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Review

Diversity, Chemical Composition, and Domestication Potential of *Allanblackia parviflora* A. Chev. in West Africa

Dennis Kyereh [1,*], Anna Maňourová [1], Prasad S. Hendre [2], Alice Muchugi [3], Marie Kalousová [1], Patrick Bustrel Choungo Nguekeng [1], Tariku Olana Jawo [1], Daniel Aninagyei Ofori [4] and Bohdan Lojka [1,*]

1 Department of Crop Sciences and Agroforestry, Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Kamýcká 129, Suchdol, 165 00 Prague, Czech Republic; manourova@ftz.czu.cz (A.M.); kalousovam@ftz.czu.cz (M.K.); patrick_bustrel@ftz.czu.cz (P.B.C.N.); jawo@ftz.czu.cz (T.O.J.)
2 World Agroforestry (CIFOR-ICRAF), United Nations Avenue, Gigiri, P.O. Box 30677, Nairobi 00100, Kenya; p.hendre@cgiar.org
3 International Livestock Research Institute (ILRI), Addis Ababa P.O. Box 5689, Ethiopia; a.muchugi@cgiar.org
4 Forestry Research Institute of Ghana, Council for Scientific and Industrial Research, KNUST, Kumasi P.O. Box 63, Ghana; dofori@csir-forig.org.gh
* Correspondence: kyereh@ftz.czu.cz (D.K.); lojka@ftz.czu.cz (B.L.); Tel.: +420-774-907-988 (D.K.); +420-734-170-763 (B.L.)

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Abstract: *Allanblackia parviflora* A. Chev. is an indigenous tree species which is found in West African rainforest zones. It is an underutilized fruit tree species that has been targeted for improvement as part of efforts to domesticate high-value indigenous multi-purpose trees for fruit and seed production in Africa. *Allanblackia* has several benefits, such as providing shade, timber, and medicine; however, the production of edible oil from its seeds is the economically most important use. There is evidence that the *Allanblackia* seed oil, which is used for cooking, the production of margarine and the manufacturing of ointments and soap, is being developed as a new agri-business in Ghana, Nigeria, Cameroon, and Tanzania. Despite the nutritional and socio-economic importance of *A. parviflora*, it is still at the early stages of its domestication process. Even though several researchers have explored the biology of this species, there is very limited scientific information available on its morphological and genetic diversity and silvicultural management in West Africa. Therefore, this systematic review presents an up-to-date overview on the uses, seed chemical composition, and morphological and genetic diversity of this fruit tree species, and proposes a way forward for future research towards improvement and domestication.

Keywords: morphology; genetic diversity; nutrition; seed oil; domestication strategies; fruit tree

1. Introduction

Forests and especially trees in the humid tropics of Africa provide a high number of non-timber forest products (NTFPs) which are important to the livelihoods of local populations [1,2]. Meanwhile, most farming systems in these areas often eliminate trees from the landscape, which has significantly contributed to deforestation and biodiversity loss [3]. The cultivation and incorporation of high-value indigenous fruit trees into the local farming systems could potentially stabilize smallholder production systems and ensure sustainability [4]. The African Orphan Crop Consortium (AOCC) [5], in collaboration with the World Agroforestry (ICRAF) [6], has been promoting studies on tree genomic resources for the improvement of selected underutilized fruit trees which have, over the years, received little or no attention from scientific research and development [7,8]. The target species for genetic improvement have products that are rich in vitamins, minerals, and other essential micronutrients in the diets of local communities [9]. The AOCC prioritized *Allanblackia* as one of the 101 under-utilized indigenous plant species identified with strong potential for ensuring food and nutrition security across producing communities in Sub-Saharan Africa [7]. *Allanblackia*, a genus belonging to the Clusiaceae family, is indigenous to the West, East, and Central African regions, with the potential for improving nutrition and providing an alternative source of income to rural populations through household consumption and the sale of seed oil [10]. Nine species exist in the *Allanblackia* genus and all of them are native to tropical Africa [11]. Three of the *Allanblackia* species, namely *Allanblackia parviflora* A. Chev., *Allanblackia floribunda* Oliv., and *Allanblackia stuhlmannii* Engl., are considered to have significant economic importance [12].

