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NOTES ON NEGLECTED AND UNDERUTILIZED CROPS

A global systematic review on conservation nd domestication of *Parkia biglobosa* (Jacq.) R. Br. ex G. Don, an indigenous fruit tree species in Sub-Sahara African traditional parklands: current knowledge and future directions

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Abstract *Parkia biglobosa* (Jacq.) R. Br. ex G. Don is one of the most common traditional parkland tree species that generates vital non-timber forest products and benefits for local people in Sub-Saharan Africa. Despite its socio-economic importance and value for local and regional economies, the species has remained at infant stage of domestication, yet declining in the nature. While several studies addressed various ecological, social and economic aspects, systematic reviews and literature syntheses on current knowledge and research gaps are lacking, despite their relevance for future research directions. Based on research publications from ScienceDirect, Google Scholar and African Journals Online, we provide a systematic literature review of the current knowledge on the ecological, socio-economic, conservation, and domestication aspects of *P. biglobosa*. We also identified important research gaps and future prospects for the species conservation and domestication. From 2060 publications initially recorded, 221 received full-text assessment after screening, of which 184 scientific papers were finally reviewed. Approximately 75% of these studies were undertaken in three West-African countries: Nigeria, Burkina Faso and Benin. Critical analyses were presented in line with perspectives on ecological, socio-economic, conservation and domestication aspects. The review highlighted the critical research gaps in distributional ecology, tree physiology, plant demography, molecular biology, genomics and evolutionary biology, but also called for more research effort from Central and East Africa, where a limited number of publications was recorded on *P. biglobosa*, in spite of being within the native distribution range. Such investigations would help in decision-making and elaboration of breeding strategies, as steps towards sustainable use and domestication of the species in Africa.

Keywords Agroforestry systems · Domestication · Indigenous fruit tree · Non-timber forest products · Africa

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Introduction

…. Africa's Indigenous Fruit Trees: A Blessing in Decline…"If we don't invest in them now,"

> Jamnadass says, "we will lose many of the species, as many of them are fast disappearing. (Cemansky 2015)

Tropical continents are home to a large diversity of indigenous fruit trees (IFTs), with about 1000 species described in America, 1200 in Africa and 500 in Asia of which 300 in the Indian sub-continent (Paull and Duarte 2011). Although only a small fraction of IFTs is marketed and even less exported, these biological resources are reported as valuable for the livelihoods of local people from tropics as potential sources of food, nutrition and income (Awodoyin et al. 2015). For instance, IFTs provide goods and services including shelter, fodder, medicine, fibre, mulch, timber, saps and resin (Leakey 2012). They have been recognized as important components of traditional agroforestry systems over the last 100 years, but have remained understudied (Gebauer et al. 2002).

Parkia biglobosa (Jacq.) R. Br. ex G. Don also known as the African locust bean, is an important multipurpose tree species, and one of the most common traditional parklands species, which provides vital non-timber forest products (Koura et al. 2011; Nyadanu et al. 2017). In addition, it is a source of shelter and litter for the soil. The pulp that is derived from its fruit is rich in sucrose while the seeds (rich in carbohydrates, proteins and lipids) serve in preparation of "soumbala or dawadawa", a fermented food condiment (Lamien et al. 1996). Furthermore, *P. biglobosa* leaves, bark, roots and flowers are used in the treatment of many diseases such as hypertension, wound and malaria (Dedehou et al. 2016).

Despite its socio-economic importance, *P. biglobosa* has remained undomesticated and exposed to constant anthropogenic pressures in its natural habitats. This is due to demographic explosion, livestock pressure, expansion of agricultural activities and overexploitation of plant organs (Lamien et al. 2011). The species populations are also characterized by ageing individuals and low regeneration rates (Sina 2006), leading to fragmentation and reduced populations across traditional agroforestry systems in West Africa. Given the substantial body of knowledge published on *P. biglobosa*, there is therefore a need for capitalizing on the available information on the conservation biology and domestication aspects of the species, and identifying knowledge gaps and further research directions.

Systematic reviews have recently been introduced in ecology and conservation sciences to address weaknesses in traditional narrative reviews which do not often account for transparent and reproducible approaches of literature search (Lortie 2014). As compared to traditional narrative reviews, systematic reviews provide various advantages including rigorous identification and screening of publications, as well as transparent inclusion of publications based on relevant eligibility criteria (Hayton 2008). Systematic reviews on IFTs through broad cross-disciplinary perspectives have gained increasing interest and become useful in summarizing the state of knowledge and identifying research gaps.

Outputs from systematic reviews mostly depend on literature indexing tools or scientific databases. Indexing tools such as ScienceDirect and Google Scholar are mostly used for identification of publications from other parts of the world as compared to Africa, possibly leading to biases in literature searches. Therefore, to help address these limitations, it is advised to combine various literature sources (Yu et al. 2016) such as ScienceDirect, Google Scholar and African Journals Online-AJOL, the latter being identified as an important African scientific database.

Here we carry out a systematic review to present an up-to-date overview of studies on domestication and conservation biology aspects of *P. biglobosa* in Africa. Specifically, the systematic review aimed at (1) exploring the ecological, socio-economic, and domestication aspects of *P. biglobosa*; (2) summarizing the scope of the available literature; and (3) presenting key findings, knowledge gaps and future prospects. We expect to provide synthesized information that would guide domestication and conservation actions of *P. biglobosa* across Sub-Saharan Africa.

Materials and methods

Literature search approach

We searched for literature on *P. biglobosa* using the following online search engines: ScienceDirect (www.sciencedirect.com), Google Scholar (www.scholar.google.fr) and African Journals Online (www.ajol.info). Both ScienceDirect and Google Scholar are international databases while African Journals Online is an African literature database.

During the search, publications over 30 years from 1987 to 2017 were considered.

In ScienceDirect, we used the following search terms: "domestication", "sustainable management", "conservation biology" and "biology of conservation" in combination with "*P. biglobosa*" or "African locust bean" or "Néré". Using the "refine" function, the search results were afterwards polished based on relevant thematic aspects of domestication and conservation biology (e.g. traditional uses, economic importance, morphological diversity, reproductive biology, eco-physiological aspects, propagation, tree productivity, molecular genetic diversity, structural characteristics, population structure, threats and conservation status). In Google Scholar and AJOL, we used the advanced search features to retrieve publications on *P. biglobosa*, based on different combinations of the following keywords: "domestication", "sustainable management", "conservation biology" and "biology of conservation" in combination with "*P. biglobosa*" or "African locust bean" or "Néré".

