VOL. 12 NO. 1,
MAY, 2026
E-ISSN 3027-0995
P-ISSN 3026-8265

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Biotechnology and Agricultural Research (JBAR)

Advances in Propagation, Genetic Improvement, and Utilization of *Cola nitida* for Sustainable Production in West Africa

Areola, Oluwatobi J.; Babatunde, Olaitan P.; Adenuga, Omotayo O.; Sobowale, Ibrahim O.; Ebunola, Tope E.; Muyiwa, Anna A.; & Tijani, Abdul-Akeem A.

Crop Improvement Division, Cocoa Research Institute of Nigeria, P.M.B. 5244, Ibadan, Nigeria.

Corresponding Author: areolaoluwatobi@gmail.com

DOI: https://doi.org/10.70382/ajbar.v12i1.023

Abstract

Cola nitida (Vent.) Schott & Endl. is one of the most important tree crops in West Africa in terms of economy, culture, and nutrition, yet its genetic improvement and sustainable production systems are still underdeveloped compared to its value. This review focuses on three key areas: propagation, genetic improvement, and utilization. On propagation, methods such as terminal bud removal in semi-lignified cuttings, cotyledon excision, scarification, and improved substrate use have shown clear improvements in germination, rooting, and seedling survival. On genetic improvement, the Cocoa Research Institute of Nigeria (CRIN) has identified compatible clones and developed new germplasm collections. Some clonal materials now flower and fruit within four years after planting, helping to address long juvenile periods and self-incompatibility. Clone AA231 has also been confirmed as a widely compatible parent useful for orchard improvement. In addition, molecular tools such as ISSR, RAPD, and SNP markers have shown high genetic diversity within CRIN collections and across Nigerian and Ivorian populations, supporting future breeding work. On utilization, studies show that *C. nitida* contains high levels of caffeine, theobromine, flavonoids, tannins, and phenolics, with proven antibacterial, antidiabetic, and antioxidant properties. However, post-harvest losses of 30-70% due to pests and diseases remain a major challenge. The review concludes that integrated investment in

improved planting material, molecular breeding tools, post-harvest systems, and organized value chains offers the clearest pathway to sustainable *C. nitida* production in West Africa.

Keywords: *Cola nitida*, Propagation, Genetic Improvement, Self-Incompatibility, Molecular Diversity, Sustainable Production, Post-Harvest Management, West Africa.

Introduction

Sustainable crop production in West Africa increasingly depends on the mobilization of underutilized indigenous tree species that already supported millions of rural livelihoods but have received disproportionately little investment in formal science and technology. *Cola nitida* (Vent.) Schott & Endl. is one such crop. A member of the family Malvaceae (subfamily Sterculioideae), it belongs to a genus of more than 125 species indigenous to tropical Africa (Adebola, 2006; Duke, 2000). Of these, *C. nitida* and *Cola acuminata* (Beauv.) Schott & Endl. are the two commercially cultivated species, with *C. nitida* carrying the larger share of domestic and international trade.

Nigeria is the world's largest producer of kolanuts, accounting for an estimated 70% of total world production, with an annual output of about 200,000 metric tonnes of fresh nuts, mostly from South-West Nigeria, which alone accounts for approximately 88% of the national produce (Asogwa et al., 2006; Asogwa et al., 2012). The species is distributed across the West African Gulf of Guinea countries, with its center of diversity in the forested zones of Côte d'Ivoire and Ghana, while the putative center of origin of *C. acuminata* is Ijare, Ondo State, Nigeria, a fact that places significant scientific and conservation responsibility on Nigerian researchers (Adenuga et al., 2012; Opeke, 2005).

The crop's importance covers multiple dimensions. As a stimulant and masticant, its use predates European contact, Leo Africanus recorded encountering a bitter nut called 'goro' in western Sudan in 1556 (Emmanuel et al., 2016). As a commercial product, its caffeine content of 1.84-2.56% made it the original active ingredient in cola soft drink formulations developed in the 1800s (Emmanuel et al., 2016). Today, kola nuts supply caffeine, theobromine, catechins, and bioactive phenolics to pharmaceutical, food, textile, and cosmetics industries across the world (Nyadanu et al., 2020; Onaivi & Enabulele, 2024). As a cultural object, *C. nitida* nuts are presented at weddings, naming ceremonies, and community gatherings across West Africa, embedding the crop in the social fabric of entire ethnic groups (Tokannou et al., 2024). About 90% of the kola produced in Nigeria is consumed domestically, with only 10% exported (Asogwa et al., 2006). Despite this multi-dimensional importance, several constraints frustrate sustainable production. Propagation is hampered by slow and erratic seed germination driven by prolonged dormancy, poor survival rates of vegetative cuttings, and a late onset of nut production that discourages farmer investment (Séry et al., 2020;

Emmanuel et al., 2016). The progeny of *C. nitida* seedlings can take six to seven years to produce their first fruit, and many trees remain unproductive for up to fifteen years or sometimes throughout their lives (Asogwa et al., 2006; Adenuga et al., 2012). The Cocoa Research Institute of Nigeria (CRIN) the sole Nigerian body mandated to carry out research into kola, has identified low yield due to self and cross incompatibility, partial and total sterility, inefficient natural pollination, field and storage pests and diseases, and old age of existing trees as the major agronomic constraints limiting production (Asogwa et al., 2012).
Against this background, there is a pressing need to bring together the growing body of research on *C. nitida* into a coherent framework that can guide investment in sustainable production. This review does precisely that, organizing available evidence around three production-critical themes: propagation advances, genetic improvement, and crop utilization. By examining what has been achieved and what gaps remain, it aims to set a clear agenda for research and development that can put C. nitida on a trajectory toward sustainable, competitive, and resilient production across West Africa.

Background: Taxonomy, Botanical Description, and Distribution

Taxonomic Classification and Nomenclature

Cola nitida belongs to the family Malvaceae (phylogenetic classification) or Sterculiaceae under the classical Cronquist system (Akouègninou et al., 2006; Tokannou et al., 2024). The genus *Cola* includes more than 125 species, of which *C. nitida* and *C. acuminata* are the two commercially cultivated species (Nyadanu et al., 2020). Adenuga et al. (2012) noted that fifty species of this genus have been described in West Africa, with twenty-eight occurring in the forest between the Cross River of south-east Nigeria and the Mungo River of western Cameroon. Three new species *C. cecidiifolia*, *C. metallica*, and *C. subopppositifolia,* were recently discovered in this Cross River-Mungo River Forest zone (Adenuga et al., 2012), further underlining the region's outstanding importance for *Cola* diversity.
The species is known by numerous local names across West Africa: 'Golo' and 'Goro' in Benin; 'Obi gbanja' among the Yoruba of Nigeria; 'Oji' in Igbo; 'Ibon' in Efik; and 'Oussé' among the Ashanti of Ghana (Orwa et al., 2009; Tokannou et al., 2024). In Hausa-speaking communities of northern Nigeria and across the broader Sahel, the nut is widely known as 'goro' and serves as a stimulant substitute for alcohol, making it a regular feature of daily trade and hospitality (Asogwa et al., 2006).

Botanical Description

Cola nitida is an understory, evergreen tree that typically grows to 9-12 meters in height, though individuals reaching 27 meters with trunk diameters up to 1.5 meters have been recorded (Orwa et al., 2009). Leaves are simple, alternate, broadly oblong to elliptic-oblanceolate, leathery, dark green, and glabrous. Inflorescences are axillary branched panicles 5-10 cm in length. Flowers are unisexual and apetalous; the pollen sacs of hermaphrodite flowers do not sporulate, meaning that pollen from male flowers is the functional pollen in all

fertilization events (Odutayo et al., 2018). Fruits are oblong-ellipsoid follicles approximately 13 × 7 cm, containing 4-10 seeds per follicle. Seeds are ovoid or sub globose and occur in red, pink, or white colour variants (Orwa et al., 2009). The distinction between two cotyledons (*C. nitida*) and three to six cotyledons (*C. acuminata*) is the primary morphological character separating the two commercial species (Nyadanu et al., 2020). The nuts contain approximately 10% protein, 1.35% fats, 45% starch, and active alkaloids including caffeine (2-3%) and smaller amounts of theobromine and kolatin (Adenuga et al., 2012; Asogwa et al., 2006).

