Chapter

Cacao Genetic Resources Conservation and Utilization for Sustainable Production in Nigeria

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Abstract

Theobroma cacao, the source of chocolate, is one of the most important tree-crop that serves the purpose of sustaining the economy of millions of households and the largest non-oil foreign exchange earnings in Nigeria. The management of cacao genetic resources as it affects sustainable production of cocoa in Nigeria is reviewed. These include details of the diversity present in the germplasm collections, their utilization in varietal development and current status of the field genebanks as revealed by DNA fingerprinting using single nucleotide polymorphisms (SNPs) markers. Factors contributing to continuing backlash in the annual outputs of cocoa in Nigeria are also highlighted. The prospects of advances in the science of cacao genomics for up-scaling production and its impacts on the improvement of the industry in the country are discussed.

Keywords: germplasm introduction, genetic diversity, cacao breeding, cacao genomics, cacao science, sustainable production

1. Introduction

Theobroma cacao L., a member of Malvaceae family [1] is a small under-story tree that produces cocoa beans used in the manufacture of chocolate, cosmetics, confectioneries and other cocoa products. Recent evident from restricted fragment length polymorphisms (RFLP) and microsatellite analyses of ancient Criollo trees, consolidated proposition of the humid tropics South American Amazon regions as its center of origin [2]. Cacao is now grown as a tree crop in the tropical regions of the world between latitudes 20° north and 20° south of the equator [3]. Cocoa is one of the most economically important agricultural commodities in Africa and has been contributing to gross domestic product (GDP), national income (NI) and foreign exchange earnings of many African producing nations. It is marketed in The United States of America, Europe, United Kingdom and Asia where its butter and solids are used by processing industries. The global exports value of dried beans is between USD 8–10 billion per annum and there has been increasing demand for chocolate in the developing economies of Brazil, China, Eastern Europe and India [4]. In West and Central Africa, more than 96% of cocoa production is carried out by smallholder farmers who rely on proceeds from cocoa beans as a major source of family income [5, 6]. The world produced 4.744 million metric tons of dried beans in 2017 and 76% of the world production comes from Africa with about 7% of the continent exports from Nigeria, ranking the country 6th in the world [4]. In Nigeria,

cocoa provides means of livelihood to more than 5 million people and serves the purpose of sustaining the economy of millions of households to live above poverty and hunger. Although most of the country's budgetary revenue comes from sale of crude oil, agriculture contributes significantly to the economy with about 70% of the population engaged in agriculture. Income obtained from cocoa exports accounts for up to 27% of the 41.48% of Nigeria's GDP attributed to agriculture [7] and it is the largest non-oil foreign exchange earnings. However, cocoa production in Nigeria has not been sustainable as it reflected in the decline of the country's export data observed for almost two decades. Many factors are responsible for the low farm productivity which in turn is contributing to continuing instability and negative downturn in cocoa production in Nigeria [8]. These include but not limited to climate variability, diseases and pests infestations and poor access to improved planting materials. Development of improved hybrid varieties with good yield quality potentials is a necessity for a sustainable cocoa production system and this is subject to the amount of genetic variability available within germplasm collection. Thus, determined and consistent efforts are required in the acquisition of the needed genetic materials/resources for their conservation, evaluation and efficient use to develop well-adapted cultivars for combating the cocoa production challenges.

2. Germplasm introduction

Cacao was first introduced into Africa from Bahia, the Amazonian Region in Brazil by the Portuguese to Principe in 1822, with the establishment of 30 cacao plants of the Amelonado type (Lower Amazon Forastero) in Principe and later expanded to the neighboring island of Sao Tome [3]. Toxopeus [9] also reported that the two cacao trees of the Amelonado variety which were successfully established in Sao Tome from a batch of plants brought in from Bahia, Brazil in 1822, became the parents of the subsequent cacao trees of the island. Further movement of cacao from Sao Tome Principe islands to Fernando Po (the present-day Bioko in Equatorial Guinea) took place in 1855 by the Spanish seafarers [9, 10]. Other introductions were also made by Swiss missionaries from Suriname, and the first set of cocoa seeds were sown on Africa mainland in 1857 [11]. However, the variety which was originally brought into the island from Brazil was in its adopted home known as 'Sao Tome Creolou,' to distinguish it from other varieties that had been introduced subsequently. Following the introduction of the variety into West Africa and its wide cultivation in the region, it became popularly referred to as 'West African Amelonado.'

