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The Biology and Ecology of *Annona muricata* l., Soursop; State of Knowledge

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Abstract: *Annona muricata* L, is a genus of tropical fruit trees in the Annonaceae family, which includes approximately 130 genera and over 2,300 species. It is an exotic species to Nigeria and since it was introduced it has become well ecologically adapted to several agro-ecological zones of the country by virtue of its broad ecological amplitude. A review of the species biology and ecology demonstrated abundance of resource utilization potentials which are yet to be fully exploited for commercialization and sustainable livelihood. A lot of genetic improvement opportunities as well as germplasm conservation potentials needing research attention were equally implicated. A monographic review approach was adopted in the present study as commonly practiced in single-species studies. The increasing resource roles both for domestic utilization as well as pharmaceutical industry justified the present study. To improve understanding and knowledge-based information for future research activities require synchronized baseline scientific information and was the object of this study. The absence of plantation in the species range in Nigeria despite its promising economic potentials was perhaps due to lack of state-of-the-art information on the biology and ecology of the species to guide would-be investors. The present review study attempted to bridge this gap in knowledge hoping that it will stimulate proactive research interests, awareness and future plantation establishment in the species.

Keywords: *Annona muricata*, Biology, Ecology, Domestication, Germplasm Conservation

1. Introduction

Annona muricata L, is a genus of tropical fruit trees in the family Annonaceae of which there are approximately 130 genera and over 2,300 species, and is a fruit tree with a long history of traditional uses [1, 2]. For domestic/commercial use, seven species and one hybrid are grown. [3]. *A. muricata*, also known as soursop, graviola, and guanabana, is an evergreen plant found primarily in tropical and sub-tropical regions of the world. Evidently, [4] four of the species which are well studied originated in South or Meso-America and one seems to have originated in Eastern Africa. These species include *Annona cherimola* Mill, (cherimoya), *A. muricata* L., (soursop), *A. reticulata* L. (custard apple), and *A. squamosa* L., (Sugar apple) [4] The African species of Annonaceae is known as *Annona senegalensis* Pers., (wild soursop). *A. muricata* L. is known as soursop in English-speaking countries and also has numerous common names [5]. *A. muricata* was indicated to be widespread in the tropics and also is frequent in frost-free subtropics of the world [3, 4].

A. muricata is a sought-after tropical fruit tree, and a plethora of phytochemical studies have been conducted on this fruit plant. The plant has been proven to have a wide range of biological activities, with the most promising being anticancer, antiparasitic and insecticidal properties [3]. Aside from being an important source of raw materials for the food industry, it is also an important indigenous medicinal plant [6]. In recent times, the demand and interest by the processing industries of sorbets juices as well as the pharmaceutical industries for cancer drugs from the soursop pulp has grown tremendously [6]. Evidently tremendous scientific evidences exit in literatures on various aspects of the species including phytochemical investigations, botany, biology, ecology and, husbandry and resource potentials [7, 2]. [8] Provided some scientific reports on the aspect of the species systematic circumscriptions and taxonomy while information on the species nomenclatural history [9]. The whole tree had been described by [8] while information on the aspect of the species biology and breeding activities were reported [10] while the species husbandry and management had been illustrated [11]

Previous scholars also provided ecological information on the species but these various information outlets remain disjointed and could not stimulate adequate research attention and awareness in the face of increasing economic importance in the species [12, 13].

For effective and sustainable research in a holistic manner on any single species study, there is the need to synchronize all accessible and available scientific information into a single scientific publication to provide sustainable baseline data for future research and development activities. Such information is not only useful for research but will equally provide the current state of knowledge in the species so that observed gaps can dovetail into areas of future research. To date, no single publication attempted to streamline this disjointed literature into a single scientific publication which is the focus of this study. It is within this purview that the current study was undertaken to harmonize all existing research information on the biology and ecology of the species. Harmonizing the information on the species biology and ecology for sustainable future research and development justifies the study. The present study therefore provides the current state of knowledge in this aspect of the species using a monographic style as it has been published [14] for *Vitellaria paradoxa* and *Parkia biglobosa* studies respectively.

2. The Species Biology

2.1. Chromosome Number

A chromosome number 2n = 14 to 16 was reported in the species [17] however, [15] indicated some variations with diploid; 2n-2x. These observed variations had been reported to create slight difficulty of interspecific hybridization and grafting in the species [7]. It was opined that some related species such as *Annona glabra* is also known to be Tetraploid [15].