Geographical Distribution and Ecology

Cola nitida is native to the West African coast from Sierra Leone to Benin, and cultivation was subsequently introduced to other parts of Africa and the wider tropics (Figure 1). In Nigeria, cultivation of *C. nitida* began sometime in the nineteenth century, it was observed growing abundantly in the Otta bush in 1854, and its cultivation was noted in Egba Division in 1902 (Asogwa et al., 2006). From Agege, cultivation spread into the forest areas following the railway line, reaching Abeokuta, Ibadan, and Offa before penetrating the Guinea Savannah and eventually the South-South and Eastern states (Asogwa et al., 2006). Today, seventeen states in Southern Nigeria cultivate *Cola* species, spanning the Delta, Imo, Abia, Cross River, Anambra, Edo, Enugu, Ebonyi, Ekiti, Osun, Lagos, Ogun, Oyo, Ondo, Kogi, Benue, and Akwa Ibom states (Adenuga et al., 2012).

Ecologically, *C. nitida* thrives in tropical lowland forests with rainfall lasting eight months or more and temperatures between 23 and 28°C, with a preferred annual precipitation of approximately 1,700 mm (Tokannou et al., 2024). The species grows best on well-drained, deep, rich soils suitable for cocoa and coffee, and can be grown in soils of inferior moisture retention that cannot sustain cocoa or coffee, provided they are deep and well-drained (Asogwa et al., 2006; Asogwa et al., 2012). Research has consistently shown that Nigeria dominates the West African publishing landscape on kola, with 192 of the 280 papers published between 1990 and 2022 originating from Nigeria, a reflection of both the country's production dominance and its research engagement with the crop (Tokannou et al., 2024).

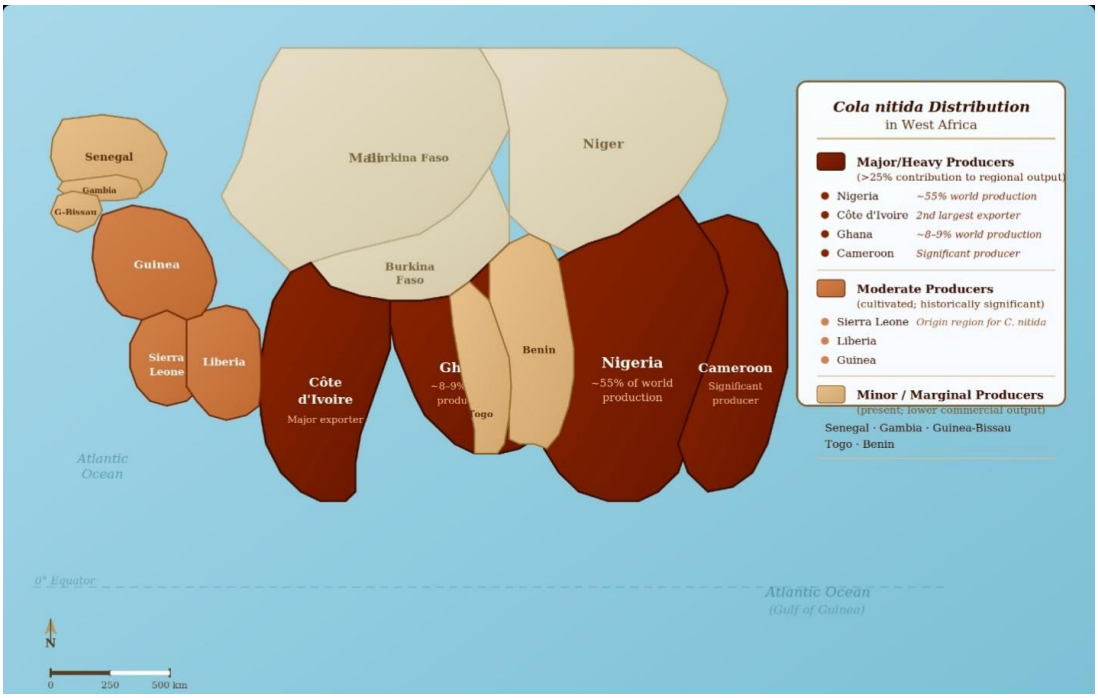


Figure 1. Distribution of *Cola nitida* in West Africa
(Based on FAO production data. Nigeria, Cote d'Ivoire, Ghana & Cameroon account for ~97% of global production. Source: FAOSTAT 2023, ScienceDirect, Gestrich et al., 2021, Techie-Obeng & Brown 2001)

Advances in Propagation and Nursery Management

Phenological Characteristics

Cola nitida flowers sporadically throughout the year, with peak flowering between August and September (Tokannou et al., 2024). The species shows two fruiting seasons: a primary season from October to January and a smaller secondary season between July and August (Ndubuaku et al., 2015; Tokannou et al., 2024). In Nigeria, the peak production period is October to December for *C. nitida* and April to June for *C. acuminata* (Asogwa et al., 2012). Under normal seedling propagation, nut production typically begins at four to seven years of age, with peak production not reached until approximately fifteen to twenty years (Emmanuel et al., 2016). This long gestation period is one of the primary economic disincentives for farmers and a major target for breeding improvement. In *C. acuminata* the gestation period is even longer, which has driven many farmers to abandon the species altogether (Adenuga et al., 2012).

Seed Germination: Constraints and Innovations

The primary propagation method for *C. nitida* is direct seed sowing. However, the species is known for slow and erratic germination due to prolonged seed dormancy, a major constraint to large-scale nursery production (Séry et al., 2020). Slow germination is partly attributed to

high polyphenol concentrations in the cotyledons, which inhibit germination physiology. Hammed et al. (2019) demonstrated that 50% excision of the embryonic portion of the cotyledon in white and pink nut varieties reduced germination time to as little as five weeks after sowing, confirming that cutting the nut before germination reduces polyphenol concentrations and facilitates dormancy-breaking.

CRIN has developed standard seed handling protocols to address these challenges. Kolanuts intended for propagation should be harvested when completely mature and of large size, uniformly cured, and stored for up to five months. Seeds should be scarified to ensure faster germination and pre-germinated in shaded seed boxes filled with moist sawdust, planted horizontally to a depth of three centimeters below the surface (Asogwa et al., 2012). Germination in *C. nitida* is typically completed within 80 days, compared to 60 days in *C. acuminata* (Asogwa et al., 2012). The pre-germinated nuts are then transplanted into baskets or polybags filled with topsoil at a depth of 7-10 cm and kept under shade until they reach transplanting size in six to eight months (Asogwa et al., 2012).

Gbedie et al. (2017) demonstrated that cutting 1 cm from the end of the cola nut opposite the hilum and soaking for 24 hours, or scarifying and soaking for 48 hours, produced germination rates of 93.94% at 84 days after sowing. Emmanuel et al. (2016) investigated mini-nut techniques using different cotyledon reduction levels (25%, 50%, 75%, and 100%) across four germination substrates topsoil, coconut husk, sawdust, and rice husk. Their results indicated that 100% nut in topsoil produced the tallest seedlings (9.40 cm), while 25% nut in rice husk yielded the highest leaf count (2.50 leaves) at 12 weeks, confirming the utility of mini-nut techniques as a viable approach to accelerate nursery production. Additionally, Ugioro et al. (2021) demonstrated that fortnightly application of gibberellic acid at 50 mg/L improved seedling growth in red-coloured *C. nitida* seeds, an important agronomic intervention that merits further investigation across genotypes.

While seed-based propagation methods remain the most widely practiced approach for establishing new kola plantations, their limitations in terms of long juvenile periods and genetic unpredictability have driven significant interest in vegetative clonal propagation. The following section reviews advances in cutting propagation and clonal multiplication, which offer a complementary and increasingly practical pathway to scaling up the deployment of genetically superior, early-bearing kola materials.

Vegetative Propagation: Cuttings and Clonal Multiplication

Vegetative propagation by cuttings allows for the clonal multiplication of superior genotypes and significantly shortens the period to first fruiting. Rooted cuttings established at CRIN have been shown to start yielding fruits within three years of planting, compared to seven years for seedlings (Asogwa et al., 2006). Cuttings for vegetative propagation should be taken from new growth that has just hardened, approximately two months after flushing, from trees that have proven to be high-yielding (Asogwa et al., 2012). Cuttings of 15-20 cm in length are planted in concrete propagators or wooden boxes with a rooting medium, and roots begin to develop

from callus tissue at the base of the cutting, on average nine weeks after setting (Asogwa et al., 2012).