The history of cacao genetic materials introduction into Africa and subsequently into Nigeria is simply illustrated in (**Figure 1**). Cacao germplasm introduction to Nigeria can be presented as a sub-set of its introduction to Africa using the two phases partitioning ideology (Exploratory Colonial Period and Expansionary Experimental Pre- and Post-Independence Period) as reviewed by Aikpokpodion [7].

2.1 Exploratory colonial period (1874–1909)

The first era of cacao introduction into Nigeria started in 1874 by Chief Squiss Ibaningo, a trader who transported pods of Amelonado cocoa from Fernando Po into Bonny (now Rivers State of Nigeria) [1]. Many of the liberated slaves who were settled on the Fernando Po Island who had worked as contract labourers in the local cocoa plantations also contributed to cacao introduction into Nigeria. In 1880, there was an evidence of cacao plantation near Agege, owned by J.P.L Davies, most probably a

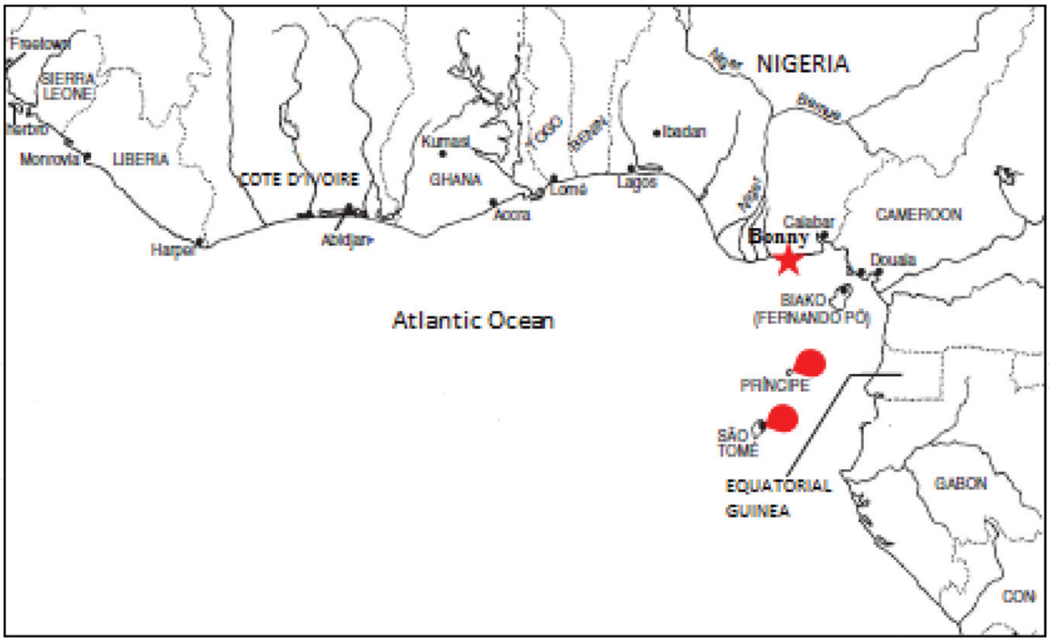

Figure 1.
Points of cacao introduction into Africa (Sao Tome and Principe) and Nigeria (Bonny Island). ● Place of first introduction to Africa in 1822. ★ Place of first introduction to Nigeria in 1857.

liberated slave [13], who had been the captain of a freighter plying the West African coast and could have obtained the seed from Fernando Po. The first cacao seedlings were planted somewhere near Ibadan prior to 1890 [14]. Berry [15] also reported that Ogunwale was the first to carry about 200 cacao pods to Ibadan for planting from Agege, which must have been from Davies' plantation. Furthermore, around 1900, the Colonial administration also introduced some red-podded cacao (Trinitario) materials to the botanical garden established in Agege Lagos in 1888 from British West Indies, presumably by the Jamaican curator of the garden. Several cacao germplasm materials were also introduced into Nigeria by the missionaries and slave traders. As a result of these various introduction efforts, a fair range of variability was presumably present on farmers' plantations with self-compatible 'West African Amelonado' types dominating the complex mixture of cacao of diverse origin. Towards the end of nineteenth century, cocoa cultivation and industry had started with 95% of national export of 21 tons in 1895 coming from the Western Region [12].