Allanblackia parviflora A. Chev., also called the vegetable tallow tree, is a high-value indigenous fruit tree species native to the humid tropics of West Africa. It is a neglected fruit tree species that has been targeted for improvement as part of efforts to domesticate high-value indigenous multipurpose trees in the humid tropics of Africa [13–16]. *A. parviflora* has several other benefits which include the provision of shade, timber, and medicine. The dried kernels consist of about 67%–73% white solid fat [17,18]. Ofori et al. [19] highlighted the importance of *Allanblackia* seed oil for cooking, the production of margarine and the manufacturing of ointments and soap. Recent studies have also suggested the use of *A. parviflora* seed oil as an alternative feedstock for biodiesel production [20]. The extracted seeds from *Allanblackia* fruits are traded by local communities, since a supply chain has been developed in Ghana, Nigeria, Cameroon, and Tanzania [21]. This market value would potentially increase livelihood opportunities for farmers and ensure the retention of trees on farms for environmental conservation. However, it has been argued that seed extraction from fruits collected from wild stands alone is not enough to meet the increasing market demand for *Allanblackia* seed oil [17,21]. This review mainly focuses on the West African *A. parviflora* species due to its neglect in research and development, especially in terms of genetics and morphology, silvicultural management, seeds chemical composition, and its high potential for domestication.

Effective tree improvement and domestication programs require an adequate understanding of the genetics and morphological diversity of the species to help in the selection and improvement of desirable characters. Assessment of the genetic diversity of tropical tree genomes requires the use of molecular techniques [22,23], and these are evident from research. For instance, microsatellite markers were used for studies on *Allanblackia floribunda* [24], and Russell et al. [25] used AFLPs markers to assess the genetic composition of populations of five important *Allanblackia* species. However, the use of DNA chips and sequencing-based DNA markers for tropical plant genome sequencing, especially for the vegetable tallow tree, is not well documented. Despite the socio-economic importance and potential of *A. parviflora* in West Africa, there is limited information on the species' genetic diversity, the chemical composition of seeds, and details of domestication efforts. The current study attempts to compile the existing published and grey literature that can contribute to knowledge about the species and help to identify potential knowledge gaps for further research. This review can also offer a baseline for future efforts on the improvement and domestication of *A. parviflora* into agroforestry systems and conservation of the genetic resource of the species.

2. Methodology

A literature search was conducted for titles, abstracts, and keywords of publications listed in the Scopus database for *Allanblackia* species, their synonyms with a range of other search terms related to their ecology and distribution, use, diversity, domestication and improvement. The search was performed for peer-reviewed articles, conference papers, online reports, and technical notes published between 1940 and 2021. The results of our initial literature search revealed 150 documents. The next task was to determine which of these documents reported directly on the key areas specifically for *A. parviflora*. We read the abstracts of all of the documents to find evidence that the diversity and domestication details of the species had been documented. We focused on the terms 'genetic and morphological diversity', 'seeds chemical composition', and 'domestication' of *A. parviflora*. Our further screening of the Scopus database revealed 11 relevant publications relating to the diversity, chemical composition, and tree improvement details of the species.

This indicated that there are very limited studies on the genetic and morphological diversity, seeds' nutritional composition, and improvement and domestication of *A. parviflora* in West Africa. To supplement the Scopus-identified references and to gain better insights into the diversity and domestication details of *A. parviflora*, we searched other scientific databases such as the Web of Science, Google Scholar, Research Gate, and websites of relevant academic institutions and organizations known to actively promote the species' development in Africa. These further searches produced an extra 13 relevant references for *A. parviflora*. Put together, we obtained a final set of 24 references that could be explored in more detail. For each of these references, we read the document in full and summarized the following information: genus *Allanblackia*; botanical description; uses; propagation; chemical composition of seeds; morphological and genetic diversity; domestication potential; and any recommendations for future research.

3. Genus *Allanblackia*

Nine species exist in the *Allanblackia* genus and all of them are native to tropical Africa [11]. The species include *A. parviflora* A. Chevalier, *A. floribunda* Oliv., *A. gabonensis* (Pellegr.) Bamps, *A. stanerana* Exell & Mendonça, *A. kisonghi* Vermoesen, *A. marienii* Staner, *A. ulugurensis* Engl., *A. stuhlmannii* Engl., and *A. kimbiliensis* Spirl. [11,26]. However, only three of all the *Allanblackia* species (Figure 1), namely *A. parviflora*, *A. floribunda*, and *A. stuhlmannii*, are considered to have substantial socio-economic benefits [12]. *A. floribunda* is distributed from the extreme southeast of Benin through Nigeria, Cameroon, and Gabon to Congo. It is a lowland forest tree species growing up to an altitude of 800 m above sea level (asl). *A. gabonensis* is a sub-montane species, found above 500 m altitude asl. It is hardly possible to use its fruits because it occurs in less accessible areas. *A. stanerana* is distributed in the coastal forests of Cameroon to Angola. The fruits are smaller, around 7 cm, and therefore are not considered as economically important. *A. kisonghi* and *A. marienii* also occur in the Congo basin. In east Tanzania, the species *A. ulugurensis* and *A. stuhlmannii* can be found in small very wet remnant forests of the Usumbara and Uluguru mountains. These species have a small forest cover and are under high pressure. Moreover, the economic use of fruits was prevalent in the 1950s. Bamps [27] reported *A. kimbiliensis* to exist in Congo-Kinshasa and Uganda, between 1250 and 1800 m asl.