A major advance at CRIN has been the successful potting of rooted cuttings in baskets, a practice perfected to the level of field deployment. The practice of potting cuttings in rigid containers is essential because newly formed roots are very brittle, and flexible pots risk breaking them (Asogwa et al., 2012). Successfully rooted cuttings require containers of at least 40 cm high and 25 cm wide to provide sufficient space for the developing root system.

Séry et al. (2020) conducted a six-month factorial experiment at the CNRA Man Station in western Côte d'Ivoire to investigate the effect of terminal bud removal on the rooting of semi-lignified plagiotropic cuttings in three improved kola genotypes. The overall survival rate of cuttings ranged from 51.7% to 86.7% across genotypes, with an average of 73.06%, exceeding the 41% survival previously recorded for dry-season tunnel cuttings (Séry et al., 2019). The study's key finding was that removal of the terminal bud significantly improved both rooting rate and root development. Cuttings without the terminal bud had a higher proportion of rooted specimens (0.81 ± 0.13 versus 0.48 ± 0.16) and produced longer taproots (15.15 ± 3.62 cm versus 7.81 ± 3.32 cm) compared to cuttings with the bud intact. The mechanism involves auxin biology: the terminal bud is a major site of auxin biosynthesis, and at high concentrations auxin inhibits root initiation. Removing the bud reduces auxin concentration in the basal tissue, releasing inhibition and promoting rooting (Séry et al., 2020). A genotype effect was also detected for taproot length and root number per cutting, underlining the importance of genotype selection in vegetative propagation programs.

The most recent and encouraging development from CRIN is the successful large-scale field establishment of clonal kola materials. After several years of exploratory germplasm collection exercises across South-West Nigeria beginning in 2014, the first set of clones was successfully established in the field in 2019. By 2023, a significant population of Cola nitida clonal materials and seedlings in the new germplasm plot at CRIN headquarters in Ibadan had already begun flowering and fruiting at exactly four years of field planting, a remarkable achievement given that seedlings normally take six to seven years or more to reach this stage. This early fruiting from clonal materials strongly indicates a possible solution to self-incompatibility and confirms that vegetative propagation is a practical and scalable pathway to shortening the juvenile period in kola production (CRIN, 2023).

Genetic Improvement: Self-Incompatibility, Breeding, and Heterosis

The Self-Incompatibility System in Kola

Cola nitida is an allogamous plant governed by sporophytic self-incompatibility (SI), a genetically controlled mechanism that prevents self-fertilization and is controlled by a single locus with multiple alleles (Nyadanu et al., 2022b; De Nettancourt, 2001). In sporophytic SI, the pollen phenotype is determined by the genotype of the pollen-producing plant, meaning that pollen carrying matching S-alleles cannot fertilize a compatible ovum. SI has been estimated to account for more than 50% of low yield in kola orchards, as incompatible pollen-

ovum combinations fail to produce pods regardless of pollination effort (Nyadanu et al., 2022a). It is further known that 70-90% of kola trees in Nigeria are self-incompatible, and when trees of the same incompatible group are planted together, plot yields are severely reduced (Asogwa et al., 2012).

The practical breeding implication of SI is profound: it restricts the number of desirable crosses, necessitates the inclusion of compatible pollinizers in commercial orchards, and requires rigorous screening of genotype combinations before large-scale planting. CRIN researchers identified incompatibility as one of the major factors limiting kola yields in Nigerian orchards (Adenuga et al., 2012), and subsequent work has confirmed its significance as a yield-limiting factor across producing countries.

A practical approach to solving the incompatibility problem in C. nitida is the use of compatible clones or progenies. Efforts in this direction at CRIN led to the identification of cross-compatible clones (Adenuga et al., 2012), and the development of promising hybrids that produce in five years with an annual average yield of about 2,000 nuts per tree per year of marketable sizes (12-15 g), compared with only 250 nuts per tree per year from unselected farmer materials (Asogwa et al., 2006). Selections observed to be self-compatible at CRIN include AA31, AA42, AB6, and AD44, while cross-compatible selections include AA42, AA62, AA86, AA213, AA231, AC71, L47, and L54, the latter groups also being early-bearing (Adenuga et al., 2012).

Yield and Nut Quality Traits in Breeding Populations

Beyond compatibility, significant genetic variation exists among kola genotypes for pod and nut yield traits. Among the breeding populations at CRIG, Ghana, number of pods, pod weight, pod length, pod width, number of nuts per pod, weight of unpeeled and peeled nuts, and outturn (%) all varied significantly ($P < 0.001$) across populations (Nyadanu et al., 2022a). Among double hybrid crosses, the standout performer was DCC19, which recorded the highest number of pods, highest pod weight, and the highest outturn (92.5%). Conversely, DCS14 had the lowest pod set (21.3%) and lowest outturn (28.7%), illustrating the wide genetic range available for selection. At CRIN, 57 kola trees were initially selected from six different kola agro-ecologies in Nigeria, a number later increased to 74 through the addition of trees from another ecology (Adenuga et al., 2012). These 74 selections formed the initial breeding population for further improvement work.

Nut quality traits, including brix (total soluble solids, a proxy for sweetness), potential alcohol content, and nut firmness have also shown significant variation among single hybrid crosses (Nyadanu et al., 2022a). Brix is particularly important in breeding because it directly influences consumer acceptability, astringency, and post-harvest shelf life. Varieties with higher brix content are preferred by consumers and tend to store better, making brix a valuable indirect selection criterion. Kola nut colour also plays a commercial role: white and pale-pink nuts fetch higher prices than darker-pink or red nuts, making colour a trait of concern in variety selection (Adenuga et al., 2012).

Odutayo et al. (2018) conducted diallele cross-pollination trials among 10 *C. nitida* genotypes maintained in the experimental plots (Plot 64/5) at the Cocoa Research Institute of Nigeria (CRIN), Ibadan. The pollinations were carried out across two distinct flowering seasons: the major season from July to September and the minor season between November and December, with the study submitted for publication in January 2017 and published in April 2018. The parental lines used in these trials, including the notably cross-compatible clone AA231, were drawn from CRIN's established germplasm holdings, which trace their origin to systematic kola selections conducted under the CRIN-Netherlands Government Kola Pilot Project (1971-1975) and further expanded through field collections documented by Adenuga et al. (2012). Clone AA231 therefore represents a parental line with a documented breeding and observational history spanning at least four decades within the CRIN gene bank system prior to the Odutayo et al. (2018) trials. Across the 18 cross-pollination combinations evaluated, AA231 consistently produced pods with a greater number of partner genotypes than any other tested clone, with the cross AA231 × AD44 achieving the highest fruit set (55.5%) and pod harvest rate (18.5%). This sustained performance across multiple seasons and partner combinations, underpinned by decades of gene bank monitoring, makes clone AA231 a well-validated and preferred parental line for orchard rehabilitation programs in Nigeria. The practical implication is direct: replacing moribund or sterile trees in existing kola groves with AA231 and other confirmed compatible selections identified at CRIN could substantially improve plot-level fruit set and overall orchard productivity.

Trait Correlations and Breeding Strategy

Across breeding populations, pod set has been found to be strongly and positively correlated with number of pods, pod weight, number of nuts per pod, and nut outturn. These correlations suggest that pod set can serve as an effective indirect selection criterion for nut yield, a practically useful finding given the difficulty of measuring nut weight directly in large breeding trials (Nyadanu et al., 2022a). The inverse relationship between pod set and pseudo-pod set (the formation of pods without viable fertilization) was also consistently negative and significant, confirming that breeding to increase pod set will simultaneously suppress pseudo-pod set.

For single hybrid crosses, significant and positive correlations were detected between nut quality traits (brix, potential alcohol, firmness) and yield traits, meaning that high-yielding genotypes tended also to produce higher quality nuts a favorable breeding scenario that allows simultaneous selection for both yield and quality (Nyadanu et al., 2022a).

Heterosis in Kola Breeding

Heterosis, the superior performance of hybrid offspring compared to both parents, is the engine of many modern crop improvement programs. Nyadanu et al. (2022a) detected a high prevalence of positive mid-parent heterosis, heterobeltiosis, and economic heterosis for pod set and outturn across double and single hybrid crosses of kola. Double hybrid crosses

displayed larger heterosis values than single hybrid crosses, suggesting that prior selection of parental lines for compatibility has enriched the gene pool for compatibility-enhancing alleles. This progressive enrichment of heterosis across generations has been documented in other crops exhibiting dominance-driven traits and was attributed to the accumulation of favorable dominant alleles (Nyadanu et al., 2022a).