2.2 Expansionary experimental pre- and post-independence period (1910–2018)

At the beginning of twentieth century, cocoa was already a valuable commodity crop in Nigeria. Therefore, further introductions of cacao genetic materials during the second era were for economic reasons with the aims of obtaining better income and premium due to greater yields and higher bean and chocolate quality. However, during the last decade, the "People, Planet and Profit" concept of sustainability has become a significant factor in cacao germplasm introduction. This has bearing with the concept of "Preventive Breeding" where clones showing resistance to regionally important diseases of cocoa growing regions could be introduced through international intermediate quarantine centers [7]. This was to ensure that there is present in the germplasm collections, adequate sources of resistance to cope with, in case of new disease spread in order to prevent local cocoa economy crash that is associated with any epidemics.

Series of additional germplasm introductions following the initial successful introduction of the Brazilian Amelonado of the Lower Amazon Forastero type have

been reviewed by authors [3, 7, 16, 17]. The 'Trinitario' and 'Criollo' types were introduced to Nigeria in 1920 which formed hybrids with the original Amelonado type [18]. The former Nigeria Department of Agriculture was established in 1910 at Moor plantation, Ibadan. Nevertheless, the formal germplasm conservation and selection programs started around 1931 by O.J. Voelckler at the Nigerian Department of Agriculture in Moor Plantation, Ibadan under the Colonial Administration [17] with the sole aim of development and release of improved planting materials. In 1933, further germplasm introductions of some Trinitario and Criollo selections were made respectively, from Trinidad and Ceylon (the present day Sri Lanka) [19]. However, the outbreak of cocoa swollen shoot virus disease in the 1930s in Ghana, Togo and Nigeria almost destroyed the cocoa industry due to narrow genetic base in the population. This led to the establishment of West Africa Cocoa Research Institute (WACRI) in 1944 with the headquarters in Tafo, Ghana and a sub-station in Ibadan by an inter-territorial research thrust under the British West African Colonial Administration. Following the institute's establishment, several accessions from Upper Amazon Forastero and 'Trinitario' populations collected by Pound [20, 21] in Trinidad were introduced in 1944 into Tafo in Ghana by WACRI to widen the genetic base of the germplasm [22, 23] and subsequently into Nigeria from Ghana. Open pollinated pods from 11 selected accessions of the Upper Amazon Trinidad introduction that were established in Ghana were also introduced into Ibadan, Nigeria to form the F_2 Amazon population and these form the source of the open pollinated "F_3 Amazon" or "Mixed Amazon" materials in Nigeria up till present time.

The Nigeria sub-station of WACRI was upgraded to national research station, the Cocoa Research Institute of Nigeria (CRIN) in 1964 to focus on research that will facilitate improved production of cocoa. Then cacao seeds from 10 different crosses were introduced from Wageningen (The Netherlands) between 1964 and 1965 to raise 390 hybrid seedlings established in CRIN. Between 1965 and 1967, a large-scale introduction of Upper Amazon cacao materials was made from Trinidad as part of the Trinidad-Nigeria Cacao Introduction Scheme sponsored by the Cocoa Alliance [24]. This consisted of 313 clones and 701 seedling progenies of intra-Nanay, intra-Parinari, intra-Iquitos and inter-P (Pound's selections) crosses derived from a total of 350 crosses [25]. These clones and hybrids introduced from Trinidad constituted the "T clones" of CRIN germplasm collections. Materials were also acquired from Costa Rica, Indonesia, Fernando Po, Kew Gardens (United Kingdom) and Miami (USA) [19]. Between 1998 and 2004, 43 clones were introduced into Nigeria through an international initiative known as "Cocoa Germplasm Utilization and Utilization: A Global Approach," a project sponsored by the United Nations Common Fund for Commodity (CFC), through the supervision of the International Plant Genetic Resources Institute (IPGRI) as the executing agency [26]. Many other genetic materials introductions have not been reported adequately purposely because it is considered of hardly any use to publish introductions made if most of them did not survive due to the difficulties in their establishment. In the late 2017 and early 2018, some clones were introduced from International Cocoa Quarantine Center, University of Reading, of which 32 clones were established in a new germplasm plot at CRIN, Ibadan.

