various plant species. Conservation practices could be motivated by species' spiritual, economic, and ecological values, among other factors (Tiétiambou et al., 2020; Balima et al., 2018; Millogo-Rasolodimby, 1993). Indeed, *Borassus akeassii* is an economically important palm species in Burkina Faso because of the income generated from the trade of its products, including sap and handicrafts materials (Yaméogo et al., 2008). The economic value of the species products is an asset that brought local people to implement some conservation actions including assisted natural regeneration and the plantation for the species conservation.

4.3. Population structure and implications for sustainable management of *Borassus akeassii*

The densities of *Borassus akeassii* population reported in our study confirm the abundance of the species in the West of Burkina Faso. It is among the most abundant and common palm species in Burkina Faso (Bayton et al., 2006; Ouédraogo, 2010). The population density of *Borassus akeassii* is comparable to those of *Borassus aethiopum* in some West Africa areas (Ouinsavi et al., 2011; Sow and Thiam, 2013).

The population of *Borassus akeassii* had a male-biased sex ratio. A biased sex ratio is more linked to environmental conditions, with females being more numerous in favorable conditions. Male-biased populations are reported to be more frequent in long-lived dioecious species that produce large fleshy fruits (Sinclair et al., 2012) like *Borassus akeassii*. Most previous studies in West Africa reported a female-biased sex ratio or an equal sex-ratio in *Borassus* populations (Atakpama et al., 2022; Barot et al., 1999; Ouinsavi et al., 2011; Salako, 2015), in general linked to the pattern of exploitation. In Burkina Faso, *Borassus akeassii* is mainly exploited for sap and leaves (Guinko and Ouédraogo, 2005; Yaméogo et al., 2008), which is not oriented through sex. Thus, the male-biased sex ratio observed in this study could be linked to the aridity of the climate. Indeed, previous studies showed that plants growing under water restriction displayed a male-biased sex ratio while plants raised under sufficient water conditions displayed a more or even female-biased sex ratio (Field et al., 2012; Sinclair et al., 2012). Western Burkina Faso has a dry tropical climate that is prone to strong seasonal and annual climatic variations.

The Simpson index of dominance above 0.1, the permutation index above zero and the fluctuating quotients between the consecutive life stages for *Borassus akeassii* are an indication that the structure of life stages distribution of the species deviates from a stable population. The unstable population structure could be linked to a selective human effect on *Borassus akeassii* individuals. Indeed, farmers act on the life stage succession by their selective preference of individuals for exploitation. The selective effect of farmers in farmlands may explain the observed unstable population structure in agroforestry systems (Madelaine et al., 2008; Idohou et al., 2016). As the structure of semi-wild palm groves is partly explained by agricultural practices, it could be used as an ecological indicator of changes in practices in relation to the socio-economic conditions of local populations (Madelaine et al., 2008). The good recruitment of *Borassus akeassii* is a potential source of ensuring the successful regeneration of the palm groves whether this scenario could be a constant recruitment over the years (Sinclair et al., 2012).

Despite the unstable population of *Borassus akeassii*, the promising potential of natural regeneration and the local conservation practices can contribute to the species sustainability. In addition, the good association between *Borassus akeassii* and crops allows the best development of palm trees due to agricultural practices (Yaméogo et al., 2016). As a result, the sustainability and conservation of the species are not currently a concern in the region. The conservation projects of *Borassus akeassii* palms should support local initiatives addressing conservation issues. An important contribution could be the documentation of the sustainable technique of tree tapping for sap extraction for palm wine in Western Burkina Faso. This documentation would serve to promote the sustainable technique elsewhere as the exploitation harms the palms populations.

5. Conclusion

This study proved that the conservation of *Borassus akeassii* is not a real concern in Western Burkina Faso where the species is found at high occurrence. Indeed, despite the observed unstable population of the species, local people actively adopt conservation practices including plantation and natural assisted regeneration, probably because of the palm's high socio-economic value. People cited many causes including harvesting responsible for the decline of the species. The good regeneration potential, the abundance of the adult

palms, and the local community-based conservation approaches involving local people could be a guarantee for the sustainability of *Borassus akeassii* in the study area. However, the combined effect of climate change and overexploitation could compromise the species conservation in the future. Thus, effective conservation actions must take into account the communities know-how conservation practices described here in combination with potential effects of climate change on the species. Moreover, the community-based conservation practices must be accompanied by the government forest and agriculture services, Non-governmental organizations, and scientists through improving the sustainable techniques, regarding palm tree tapping and leaves harvesting. This will clearly contribute to the conservation of this multipurpose palm species that is undergoing exploitation pressure.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.gecco.2022.e02284](https://doi.org/10.1016/j.gecco.2022.e02284).