Study selection and compilation

Search results were screened for all databases using titles, abstracts and keywords of the publications. Published case studies outside the native range of the species, as well as those identified as duplicates were excluded (Fig. 1). Letters, encyclopaedia, case-reports, books, manuals and guidelines were also excluded. For final inclusion in the review, all publications were screened through four steps: (1) checking the relevance of the publication based on the title; (2) reading abstracts to determine whether it is relevant for the review; (3) downloading and reading the full article when step two did not provide adequate information to warrant its inclusion in the review; and (4) retrieval of publications that met the inclusion criteria for this review.

The following information was compiled on the publications retained for this review: (i) journal and title of the publication; (ii) keywords of the publication (iii) year of the publication; (iv) country of the study; (v) study location within country; (vi) coordinates of study location; and (vii) aspect(s) addressed in the study which may be either of the following: (1) traditional uses; (2) socio-economic importance; (3) morphological diversity; (4) reproductive biology; (5) ecophysiology related aspects; (6) propagation, growth and development; (7) productivity and harvesting; (8) genetic diversity; (9) structural characteristics, threats and conservation status of *P. biglobosa*; and (10) two or more abovementioned aspects. Using ArcGIS 10.2 (ESRI, Redlands, California, USA), we constructed the maps showing the spatial distribution of the number of publications in the sub-regions and countries, along with the native occurrence corridor of the species in the Sub-Saharan Africa. Final retained publications were read in detail to summarize the available information and knowledge, based on the different aspects as mentioned above.

Results

Selected publications and journals

A total of 2060 publication records were initially identified across the three scientific databases. Out of these, 1839 publications (e.g. studies with unrelated topic, studies outside the species natural distribution range, as well as duplicates) were excluded during the screening and refining steps. 221 eligible publications were thus considered for full abstract (and text) screening, a process out of which a total of 184 publications (80 in ScienceDirect, 41 in Google Scholar, and 63 in AJOL) were finally included in the systematic review (Fig. 1). These 184 studies were published over three decades (1987–2017), as considered for this review, and in 73 journals with 4, 36, and 33 journals identified by ScienceDirect, Google Scholar and AJOL respectively. However, only 68 journals were further found after removing five duplicated journals across the three databases.

Spatio-temporal patterns

Over the three-decade period, the number of papers on domestication and conservation aspects of *P. biglobosa*, increased generally, but with some fluctuations (Fig. 2). About 88.04% of the papers included in our review were published from 2004 to 2016. The highest number of papers (n = 22) was recorded in 2016 while the lowest (n = 1) in 1992. Nevertheless, no publication was recorded from the three databases before 1992. Similarly, no publication was recorded from 1993 to 1995, and in 2003.

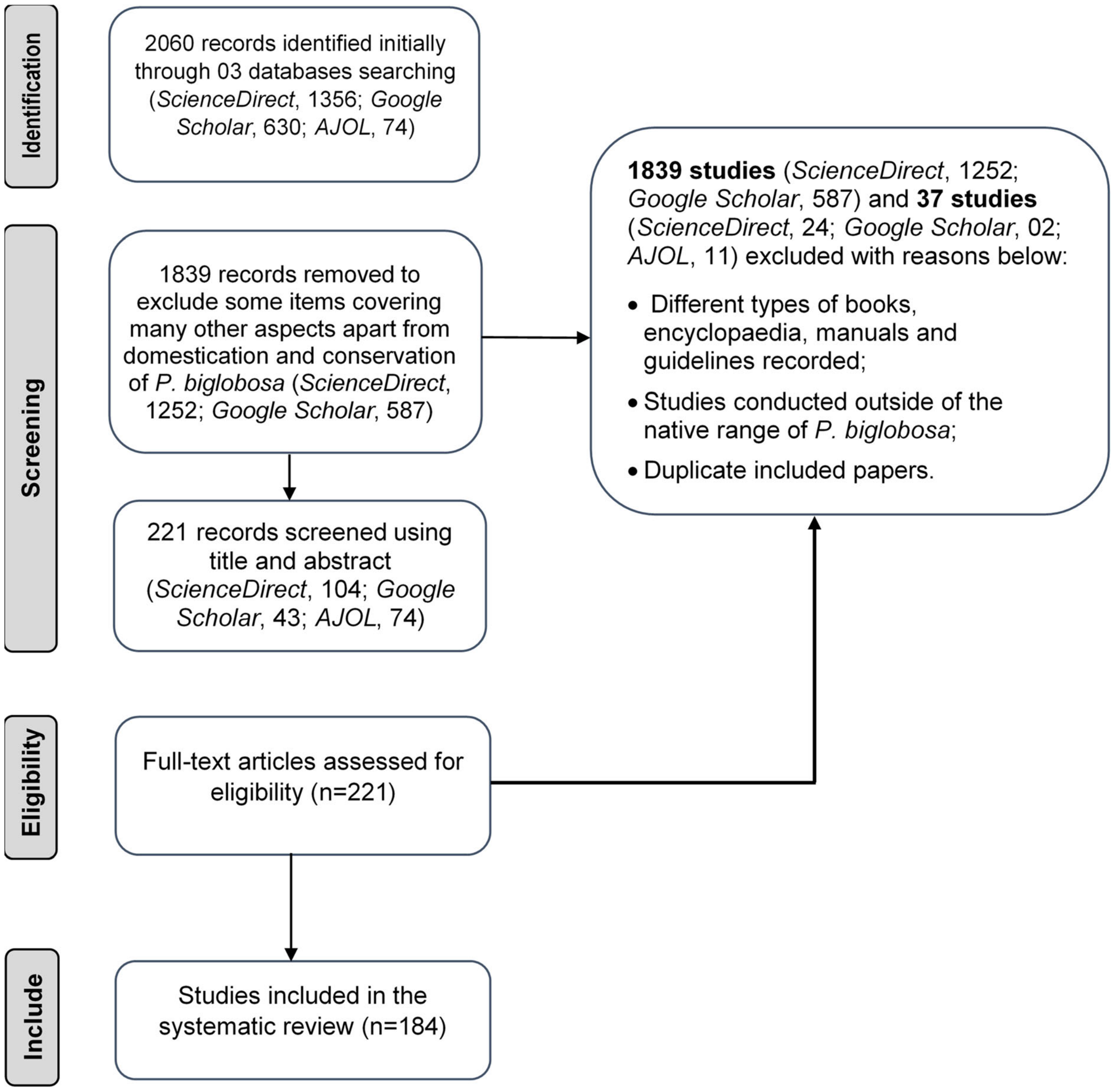

Fig. 1 Diagram showing the selection of 184 studies included in the systematic review on *Parkia biglobosa*