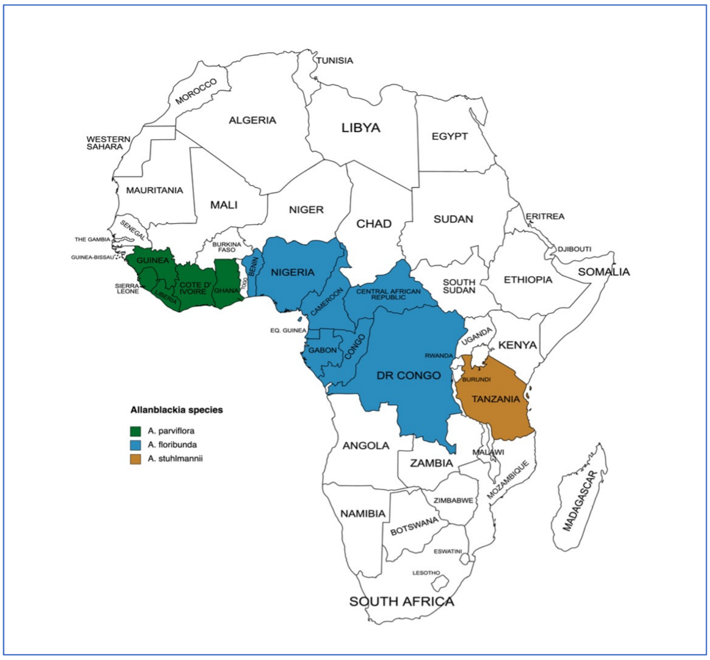

Figure 1. Distribution of key *Allanblackia* species across the African continent (source: author's drawing).

A. parviflora is a high-value multipurpose tree indigenous to West Africa [13–16]. The species native zone of distribution includes Guinea, Sierra Leone, Liberia, Cote d'Ivoire, and Ghana (Figure 1) [28,29]. *A. parviflora* is more abundant in evergreen forest types, especially on slopes and away from disturbed areas, and as well being found in semi-deciduous forest types [17,29,30]. For example, in Ghana, the tallow tree occurs across three main ecological zones; moist semi-deciduous, moist evergreen, and wet evergreen forest zones with annual rainfall ranging between 1250 and 1500 mm, 1500 and 1750 mm, and >1750 mm, respectively [4,10], with monthly minimum and maximum temperatures of 22–34 °C. The species thrives well in soils low in calcium, potassium, magnesium, and base saturation with optimum pH ranging from 3.8 to 4.1 [31].

4. Botanical Description

A. parviflora is an evergreen, medium-sized tree that grows to a height of about 40 m [4]. The stem is cylindrical or slightly fluted, the diameter at breast height (DBH) is rarely greater than 50 cm with narrow crown architecture, the branches are short and horizontal, while the leaves are large, having a shiny surface and numerous lateral nerves forked near the margins (Figure 2). The bark is reddish-brown, with small circular or rectangular scales over small red pits. Additionally, the inner bark is reddish-brown with sometimes pale-yellow streaks, exuding a colourless or pale yellowish sap [28,32]. Flowers are unisexual, fragrant, regular, five-merous and of pink/red or white/cream colour (Figure 3). The pedicel is 1–3 cm long, sepals are ovate or obovate, unequal, 6–18 mm × 4–15 mm, and glabrous, whereas the petals are obovate, and 20 mm long. The male flowers have several stamens in five bundles opposite the petals, which are 18 mm long, and the anthers are arranged on the internal face of the bundle, while the disk is star-shaped with smooth or slightly folded glands. Female flowers have a superior, incompletely five-celled ovary and sessile stigma. Fruits are large, ellipsoid berries 10–50 cm × 15 cm in size, with five longitudinal ridges and are brown and warty. Seeds are ovoid 3 cm × 2 cm × 1.5 cm, enclosed by a pinkish aril. Seedlings with hypogeal germination and epicotyl are 4–5 cm long [29]. The species is dioecious [4] and can produce more than 250 fruits per year [17], with about 24 seeds per fruit on average (Figure 4) [33].