2.2. Inflorescences, Flower Development and Anthesis

Figure 1. *Annona muricata (Soursop) flower at the blooming stage [7].*

A. muricata flowers are hermaphrodite, usually fragrant, and solitary or in groups of two or four, with fascicles of three green sepals and six petals arranged in two vertical [7]. It was also opined that the external verticils have three yellow-greenish petals while the internal verticils have three yellowish petals. [7] adequately described the floral structures The species has flowers which are have numerous, conglomerated and spirally arranged stamens beneath and around an upper globose (conical) shaped dome of numerous united carpels, each with one ovule [11]. Following fertilization, the united carpels will form a syncarp, also known as a composite fruit.

2.3. Pollination and Potential Pollinators

A. muricata flowers are protandrous, and pollen is shed as the outer petals open in the evening. [16]. It was also opined that the inner petals open much later and only slightly, allowing small insects drawn to the flowers' fragrance to enter. [16]. Insect beetles of several species were reported as important in carrying out natural pollination [16]. However, [17] opined that, these insects effect cross-pollination, albeit insufficiently, because few flowers set fruit and many fruits are misshapen due to numerous unfertilized ovules. Natural pollination in the species is complex, resulting in low fruit productivity when wind and insect pollination are low (1.5%) [16]. It was also reported that hand pollination is effective in improving fruit yield and quality however [17] observed that about 150 flowers can be pollinated by a skilled labourer in 1hour with a success rate of 80-100%. [18] reported the activities nitidulid beetles (Carpophilus and Uroporus spp.) as potential pollinators though no significant evidence was found in most cases. [19] highlighted that the beetle breeds quickly in the remains of the fruit and it has often been recommended that rotting fruit be left on fruiting tree as it serves as an attractant to insect pollination in the species. According to some reports, the presence of nitidulid beetles per flower can increase fruit set by 25% while sporadic flowering and fruiting can occur all year round under favourable conditions.

2.4. Life Cycle and Phenology

In the genus *Annona,* flowering and fruiting seasons had been reported to be under the influence of geographical locations [17]. The species phenology in Nigeria showed that *A. senegalensis* flowers during the dry season to the beginning of the rainy season (January-April) while in *A. squamosa* flowering occurs during the mid-rains (May and July) [20]. However in *A. muricata* flowering was reported to occur both in the early and late rainy seasons (March to October) [20]. It was observed that most *Annonas* are cultivated in tropical areas, where temperatures do not vary very much and the seasons are divided into rainy and dry seasons [7]. [21] indicated fruiting period is generally from the beginning of the rainy season to the late rains. *A muricata* like other members in the genus is a deciduous tree with defoliation and leaf flushing during the dry season (November to January) to early rains (April-May) before the commencement of flowering.

Flushing of leaves and flowering occur simultaneously in some locations in the genus but in *A. muricata* these events occur throughout the year [20]. The period from pollination to fruit maturity averages 5-6 months and sour soup tends to flower and fruit continuously [7]. In western Tanzania

however, fruiting occurs in the wet season (December to March) while, [7] observed that in Nigeria fruiting occurs from March to May. The phenology of fruit trees is important for planning, management, harvesting and commercialization in the plant [20].

2.5. Fruit Set and Maturation

According to [16] fruiting starts in the species from 2-5years after planting and produces 10-50 fruits, depending on pollination efficiency and nutrient status (13). Fruit growth follows a typical sigmoidal pattern, with maturation taking place (16-24 weeks). Low humidity (< 60% RH) and a temperature of lower than 130°C near fruit maturity can worsen the severity of fruit skin rusetting while also delaying maturation.