At CRIN, the Kola Pilot Project sponsored by the Government of the Netherlands and supervised by the International Labour Organization (1971-1975) contributed to significant early selections. Three sets of clonal selections from that effort, Clonal Selection I (28 trees), Clonal Selection II (73 trees), and Clonal Selection III (530 trees), all yielded between 532 and 2,893 nuts per tree per year, confirming the productive potential that proper selection and hybridization can unlock (Adenuga et al., 2012).

Genetic Diversity as a Foundation for Crop Improvement

Morphological Variability

Cola nitida displays remarkable morphological diversity across its range, attributable to genetic differentiation, environmental adaptation, and farmer selection (Dah-Nouvlessounon et al., 2016; Onomo et al., 2006; Tokannou et al., 2024). A study by Ouattara et al. (2025) assessed 15 morphological traits covering leaf dimensions, follicle characteristics, and nut traits across 23 *C. nitida* genotypes from two geographic origins: Côte d'Ivoire and Nigeria. Significant differences ($P < 0.001$) were detected between the two origins for all traits except nut length. Nigerian genotypes generally had larger leaf dimensions, thicker cortex, and individually larger and heavier nuts, while Ivorian genotypes produced more nuts per follicle and higher total nut weight per follicle, reflecting a contrasting yield strategy between the two origins. Cluster analysis of the 23 genotypes revealed three distinct clusters regardless of geographic origin, indicating that phenotypic similarity cut across country boundaries.

In Nigeria, variability in nut production is extreme: in any given kola plot, the percentage of trees that bear fruits varies from year to year, and there is variation from tree to tree and even among ramets (rooted cuttings) (Asogwa et al., 2012). This variability is attributed to the widespread occurrence of self and cross incompatibilities, and the interplanting of both *C. nitida* and *C. acuminata* in Nigerian kola groves, which has given rise to high levels of unproductivity where 75% of fruits are produced from only 25% of trees, resulting in a national average production as low as 250 fresh nuts per tree per hectare (Asogwa et al., 2012). The CRIN germplasm collection, which has been recently expanded through systematic exploration of kola-producing locations in South-West Nigeria since 2014, was assembled specifically to address the narrow genetic base of the institute's existing holdings. The collection exercise was guided by clear objectives: identifying superior genotypes in farmers' plots; collecting clones and seeds for nursery raising and field planting; establishing the collected genotypes as new plant introductions in CRIN's germplasm plots at headquarters and sub-stations; characterizing the germplasm using morphological and molecular markers; and selecting superior parents for the development of improved varieties (CRIN, 2023).

Molecular Genetic Diversity

ISSR-Based Diversity Analysis at CRIN

Sobowale et al. (2025) carried out ISSR-based molecular characterization of forty kola accessions maintained in the newly established germplasm collection at CRIN headquarters in Ibadan. Fresh young leaf samples were collected from each accession and DNA extraction and genetic profiling were conducted at the Bioscience Laboratory of the International Institute of Tropical Agriculture (IITA), Ibadan. Ten ISSR markers were used, generating a variable number of alleles ranging from 9 to 27 per marker. The polymorphism information content (PIC) values across all markers ranged from 0.584 (UBC866) to 0.944 (UBC834), with an average PIC value of 0.832 highly informative and confirming substantial genetic variability among the accessions. Marker UBC834 revealed the highest genetic diversity (0.946) among all primers used.

Unweighted Pair Group Method with Arithmetic Mean (UPGMA) analysis generated a dendrogram that partitioned the 40 accessions into four primary clusters, with Cluster I being the largest (20 accessions in two sub-clusters), Cluster II containing a single highly distinct accession (CN8), Cluster III containing 17 accessions (in two sub-clusters), and Cluster IV containing two accessions. The first linkage was formed between accessions CN34 and CN35 at 0.97 dissimilarity, indicating they were the closest pair among all accessions. All 40 accessions were distinct from one another at 100% dissimilarity, confirming that the collection harbours genuine genetic breadth. Based on the dendrogram, accessions exhibiting significant genetic distance are recommended as optimal parental candidates for hybridization, as their combination maximizes the probability of generating novel genetic combinations and enhancing desirable agronomic traits including earlier flowering, higher fruit yield, and greater nut weight (Sobowale et al., 2025).

RAPD-Based Diversity Analysis Across Nigerian States

Akinro et al. (2019) employed RAPD markers to characterize genetic diversity among 21 accessions of Cola species (11 *C. acuminata* and 10 *C. nitida*) collected from different producing states of Nigeria. Fifteen optimized arbitrary primers generated amplification products ranging from 170 to 1,650 bp, with a mean of 6.9 bands per primer. The percentage of polymorphic loci was 58.33% in C. acuminata and 71.47% in *C. nitida*, confirming substantial genetic variation within both species. Jaccard's similarity coefficients among *C. nitida* accessions ranged from 47.4% to 65.9%, indicating moderate to high levels of genetic dissimilarity. UPGMA clustering grouped populations from Anambra, Ekiti, Ondo, Benue, Kogi, Ogun, Edo, and Osun states together, while Cross-River populations were the most distinct, suggesting greater genetic differentiation and conservation value for that population. Gene flow through seed exchange and trade networks, rather than simple geographic isolation, was identified as a likely driver of genetic structure in C. nitida.

SNP-Based Diversity Analysis

Ouattara et al. (2022) applied SNP markers generated through Genotyping-by-Sequencing to characterize the genetic diversity and population structure of 30 *C. nitida* clones from Côte d'Ivoire (n = 14) and Nigeria (n = 16). After quality filtering, 145 SNPs were retained, all highly polymorphic with a Polymorphism Information Content (PIC) value of 0.38. No duplicate genotypes were found among the 30 clones, confirming that 145 SNPs were sufficient to uniquely identify each clone. Genetic diversity within each origin was moderate to high: mean gene diversity was 0.42 ± 0.01 for Côte d'Ivoire and 0.41 ± 0.01 for Nigeria. Analysis of Molecular Variance (AMOVA) analysis showed that 82% of total genetic variation occurred among clones within origins, with only 18% attributed to between-origin differences. Structure analysis confirmed K = 2 as the optimal number of genetic groups, corresponding to the two countries of origin, with moderate genetic differentiation (FST = 0.11). Four Nigerian clones showed affiliation patterns closer to Ivorian clones than to the Nigerian cluster, possibly reflecting historical germplasm exchange between the two countries (Ouattara et al., 2022).

SSR Markers and Cross-Species Transferability

Dupiol et al. (2025) developed 14 new polymorphic microsatellite (SSR) markers for *Cola acuminata* using Genotyping-by-Sequencing data from two individuals from Cameroon. These markers exhibited high polymorphism, with a mean of 14.14 alleles per locus. Critically, 13 of the 14 SSR markers were successfully transferable to *C. nitida*, confirming that the two species are closely related and share substantial genomic regions. This 93% transferability rate represents a foundational advance for future conservation genetics, germplasm management, and comparative genomics studies across the genus *Cola*. Analysis of three cultivated *C. acuminata* populations from Cameroon showed that savannah populations likely represent genetically impoverished subsets of more diverse forest populations, a pattern with direct implications for conservation strategies in Nigeria, where the putative centre of origin of *C. acuminata* is Ijare, Ondo State (Dupiol et al., 2025; Adenuga et al., 2012).

Utilization: Nutritional Composition, Phytochemistry, and Bioactive Compounds

Proximate Composition of the Kola Nut

The nutritional composition of *C. nitida* nuts has been extensively documented. According to Dah-Nouvlessounon et al. (2016) and Odebunmi et al. (2009), as cited in Tokannou et al. (2024), the nut contains approximately 10.06% protein, 8.30% reducing sugars, 12.46% water, 0.20% fat, 4.31% crude fiber, 0.34% potassium, and 0.04% phosphorus. Orwa et al. (2009) reported that *C. nitida* nuts consist of 13.5% water, 9.5% crude protein, 1.4% fat, 45% sugar and starch, 7% cellulose, 3.8% ash, 2.8% caffeine, and 0.05% theobromine. The nuts are therefore a rich source of both stimulant compounds and macronutrients, justifying their traditional use as a substitute for food during fasting and physical exertion.