Figure 2. A typical *A. parviflora* A. Chev. tree growing in the wet evergreen forest zone of Ghana (source: author's archive).

Figure 3. *A. parviflora* flowers showing different colors and sexes. (**a**) White/cream female flower with a developing fruit, (**b**) white/cream male flower, (**c**) pink/red female flower, (**d**) pink/red male flower (source: author's archive).

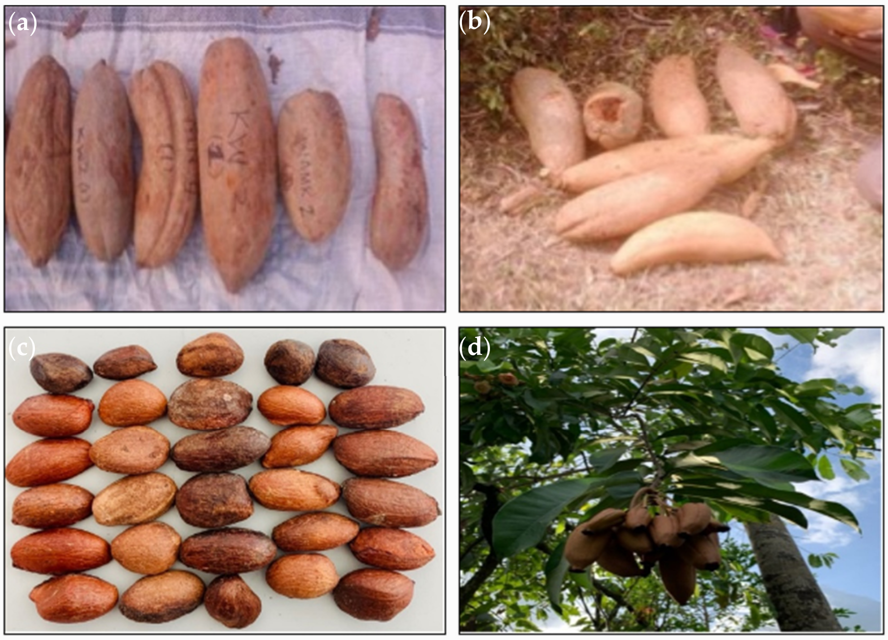

Figure 4. Morphological features of *A. parviflora*. (**a**) Fruits with round or large ends; (**b**) elongated fruits with long ends (adapted from [4] with permission from Springer Science + Business Media B.V. 2009); (**c**) seeds with various shapes and sizes; (**d**) branches with leaves, flowers and developing fruits (source: author's archive).

5. Propagation

Under nursery conditions, untreated *Allanblackia* seeds can take more than a year to germinate at success rates lower than 20% [34]. The thick hard nature of the seed coat, as well as the long seed dormancy period, result in a lack of uniformity in germination and subsequent plant growth. The use of seeds and seedlings in *A. parviflora* cultivation is therefore limited by not only the long period of seed dormancy but also its recalcitrant nature and poor seed storage techniques. In Ghana, Ofori et al. [35] observed that removal of the seed coat and incubating the seeds in polythene bags at a temperature range of 23–31 °C improved seed germination, with seed germination starting from week two and reaching a rate of up to 75% at 10 months. Another limitation associated with the fruit production of *Allanblackia* species is the dioecious nature of the species, which relates to the production of either male or female seedlings. This makes it difficult to identify the sex of the tree at the juvenile stage. Therefore, the assessment of genetic diversity and the selection of desired tree traits could significantly enhance efforts in developing quality planting materials of a known sex for propagation [4].

Vegetative propagation methods were also developed to produce quality planting stocks with a known genetic quality, sex, and decreased gestation period when ontogenetically matured parts were employed. Grafting, leafy stem cuttings, and air layering were used, leading to the first flowering on one- to two-year-old grafts [36–39]. Some of the challenges faced with the vegetative multiplication procedure were that the root system quality was poor and the rate of rooting was low, leading to a reduced number of roots per cutting. Plagiotropism in *Allanblackia* has also been detected in cuttings, but this issue has already been resolved through the adoption of orthotropic (vertically oriented) shoots [33,34]. However, since vegetative propagation alone is unlikely to deliver any lasting advantage, cloning needs to be closely integrated with upstream breeding and conservation efforts. The poor seed germination capability of *A. parviflora* should not be a basis for abandoning the production of planting stocks through seeds. This is because the species population should have the ability to recombine to add to the gene pools of later generations for the preservation of genetic heterogeneity in populations [40,41] and to allow the selection to be made from successive generations [42]. Ennos et al. [43] pointed out that in doing so, the species would have the ability to tolerate changing environmental conditions for long-term sustainability.