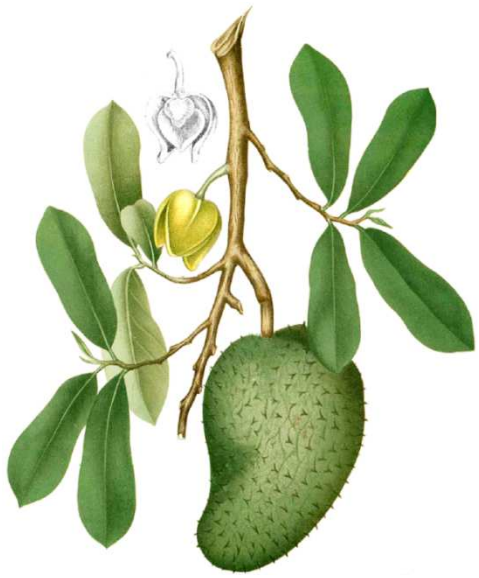

Figure 2. *Floral structure and mature fruit in Annona muricata [7].*

2.6. Reproductive Biology in the Species

Considering the genetic distance between *A. muricata* and other species, it was stated [23] in their cross-pollination conducted primarily to determine the compatibility for increasing fruit set and occasionally for new hybrid development that cross-pollination had remained a problem. However [7] observed that cross-pollination among *A. muricata* and other species such as cherimoya, custard apple, or sugar apple has not been very successful. [24] indicated extensive morphological diversity, much of it genetically based within all species not only offers great breeding potential but also lowers the possibility of easily selecting a cultivar with all the possible desirable characters. However [7] highlighted that considerable variation exists among cultivars and seedlings of cherimoya, but soursop and sugar apple are reputed to be less variable.

Understanding the biology in the species and development of new cultivars has remained a difficult task to carry out, especially in Africa [25]. New varieties of a plant might evolve due to transfer from the point of its natural origin. In many cases, the major constraint of developing new cultivars in *Anonna* species is an agronomic factor as well as a lack of prolific cultivars to start a genetic improvement program [7]. [7] was the first to realize the possibilities for the improvement of *Annonas* genetically and thereafter initiated the breeding program in Florida and the Philippines. A lot of limiting factors were observed because only one line was evaluated and a small number of progenies, no new cultivars were selected at that time.

2.7. Breeding Systems

For all breeding systems [7] opined that the first objective of a breeder is to determine the specific traits that are important for the new cultivar. These traits may help a breeder to select potential groups to use in an *Annona* breeding program to obtain desired progenies. These progenies may not have all the desirable traits, but at least the most important to the grower are considered. [7] observed that most *Annona* species and cultivars differ in environmental adaptation productivity, and fruit quality, therefore different conventional methods can be used in their breeding. [26] indicated that there is no specific breeding program to improve this characteristic however mentioned the prospects to collect and chemically identify wild soursop variations with insect growth-regulation activity. *A. muricata* is still largely propagated by seed, and the progenies can be selected and separated into groups based on pulp acidity and sweetness.

Findings indicated that Morada an ecotype introduced from Brazil to Columbia produces large fruits with an average weight of 3.8Kg, but have very acid pulp which is a constraint for the fresh fruit market [7]. A local soursop selection from Bahia State named ecotype A produced small fruits of less than 1.8kg but has sweet pulp, appropriate for the fresh fruit market. [27] however hinted that crossing between these two might produce a medium-weight fruit with a commercially acceptable sweet pulp taste. [27] indicated that several genotypes and some related species could be used in the soursop breeding program for rootstock improvement since there is acceptable rootstock/scion compatibility between these two species. This observation is an eye-opener for the species genetic improvement in Nigeria. [28] however, reported that in Australia, Custard Apple Growers Association established a breeding program by first producing tetraploids through gamma irradiation or colchicine and then crossed these to diploids to produce seedless triploids. [7] stated several other potentially useful methods of obtaining seedless individuals in *Annonas*. These methods may include:

1) Trying to identify progeny from diploid x diploid crosses with small seed sizes and numbers.
2) Producing triploids from diploid x teteraploid and tretraploid x diploid crossing, as done in Australia.
3) Producing triploids through the protoplast fusion of diploids and haploids.
4) Irradiation of bud wood to knock out genes for seed production.
5) Crossing of low seeded parents (as the seed number is a heritable character).

6) Development of self-incompatible parthenocarpic hybrids.
7) Using endosperm culture to get triploids.

3. Species Ecology

3.1. Geographical Distribution

3.1.1. Affinities and Origin

According to [29] *A muricata* is native to the warmest tropical areas in South and North America and is now widely distributed throughout tropical and sub-tropical parts of the world, including India, Malaysia, and Nigeria. [29, 8] reported that is plant species of tropical American origin while [30, 31] opined that is probably native to Central America and northern South America. However [32] archaeological evidence indicates both *A. muricata* and *A. cherimola* were present in pre-Hispanic Peru rather than an introduction by Spaniards, as was thought by 17th-century records. [33] reported that it was one of the first fruit trees carried from America to the Old Worlds Tropics. However [34, 7] highlighted Annonaceae to be mostly tropical and sub-tropical although some species can be grown in temperate climates.