The 184 publications came from the three sub-regions of Africa covering the native distribution range of *P. biglobosa*. Most of these publications came from West Africa (n = 172), followed by Central Africa (n = 4), and East Africa (n = 1) (Fig. 3a). The seven remaining records were across different regions. In terms of country distribution, these studies were conducted in 16 countries, mainly Nigeria (n = 91), Burkina-Faso (n = 25) and Benin (n = 22) (Fig. 3b).

Most publications focused on traditional uses of *P. biglobosa*, and to some extent, on two or more aspects (Fig. 4). As compared to the traditional use, there were fewer studies on structural characteristics, threats and conservation status, and socio-economic aspects (Fig. 4). Aspects such as morphological diversity, ecophysiology, reproductive biology, genetic diversity, tree productivity and harvesting, propagation and growth development were little investigated (Fig. 4).

Discussion

Temporal trends of studies on *P. biglobosa*

Our findings revealed that publications on *P. biglobosa* were very few between 1987 and 2003, with no records in pre-1992, 1993 to 1995 and 2003 suggesting that there was little attention regarding domestication and conservation biology of African locust bean in earlier studies. However, research on the domestication and conservation of the species has increased substantially over the last decade. For instance, among the 184 publications identified over the three-decade period, 148 were published from 2008 to 2017 and about 22 were recorded in 2016 alone, reflecting the increasing research interest on *P. biglobosa* in Africa. The peak of publications also coincides with the increasing interest in specific areas including traditional uses, socio-economic importance, seed-based propagation, structural characteristics, conservation status and other disciplines (food science and technology, biotechnology, mycology). The reason for this research interest in *P. biglobosa* could be found in the global trend in research funding that is mainly concerned about hot and worldwide appealing topics. For example, the International Centre for Research in Agroforestry (ICRAF) also known as the World Agroforestry Centre, has been identified as a driving stakeholder of much of the research actions on African indigenous fruit trees of which *P. biglobosa* (ICRAF 2017). The centre encourages many researchers and conservationists to address innovative research on domestication of declining native fruit trees (Cemansky 2015). Besides, the increasing research interest on *P. biglobosa* could also be attributed to the vital role that it plays in the livelihoods of rural communities and the diverse call for its integration in local development policies (Koura et al. 2011). For instance, *P. biglobosa* was reported as a food and nutrition security plant for local people during food shortage and one of the priority wild edible fruit trees in Sub-Saharan Africa (Ouédraogo 1995). This is consistent with reports highlighting that mature pods of *P. biglobosa* are collected for direct domestic usage when other foods are becoming scarce (Nyadanu et al. 2017; Ouédraogo 1995).

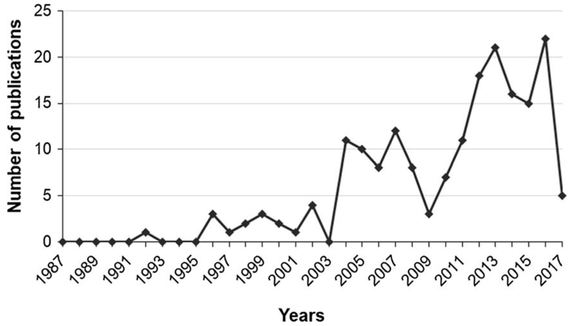

Fig. 2 Temporal variation in the number of publications on *P. biglobosa* from the native distribution range

Spatial trends of studies on *P. biglobosa*

The present review revealed that about 93% of the search results on *P. biglobosa* were from West Africa, suggesting greater research effort in this sub-region, as compared to other regions. For instance, about 75% of publications were recorded in Nigeria, Burkina-Faso and Benin. This trend could be explained by the intensive domestic use and the high economic value reported for the species in West Africa (Koura et al. 2011). Indeed, most of the papers in West Africa addressed traditional uses and socio-economic aspects (Ouédraogo 1995; Vodouhê et al. 2011). This is why scientists should address the sustainable management policies with necessary conservation and domestication actions to ensure *P. biglobosa* successful cultivation as new crop for improving the livelihoods of rural communities in Africa. With many other plant species such as *Adansonia digitata* L., and *Vitellaria paradoxa* C.F. Gaertn, *P. biglobosa* plays a pivotal role in rural livelihoods and ecosystems across Sub-Saharan Africa (Assogbadjo et al. 2008; Karambiri et al. 2017). However, countries in Central Africa (03) and East Africa (01), recorded only few publications, suggesting a limited contribution from these sub-regions to the body of knowledge on domestication and conservation aspects of the species. Two main reasons could justify the relative lower number of publications in Central and Eastern Africa: first, it is probably because research is driven by knowledge of the plant and its use by local people, both varying greatly across sub-regions in Africa, as result of ethnic differences and dynamic of knowledge transfer from generations to generations, and availability of the species (Koura et al. 2011); second, it may also be due to the fact that the species population is more distributed and abundant in West Africa, than in Central and East Africa,