6. Uses

The importance of *A. parviflora* includes the provision of timber, shade, and medicine, while the production of oil from seeds is considered the most important economic use [19,35,44]. In Liberia, the wood (usually called lacewood) is traditionally used in house construction for walls, doors and window frames [29]. It is a potential candidate species for use in agroforestry systems due to its attributes as an alternative income source as well as its ability to provide shade to other crops such as cocoa [45]. The pounded bark can be rubbed on the body to relieve pain. In Côte d'Ivoire, a decoction of the fruit pulp is used to treat elephantiasis of the scrotum [29]. The seeds are usually eaten by children as a high-energy snack [46,47]. Some wild animals such as the giant rat, squirrels and brush-tailed porcupine also depend on *Allanblackia* seeds for their survival [17]. The kernel consists of about 67%–73% solid white fat when dried [17,18]. The pressed crude oil from the dry seeds is approximately one-third of the seed dry weight [48,49], and has traditionally been used for cooking and soap making [19,50,51]. It has also been reported that the seedcake can be used as a protein-rich animal feed after the seeds are ground and pressed to extract the oil [47]. A recent study also suggests the potential of *A. parviflora* seed oil as an alternative for biodiesel production [20]. The seeds, when harvested in large quantities for export, could serve as an important income generation source for producing countries. Market value chains for *Allanblackia* seeds collected from wild stands and/or remnants from farmlands have been developed by Unilever (which provides a guaranteed price for harvested seeds) and other commercial parties in Ghana, Nigeria, Cameroon, and Tanzania [21,45,48]. Aside from the increase in livelihood opportunities for farmers participating in this rural-based enterprise, it also contributes to biodiversity conservation in these landscapes. Unilever discovered new uses of *Allanblackia* seed oil at an industrial level to produce cosmetic products and margarine [21], thus raising the international demand to a commercial scale. The *Allanblackia* seed oil is superior to other alternative oils such as palm oil due to its moderately high melting point [17,18]. Oppong [52] pointed out that Unilever needs 2000 t of *A. parviflora* seeds from Ghana; however, only 110 t (just 5.5%) on average are supplied annually [53], emphasizing its importance and need for large-scale planting. The *Allanblackia* seed oil has received an endorsement from the European Union (EU) Novel Food Regulations that approves its safe usage in food products [54].

7. Chemical Composition of *A. parviflora* Seeds

A study conducted on the fatty acid composition of *A. parviflora* seeds revealed that their composition is primarily of stearic (51.6%) and oleic acid (43.9%), with minor quantities of myristic (1.8%), palmitic (2.5%), and eicosanoic acid (0.2%). The main triglyceride constituents were identified as 2-oleostearin (60.1%), 1-stearo-diolein (26.9%) and 2-oleopalmitostearin (6.9%) [55]. Stearic acid percentages ranging from 44% to 66% and oleic acid ranging from 25% to 48% per tree sample were documented for *A. floribunda* [56]. *A. floribunda* seeds have also been reported to contain a lot of edible oil (67.6%) which is rich in stearic acid [57], and these values are similar to those observed for *A. parviflora* seeds. The values confirm the high fat content in the seeds of *Allanblackia* species (Table 1). Adubofuor et al. [51] researched the seeds of *A. parviflora* grown in Ghana, from which oil was extracted by either the use of a screw press or Soxhlet extraction (petroleum ether), revealing an average of 68% oil. The gas chromatography method was employed to assess the fatty acid composition of the seed oil as 2.9% palmitic acid, 52.3% stearic acid, and 44.8% oleic acid. The key minerals found in the seeds were potassium (8.41 mg/kg) and phosphorus (8.34 mg/kg). Nutritional analyses showed that the seeds contained 4.3% protein, 2.0% ash, 5.7% crude fibre and 17.1% carbohydrates, with the moisture content being 3.4%. Additionally, Sefah et al. [58] confirmed the moisture content of *A. parviflora* seeds to be 3.2%.

Table 1. Major fatty acids composition and oil yields of *Allanblackia* seeds.