Both *A. muricata* and *A. cherimola* were believed to have been introduced to Asia by the Spanish galleon trade, while *A. muricata* is now widely cultivated throughout the Asia Pacific region for its edible fruit [35, 29]. However, [33] indicated that the time of introduction of *A. muricata* to the West Indies and Caribbean region remained uncertain, but Sir Hans Sloane observed it was growing in Jamaica in the early 16th century. According to [33] the fruit was reported to as abundant in the West Indies and northern South America in 1526. [33, 36, 37] also observed that the species was present in Puerto Rico before the 1880s, as evidenced by its inclusion in both Bello's and Britton and Wilson's works on Puerto Rico and the Virgin Islands. It has also been grown in Florida probably since the 1870s.

M., Kumar, S. et al. (2021) [38] opined that the Linnaean Society's Botanical Journal has published a special issue on the systematics and evolution of Annonaceae, while [39] Annonaceae have been an easily identifiable entity since the beginning of the standardized use of plant family names, with the publication of Genera plantarum by de Jussieu (1789). For centuries, numerous cultivated species have added to the family's recognition. [7, 40] observed that many species are used on a local scale for their fleshy, edible fruits, while others are used for aromatic, spicy, medicinal, or mechanical properties. [13] also indicated that *Annona* spp. had already been widely distributed across the Atlantic and was among the most popular fruits grown in the first Dutch settlement at the Cape of Good Hope.

3.1.2. Present Distribution, Range, and Habitat Habitat

Annona grows at a range of altitudes and those with the widest adaptation to altitude are also those with the widest adaption to latitude. [37, 12] reported that *A. muricata* though widely cultivated, it is found in densely forested hillsides, mountain woodlands, and shaded ravines in Puerto Rico and humid pre-montane forests in Colombia. [41] opined that it is also grown in Ecuador's coastal island, and Amazonian regions, where the species is native. The species has also been found in disturbed lowland areas throughout its range In Nigeria, it is grown as a component of compound farming or as a fruit tree within residential (pers comm.). [42] also corroborated that the species has become a component of wild forest fruits or naturalized in thickets, pastures, and along roads. On farms, it is grown along with other fruits trees such as *Anacardium occidentales* (Cashew), *Mangifera indica* (Mango), and *Persia americana* Pear.

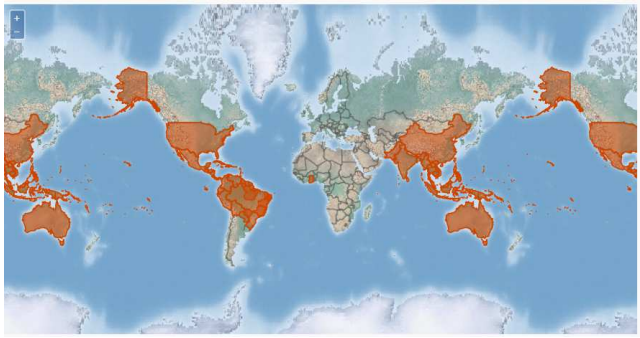

Figure 3. *Present Global Distribution of Annona muricata [9].*

3.1.3. Range

According to [13] *A. muricata* is found throughout the West Indies, except for the Bahamas, and from Mexico to Brazil. It is grown in Puerto Rico, most commonly on the Cordillera slopes, but also in Vieques, St Croix, St Thomas, St John, Tortolla, and Virgin Gorda. Apart from these countries [13] also reported presence in India, Indonesia, Laos, and Mauritania. Papua New Guinea, Philippines, Reunion, Thailand, US, Vietnam, Cambodia, China. However [9] in the mainland Africa, it has been reported in Eritrea, Ethiopia, Tanzania, and Uganda. [13 reported occurrence in several West African countries (Republic of Benin, Cote d'Ivoire, Nigeria, Togo, Liberia, Ghana, and Guinea) where it is being domesticated. [42] reported that soursop occurs in several parts of Nigeria extending from to Derived savannah to southern limit of the Guinea savannah as observed in Kogi, Benue, and Taraba States (*pers. comm*.) It was also reported to [42] as a component of home gardens in many parts of Nigeria and it has become well ecologically adapted.