3. Status of Nigeria cacao field genebank

The genetic resources of cacao are composed of genetic variability that serve as the raw materials for the development of new varieties and cultivar improvement to enhance the production system for sustaining cocoa industry. These materials are conserved *ex situ* in field genebanks (germplasm plots of CRIN) and various

seed garden plots in major producing state of the country as well as *in situ*, that is in farmers' fields across the growing ecology. Appreciable diversity among these materials is of fundamental importance in the sustainability of cocoa production as it provides the necessary adaptation to the prevailing biotic and abiotic environmental challenges and enables changes in the genetic composition to cope with changes in the environment. The set of materials introduced during the Colonial era and the widely cultivated cacao in Nigeria in the early twentieth century (Amelonado and Trinitario varieties) were known to have narrow genetic base. However, the incidence of CSSV epidemics in the 1930s led to the introduction of Upper Amazon materials into the country's cacao genepool. Furthermore, several targeted germplasm collection efforts were made from mid-1960s up till recent times by CRIN breeding programme to broaden the diversity of Nigeria cacao genetic base. Research reports from the studies of genebanks collections and cacao accessions collected from farmers' fields in growing ecologies using 12 microsatellite markers showed that there is an appreciable improvement in Nigeria cacao genetic diversity [7, 16, 17, 27]. Of the 574 accessions studied, a total of 144 alleles were detected with a mean allelic richness of 4.39 alleles per locus. Upper Amazon parent population was observed to have largest genetic diversity (H_{nb} = 0.730), followed by the Posnette's Introduction (H_{nb} = 0.704) while the least (H_{nb} = 0.471) was recorded in the local parent population. Population structure analysis of cacao types grown in farmer's fields showed that the Upper Amazon Forastero, Amelonado, Trinitario and others constitute 66, 24, 6 and 4% of cacao grown, respectively (**Figure 2**).

More recent diversity studies using simple nucleotide polymorphism (SNP) markers [28], revealed the presence of cacao genetic groups that cut across the major primary populations in Nigeria germplasm collection (**Figure 3**) thus indicating appreciable improvement in the genetic base. This progress has been attributed to the international clones recently introduced into the country's cacao collection. However, there is paucity of report on the evaluation of recently introduce germplasm materials to enhance their utility in varietal development. This may have been responsible for authors' reports that a small proportion of the genetic diversity available in field genebanks at CRIN had been used to develop improved varieties supplied to farmers as planting materials [7, 17, 28]. In addition to this, the impact of mislabeling and off-type among the parental clones in the seed gardens and germplasm accessions of Nigerian field genebanks have been

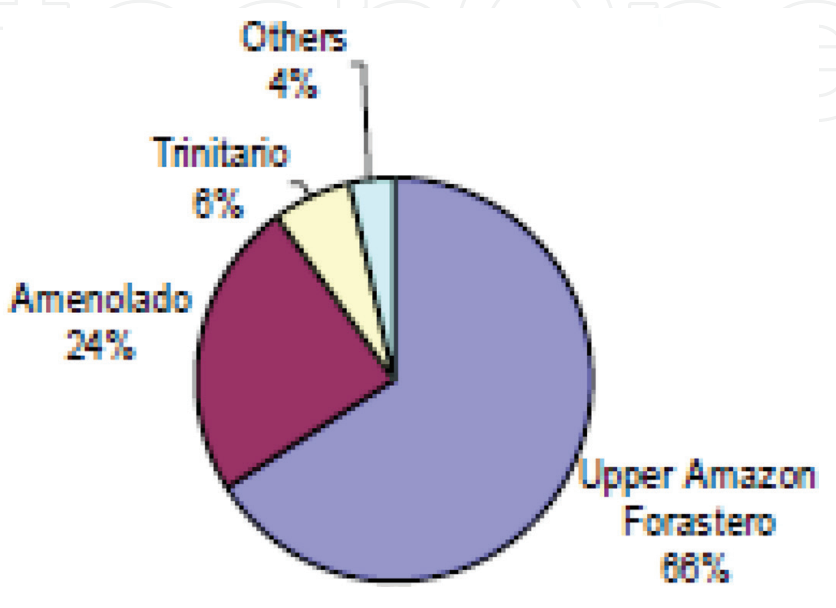

Figure 2.
Population structure indicating cacao types grown on farmers' fields in Nigeria.