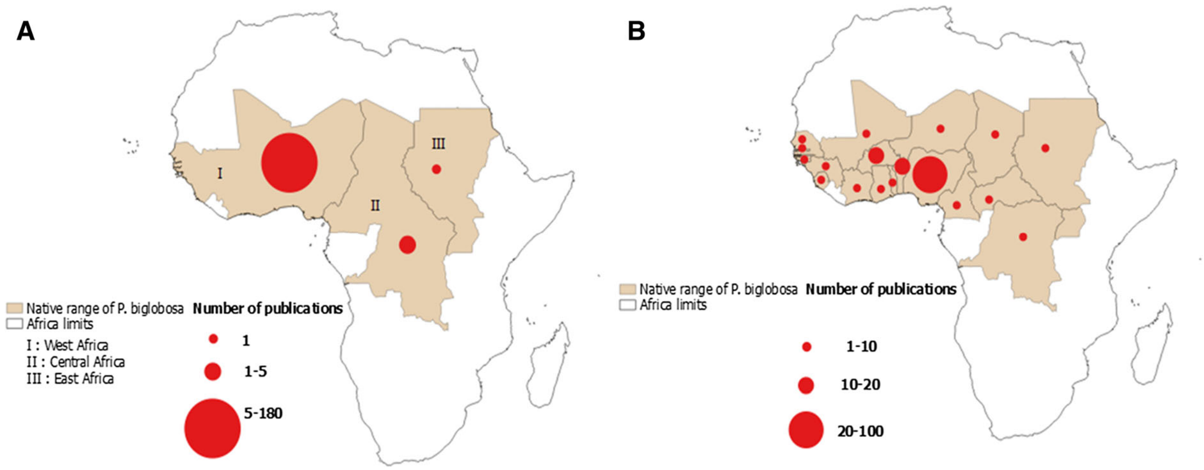

Fig. 3 **a** Spatial distribution of number of publications recorded across the sub-regions covering the native distribution range of *P. biglobosa*, **b** spatial distribution of number of publications recorded across countries forming the native distribution range of *P. biglobosa*

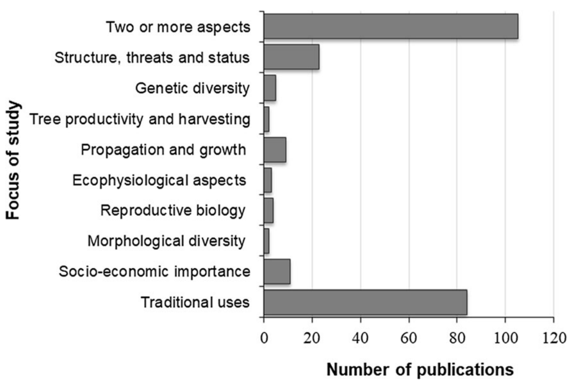

Fig. 4 A comparison of number of publications following study focus on *Parkia biglobosa* across its native range

where alternative plant species have probably received more research interest than *P. biglobosa* (Hall et al. 1997; Lamien et al. 1996). Thus, its limited distribution in Central and East Africa may have reduced the research interest. This may also reflect gaps in search literatures and documentation of many aspects of domestication and conservation of *P. biglobosa* in these two sub-regions.

Traditional uses of *P. biglobosa*

Parkia biglobosa is one of the well-known multipurpose indigenous agroforestry fruit tree species with considerable importance in Sub-Saharan Africa (Fig. 5); it plays a key role in the livelihoods of local people (Fig. 6).

Food uses

Parkia biglobosa is a highly valued fruit tree species (Fig. 7a) which is widely used for food purposes (Ouédraogo 1995). The fruit pulp and the fermented seeds are both suitable for human consumption. The mealy pulp from the species' fruits is a major source of energy and nutrients including carbohydrates, proteins, lipids, carotenoids, vitamins A, B, C, and oligo-elements (Nyadanu et al. 2017). Previous findings highlighted the importance of the pulp, being one nutritional and mineral supplement for rural communities (Koura et al. 2011; Ouédraogo 1995). For instance, the collected pulp can be transformed into pure meal (paste/dough) or mixed with millet flour, which is prominent component in local people diet (Fig. 7b). The pulp and millet flour mixture can also be used to produce couscous, porridge, fritters and cakes. However, the seed is the plant organ mostly used in people diet (Fig. 7c); the fermented seeds are processed to make an aromatic and tasty paste (with a considerable protein content), widely used as food condiment (Fig. 7d) in West Africa (Nyadanu et al. 2017). Due to its high protein content, and local availability, the food condiment is considered as a substitute for animal protein (meat or cheese). Therefore, the promotion of this food condiment can

substantially contribute to reduce malnutrition caused by lack of micronutrients in Africa. Apart from these documented uses, the roasted seeds can also be used as a coffee substitute known as "*Sudan coffee*" or "*café nègre*" while the ground seeds can also be mixed with *Moringa oleifera* leaves in soup, and to make doughnuts (Sina and Traoré 2002). It is also worth mentioning that *P. biglobosa* leaves are appreciated as fodder for livestock, but mixed with other feed resources due to their low concentration in phosphorus, magnesium and sodium (Lamien et al. 2011).

Medicinal uses

Parkia biglobosa plant organs are used either as main recipe or in combination with other plants to treat several human and animal illnesses both internally and externally. According to previous studies, the roots, the bark, the flowers and the seeds are used to treat more than 80 diseases in West Africa (Dedehou et al. 2016; Ouédraogo 1995). For instance, the bark and leaves are both used in traditional treatment of parasitic infections, circulatory system disorders such as arterial hypertension with disorders of the respiratory system, digestive system and skin (Sina and Traoré 2002). Specifically, hot decoction with the dried bark (in form of medicinal tea) helps in management of diarrhoea while the boiled bark (Fig. 7e) is often recommended for fever, wounds and infections (Nyadanu et al. 2017). Besides, the root-based decoction is used for treating coccidiosis of poultry in veterinary medicine (Sina and Traoré 2002). Given the abovementioned medicinal potential of *P. biglobosa*, we suggest that further research address the ethnopharmacological benefits to ensure the development of standardized phytomedicines from the species in Africa. Hence, detailed studies of biological activities and toxicity in *P. biglobosa* could help to clarify this perspective.