Allanblackia Species	Stearic Acid (%)	Oleic Acid (%)	Oil Yield (%)	References
A. parviflora A. Chev.	51.6–52.3	43.9–44.8	64.2–68	[51,55,59]
A. floribunda Oliv.	44.2–66.1	25–48.4	60–67.6	[55–57,60,61]
A. stuhlmannii Engl.	45–58	40–51	50	[62]

Nutritional values from *A. parviflora* seeds were compared with those from *A. floribunda* and other tropical fruit trees such as *Vitelaria paradoxa* Kotschy and *Theobroma cacao* L.,1753 and are summarized in Table 2. Even though nutritional values were generally lower than those stated for *V. paradoxa* kernels and *T. cacao* beans, the energetic value of *Allanblackia* seeds was 2863 kJ/100 g, higher than that of both shea kernels and cocoa beans [51]. This observation supports the traditional consumption of *Allanblackia* seeds as a high-energy snack in some parts of Africa [29,47]. However, further research that compares the nutritional potential of *A. parviflora* to site-specific genetic and morphological data may be critical for the effective design and implementation of domestication strategies and serve as justification for the conservation of the genetic resource. Crockett [12] concluded that the phytochemistry of the seed oils of almost all *Allanblackia* species is poorly documented, and more specifically concerning the presence and/or content of lipophilic secondary metabolites and nutritional values.

Table 2. Proximate composition of *Allanblackia* seed kernels compared with shea kernels and cocoa beans (adapted from [51] with permission from Academic Journals, 2013).

Component	*A. parviflora* [1]	*A. parviflora* [2]	*A. floribunda* [3]	*V. paradoxa* [4]	*T. cacao* [5]
Moisture (%)	2.48 ± 0.01	3.40 ± 0.03	2.24 ± 0.02	3.3	5
Fat (%)	69.6 ± 0.27	67.59 ± 0.02	ND	31.7	58
Protein (%)	4.16 ± 0.42	4.27 ± 0.01	19.25 ± 0.02	7.7	13
Ash (%)	1.49 ± 0.15	1.98 ± 0.11	2.58 ± 0.02	4.6	3
Crude Fibre (%)	ND	5.70 ± 0.02	4.21 ± 0.03	6.2	10
Carbohydrate (%)	ND	17.06	61.26 ± 0.05	46.6	11
Lipids (%)	ND	ND	10.46 ± 0.03	ND	ND
Energy (kJ/100 g)	ND	2863.44	ND	2085.80	2554

ND = not determined, ± = standard deviation. Source: [1] [59], [2] [51], [3] [63], [4] [64], [5] [65].

8. Morphological and Genetic Diversity

Genetic diversity analysis is very essential in any tree improvement programme for the identification of quality genotypes and proper clonal deployment. Both morphological [4] and molecular [24,25] differences among *Allanblackia* tree species show significant genetic diversity within the species. Peprah et al. [4], in a study on variation in fruits and seed morphology of 109 *A. parviflora* trees growing in different parts of Ghana, reported no differences in fruit yield, fruit shape and seed health among the ecological zones. However, significant differences in fruit shape and size were observed among the individual trees sampled (Figure 4). According to Leakey et al. [66], variation in fruit parameters at the level of the provenance indicates that genetic variation exists within the species since the environment is similar. The results suggest a high genetic improvement potential through individual selection [4]. In the interim, the adoption of fruit size and seed yield as targeted selection criteria is assumed to be a valid approach for collection and has been used in sampling. The seedlings and grafts raised from these selected trees are disseminated to farmers for farmland cultivation. Moreover, the vegetative propagules (grafts, seedlings, and cuttings) from these superior trees are employed for the setting up of mother blocks, i.e., constructed plots consisting of grafts, seedlings, and cuttings for advanced (vegetative) propagation, and the creation of gene banks for the purposes of conservation [33,67]. In Ghana, two mother blocks have been constructed with 20 superior clones. Moreover, a 3 ha gene bank established with seedlings from 120 mother trees has been constructed in addition to the clonal stocks in the mother blocks [34].

Other species of the *Allanblackia* genus have received some level of research attention in terms of comparing morphological data to the genetics of a given provenance which is vital for developing sound and effective domestication strategies. For instance, morphological and genetic diversity assessment using genetic markers have been reported for *A. floribunda* in Cameroon [24,25] and *A. stuhlmannii* in Tanzania [25,68]. However, there is very limited knowledge on studies focusing on the genetic diversity of *A. parviflora* in West Africa using molecular markers even though some work has been done on the morphological aspects in Ghana [4,17,58]. Genetic markers are employed, for instance, for the estimation of differences between natural and domesticated plant populations, gene flow, fingerprinting, genetic structure, and hybridization, and are therefore essential in breeding programmes and development of new varieties [69,70]. Modern molecular markers such as DNA chips and sequencing-based DNA markers (for example, single nucleotide polymorphisms—SNPs) are used for the assessment of genetic diversity and are based on phenotypic differences that are controlled genetically [71]. However, the use of genetic markers, such as SNPs, for genetic diversity studies of *Allanblackia* in the West African region where the species' occurrence has not been adequately explored. Several factors usually make SNPs the preferred choice of markers because they are platform-independent, reproducible across laboratories, and the subsequent databases can be shared worldwide. Moreover, due to the high frequency of SNPs, ease of design from transcriptome or genome assemblies, and the availability of high throughput SNP assay platforms, SNP genotype data are easy to collect in large amounts [72].