Phytochemical Profile of *C. nitida* Nuts from Nigerian Studies

Ugioro et al. (2020) evaluated the phytochemical content and enzyme activities of fresh *Cola nitida* nuts of varying weights (1-10 g, 11-20 g, and above 21 g) and colours (red, pink, and white). Phytochemical screening showed a consistent trend of increasing phytochemical content with increasing nut weight. Anthraquinone ranged from 3.51 g/100 g to 6.38 g/100 g, tannin from 2.75 g/100 g to 4.42 g/100 g, and alkaloid from 1.44 g/100 g to 2.06 g/100 g across the weight classes. Pink nuts above 21 g had the highest saponin (4.01 g/100 g) and alkaloid (1.87 g/100 g) content, while red nuts recorded the highest flavonoid (3.01 g/100 g) and anthraquinone (4.22 g/100 g) content. White nuts recorded the lowest values across most phytochemical parameters.

Chemical composition analysis by Ugioro et al. (2020) showed that vitamin C had the highest value across all nut sizes, ranging from 4.21 to 5.75 g/100 g, followed by caffeine (3.32-5.42 g/100 g) and theobromine (1.65-2.28 g/100 g). Red nuts above 21 g had the highest mean values across all chemical constituents, vitamin C (5.55 g/100 g), caffeine (4.46 g/100 g), theobromine (2.29 g/100 g), and polyphenol (3.61 g/100 g), compared with pink and white nuts. Enzyme activity analysis showed that total amylase activity was highest (0.137-0.148 mg glucose/min/g protein) across all nut sizes, followed by catalase activity. Proteinase activity was consistently the lowest. These findings confirm that larger and red-coloured nuts consistently carry higher concentrations of bioactive compounds, a practically useful insight for both quality breeding and industrial raw material procurement.

Nafiu et al. (2017) performed qualitative and quantitative phytochemical analysis on aqueous and methanolic extracts of white and red kola nut varieties obtained from Sokoto, Nigeria. Qualitative screening confirmed the presence of alkaloids, tannins, flavonoids, saponins, cardiac glycosides, steroids, and volatile oils in both varieties. Quantitative analysis revealed that white kola nut had significantly higher saponin content (20.60%) compared to red kola nut (10.80%), while red kola nut had higher alkaloid content (16.07% versus 14.40%). The differences between varieties were attributed to environmental, genetic, and agroclimatic factors, consistent with evidence that light, rainfall, and temperature influence secondary metabolite accumulation in plants.

Antimicrobial Properties of *Cola nitida* Extracts

Onaivi and Enabulele (2024) evaluated the antibacterial activity of ethanol, methanol, and aqueous extracts of *C. nitida* seeds against *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa* using the Kirby-Bauer disc diffusion method. Results showed moderate activity against *S. aureus*, low activity against *E. coli*, and resistance by *P. aeruginosa* to most extracts. The relatively low activity was attributed to extraction-related losses of active compounds, as phytochemical screening confirmed the presence of alkaloids, tannins, saponins, polyphenols, kolatine, caffeine, and theobromine in all extracts.

Odonye et al. (2021) extended this work using ethanol and aqueous extracts of *C. nitida* seeds at 30 mg/mL and 60 mg/mL against *S. aureus*, *Salmonella typhi*, *E. coli*, and *P. aeruginosa*.

Ethanol extracts at 60 mg/mL produced inhibition zones of 22 mm (*S. typhi*), 24 mm (*S. aureus*), 18 mm (*P. aeruginosa*), and 24 mm (*E. coli*) at 24 hours. The minimum inhibitory concentration of aqueous extract against *P. aeruginosa* was 3.75 mg/mL, the lowest MIC recorded in the study and tannins and flavonoids were identified as the likely active antibacterial compounds.

Antidiabetic Properties and Bioactive Alkaloids

Cola nitida nuts are used in Nigeria to manage diabetes, and several studies have validated this traditional use. Oboh et al. (2014) confirmed the antidiabetic potential of *C. nitida*. Erukainure et al. (2019) attributed the antidiabetic activity to a synergistic interaction between caffeine and theobromine content. Dorathy et al. (2014) demonstrated that aqueous extracts significantly reduced blood glucose, cholesterol, and bilirubin in diabetic subjects without inducing toxic effects. The nuts are rich in catechin (27-37 g/kg), caffeine (18-24 g/kg), and epicatechin (20–21 g/kg) compounds with well-documented antioxidant and hypoglycaemic activities (Atawodi et al., 2007, as cited in Tokannou et al., 2024).

Industrial and By-Product Utilization

Beyond the raw nut, CRIN has developed a range of value-added products from kola and its by-products. These include kola chocolate, kola wine, kola-based soft drink (CRIN-KOLA), kola pod husk-based organic fertilizer, kola pod ash-based liquid detergent, and the use of kola testa as feed for African giant land snails (Asogwa et al., 2006; Asogwa et al., 2012). Notably, CRIN researchers demonstrated that kola pod husk can replace up to 60% of maize in poultry feed formulations (Olubamiwa et al., 2002, Asogwa et al., 2006). The liquid detergent product attracted contracts from both the Directorate for Food and Rural Infrastructure (DFFRI) and the Ministry of Defense. Kola chocolate adapted from the CRIN cocoa-bean flour chocolate technology has been in laboratory-scale production at CRIN for several years, though commercial production has been constrained by the cost of specialized equipment (Asogwa et al., 2006).

These diversified utilization options are commercially significant because they create demand for kola at various quality grades and sizes, meaning that nuts not meeting the premium fresh-nut market standard can be directed to industrial processing. This has direct implications for farm-level profitability and post-harvest loss reduction.

Socioeconomic Utilization: Marketing, Trade, and Value Chain

Economic Value and Trade

The socioeconomic significance of C. nitida in West Africa is difficult to overstate. Nigeria is the world's largest producer, accounting for approximately 70% of total global production (Asogwa et al., 2006; Adenuga et al., 2012). The crop has been granted cash crop status by the Central Bank of Nigeria and is being promoted for export by the Nigeria Export Promotion Council alongside cocoa, coffee, cashew, palm kernel, and palm oil (Asogwa et al., 2006). In

Côte d'Ivoire, the leading exporter, annual production has been estimated at 260,000 tonnes of fresh kola nuts (N'Guessan et al., 2019). Ghana exported approximately USD 527,000 worth of kola nuts in 2019, representing about 9.2% of global market share (Nyadanu et al., 2022b). Soil fertility has been identified as a key determinant of kola yield variability across Nigerian farms. Farms with high organic matter content consistently yield larger and heavier kola nuts, with nitrogen, phosphorus, potassium, calcium, and magnesium all showing positive correlations with kola yield (Eze et al., 2015; Lowor and Aculey, 2011). Soil acidification, phosphorus deficiency, and aluminum toxicity were identified as the most common limiting factors in kola production, with soils below pH 5.5 unable to sustain productive kola cultivation (Lowor and Aculey, 2011; Eze et al., 2015). These findings underscore the need for targeted soil fertility management as a prerequisite for commercial kola expansion (Eze et al., 2015).

Cultural and Traditional Uses

Beyond commerce, *C. nitida* holds deep cultural meanings across West Africa. In Nigeria, kola nuts are presented at dowry ceremonies, friendship rituals, and community meetings, symbolizing peace, friendship, and sympathy (Asogwa et al., 2006; Adenuga et al., 2012). At weddings and naming ceremonies, the kola nut conveys fertility, prosperity, and consent. The Yoruba offer it during ceremonies as a sign of goodwill, while it serves the Igbo during marriage rituals, conflict resolutions, and community gatherings (Starin, 2013). Kola is also the only stimulant permitted to Muslims, generating a heavy and consistent trade flow from the humid southern regions to the northern arid parts of West Africa (Asogwa et al., 2006). These cultural dimensions make kola not merely an agricultural commodity but a socially embedded product whose conservation has dimensions that go well beyond economics.

Kola Nut Marketing Challenges

Ashaye et al. (2017) examined kola nut marketing in Sagamu and Ikenne Local Government Areas of Ogun State, Nigeria. Their survey of 120 respondents revealed that the majority of kola nut marketers were female (57.5%), within the 41-50 age bracket (35%), and had only primary education (71.7%). Most sourced funding through personal savings (45.83%). The three major constraints rated as 'very severe' were high transportation costs, lack of storage facilities, and poor access to credit. Road network quality and storage facility availability were rated as severe constraints. These findings highlight the need for government and development partner interventions in rural road construction, cold chain and storage infrastructure development, and accessible credit facilities for kola value chain actors.