Timber and other uses

The wood is suitable for making kitchen implements such as mortars and pestles. Its use for carving, firewood and paper production is also reported in West Africa (Sina and Traoré 2002). Moreover, house and musical items (sponges, strings, and baskets) can also be made from the pods' fibers (husks) and roots. The boiled pods are used to dye pottery black while the ash is applied as a mordant (Nyadanu et al. 2017). Similarly, a study by Koura et al. (2011) reported that the boiled husks are mostly used by local people to stiffen the wall with house buildings in Benin (Fig. 7f). Meanwhile, the bark is reported to be rich

Fig. 5 African locust bean tree from wild habitat in Benin

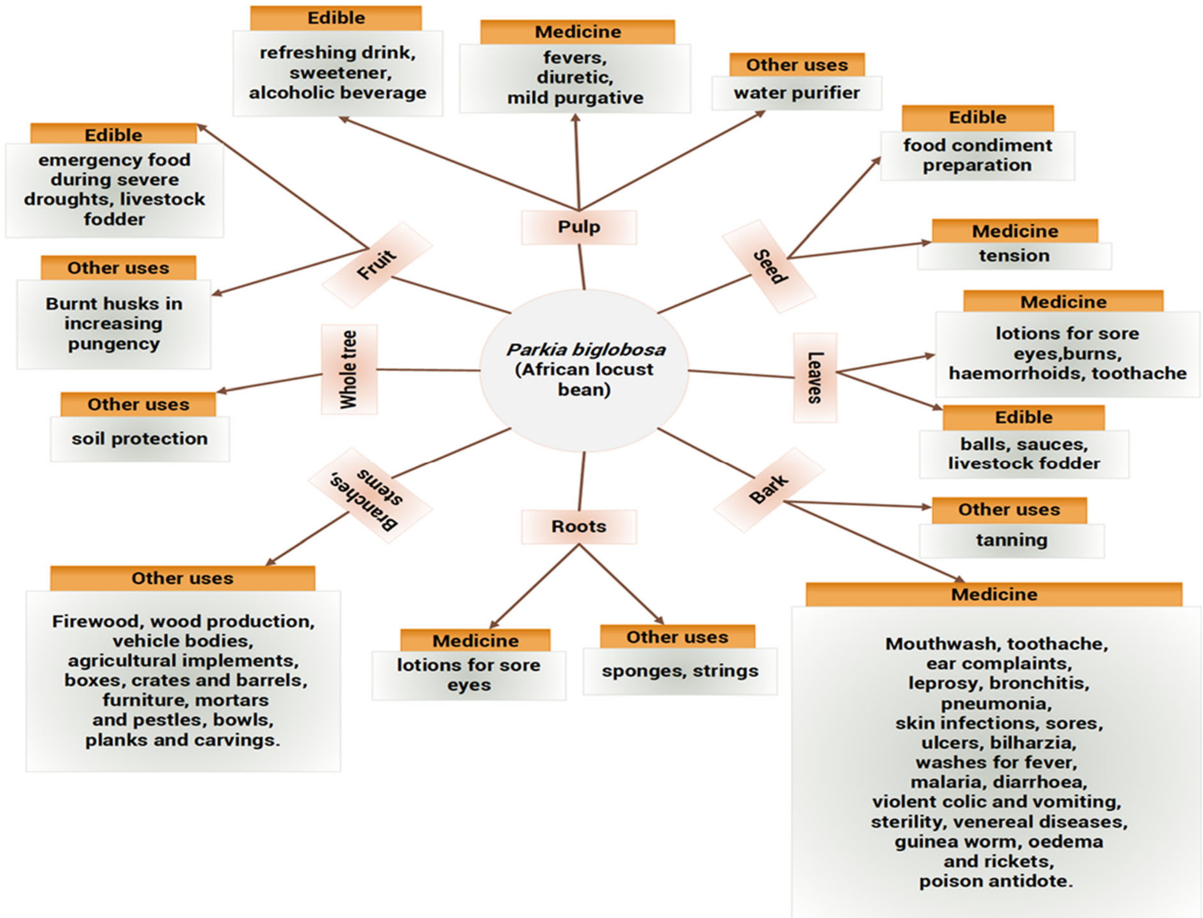

Fig. 6 Overview of traditional uses from different parts of *Parkia biglobosa* in Africa

in tannins and may be used for tanning hides, but the resulting leather is often of moderate quality, reddish, uneven, and darkens when exposed to light (Sina and Traoré 2002). The leaves have an excellent reputation for soil improvement when applied as green manure. The importance of *P. biglobosa* has also been highlighted in beekeeping as a good source of nectar, making the species suitable for the placement and management of honeybee hives. It further has an ornamental potential because it may serve as a decorative avenue tree. Finally, the species has also been reported to have great medico-magic potential and plays a crucial role in rituals including those associated with birth, baptism, circumcision, marriage and burials among rural communities in West Africa (Ouédraogo 1995).

Socio-economic importance of *P. biglobosa*

The main economic importance of *P. biglobosa* relates to its seeds, which are subject to trade in local markets. The *soumbala*—a highly valued food product from the plant seeds—is widely consumed in West Africa; it is used in one daily meal for up to 90% of the year in some areas (Sina and Traoré 2002). As a result, the seed with its derived products are traded in local markets; for example, about 200,000 tons of *P. biglobosa* seeds are collected every year in northern Nigeria for both commercial and domestic purposes (Lamien et al. 2011). The harvesting of *P. biglobosa* fruits and extraction of seeds are lucrative activities for farmers who commercialized the seeds as raw material to the processors (especially women) to make the food condiment (the most marketed food product). As a result, the marketing chain of *P. biglobosa* is at two

Fig. 7 Traditional uses of *P. biglobosa* in Africa: **a** fruits harvested from mature trees for domestic uses, **b** pulp collected from harvested fruits for food uses, **c** seeds traditionally used in food purposes, **d** a food condiment increasingly used in traditional sauces cooking after seed processing, **e** bark derived from African locust bean tree locally used in medicine, **f** strengthening of wall with house buildings using the boiled husk in Tanguiéta district (Benin)

stages including the sale of the dry seeds and that of the processed seeds (food condiment) (Lamien et al. 2011). A study by Vodouhê et al. (2011) in the Pendjari Biosphere Reserve in Benin, revealed that *P. biglobosa* can contribute up to 53% to family net income during its fructification period. However, the processing and production of condiment from the seeds have remained very tedious and traditional with little or low technology input. Therefore, future investigations should focus more on the economic botany, processing technology of derived products as well as prerequisites for its further packaging and commercialization. Such knowledge will provide valuable insights for developing the African locust bean value chain, promoting its sustainable utilization and conservation, and hence enhancing its contribution to local livelihoods.