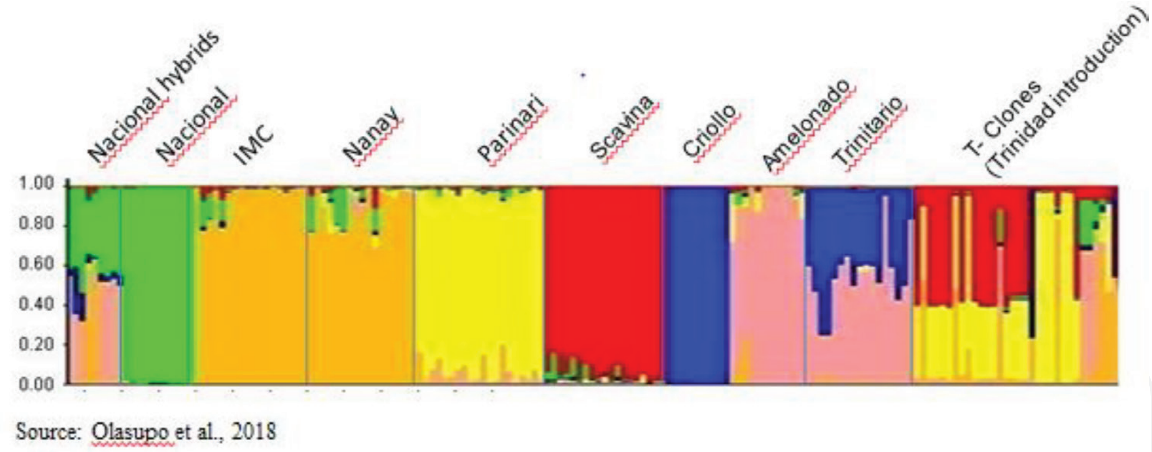

Figure 3.
Population structure of Nigeria cacao germplasm collections.