9. Domestication Potential

Domestication is usually a complex of evolutionary processes in which human use of plant or animal species results in morphological and physiological changes that differentiate domesticated taxa from their wild ancestors [73,74]. The tree domestication process begins with a description of the naturally existing intra-specific diversity of the species, identification, and selection of individual mother trees with superior characters. This is accompanied by vegetative propagation of the mother trees, distribution of the planting stocks to farmers and finally cultivation of these enhanced materials on farmlands [75]. An important method to improve food and nutritional security is through the domestication of new tree crops. Specifically, the aim of domesticating neglected/underutilized but valuable tree species is to encourage sustainable agriculture through diversification of species with income generation ability, diet and health improvement, meeting domestic needs and the restoration of functional agroecosystems [16,76].

The identification of best individuals with superior desirable features has been highlighted as one of the critical factors in the selection of tree species for domestication [15]. Leakey and Asaah [76] stated that a practical approach is to seek for trees that have desired character combinations such as larger fruits with sweeter pulp. Thus, assessment of the nutrient variability and morphological characteristics of fruits and seeds is one of the most significant steps determining the superior planting stocks for domestication. It has been proven on baobab trees (*Adansonia digitata* L.) in Mali, where the authors chose various morphological and phytochemical characteristics (such as fruit and pulp weight, pulp fraction, colour, vitamin C, calcium, and iron content) as selection criteria for domestication [77]. They found two trees from Bendjiely and one from Bandjougoula to have the best combination of superiority for most of the studied traits. Ben 26 (one of the studied ecological areas), although low in calcium content, revealed the best combination of vitamin C, high pulp weight and iron content. Choosing these trees for domestication in regard to fruit production will increase average fruit pulp fraction by between 35% and 50%, vitamin C content by 80%–87%, pulp weight by 47%–83%, and iron content by 34%–90% of the average [77]. It must, however, be noted that different environmental factors, such as climate and soil type, coupled with genetic heritability, may have a significant effect on the development of superior characters [23]. In Ghana, Peprah et al. [4], characterizing *A. parviflora* for the selection of elite morphotypes for domestication across three provenances, considered parameters such as fruit size, seed weight, number of seeds per fruit, fruit weight, fruit length, and fruit diameter. Significant variations were observed among the selected individual trees and not among different provenances. The number of seeds per fruit ranged between 18 and 48 (mean of 26.5 ± 1.18). There were substantial differences in fruit shape which ranged from round to oblong, but these shapes were not site-specific. Some fruits were elongated with a low diameter:length ratio, with others being the opposite. Significant differences ($p < 0.05$) in fruit volume were recorded among the various trees sampled. The fruit volume (V), expressed as $V = \pi r^2 L/2$ (where 'L' represents fruit length and 'r' the radius of fruit), ranged from 528.3 to 2793.52 cm^3 (average of 1545.22 cm^3). A high heritability ($h^2 = 0.822$) in fruit size and genetic gain (G = 20.1%) in fruit size for the selection of trees with above-average fruit size were observed. A significant positive correlation was observed between fruit volume and seed weight ($r = 0.54$, $p < 0.05$). Fruit volume was a suitable indicator, since it is a function of the diameter and length but is independent of weight. Seed yield was also indicated as one of the superior characteristics to be considered in the selection and improvement programs of *A. parviflora*. Moreover, total seed weight per fruit positively correlated with fruit size, and thus, selections based on fruit size suggest a substantial potential for high seed yield. From the results, the authors concluded that a large proportion of the fruit morphology observed in *A. parviflora* might be genetically controlled. However, there is a significant gap in knowledge on the genetic diversity of *A. parviflora*. Therefore, in the future, there will certainly be a need to develop genetic markers to further assess variations within and between the species provenances. Even though this technique is expensive, genetic studies are still needed relating the morphology and phytochemistry of the seeds [78] to support effective tree improvement and domestication programs with sound data.