3.1.4. Geology and Soil Types

It has been reported that all *Annona* species can grow in a variety of soil types, from sandy loam to clay loams, but the most preferred is rich well-drained loam soils, fairly, deep loams rich in organic matter and low in salts and with a pH range of 5.5-6.5 [7, 13] while [7] indicated that its soil requirements is similar to what has been reported for *Annona squamosa* another edible species of *Annonas.*

3.1.5. Site Requirements

A. muricata can tolerate dry soil conditions, but when there is a prolonged drought, the trees shed most of its leaves hence would benefit from supplemental irrigation under cultivation

[13]. It was also highlighted [13] that best growth can be achieved in deep, rich, well-drained, semi-dry soils [7] opined that water-logging is a major cause of floral abscission and root rot in the species while areas with stagnant water should also be avoided though the species can tolerate dry soil conditions but [43] indicated that 1000mm precipitation during the wet season is suitable. [7, 42] observed that the species requires a high light intensity to grow and it is recommended that tropical savannah is best suited climate and this perhaps is responsible for its faster growth in the savannah zone of Nigeria.

3.1.6. Environmental Factors: Temperature Requirements

Temperature has been reported as a limiting factor, mainly for the tropical *Annonas*, soursop, custard apple, sugar apple, and wild soursop [7]. Low temperatures (<14°C) may damage or even kill young trees, although adult plants may show some tolerance. It was further opined [7] that when high temperatures (>30°C) are experienced and low relative humidity (RF) occurs poor pollination is frequent in the species. However, moderate temperature (25-30°C) and high humidity (80%) greatly improves pollination and fruiting According to [23] soursop is least tolerant (15-25°C) to low temperature while cherimoya is more tolerant to low temperature (7-18°C).[7] observed that based on its environmental requirement, soursop like other *Annonas,* will thrive better in the southern hemisphere under tropical conditions. According to [42], soursop is considered to be a plant of low altitudes and hot and humid conditions.

A. muricaa is well adapted to areas of high humidity and relatively warm conditions; while temperatures below 5°C (41 °F) will cause damage to leaves and small branches, and temperatures below 3°C (37°F) can be injurious especially to the fruits which become dry and of low concentrate. However, [43] indicated that good productive orchards had been reported at altitudes of up to 1100m above sea level. [43] observed that frost kills young trees but older trees show some tolerance while pollination and fruit formation are hampered by extreme low temperatures, high temperatures, and low humidity. [7] concluded that soursop undoubtedly is the most tropical *Annona species* largely cultivated mainly in tropical regions.

3.1.7. Limiting Environmental Factors on Its Cultivation

Climatic and edaphic factors have a major influence on growth, fruit set, fruit size, and quality of commercial *Annonas* [45]. They pose major constraints in the establishment of *Annona* breeding systems since they directly influence response through the genotype-environment interactions. High rainfall and high humidity during the peak of flowering season greatly enhance fruit production of most *Annonas* by preventing desiccations of stigmas, prolonging their receptive period, and increasing fruit set and early fruit growth [45]. Conclusively, both soursop and sugar apple grow and produce very well in the semi-arid conditions of north-eastern Brazil with very low rainfall, but require irrigation. It has been concluded that soursop grows much better and produces very well under high rainfall conditions in the Tropical regions [7].

4. Discussion: Conservation and Domestication Perspectives

A. muricata is a valuable tropical tree, and a plethora of phytochemical studies have been conducted on this fruit plant. Among all previous studies on this plant [3] the most promising activities are its anticancer, anti-parasitic, and insecticidal properties. The species has been shown to have a broad spectrum of biological activities. Aside from being an important source of raw materials in the food industry and pharmaceuticals, it also has a number of local applications, particularly in rural health care services (*pers comm.*). Review of literatures [42] on the species biology and ecology present a novel knowledge-gap filling especially in the promotion of concerted research interests and awareness from conservation and domestication perspectives. In recent times, its potential in the pharmaceutical industry for the production of anti-cancer drugs has been amplified but unfortunately, no plantation exists in its range in Nigeria to support raw materials base for would-be industrialist. Most of the stands in existence are small size plots (less than hectare) and perhaps responsible its low utilization which has remained at subsistence level as it is casually consumed as snacks like some other indigenous fruit trees including; *Chrysophyllum albidum* (African star apple) and *Dacryoidis edulis* African plum and *Garcinia kola* [47, 48]. In Nigeria, awareness of the species economic importance has increased but commercial planting in form of plantation is yet to be fully realized. This is perhaps due to lack of synchronized information on the species biology and other environment requirements to aid its domestication has it is being captured in the present study.