Genotype	Sample ID	Assessment	Tc32	Tc144	Tc193	Tc230	Tc242	Tc372	Tc529	Tc560	Tc591	Tc619	Tc645	Tc723	Tc872	Tc917	Tc929	Tc994	Tc998	Tc1060	Tc1442
AMAZ 15-15	ICGT, Trinidad	Reference	TT	AC	AC	AA	CT	AA	AC	GG	AA	CT	GG	TT	CG	CC	GG	CC	AA	CT	TT
AMAZ 15-15	IBAM1515-04_NIG132	True to type	TT	AC	AC	AA	CT	AA	AC	GG	AA	CT	AA	00	CG	CC	GG	CC	AA	CT	TT
AMAZ 15-15	IBAM1515-02_NIG1918	Offtype	TT	AC	AA	AA	CC	AA	AC	GG	AC	TT	AG	GG	CG	00	CG	CC	AG	CT	TT
AMAZ 15-15	IBAM1515-01_NIG1901	Offtype	TT	CC	AA	AG	CC	AA	CC	GT	AA	CC	AA	GT	CG	CT	GG	CC	AG	CC	CC
AMAZ 15-15	IBAM1515-03_NIG1876	Offtype	AT	CC	AA	AG	TT	AA	AC	GT	AA	CC	AA	GG	GG	CT	GG	CT	AA	CT	CC
PA 150	ICGT, Trinidad	Reference	AA	AC	AA	GG	CC	AA	AC	TT	AC	TT	AA	GG	GG	CT	CC	CC	AG	CC	CC
PA 150	IBPA15005B_NIG1947	True to type	AA	AC	AA	GG	CC	AA	AC	TT	AC	TT	AA	GG	GG	CT	CC	CC	AG	CC	CC
PA 150	IBPA15005_NIG387	True to type	AA	AC	AA	GG	CC	AA	AC	TT	AC	TT	AA	GG	GG	CT	CC	CC	AG	CC	CC
PA 150	IBPA15009_NIG391	True to type	AA	AC	AA	GG	CC	AA	AC	TT	AC	TT	AA	GG	GG	CT	CC	CC	AG	CC	CC
PA 150	IBPA150-12B_NIG208	Offtype	AA	AC	AA	GG	TT	AT	CC	GT	AC	CT	AA	GG	CC	CT	GG	TT	AG	CC	TT
PA 150	IBPA15022B_NIG1955	Offtype	TT	AC	AA	AG	CC	AA	CC	TT	CC	TT	AG	GG	CG	00	GG	CT	AG	CC	CT
PA 150	ADPA15013_NIG723	Offtype	AA	AC	00	AG	CT	AT	AC	GG	AA	TT	AG	GG	CG	CC	GG	CT	AG	CT	TT
Playa Alta	CATIE, Costa Rica	Reference	TT	CC	AA	AG	CC	AT	CC	TT	AC	TT	GG	GG	CG	TT	GG	CC	AA	CT	CC
Playa Alta	IBPLA04_NIG392	True to type	TT	CC	AA	AG	CC	AT	CC	TT	AC	TT	GG	GG	CG	TT	GG	CC	AA	CT	CC
Playa Alta	IBPLA03_NIG393	True to type	TT	CC	AA	AG	CC	AT	CC	TT	AC	TT	GG	GG	CG	TT	GG	CC	AA	CT	CC
Playa Alta	IBPLAY-12_NIG450	True to type	TT	CC	AA	AG	CC	AT	CC	TT	AC	TT	GG	GG	CG	TT	GG	CC	AA	CT	CC
Playa Alta	IBPLA11_NIG1873	Offtype	AT	AA	AA	AA	CC	AA	AA	TT	AC	TT	GG	GG	CG	CT	CG	CT	AA	CC	CT
Playa Alta	IBPLA010_NIG1897	Offtype	AT	CC	AA	AG	TT	AA	AC	GT	AC	CC	AA	GG	GG	CT	GG	CT	AA	CT	CC
Playa Alta	IBPLA09_NIG1898	Offtype	AT	AA	AC	AG	CT	AT	AC	GT	CC	TT	GG	GT	CG	CT	GG	00	AA	CC	TT
SCA 6	ICGT, Trinidad	Reference	AA	AC	CC	AA	CT	AA	AA	GG	CC	TT	AG	GG	CC	CC	CC	CC	AA	CT	CT
SCA 6	IBSCA605_NIG383	True to type	AA	AC	CC	AA	CT	AA	AA	GG	CC	TT	AA	GG	CC	CC	CC	CC	AA	CT	CT
SCA 6	IBSCA604_NIG388	True to type	AA	AC	CC	AA	CT	AA	AA	GG	CC	TT	AA	GG	CC	CC	CC	CC	AA	CT	CT
SCA 6	IBSCA602_NIG458	True to type	AA	AC	CC	AA	CT	AA	AA	GG	CC	TT	AA	GG	CC	CC	CC	CC	AA	CT	CT
SCA 6	IBSCA6-08_NIG196	Offtype	AA	AC	CC	AA	CT	TT	AC	TT	AC	TT	GG	GT	GG	TT	GG	TT	AA	CT	TT
SCA 6	IBSCA6-11_NIG1882	Offtype	TT	CC	AA	AG	CC	AA	CC	GT	AA	CC	AA	GT	CG	CT	GG	CC	AG	CC	CC
SCA 6	IBSCA607_NIG1891	Offtype	TT	CC	AA	AG	TT	AA	AA	GG	CC	TT	AA	GG	CC	CT	GG	CT	AA	CC	CT
SCA 6	IBSCA6-06_NIG1944	Offtype	TT	CC	AA	AG	CT	AA	AA	GT	AC	CT	AA	GG	CC	CC	GG	TT	AA	CC	TT

Table 1.
Examples of DNA fingerprints based on multi-locus matching of 28 SNPs between original references and Nigerian cacao collection (showing truncated profiles).

a significant problem hindering their efficient conservation and use for breeding programs. The occurrence of mislabeling and offtypes was first observed in the Nigerian cocoa germplasm collection by the application of SSR markers for genotyping [17]. This was recently consolidated by Olasupo et al. [28] through the application of SNPs for DNA fingerprinting of field genebank collections in which high level of mislabeling was detected in the recently introduced international germplasm materials (**Table 1**). Mislabeling has been identified as one of the key factors contributing to the high rate of unwanted/unproductive progenies produced in seed gardens because this can seriously compromise the quality of seedlings that would be distributed to farmers [17, 29]. Labeling errors in cacao field genebanks have been attributed to error from the source of germplasm introduction [30], human mislabeling errors in the nursery [31], sprouted rootstocks overtaken the scions due to poor germplasm management and multiplied error effect of using wrongly identified clones for new seed garden establishment [28].