Morphological diversity in *P. biglobosa*

There is a considerable morphological diversity in *P. biglobosa*, attributable to a wide range of factors such as environment (soil, climate), probable manipulation by human, and phenotypic plasticity, promoting the presence of different ecotypes in West Africa (Ouédraogo 1995). For instance, previous studies showed that *P. biglobosa* exhibited variations in leaf morphology and fruit size. Specifically, the species leaf morphology was found to vary from Western to Eastern Africa, with a positive correlation between the length of leaflets and longitude (Ouedraogo et al. 2012). This east–west morphological variation in leaf features of African locust bean corroborates similar findings reported by Hopkins (1983) based on 85 herbarium specimens. According to Millogo (2014), there is also a longitudinal variation in the species seed morphological traits (length, width, thickness, weight), making two sub-groups along the West–East gradient in Africa. However, little is known about the species fruit' traits variation from West Africa (Ouédraogo 1995). Research that addresses morphological characterization of the species traits, especially fruit and its subsequent components should be undertaken to complement existing knowledge systems of African locust bean for future domestication purposes from West Africa. Further studies should also examine the role of environmental conditions in driving phenotypic trait variation in *P. biglobosa*, since several previous studies have established strong relationships between morphological variability and climatic conditions for many plant species (Hounkpèvi et al. 2016). These studies should also consider the fact that human activities (land use changes, indirect manipulations, etc.) are a strong driver of variation in species morphological traits (Júnior et al. 2018).

Reproductive biology of *P. biglobosa*

The African locust bean is a monoecious species. The inflorescence shows a complex structure mainly composed by the red flowers forming an apical capitulum with a basal constricted receptacle (Lassen et al. 2012). Although three types of flowers including fertiles (2206), staminoides (85) and nectar flowers (261) are found in the hermaphroditic capitulum, only up to 25 pods are counted in the infructescence. Such trend is attributed to protandry in *P. biglobosa,* which is identified as a mechanism allowing either to limit or avoid the selfing (Ouédraogo 1995). A study by Hopkins (1983) revealed that the anthesis in *P. biglobosa* is nocturnal and lasts one night. The seeds have a thick, resistant testa with large cotyledons forming about 70% of their weight (Sina and Traoré 2002). The leaves fall quickly when high number of flowers appear. Moreover, it is found that the new foliage flushing is mainly recorded after a peak of the flowering in *P. biglobosa* (Lamien et al. 2011). The flowering period covers the dry season, which lasts from December to April in West Africa, beginning late with increasing latitude but remains sometimes irregular in other months. Furthermore, *P. biglobosa* is shown as bat-pollinated, and in areas with few bats the main pollinators are honey bees or other insects such as pollen and nectar-lapping visitors (Lassen et al. 2012). Recent studies also support similar findings, highlighting that about thirty potential pollinating species visit African locust flowers (Lompo et al. 2017). Specifically, the bats are identified as long-distance pollinators whereas the honey bees are described as short-distance pollinators (Lassen 2016). The seeds are further dispersed by rodents (squirrels and rabbits), primates (baboons and chimpanzees) and birds (parrots) but humans are probably the main seed dispersers in traditional agroforestry systems in West Africa (Lassen et al. 2012).

Environmental conditions and ecophysiological aspects

Parkia biglobosa supports a wide range of climatic conditions across its native distribution range (Hall et al. 1997). For instance, the species can grow in areas with a rainfall of 500–800 mm in the Sahel, but also occurs in ranges with higher rainfall as well, 2200 mm in (Guinea Bissau), and 4500 mm in (Sierra Leone) and (Guinea-Conakry) (Lompo et al. 2017). Its optimal temperatures vary between 26 °C and 28 °C (Sina and Traoré 2002). Although it prefers deep loamy soils, *P. biglobosa* can also accommodate xeric areas, as it may also occur on lateritic soils and rocky hills (Lamien et al. 2011). In terms of altitude, the species is found at altitudes ranging from 50 m asl (in Senegal and Gambia) up to 1350 m asl in the mountains of the Fouta Djallon in Guinea Conakry (Hall et al. 1997).

The plasticity of *P. biglobosa* to drought stress has been examined in West Africa, and authors found that the species seedlings are more vulnerable to water stress, which can cause mortality under severe stress regime (Bouda et al. 2013). For instance, growth parameters of *P. biglobosa* seedlings decreased under water stress, supporting similar observations made on other agroforestry tree species [e.g. *Khaya senegalensis* (Desv.) A. Juss] in the Sub-Saharan Africa (Ky-Dembele et al. 2010). Similar results were also reported earlier by several other authors, including Ræbild et al. (2012) and Sina (2006). According to Ouedraogo et al. (2012), *P. biglobosa* occurs widely under different climatic conditions in West Africa, which suggests the presence of a continuum of locally adapted populations. Thus, further studies should take into account such patterns with water stress tolerance in exploring ecophysiological performances along climatic gradients. Yet, other stressful factors including radiation, temperature and wind have also been reported to induce important physiological modifications in plant species (Levizou et al. 2004). Therefore, in a perspective of identifying the stress-tolerant genotypes in *P. biglobosa*, further investigations should also target its responses to a wide range of abiotic factors known to influence the physiological performances of the plant species.

Propagation, growth and development

Production technology

African locust bean is mostly propagated by seeds, although rooting cuttings, air layering and tissue culture may also be used (Lamien et al. 2011). For instance, stem cuttings taken from juvenile plants and layering of 11–25 years old trees showed good results in Burkina Faso and Nigeria while in vitro micropropagation trials using meristems of young seedlings

revealed a high rate of 72% in the United Kingdom. Consequently, micro-propagation protocols for African locust bean could be useful in producing desirable planting materials (Sanou et al. 2004). However, vegetative propagation of *P. biglobosa* using stem explants is still constrained by the rooting capability of stem explants and the nodal position on the species' shoot (Teklehaimanot et al. 1996). This is certainly why direct seeding has been reported as more convenient for rapid propagation of the species (Sina 2006). Its seeds are pre-treated with concentrated (97%) sulfuric acid (H_2SO_4) for 10 min to break dormancy, and subsequently immersed in water for 24 h before sowing (Sina and Traoré 2002). This pre-treatment was mostly recommended because of the hard coat of the seeds. Thus, Bouda et al. (2013) reported that using such pre-treatment seemed to increase germination rate. However, the seeds may also be immersed in boiling water to soften the shell and thereafter soaked overnight to improve the germination performances. Therefore, as a contribution to field propagation and afforestation programs, further investigations are required, and should take into account the large spectrum of seed pretreatments (e.g. mechanical scarification and cold stratification) in order to identify the most efficient (in terms of time and performance) method as well as the best planting materials (Sozzi and Chiesa 1995).