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Abstract

Wild palms occur in tropical and subtropical regions where people use them for many purposes. Despite their low diversity in semi-arid and arid areas, they highly contribute to the livelihoods of local people. Therefore, the overexploitation and climate change threaten palms in arid and semi-arid areas. This study investigates the ecological and conservation patterns of wild palm species under current and future climatic conditions in Burkina Faso in order to propose sustainable management strategies for their conservation. The methods consist in a combination of individuals' interviews (258 people surveyed), inventories (in 120 plots), direct observations, species distribution modelling and climate niche factor analysis. The interview reported the importance of seven palms species in Western Burkina Faso. The importance of wild palm species depends on socio-cultural factors such as ethnic group, gender and age category. Wild palms that are considered useful are the one benefiting much of conservation care (e.g. *Borassus akeassii* and *Elaeis guineensis*). The inventories showed that *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* and *Raphia ssp* had instable populations in Western Burkina Faso. A diversity of trees species co-occurred with palms with a significant lowest diversity in *Borassus akeassii* habitats (30 species) compared to *Elaeis guineensis* (97 species), *Phoenix reclinata* (63 species) and *Raphia ssp* (73 species). More than half (65%) of *Phoenix reclinata* juveniles come from tillering, while *Borassus akeassii*, *Elaeis guineensis* and *Raphia ssp* are regenerated only by seeds. The morphological assessment suggests that a species similar to *Raphia vinifera* co-occurs with *Raphia sudanica* in Western Burkina Faso. This increases the flora of native palms of the country to eight (8), including two species of *Raphia*. The species distribution models identified water related variables such as precipitation and topographic position index as determinant variables of palms distribution in Burkina Faso. The potential suitable areas of wild palms were comprised between 10 and 15 % of the country and are located in the Sudanian climatic zone under current climatic conditions. Climate change may induce range expansion (up to 28.51%) or contraction (up to -16%) depending on the palm species, global circulation models and climatic scenarios. The climate change vulnerability assessment indicates that *Borassus akeassii* is less vulnerable to climate change than *Elaeis guineensis*, *Phoenix reclinata* and *Raphia sudanica*.

Keywords: Arecaceae – Diversity – Vulnerability – Semi-arid areas – Climate change.

Résumé

Les palmiers sauvages sont présents dans les régions tropicales et subtropicales où les populations les utilisent à de nombreuses fins. Malgré leur faible diversité dans les zones semi-arides et arides, ils contribuent fortement à la subsistance des populations locales. Par conséquent, la surexploitation et le changement climatique constituent des menaces au devenir des palmiers dans les zones arides et semi-arides. Cette étude a examiné les déterminants écologiques et de conservation des espèces de palmiers sauvages dans les conditions climatiques présentes et futures au Burkina Faso afin de proposer des stratégies de gestion durable pour leur conservation. La méthodologie a consisté à une combinaison d'entretiens individuels (258 personnes enquêtés), d'inventaires forestiers (dans 120 placeaux), d'observations directes, de modélisation de la distribution des espèces et d'analyse des facteurs de niche climatique. Les enquêtes ont rapporté l'importance de sept espèces de palmiers à l'Ouest du Burkina Faso. L'importance des espèces de palmiers sauvages dépend des facteurs socioculturels tels que l'ethnie, le genre et les catégories d'âge. Les palmiers sauvages qui sont considérés comme utiles sont ceux qui bénéficient le plus des soins de conservation (par exemple *Borassus akeassii* et *Elaeis guineensis*). Les inventaires ont montré que *Borassus akeassii*, *Elaeis guineensis*, *Phoenix reclinata* et *Raphia ssp* avaient des populations instables dans l'Ouest du Burkina Faso. Plusieurs espèces d'arbres cohabitent avec les palmiers avec une diversité significativement plus faible dans les habitats de *Borassus akeassii* (30 espèces) par rapport à *Elaeis guineensis* (97 espèces), *Phoenix reclinata* (63 espèces) et *Raphia ssp* (73 espèces). Plus de la moitié (65%) des juvéniles de *Phoenix reclinata* provient du tallage tandis que *Borassus akeassii*, *Elaeis guineensis* et *Raphia spp* se régénèrent uniquement par les graines. L'évaluation morphologique suggère qu'une espèce similaire à *Raphia vinifera* co-habite avec *Raphia sudanica* dans l'Ouest du Burkina Faso. Cela porte la flore native des palmiers du pays à huit (8), avec deux espèces de *Raphia*. Les modèles de distribution des espèces ont identifié les variables liées à l'eau telles que les précipitations et l'indice de position topographique comme des variables déterminantes de la distribution des palmiers au Burkina Faso. Les zones potentiellement favorables à la conservation des palmiers sauvages varient entre 10 et 15 % de la superficie du pays et sont localisées dans la zone soudanienne sous conditions climatiques actuelles. Le changement climatique peut induire une expansion de ces aires favorables (jusqu'à 28,51%) ou une contraction (jusqu'à -16%) selon l'espèce de palmiers, les modèles de circulation globale et les scénarios climatiques. L'évaluation de la vulnérabilité au changement climatique indique que *Borassus akeassii* est moins vulnérable au changement climatique que *Elaeis guineensis*, *Phoenix reclinata* et *Raphia sudanica*.

Mots clés: Arecaceae – Diversité – Vulnérabilité – Zones semi-arides – Changement climatique