A chromosome number of 2n =14 to 16 in the species which was lower than that reported for *Parkia biglobosa* (2n = 24) which is perhaps due to taxonomic family differences [14]. One of the features in fruit trees' pollination biology is the possession of attractive flora structures which was demonstrated by *A. muricata.* The opening of the inner petals much later and only slightly, enabling small insects attracted by the fragrance of the flowers to gain entry [16] was similar to what was recorded [49] in *P. biglobosa* which also displays a reddish capitulum. [7] opined that despite cross-pollination behavior in the species, opportunity for assisted pollination has also been indicated (7) which is similar to what was observe in *Parkia biglobosa.* This character in the species can be exploited for genetic improvement after provenance evaluation in its range in Nigeria.

Flowering in the species also varies greatly but early to late rains (April-October) had been opined [20]. This phenological behavior was similar [50] to that observed in *Adansonia digitata* in its range in Nigeria. [49, 50] highlighted that fruiting in the species also coincides with the early dry season and is in agreement with what was reported for *P. biglobosa* and *A. digitata* in Nigeria. This information provides baseline information for fruits collection in the species for

domestication and genetic improvement in the near future. Crosses between *A. muricata* and other *Annona*s had not been very successful due to genetic variation and morphological differences. However [7] indicated that assisted pollination is possible in the species which provide the opportunity of crossing individuals with small fruit size but with sweet pulp fruit with that of big fruit size and sour fruit pulp fruit. Various methods for the species genetic improvement had been reported and these offer opportunities for future genetic improvement and domestication.

The review of literature on the ecology of *A. muricata* provides an interesting opportunity for its conservation as the species demonstrated broad ecological amplitude in Nigeria despite being an exotic species. The ecology of this species had not been fully understood because of its exotic nature however it has become well ecologically adapted to several agro-ecological zones in Nigeria. Several small stands had been observed from the rainforest ecozone to the Guinea savannah ecozone of Nigeria in a number of states including; Oyo, Ondo, Ekiti, Kogi, Benue States and even in Taraba (*pers. comm*). Similar studies [14] on provenance evaluation for *P. biglobosa* and *V. paradoxa* in its range in Nigeria and Ghana respectively provides opportunity for provenance evaluation trial in the species for selection of proven lines and subsequent orchard establishment in Nigeria.

In terms of habitat, [12] reported it is widely cultivated, *A. muricata* is found in densely forested hillsides, mountain woodlands, and shaded ravines in and pre-montane forests. [51, 14] reported similar for *Vitellaria paradoxa* and *Parkia biglobosa*. [7, 13] observed *A. muricata* to be well adapted to different soil types ranging from sandy to loam of varying geology with pH, this offers great domestication research field trials in the species during provenance study for genetic improvement and germplasm conservation. The species is sensitive to extremely low temperatures as well as waterlogged areas hence such areas should be avoided in germplasm conservation trials. Quality variations in fruit set, fruit size and pulp sweetness are traits that influence quality of commercial *Annonas* by climate and soil factors and they constitute constraints in establishing *Annona* breeding systems because of their directly influence on genotype-environment interactions. Future research studies [45] should give these factors serious considerations in future species trials study.

5. Conclusion and Recommendations

A. muricata despite being an exotic fruit tree, its biology and ecology shared several morphological and edaphic similarities with a number of Nigeria indigenous multipurpose fruit trees such as *P. biglobosa, V. paradoxa,* and *A. digitata.* These observed similarities are probably responsible for its good adaption to several ecological zones in Nigeria. This ecological adaptation portends greater potentials in large-scale plantation establishment in several agro-ecological zones of Nigeria. However, its genetic improvement must constitute the first priority in form of provenance evaluation, selection of desirable progenies, and incorporation of various desirable traits in the fruit which is its main economic product. That should be followed by fruit orchard establishment to provide source of germplasm for improved fruits for subsequent plantation establishment. From these review of literatures, a lot of potentials and opportunities existing in the species domestication and the need for greater research attention are amplified in the present study to increase its commercial values. It will also enhance large scale regular plantation establishment in multi-locations which is likely to create both domestic and global markets in the species in form of source of raw material to industries as well as potential source of foreign exchange earnings for Nigeria.

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