The kola nut's perishability remains a fundamental barrier to export market integration. Kola nuts are highly perishable and susceptible to kola weevils and storage fungi, making long distance trade without proper preservation systems commercially impractical (Azeez, 2021). Unlike cocoa, which undergoes fermentation and drying to produce a stable commodity, kola nuts are typically traded fresh in Nigerian markets and suffer significant postharvest losses (5-

50%) due to inadequate storage. Modified atmosphere storage using botanical leaves can significantly enhance kola nut shelf life, but such technologies are not yet widely available in Nigerian producing communities.

Pest Management, Post-Harvest Quality, and Sustainable Production

Major Pests and Pathogens

Cola nitida faces serious quality losses from pest attacks both in the field and during storage. In the field, the species is parasitized by mistletoe species of the Loranthaceae family (Tokannou et al., 2024). During and after harvest, the primary insect pests are the kola weevils *Balanogastris kolae* (Desbr.) and *Sophrorhinus* spp., which are field-to-store pests all trees in West Africa are believed to be infested (Asogwa et al., 2012). Fungal pathogens particularly *Aspergillus niger* var. *niger*, *Aspergillus flavus*, *Fusarium* spp., *Penicillium* spp., *Alternaria* spp., and *Mucor spinosus* cause 30-70% nut losses during storage if not properly managed (N'Guessan et al., 2019). Internal rot caused by *Fusarium solani*, fresh rot by *Fusarium moniliforme*, and storage dry rot are the major fungal diseases affecting both field-harvested and stored kolanuts (Asogwa et al., 2012).

CRIN's research has identified the percentage of kola weevil infestation ranging from 30-100% across different growing situations, and has confirmed that timely harvesting significantly reduces weevil damage. Idowu and Ojelade (1995, as cited in Asogwa et al., 2012) observed that minimal weevil damage (35.4%) was recorded on kolanuts from timely harvested pods, compared with 58.3-83.3% from delayed harvests. Kola fruits usually mature four to five months after pollination, at which point the fruit changes colour from deep green to a paler tint and is ready for picking (Asogwa et al., 2012).

Traditional and Recommended Pest Control Methods

CRIN has identified cultural methods as the most practical and safe approach for controlling kola weevils and diseases, given that kolanuts are consumed raw and pesticide residues on edible nuts present food safety risks (Asogwa et al., 2012). Recommended cultural practices include early harvesting of mature pods, prompt removal of fallen pods and pods remaining on the tree at the end of the main season, removal of dead and moribund pods between crops, dehusking of pods far away from kola groves, and burying of pod husks to prevent larval development (Asogwa et al., 2012).

For disease management in storage, CRIN researchers have recommended soaking nuts in 1% sodium hypochlorite (Milton solution) immediately after skinning to minimize microbial infection (Asogwa et al., 2012). Botanicals including *Ocimum gratissimum* and *Azadirachta indica* leaf extracts have also shown efficacy in controlling storage rot pathogens (Otuonye and Adedeji, 2006, 2010; Asogwa et al., 2012). Edible salts and wood ashes have been successfully used to protect both fresh and stored nuts from fungal disease (Asogwa et al., 2006).

Post-Harvest Quality Management

N'Guessan et al. (2019) applied the HACCP (Hazard Analysis and Critical Control Points) method to analyze post-harvest kola nut processing practices across three cities in Côte d'Ivoire, Anyama, Bouaké, and Agboville. A survey-based assessment found that none of the processing and storage centers in any of the three cities complied with Good Hygiene Practice recommendations across 15 evaluated parameters. The HACCP analysis identified three Critical Control Points: reception (chemical risk from pesticide residues), sorting (physical risk from foreign bodies and injured nuts), and soaking in biopesticide solution (biological risk from weevils and fungi). The sorting step was identified as particularly important because any lot containing weevil larvae will continue to deteriorate during storage, spreading losses through the supply chain. N'Guessan et al. (2019) recommended improvements including an initial wash with pulp to remove soil, application of an approved biopesticide, and use of polystyrene trays for storage to reduce contact contamination.

Agroforestry, Conservation, and Climate Change

***Cola nitida* in Agroforestry Systems**

Cola nitida is naturally suited for integration into multi-species agroforestry systems. It is commonly intercropped with *Coffea canephora*, *Theobroma cacao*, and *Raphia hookeri* in West African agroforestry, providing shade for lower-canopy crops while generating nuts as an additional income stream (Tokannou et al., 2024). The standard spacing for plantation kola is 10 × 10 metres, and early weeding combined with interplanting with shade trees is strongly recommended (Orwa et al., 2009). Studies on soil fertility in Ondo State, a major kola-producing state, confirm that growing conditions including shade, moisture, and soil nutrient balance significantly affect kola productivity, pointing to the need for site-specific agroforestry management guidelines (Akintan et al., 2022).

Conservation Strategies

CRIN's germplasm expansion program represents Nigeria's most significant recent contribution to kola conservation. By systematically collecting superior genotypes from farmers' plots across South-West Nigeria and establishing them as clonal field gene banks at CRIN headquarters in Ibadan and at sub-stations, the institute has both broadened the genetic base available for improvement and shortened the juvenile period of materials in the collection (CRIN, 2023). At the regional level, research institutions such as CNRA in Côte d'Ivoire and CRIG in Ghana maintain ex situ field gene bank collections for *C. nitida*, though politico-military crises and urbanization have caused significant losses to some of these collections, underscoring the urgency of systematic conservation with redundancy across multiple sites (Ouattara et al., 2022).

The Cross River-Mungo River Forest zone in southeast Nigeria has been highlighted as a particularly important area for further germplasm collection, given the extreme floristic richness of the Gulf of Guinea area and the recent discovery of three new *Cola* species in that

zone. Southern Nigeria, bounded by the Gulf of Guinea, offers outstanding opportunities for further diversity collection that can broaden the genetic base of kola improvement programs (Adenuga et al., 2012).

Knowledge Gaps and Priorities for Advancing Sustainable Production

Despite significant research advances, critical knowledge gaps remain. On ecophysiology and fertilizer responses, very little work has addressed the effects of different fertilizer types and doses on *C. nitida* seedling growth and plantation productivity. Fertilizer response trials, particularly with reference to gibberellic acid, nitrogen, phosphorus, and micronutrients, are urgently needed across the range of Nigerian production environments.

On agroforestry optimization, while *C. nitida* has been advocated for agroforestry integration, the specific management practices, spacing, companion species, and soil conditions that maximize productivity within these systems have not been systematically characterized. Questions remain about which agroforestry designs most effectively improve farmer livelihoods across different agro-ecological zones.

On genome assembly and molecular breeding tools, the lack of a reference genome for *C. nitida* remains a critical constraint for molecular breeding. SSR and SNP markers available for closely related species have been used as surrogates (Ouattara et al., 2022; Dupiol et al., 2025), but a purpose-built *C. nitida* genome assembly would dramatically accelerate trait mapping, marker-assisted selection, and genomic selection. CRIN's ISSR characterization of its new germplasm collection (Sobowale et al., 2025) provides a foundational dataset upon which more comprehensive marker-assisted breeding can be built.

Closely linked to this priority is the need to address two persistent biological constraints that impede both breeding efficiency and large-scale propagation, self-incompatibility and seed recalcitrance. The self-incompatibility system in *C. nitida* restricts controlled hybridization, limits effective pollen transfer in small plantation settings, and contributes to chronically low fruit set even under adequate agronomic management. The molecular architecture of the incompatibility loci remains uncharacterized, and no deliberate manipulation has been reported, yet this represents a compelling target for CRISPR-Cas9 and related gene-editing platforms, through which targeted modification of S-locus-associated genes could relax incompatibility barriers in elite genotypes. Given the phylogenetic proximity of *C. nitida* to *Theobroma cacao*, transformation and editing protocols established for cacao including *Agrobacterium tumefaciens*-mediated delivery into somatic embryos (Fister et al., 2018; Maximova et al., 2002), provide a credible framework for adaptation to kola. Compounding this challenge, *C. nitida* produces recalcitrant seeds that are desiccation-sensitive, rapidly lose viability after separation from the fruit, and cannot be stored under conventional conditions (Berjak and Pammenter, 2008), severely constraining ex situ conservation, germplasm exchange, and the preparation of explants for in vitro regeneration pipelines. Systematic transcriptomic characterization of the desiccation-tolerance deficit in *C. nitida*, likely involving incomplete activation of late embryogenesis abundant proteins, dehydrins, and

ABA-responsive pathways is urgently needed, and gene-editing strategies to upregulate these programs in propagules offer a longer-term but transformative prospect. Establishing a reliable, genotype-independent somatic embryogenesis protocol for *C. nitida* is therefore a foundational prerequisite for both mass clonal multiplication and the delivery of gene-edited constructs, and must be treated as a priority infrastructure investment. Regulatory frameworks governing gene-edited crops in Nigeria, Côte d'Ivoire, and Ghana remain nascent, and proactive engagement between national research systems and biosafety bodies will be essential for translating these advances into field-deployable varieties.