For the past few years, ICRAF and its partners have been developing techniques for seed germination and vegetative propagation of *Allanblackia*. Due to the high demand for genuine and adequate quantity planting stocks for quick expansion, inter-planting in agroforestry systems, replanting, etc., ICRAF and its partners are selecting quality mother trees and improving them to assist farmers to cultivate *Allanblackia* in four African countries, namely, Cameroon, Ghana, Nigeria, and Tanzania [34,62]. Considering the projected demand, the search for superior planting stocks has increased significantly throughout its natural range, particularly in the countries where utilization has recently occurred. The development and selection of production technology for suitable varieties, standardization of agronomic practices and techniques, and the conservation of such materials have been the main research focuses of the *Allanblackia* domestication program [62]. Seedlings are currently the easiest solution for farmers, and hence are the most widely used germplasm when cultivating *Allanblackia* on farmlands [62]. However, after identifying trees with superior desirable traits, these could be multiplied vegetatively, since such a method of propagation assures the conservation of the traits of interest [15]. Shrestha et al. [79] pointed out that if the existing limitations to planting are resolved, the anticipated incomes from cultivating *Allanblackia* species will compare well with other tree crops such as cocoa and oil palm. These efforts will increase both the quantity and quality of the product, as well as the efficiency of the *Allanblackia* supply chain [34]. It should be noted that the process of *A. parviflora* domestication cannot be successful only through the development of vegetative propagation techniques, but rather after producing solid information on species morphological, genetic and phytochemical characteristics.

Unilever, the current main buyer of *Allanblackia* seed oil, has projected that the potential market for oil is more than 100,000 t per year. However, the three countries (Ghana, Nigeria and Tanzania) currently participating in the supply chain development of Unilever are having difficulties achieving the basic minimum requirement of 240 t of oil to sustain the *Allanblackia* oil business [34]. Nigeria, Ghana and Tanzania produce a mean of about 60, 110 and 450 t of seeds, respectively, which will lead to about 20, 40 and 150 t of oil annually, respectively [53]. Since the market demand for *Allanblackia* seed oil is higher than the supply from both the natural forest (wild) and remnants on farmlands, there is a serious threat that wild picking of *Allanblackia* seeds may lead to over-exploitation of this valuable resource in such a way that it will jeopardize natural regeneration [34], and subsequently cause its extinction. Therefore, there is a great necessity for *Allanblackia* domestication and improved tree incorporation into farming landscapes to promote food security and ensure poverty alleviation, thereby enhancing the livelihoods of rural populations and lowering the pressure on wildly grown populations in natural forests.

10. Conclusions

A. parviflora is one of the priority fruit tree species identified for improvement and domestication in Sub-Saharan Africa. It has been targeted for improvement for the production of oil from the seeds, for benefits not only to the local populations but also the economies of producing countries. Despite the great potential of this species, there are still significant knowledge gaps that require urgent research attention.

This review shows that the most important economic use of *A. parviflora* is the production of edible oil from the seeds. This might justify why ICRAF and its partners already started with the first domestication steps by selecting superior individuals/populations in Ghana, Cameroon, Nigeria, and Tanzania, while Unilever remains a major buyer of the *Allanblackia* seed oil. However, scientific information on the seeds' phytochemical composition and variability is scarce. Additionally, only a little or no information is available on the diversity and management of the species in the regions where it is naturally found. More specifically, basic information on genetic diversity, silvicultural management, productivity, methods of propagation and cultivation are not well documented. The development of morphological descriptors, the use of modern molecular markers for genetic diversity assessment, and studies on the phytochemistry of seeds are therefore highly recommended. Moreover, qualitative research on the preferences of local populations who produce *A. parviflora* seeds should be conducted to reveal their preferred traits of interest for development. The selection of superior mother tree populations may begin once these attributes are determined. The next step after identifying trees with superior desirable traits will be the multiplication of best individuals. Extensive studies on vegetative propagation and propagule regeneration of the species are urgently needed, as the currently available information is not ample. Seedlings from generative propagation are currently the easiest solution for farmers, but there is a limitation to such a method due to the dioecious nature of the species which makes it difficult to identify the sex of the tree at the juvenile stage. While research efforts should be focused on determining the sex of trees at a young age, studies on multiplication by vegetative propagation is crucial, since such a method of propagation assures the conservation of the traits of interest. We conclude that *A. parviflora* has great potential to ensure food and nutritional security and alleviate poverty among rural populations in West Africa, and therefore could be domesticated to promote widespread planting in agroforestry systems and for the conservation of the genetic resource if the knowledge gaps identified in our review are fulfilled.

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