In addition, the genetic diversity of cacao that constitute valuable resources in field genebanks useful to sustain cocoa production in Nigeria are further threatened with the following challenges:

1. Lack of funding for long-term management of collections, for research on diversity, evaluation and use in breeding

2. The field genebank collections are predisposed to the challenge of climate variability and its associated diseases and pests outbreak

3. Insufficient well trained personnel (expertise) for effective collection, conservation and management of germplasm materials

4. Urbanization and scarcity of land have led to the loss of many germplasm plots thereby resulting into extinction of some valuable genetic resources.

5. Problem of old age germplasm plots and the need to rejuvenate the old trees

6. Loss of germplasm to natural disaster (such as fire outbreak). There is the need for duplication of most of the field ***genebanks to serve as back-up (preferably *in vitro* or cryo-preservation)

7. Insufficient genetic variation in the collections to enhance effective selection of some specific traits.

Therefore, there is the need for all the stakeholders to protect the diversity of cacao germplasm collections with the aims of continuous supply of planting materials that have great potentials for high yield, disease and pest resistance, good architecture, drought tolerance and excellent flavor quality in the future.

4. Breeding efforts and impacts on national output

Cacao breeding research in Nigeria can be partitioned into four phase:

First Breeding Phase (1931–1956): The first phase of Nigeria cacao breeding started in 1931 [19]. Some of the trials conducted include the progeny trials of 1942 and 1945 by Voelcker which was the first of its kind in cacao research worldwide. Other trials conducted within this period include clonal trial in 1953 and the double cross hybrid vigour trial in 1954. The major breeding challenge during this period was low level of genetic variability among the parental accession. The main output of the programme was the identification of some materials with hybrid vigour and clonal propagation of the materials. These were N38 and other clonal selections—NT (Nigerian-Trinidad hybrid) 39, 114, 164, 215, 216, 284, 310, and 655. Others selections from the local clones and West African Amelonado population were HH268 and IS36.

In 1938, the West African Cocoa Research Institute (WACRI) started a *Cocoa Improvement and Varietal Development Programme* with the main objective of dealing with the threat posed by the cocoa swollen shoot virus (CSSV) disease in the West African sub region, particularly Ghana and Nigeria. The two main outputs were obtained from this programme.

i. First, introduction of the Upper Amazon genetic materials into Ghana and Nigeria cacao genepool which was very efficient in combatting the CSSV menace.

ii. Two general purpose varieties were also obtained from the programme. The F_3-Amazon—a third generation progenies resulting from open pollination

of the eleven approved Amazon T (Trinidad) types having broad parental background and have been shown to be superior to West African Amelonado in establishment ability, vegetative vigor, precocity (earliness in bearing) and yield. F_3-Amazon variety is also tolerant of CSSV and capsid attack [23, 32]. The Mixed Series II Hybrids (WACRI Series II) varieties were produced from crosses of Upper Amazon cacao with local selections. The hybrids showed better establishment ability (adaptability), precocity and higher yields than F_3-Amazon [33, 34]. In Nigeria, the yield of Series II Hybrids could be higher than F_3-Amazon yield by as much as 30% (165 kg/ha) [34].

Second Breeding Phase (1961–1970): The main focus during this period was on breeding of cocoa variety for specific ecological needs [35] with four primary objectives:

i. Select superior genotypes with high yield and desirable commercial qualities.

ii. Drought resistance or establishment ability

iii. *Phytophthora* pod rot resistance

iv. Cocoa swollen shoot virus (CSSV) resistance or tolerance

Two major outputs of this programme include selection of 12 "CRIN Establishment Ability" Elites which had a significant and prolonged experience in the south western part of Nigeria due to increased deforestation. A large number of germplasm was also introduced from Trinidad through a programme sponsored by the Cocoa Alliance, London [19].

Third Breeding Phase (1971–1980): The objective of this programme among others was to develop varieties that are resistant to or tolerant to pod rot disease caused by *Phytophthora megakarya* and *P. palmivora*. This programme was not fully implemented due to inadequate experts in the Breeding unit coupled with the challenge of self-incompatibility, a limitation to selfing of the Upper Amazon cacao trees [24]. Inadequate funding of breeding research was anther limiting factor.