On breeding for drought tolerance and pest resistance, screening of germplasm collections for these traits, combined with molecular marker identification for associated quantitative trait loci (QTLs), would accelerate progress in the face of climate change. Nigeria, as the world's largest kola producer and the country with the greatest stake in the crop's future, has a particular responsibility to lead in these areas.

On post-harvest technology and value chain development, the absence of formal quality standards, cold chain infrastructure, and organized marketing systems leaves the kola nut value chain highly vulnerable to losses and price instability (Ashaye et al., 2017; N'Guessan et al., 2019). Research is needed on biopesticide formulations for post-harvest use, controlled atmosphere storage, and development of value-added products, including kola wine, functional beverages, and pharmaceutical extracts that can support higher farmgate prices and make kola commercially competitive with better established export commodities.

On socioeconomic and cultural research, the consequences of declining *C. nitida* populations on the sustainability of traditional rites and ceremonies linked to kola use have not been systematically documented. Understanding the social factors that motivate or deter farmers from actively propagating and conserving *C. nitida* is essential for designing effective extension and conservation programs.

Conclusion

The case for investing in the propagation, genetic improvement, and utilization of *Cola nitida* as a pathway to sustainable production in West Africa is clear and compelling. Despite strong cultural relevance, rising demand, and significant untapped genetic potential, the crop remains constrained by inefficient propagation systems, low-yielding orchards, high post-harvest losses, and weak value chains that limit farmer returns.

Practical advances in propagation and breeding have demonstrated that early-bearing, high-yielding, and genetically compatible planting materials are achievable and scalable. At the same time, the crop’s broad industrial and nutraceutical potential presents real opportunities for value addition beyond the fresh nut market.

Sustainable production will therefore depend on coordinated investment across propagation, genetic improvement, post-harvest management, and value chain development. Unlocking this potential requires translating existing scientific knowledge into accessible, farmer-oriented

systems that improve productivity, reduce losses, and enhance market value across the kola sector.

References

Adebola, P. O., & Morakinyo, J. A. (2005). Chromosome numbers in Cola nitida and Cola acuminata. Plant Genetic Resources Newsletter, 132, 57-59.

Adebola, P. O., & Morakinyo, J. A. (2006). Morphological variability within kola (Cola nitida) germplasm in South-Western Nigeria. Plant Genetic Resources Newsletter, 132, 57-59.

Adenuga, O. O., Mapayi, E. F., Olasupo, F. O., Olaniyi, O. O., & Oyedokun, A. V. (2012). Nigeria's cola genetic resources: The need for renewed exploration. *Asian Journal of Agricultural Sciences, 4*(3), 177-182.

Akintan, C. I., Akintan, A. O., Sobola, O. O., & Akomolede, L. A. (2022). Growth response of *Garcinia kola* (Heckel) plant to natural shade in a rainforest environment of Nigeria. Agro- Science, 21(2), 136-139. https://doi.org/10.4314/as.v21i2.16

Akinro, L. A., Adesoye, A. I., & Fasola, T. R. (2019). Genetic diversity in Cola acuminata and Cola nitida using RAPD primers. *Journal of Research in Bioscience,* 15(1), 1-12.

Akouègninou, A., van der Burg, W. J., & van der Maesen, L. J. G. (2006). Flore Analytique du Bénin. Backhuys Publishers.

Asogwa, E. U., Anikwe, J. C., & Mokwunye, F. C. (2006). Kola production and utilization for economic development. African Scientist, *7*(4), 217-222.

Asogwa, E. U., Anikwe, J. C., Mokwunye, F. C., & others. (2012). Strategies for improving production and storage of kolanuts in Nigeria. *American-Eurasian Journal of Agricultural & Environmental Sciences, 12*(1), 37-43.

Ashaye, W. O., Daramola, R. B., Anyaeji, F. O., Wahab, A. A., & Alao, B. I. (2017). Marketing of kolanut (Cola nitida) in Sagamu and Ikenne Local Government Areas of Ogun State. *Journal of Agricultural Economics and Extension*, 3(1), 29-37.

Azeez, O. M. (2021). Post-harvest management and preservative quality of kola nuts against pest infestation for local and international markets: A review. *Global Academic Journal of Agriculture and Biosciences, 3*(4), 50–60. https://doi.org/10.36348/gajab.2021.v03i04.001

Berjak, P., & Pammenter, N. W. (2008). From Avicennia to Zizania: Seed recalcitrance in perspective. *Annals of Botany*, *101*(2), 213-228. https://doi.org/10.1093/aob/mcm168

Cocoa Research Institute of Nigeria. (2023). CRIN records breakthrough in cola research. https://crin.gov.ng/crin-records-breakthrough-in-cola-research

Dah-Nouvlessounon, D., Adoukonou-Sagbadja, H., Diarrasouba, N., Sina, H., Adjanohoun, A., Inoussa, M., ... & Moussa, L. B. (2016). Morphological and genetic variability in Cola nitida (Vent.) Schott & Endl. populations in Benin. Genetic Resources and Crop Evolution, 63, 1083-1097.

De Nettancourt, D. (2001). Incompatibility and incongruity in wild and cultivated plants (2nd ed.). Springer-Verlag

Dorathy, I.U., Okere, S.O., Daniel, E.E., Mubarak, L.L. (2014). Phytochemical constituents and antidiabetic property of *Cola nitida* seeds on alloxan-induced diabetes mellitus in rats. *British Journal of Pharmaceutical Research*, 4(23), 2631-2641.

Dupiol, P., Chakocha, A., Avana Tientcheu, M. L., Charahabil, M. M., Mariac, C., Barnaud, A., & Duminil, J. (2025). Development of new microsatellite markers for Cola acuminata (Malvaceae), a socio-economically important fruit tree species in Central Africa. Applications in Plant Sciences, 13(1), e11576.

Duke, J. A. (2000). Handbook of Nuts: Herbal Reference Library. CRC Press.

Emmanuel, I. B., Aghimien, E. V., Ekaun, A. A., & Geply, O. A. (2016). Effect of mini-nut techniques on the growth of Cola nitida (kola) seedlings. *Journal of Forestry Research,* 8(2), 52-58.

Erukainure, O.L., Sanni, O., Ijomone, O.M., Ibeji, C.U., Chukwuma, C.I., Islam, M.S. (2019). The antidiabetic properties of the hot water extract of kola nut (*Cola nitida* (Vent.) Schott & Endl.) in type 2 diabetic rats. *Journal of Ethnopharmacology*, 242, 112033. https://doi.org/10.1016/j.jep.2019.112033.

Eze, C. O., Okoli, B. E., & Eze, S. U. (2015). Influence of rural processing methods and postharvest storage environments on the quality characteristics of kola nut (*Cola acuminata*). *African Journal of Biotechnology*, 14(6), 466–473. https://doi.org/10.5897/AJB2014.13850

Fister, A. S., Landherr, L., Maximova, S. N., & Guiltinan, M. J. (2018). Transient expression of CRISPR/Cas9 machinery targeting TcNPR3 enhances defense response in *Theobroma cacao*. *Frontiers in Plant Science*, *9*, 268. https://doi.org/10.3389/fpls.2018.00268

Gbedie, N.A., Bonsson, B., Ouattara, Y., Bahan, L.M.F., Kouadio, K.T., Traoré, S.M., Legnate, N.H., Keli, Z.J. (2017). Methods for breaking the dormancy of fresh kola nuts (*Cola nitida* (Vent.) Schott and Endlicher). (Méthodes de levée de dormance de la noix de cola fraîche (*Cola nitida* (Vent.) Schott and Endlicher)). *Journal of Applied Biosciences*, 120, 11999-12005.