Growth and development

Seedlings of *P. biglobosa* show a semi-hypogeal germination with a coat associated to the fleshy, pale green cotyledons. For instance, the first leaf appearing in growth period is known as a cataphyll with subsequent juvenile leaves which are bipinnate (Ouédraogo 1995). Thus, the taproot firstly derived from seed emergence develops before the expansion of lateral roots (Lamien et al. 1996; Sina and Traoré 2002). Furthermore, previous findings showed that *P. biglobosa* seedlings may reach 1 m of height per year with young trees able to reach 7 meters in 6-year-old plantations (Sina 2006). However, the species starts flowering at 5–7 years while still comparatively small but it reaches the maximum height after 30–50 years (Sina and Traoré 2002).

Fruit tree productivity and harvesting

Parkia biglobosa is an important agroforestry plant that has considerable yield and productivity in West Africa (Ouédraogo 1995). Nonetheless, the estimation of annual production of fruits is difficult because the fruits are sometimes randomly harvested and used by local people. Consequently, the annual fruit production can vary between 25 and 130 kg/tree, depending on the year and the environment whereas the average annual production is 900 kg/ha for the seeds, 2200 kg/ha for the pulp and 1900 kg/ha for the husk (Sina and Traoré 2002). However, the production of *P. biglobosa* in farmlands is on average higher than that of trees growing in other habitats where the fruits are often collected from April to May (Sina and Traoré 2002). This observed tendency in species' fruit production from farmland may be due to the positive effect of low diversity of woody species in such habitat. Indeed, this low diversity in cultivated lands reduces the intra and interspecific competition for local resources (soil nutrients, water) among tree species, which in turn may increase their fruit production (Aleza et al. 2018). Moreover, soil fertilization from agriculture, basically provided to annual crops may benefit from associated trees leading to their high fruit production across traditional agroforestry systems (Teklehaimanot 2004). Therefore, further studies should examine more the potential impacts of land-use type and environmental conditions on fruit production of this multipurpose tree species in Sub-Saharan Africa. Such knowledge will provide valuable insights for ensuring the persistence of this IFT, and avoiding a shortage of African locust bean products.

Fruit harvesting is tedious and time consuming, as a yield of 27 kg to 60 kg of dried seed in year can be achieved by harvesting four to nine mature trees (Teklehaimanot 2004). The harvesting is usually manual, either from the ground using long-staked cutters, or by climbing trees. The development of low-cost technologies allowing a quick collection of mature fruits would facilitate harvest and postharvest operations.

Molecular genetic diversity

Scientific research integrating molecular data may complement morphological classifications and help in

revealing the phylogenetic relationships with different ecotypes and the evolutionary trends of African locust bean. The use of molecular markers is known as one of the best approach to study local genetic material and explore genetic diversity in plants (Wang et al. 2016). In line with this, only few molecular aspect-related studies assessed the genetic diversity of *P. biglobosa*. In Nigeria, the genetic profile of *P. biglobosa* from different agroecological zones using Random Amplified Polymorphism DNA (RAPD) indicates a weak genetic diversity (e.g. expected heterozygosity, H_E= 0.05–0.18 and observed number of alleles, *ONA* = 1.11–1.65) in 23 accessions (Amusa et al. 2014). This reduced level of genetic diversity also corroborates other studies that used another molecular marker (seed protein electrophoresis) (Adesoye and Apo 2015). Occurrence of a narrow genetic base from the accessions of *P. biglobosa* would suggest that they resulted not only from a common gene pool but also from outcrossing nature of species over a long time leading to a high homozygosity. Besides, a study by Lompo et al. (2017) examining the previous allozyme data available on *P. biglobosa* enabled distinction of three diversity' regions including the centre of West Africa identified to cover a high allozyme diversity compared to the Central Africa and marginal parts of West Africa where a low allozyme diversity was recorded. Thus, future studies should target more specific molecular markers when assessing genetic diversity in *P. biglobosa* as contribution to enhance the selection of germplasm for conservation purposes.

Structural characteristics, threats and conservation status

A growing number of studies has shown that density of African locust tree population varies considerably across the species range. Earlier studies reported up to 40 trees/ha in the Central African Republic as compared to Burkina Faso where density varied between less than one tree per ha in the sub-Sahelian zone to up to 25 trees/ha in the Sudanian zone (Lompo et al. 2017; Ouédraogo 1995). According to Nchoutpouen et al. (2009), *P. biglobosa* had on average 2.04 trees/ha in Cameroon with a disparity ranging from savanna (6.7 trees/ha) to other land-use systems (0.05 trees/ha). Similar observations were made by the same authors with *P. biglobosa* seedlings, with the average regeneration density decreasing from 55 plants/ha in savanna to one plant per ha through other land use systems (farmland and fallow). Yet, lack of the natural regeneration is also mentioned in West Africa (Teklehaimanot 2004). Thus, these studies collectively suggest that *P. biglobosa* has a relatively poor regeneration potential across its native range, which may be partly explained by the extensive collection of its seeds.

This variability in tree density according to the land use could be partly due to the fact that *P. biglobosa* still grows in the wild, with less rural communities' effort to domesticate and cultivate the species. Besides, the low potential of regeneration within traditional parklands could be explained by the high anthropogenic pressure due to extensive agriculture, browsing, and overharvesting which jeopardize its natural regeneration and population structure (Padakale et al. 2015). This reported low regeneration density corroborate results from other studies, which found that the natural stands of many other multipurpose trees are declining in Africa (Traoré et al. 2013). Apart from the effects of multiple stressors on the recruitment, the ageing species natural stands may also lead to the reduced density and local extinction, especially in population overexploited (Ræbild et al. 2012; Sina 2006).

Intensive fruit harvest and reduction of the fallow period in drier climatic conditions have been identified as significant drivers of *P. biglobosa* population structure. Thus according to Teklehaimanot (2004), substantial change in the distribution range of *P. biglobosa* is driven by both anthropogenic and environmental factors. As also pointed by Lamien et al. (2011), the species population is quickly declining because of demographic explosion, livestock-population pressure, increasing land fragmentation, and overexploitation of plant parts for domestic and commercial uses. On the other hand, successive drought events occurring in recent years from West Africa were reported as main factors inducing the poor regeneration of the tree (Lamien et al. 2011). Thus, reduced rainfall may impose significant threats to the species, particularly to populations in more arid regions (Ouedraogo et al. 2012). The vulnerability of *P. biglobosa* populations to intensive harvesting and harsh climatic conditions calls for more in-depth studies to understand the species demography and population dynamics.