Fourth Breeding Phase (1998–2008): This was a 10-year CFC/ICCO/IPGRI project with primary objective to develop new cacao varieties that will be high yielding, early bearing, resistant to Phytophthora pod rot, resistant to mirids and also have good and acceptable physical and chocolate flavor quality. The on-station and on-farm evaluations in this programme by CRIN resulted in the selection and consequent registration and release of eight new varieties (CRIN Tc-1, CRIN Tc-2, CRIN Tc-3, CRIN Tc-4, CRIN Tc-5, CRIN Tc-6, CRIN Tc-7 and CRIN Tc-8) in 2010. These hybrid varieties have diverse genetic base, they are early bearing, high yielding, with very low input, resistant to major pests and diseases of cacao, highly adaptable to cacao ecologies of Nigeria. The low input for high productivity attributes of these varieties is of great benefit for sustainable production of cocoa in Nigeria.

5. Current production challenges

Although remarkable breeding efforts have been invested through germplasm acquisition and development of improved varieties with high yielding potentials, cocoa yield at the farm level in Nigeria is still low when compare with the yield

potentials of improved varieties and there is continuous decline in the national output over the past three decades. Sustainable production of cocoa is achievable when prior attention is given to all factors involved in the production line. The following key constraints have been reported by [8] to be responsible for the low yield and production of cocoa in the country.

i. In adequate supply of improved planting material
ii. Poor access to improved planting materials
iii. Old age of trees
iv. Black pod disease
v. Poor price of cocoa beans
vi. Stem borer
vii. Mirid
viii. High cost of labour
ix. High price of chemicals and inputs
x. Loss of soil fertility/poor soil
xi. Adulterated chemicals
xii. Termites
xiii. Bryophyte

The solutions to most of these problems require intensive and focused breeding. Therefore funding cacao breeding research aimed at addressing these challenges should be given prompt attention. The role of the government in proffering solution to some of these problems cannot be over emphasized. Government would need to subsidize farm inputs needed for cocoa production. In addition to this there is the need for public private partnership efforts and intervention of stakeholders in cocoa industry to address these challenges.

6. Advances in science for cocoa production sustainability

Recent advancement in the fields of genetics, breeding and biotechnology has been used to the benefit of cacao improvement worldwide. The first molecular markers used for cacao genetic diversity study were isozymes [36], but these have limited numbers of loci and low polymorphisms. Significant progress has been made in the past two decades in cacao genomic mapping and germplasm characterization as reviewed by Guiltinan et al. [5]. More attention needs to be given to genomic sciences of cacao since these tools could be used in addressing many of the unanswered questions in the area of yield, pests and diseases, drought, architecture and flavor quality for sustainability of cocoa production. One of the major challenges of cacao

Figure 4.
Cacao establishment on well irrigated land without the use of plantain shade.

breeding is its long gestation period which takes a minimum of 2–3 years (from seed to seed). Cacao breeding is yet to tap from the advantage of marker assisted selection in reducing the breeding cycle as it is applicable in many other crops.

Tissue culture technique is useful not only for cryo preservation of germplasm materials. Application of somatic embryogenesis through temporary immersion technology will enhance mass clonal production of improved seedlings for large scale distribution to farmers to solve the problem of insufficient planting materials. Recent advancement in cacao science have been reported [37] that makes it possible for cacao planted on well irrigated land to survive without the conventional use of plantain as shade crop (**Figure 4**). This technology has the potential to solve the challenge of deforestation associated with new cacao establishment. This will also help to extend Nigeria cacao growing ecology to savannah region for increased productivity.

7. Conclusions

The sustainability and future of Nigeria cocoa production is hinged on the amount of diversity of genetic resources conserved and utilized in development of planting materials for farmer. Funding of cacao germplasm collections and research on its conservation, evaluation and use for breeding should be a top priority and collective efforts of public private partnership. There is the need for targeted exploitation of useful underutilized genetic resources available in the germplasm collections for varietal development in future breeding program. Conservation of cacao genetic materials in Nigeria needs re-organization and efficient re-hauling by establishment of correctly identified clones in new breeders' core collection germplasm plot using technologies of barcoding labeling and drip irrigation systems. Cocoa production in Nigeria will be revived to attain sustainability if the sector could tap from the great potentials of scientific innovations and technological advancement to the advantage of the industry.

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Conflict of interest

The authors declared that they have no conflict of interest.

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