Hammed, L.A., Adebayo, S.M., Bodunde, J.G., Olaiya, A.O., Olaniyan, A.B., Olosunde, O.M. 2019. Mini-nut propagation technique of kola (*Cola nitida*, (Vent.) Schott and Endl.): Prospects for germination and propagation of kola plantlets in the pre-nursery. *International Journal of Fruit Science, 19(2), 179-190.*

Lowor, S. T., & Aculey, P. (2011). Analysis of some soil and leaf nutrient status of kola nut (*Cola nitida* and *Cola acuminata*) in Africa. *Agriculture and Biology Journal of North America*, 2(8), 1033-1038. https://doi.org/10.5251/abjna.2011.2.8.1033.1038

Maximova, S. N., Alemanno, L., Young, A., Ferriere, N., Traore, A., & Guiltinan, M. J. (2002). Efficiency, genotypic variability, and cellular origin of primary and secondary somatic embryogenesis of *Theobroma cacao* L. *In Vitro Cellular & Developmental Biology - Plant*, *38*(3), 252-259. https://doi.org/10.1079/IVP2001257

Nafiu, A., Mustapha, S. W., & Sadiya, A. W. (2017). Quantitative study and secondary metabolites determination of aqueous and methanolic extracts of two varieties of cola nuts. *International Journal of Research in Pharmacy and Biosciences*, 4(9), 23-29.

Ndubuaku, T.C.N., Asogwa, E.U., Hassan, A.T. (2015). Distribution of kolanut weevil (*Balanogastris kolae*) (*Coleoptera*: *Curculionidae*) in *Cola nitida* stored in baskets. *African Journal of Plant Science*, 9(1), 13–16.

N'Guessan, J. M., Nimaga, D., Akpo, A. F., & Amani, N. G. (2019). Analysis of post-harvest treatment practices for kola (Cola nitida) using the HACCP system in three cities of Côte d'Ivoire. GSC Biological and Pharmaceutical Sciences, 8(1), 51-63.

Nyadanu, D., Lowor, S. T., Akpertey, A., Tchokponhoue, D. A., Pobee, P., Dogbatse, J. A., Okyere, D., Amon-Armah, F., & Brako-Marfo, M. (2020). Genetic variability of bioactive compounds and selection for nutraceutical quality in kola [Cola nitida (Vent.) Schott and Endl.]. PLoS ONE, 15(11), e0242972.

Nyadanu, D., Lowor, S. T., Pobee, P., Dogbatse, J. A., Akpertey, A., & Brako-Marfo, M. (2022a). Heterosis patterns and sources of self-compatibility, cross-compatibility and key nut traits within single and double hybrid crosses of kola [Cola nitida (Vent) Schott and Endl.]. Scientific Reports, 12, 14612.

Nyadanu, D., Dogbatse, J. A., Pobee, P., Akpertey, A., Lowor, S. T., & Brako-Marfo, M. (2022b). Disentangling genetic variation and heterosis pattern for sexual compatibility and key nut traits within self, single and double hybrid crosses of kola [Cola nitida (Vent) Schott and Endl.]. *Frontiers in Plant Science*, 13, 883640.

Oboh, G., Nwokocha, K.E., Akinyemi, A.J., Ademiluyi, A.O. 2014. Inhibitory effect of polyphenolic–rich extract from *Cola nitida* (Kolanut) seed on key enzyme linked to type 2 diabetes and Fe2+ induced lipid peroxidation in rat pancreas *in vitro*. *Asian Pacific Journal of Tropical Biomedicine,* 4(1), S405-S412.

Odebunmi, E.O., Oluwaniyi, O.O., Awolola, G.V., Adediji, O.D. 2009. Proximate and nutritional composition of kola nut (*Cola nitida*), bitter cola (*Garcinia cola*) and alligator pepper (*Afromomum melegueta*). *African Journal of Biotechnology*, 8(2), 308-310.

Odutayo, O. I., Adeyemi, F. A., Adebola, P. O., & Sotimehim, O. I. (2018). Compatibility studies in Cola nitida genotypes. *Journal of Plant Breeding and Crop Science*, 10(4), 80-85.

Odonye, D. D., Upla, P. U., Ladi, A. L., Odonye, E. P., Adamu, A., Adikwu, P., Tsaku, M. I., Okposhi, U. I., Hadi, N. S., & Al-Mustapha, F. Y. (2021). Phytochemical screening and antibacterial activity of Cola nitida seed on selected bacterial isolates. GSC Biological and Pharmaceutical Sciences, 16(2), 166-177.

Olubamiwa, O.; Hamzat, R. A.; Ipinmoroti, R. R.; Jayeola, C. O. and Yahaya, L. E. (2002) Current Advances on the Utilization of Kola and By-products in Nigeria. Paper presented at an investor's forum on kola and by-products utilization for national development organized by CERUD, CRIN, RMRDC, NEPC and KOLAN, October 8, 2002, Ikorodu, Lagos, Nigeria.

Onaivi, T. J., & Enabulele, O. I. (2024). Antimicrobial properties of Cola nitida. Benin *Journal of Experimental Biology*, 14(1), 45-53.

Onomo, P.E., Niemenak, N., Ndoumou, D.O. (2006). Isoenzyme variability of three Cola (*Cola acuminata* (Pal. de Beauv, Schott and Endlicher), *Cola nitida* ((Vent) Schott and Endlicher) and *Cola anomala* (Schott and Endlicher) germplasm in Cameroon. Pakistan *Journal of Biological Sciences*, 9(3), 391–397. https://scialert.net/abstract/?doi=pjbs.2006.391.397.

Opeke, L.K., 2005. Tropical Commodity Crops. Spectrum Books Limited, Ibadan, Nigeria.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Anthony, S. (2009). Agroforestree Database: a tree reference and selection guide. Version 4.0. World Agroforestry Centre. Available at: http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp

Otuonye, A. H., & Adedeji, A. R. (2006). Evaluation of selected plant extracts for the control of the storage rot diseases of kolanuts. *Annual report of the Cocoa Research Institute of Nigeria*, 29-30.

Ouattara, Y., Koffi, K. G., Séry, D. J. M., Saraka, D. M., Pokou, N. D., Gba, K. K. M., Bonsson, B., Akaffou, D. S., & Sié, R. S. (2022). Genetic diversity and structure of kola tree (Cola nitida) clones germplasm in Côte d'Ivoire using Single Nucleotide Polymorphism markers. Genetic Resources and Crop Evolution, 69, 2311–2325.

Ouattara, Y., Séry, D. J. M., Saraka, D. M. Y., Bouet, A., & Sié, R. S. (2025). Morphological variability of 23 kola genotypes [Cola nitida (Vent.) Schott & Endl.] from Côte d'Ivoire and Nigeria. Tropical Agriculture (Trinidad), 102(1), 1–16.

Sobowale, I. O., Adenuga, O. O., Adebiyi, S., Orisajo, S. B., & Areola, O. J. (2025). Characterization of juvenile kola (Cola spp.) in Nigeria using inter simple sequence repeat (ISSR) markers. *Journal of Plant Biota*.

Séry, D. J. M., Bonsson, B., Brou, Y. C., Gbédié, N., Ouattara, Y., Légnaté, H., & Keli, Z. J. (2020). Improvement of the kola tree cuttings root (Cola nitida) in nursery by removing the terminal bud of the semi-lignified plagiotropic cuttings. *Journal of Research in Forestry, Wildlife and Environment*, 12(2), 48-58.

Starin, D. (2013). Kola nut: So much more than just a nut. *Journal of Royal Society of Medicine*, 106(11), 433–435. https://doi.org/10.1177/0141076813507708

Tokannou, I. E. T., Sanogo, S., Houndonougbo, J. S. H., Salako, K. V., & Fandohan, A. B. (2024). Three decades of research efforts on the uses, conservation, and management of *Cola nitida* (Vent.): State of knowledge and prospects in Africa. Bois et Forêts des Tropiques, 355, 59-75.

Ugioro, O., Idrisu, M., Asowata, F. E., Adejobi, K. B., Agbebaku, E. E. O., Baba Nitsa, M., & Oyeledun, K. O. (2020). *Evaluation of phytochemical and enzyme activities of fresh kola (C. nitida Vent.) of varying weights (g) and colours*. *Global Scientific Journal, 8*(10).

Ugioro, O., Asowata, F. E., Baba Nitsa, M., Ayegboyin, K. O., & Oyeledu, K. O. (2021). Red *Cola nitida* seedlings as influenced by plant growth substances. In S. B. Orsajo, R. R. Ipinmoroti, & A. R. Adedeji (Eds.), *The role of horticulture in food security and sustainable health in era of climate change and COVID-19 pandemic: Book of proceedings of the 39th annual conference of the Horticultural Society of Nigeria* (pp. 782-790). Cocoa Research Institute of Nigeria.