Until now, no official conservation status has been reported for *P. biglobosa* on the IUCN Red List of Threatened Species despite its current vulnerability across its native distribution range. As the species is reported to be rapidly declining, effective conservation actions become necessary for sustainable use. Thus, several approaches including both in situ and ex situ conservation were implemented by the ("Centre National de Semences Forestières", Burkina Faso) in order to conserve the genetic resources of *P. biglobosa* in West Africa (Ouédraogo 1995; Sina 2006). In a perspective of safeguarding *P. biglobosa* germplasm, Ouedraogo et al. (2012) also conducted ex situ experiments emphasizing the ability of *P. biglobosa* to grow under different climatic conditions in West Africa. But apart from 48 characterized stands found in Burkina Faso, the number of protected *Parkia* populations in situ remain unknown so far across its native distribution range (Lamien et al. 2011). This offers new research perspectives on demographic studies and viability analysis of *P. biglobosa* populations at a large scale in Sub-Saharan Africa.

Strengths and limitations

This systematic review provides insights into the domestication and conservation of African locust bean through broad cross-disciplinary perspectives in Africa. Our review shows the importance of screening the available literature about IFTs in identifying research gaps with ways forward to sustain the current research efforts on biological resources from Sub-Saharan Africa. However, it has its own weaknesses due to publication bias that could be derived from search results and thus any such bias may have been transferred to the present review. Besides, a large body of recorded papers included in this review did not cover certain aspects (e.g. phytochemical properties and biological activities etc.), which are worth addressing and discussing, especially for plant genetic resources.

Conclusion, knowledge gaps and future prospects

Parkia biglobosa is a multipurpose tree species widely used at different levels but undergoes constant anthropogenic pressures across traditional agroforestry systems (Lamien et al. 2011). In case no conservation measure is taken, the species natural stands are at a risk of local extirpation in the next decades. There is a need for research on domestication perspectives of the species in Sub-Saharan Africa. Our review brought out several gaps in the knowledge of *P. biglobosa* in Africa. For instance, only few studies are recorded both from the Central Africa (n = 4) and East Africa (n = 1) sub-regions as compared to West Africa (n = 172). This tendency reflects a heterogeneous and uneven distribution of publications about *P. biglobosa* across its native distribution range. Thus, our review summarizes previous findings and supports the general assumption that the number of publications on biological resources depends on their potential economic value, conservation status and strength of scientific research (Juárez-Orozco et al. 2017). There are critical research gaps with regard to several aspects of the species domestication and conservation including ecology, physiology, demography, molecular biology, genomics and evolutionary biology. Further studies addressing domestication, conservation and sustainable management issues of *P. biglobosa* should mostly target these above-mentioned study aspects. Specifically:

1. There is little information on genetic resources improvement based on selection of wild morphotypes of African locust bean in Sub-Saharan Africa. This offers new research opportunities on *P. biglobosa* germplasm characterization and domestication purposes. The process of plant domestication sometimes requires some preliminary investigations including prior morphological and biochemical analyses as well as molecular genetic studies for identification of best cultivars. More specifically, there is a need to examine the morphological variation in *P. biglobosa* genotypes in order to pave the way for the species domestication and conservation in Africa.
2. Little is also known about the ecophysiological performance of African locust bean despite its ability to grow under a wide range of climatic conditions in Africa. For instance, few studies revealed that *P. biglobosa* is highly sensitive to water stress affecting emergence of its seedlings from Burkina Faso (Bouda et al. 2013). There is therefore a need to investigate the physiological performances of *P. biglobosa* against environmental stress (biotic *vs* abiotic) as contribution to

identify the best plant material that could have ability to grow under stressful conditions for breeding and domestication purposes. This is especially critical for adapting to ongoing changes in climatic conditions.

3. The lack of knowledge about the distributional ecology and environmental drivers limits our understanding of the factors that explain not only latitudinal abundance but also geographic distribution of *P. biglobosa* across its native range. Assessing these factors is necessary to understand the ecological mechanisms underlying its spatial distribution and abundance (Hill et al. 2017).
4. Prior studies also showed that the plant populations are declining as a result of increasing ecological and anthropogenic pressures in the tropics. Yet, no long-term investigations of the species population dynamics under different disturbances exist to inform on the life history of the species, which may be relevant in planning its conservations actions.
5. There is limited information on economic contribution of *P. biglobosa* to rural household incomes in Sub-Saharan Africa. Indeed, previous studies point out that trade in IFTs contribute significantly to the rural livelihoods through income generation. Thus, Vodouhê et al. (2011) noted that harvesting of *P. biglobosa* products (seeds, pulp) accounts for about 53% of the total cash income of the rural households in Pendjari Biosphere Reserve of Benin. However, the livelihood maintenance is related not only to social attributes (e.g. gender and household size) of rural households but also to external factors like distance to markets (Heubach et al. 2011). There is therefore a need for clarifying the social drivers underlying the potential economic value of *P. biglobosa* in Africa. Such investigations are worth addressing in order to determine the relative contribution of IFTs to household income as compared to other income sources among local communities in Africa.
6. Finally, because of its slow growing performance, research studies on the potential for vegetative propagation of *P. biglobosa* are needed. Indeed, previous studies showed that *P. biglobosa* takes long time (between 5 and 7 years) for first fructification (Sina and Traoré 2002). This highlights the need for more research to shorten the species production cycle with more focus on vegetative propagation techniques like grafting and cutting. Such studies were undertaken on Shea butter tree (*Vitellaria paradoxa*) and revealed that grafting has enabled to reduce the period to the first fruiting from 20 to 6 years (Kalinganire et al. 2007). Similar studies were successfully conducted on baobab, *Adansonia digitata* to assist its domestication in East Africa (Anjarwalla et al. 2017). There may be possibilities for reducing the first fructification to less than five years in *P. biglobosa* too. Such achievement will be a major advance in the domestication of the species.

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Data availability The datasets generated during and/or analyzed during the present study are available from the authors upon request.

Compliance with ethical standards

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

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