agronomy

MDPI

Review

Bambara Groundnut (*Vigna subterranea* [L.] Verdc.) Production, Utilisation and Genetic Improvement in Sub-Saharan Africa

Nomathemba Gloria Majola [1,2], Abe Shegro Gerrano [2,*] and Hussein Shimelis [1]

[1] School of Agricultural, Earth and Environmental Sciences, College of Agriculture, Engineering and Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg 3209, South Africa; glorianomathemba@gmail.com (N.G.M.); Shimelish@ukzn.ac.za (H.S.)

[2] Agricultural Research Council—Vegetables, Industrial and Medicinal Plant Institute, Private Bag X293, Pretoria 0001, South Africa

* Correspondence: agerrano@arc.agric.za

Abstract: Bambara groundnut (*Vigna subterranea* [L.] Verdc.) is a nutritionally rich grain legume crop indigenous to Africa. It is tolerant to drought stress and has become adapted to grow under low input and marginal agricultural production systems in Africa and Asia. Bambara groundnut is an orphan crop, and represents a neglected and under researched plant genetic resource. Modern crop management, production technologies, and value chains are yet to be developed in Africa to achieve the potential economic gains from Bambara groundnut production and marketing. In sub-Saharan Africa (SSA) the production and productivity of Bambara groundnut is low and stagnant because of diverse abiotic and biotic stresses and socio-economic constraints. Improved crop management and post handling technologies, modern varieties with high yield and nutritional quality, value addition, and market access are among the key considerations in current and future Bambara groundnut research and development programs. This paper presents progress on Bambara groundnut production, utilization, and genetic improvement in SSA. It presents the key production constraints, genetic resources and analysis, breeding methods and genetic gains on yield, and nutritional quality and outlook. The information presented will guide the sustainable production and effective breeding of the crop in order to pursue food and nutrition security, and improve livelihoods through Bambara groundnut enterprises.

Keywords: Bambara groundnut; breeding methods; genetic resources; nutrition security; Southern Africa; orphan crops

Citation: Majola, N.G.; Gerrano, A.S.; Shimelis, H. Bambara Groundnut (*Vigna subterranea* [L.] Verdc.) Production, Utilisation and Genetic Improvement in Sub-Saharan Africa. *Agronomy* **2021**, *11*, 1345. https://doi.org/10.3390/agronomy11071345

Academic Editor: Salvatore Davino

Received: 8 May 2021
Accepted: 26 June 2021
Published: 30 June 2021

1. Introduction

The lack of modern agricultural production technologies and improved varieties are among the main factors affecting crop production and leading to food insecurity and impoverished livelihoods in sub-Saharan Africa (SSA). A larger proportion of essential human food is derived from only some ten crop plant species [1]. Most nutritionally rich and unique hidden crop genetic resources are yet to be used, explored, and promoted for human wellbeing and potential niche markets.

The current crop production systems in tropical and subtropical regions are dependent on the cultivation and use of a very limited number of commodity crop species. This means that most indigenous crop species remain neglected by researchers and lack modern scientific advancements in both pre-harvest and post-harvest methodologies and technologies. Most of the native or African "orphan" crop species such as Bambara groundnut (*Vigna subterranea* [L.] Verdc.), groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L.) have unique benefits in food, nutritional, and health security for humankind [2]. Furthermore, neglected crop plant species have a long agricultural history, are valuable components of the smallholder farming systems, and are considered as future food security crops. These species have intrinsic eating quality attributes and resilience to the biotic and abiotic stresses associated with climate change. They have adapted and co-evolved under the prevailing farming and environmental conditions, pest and disease pressure, and low input farming systems in Africa. However, orphan crop species have received limited research and development attention by researchers and policy makers and, hence, their economic value, production methods, product development, and commercialization have not yet been fully explored [1]. Due to a lack of systematic genetic improvement, the grain yield of most orphan legumes is low (<0.85 t ha^{-1}) and stagnant compared to the limited number of food security crop species such as rice, maize, wheat, barley, sorghum, etc.

Bambara groundnut (2n = 2x = 22) is one of the grain legume crops indigenous to Africa. Bambara groundnut is known by different names in sub-Saharan Africa (SSA). For instance, it is referred to as earth pea, jugo bean, nyimo beans, or ditloo in Southern Africa. Figure 1 presents Bambara groundnut's center of origin and diversity, major production countries, and suitable regions for production in Africa. It is believed to have originated from the Timbuktu areas in central Mali, West Africa [2]. However, the primary centre of genetic diversity of Bambara groundnut is the north-eastern region of Nigeria and northern Cameroon (Figure 1). Also, a secondary centre of diversity exists outside Africa and includes Sri-Lanka, Malaysia, the Philippines, and India [3]. It is predominantly self-fertilizing crop with cleistogamous flowers. It is cultivated extensively by small-scale farmers in the drier regions of SSA under the traditionally low-input and marginal agricultural production systems.

Figure 1. Bambara groundnut center of origin and diversity, major production countries, and suitable regions of production in Africa [Figure by N. Majola].

The annual production of Bambara groundnut is estimated to be 0.2 million tonnes from an area of 0.25 million hectares worldwide [4]. Sub-Saharan Africa is the largest producer of Bambara groundnut, while a small quantity is produced in Southeast Asia (e.g., Thailand and Indonesia), the United States of America (USA), and Australia. West Africa is the main Bambara groundnut production region in SSA, where Burkina Faso, Niger, and Cameroon are the leading producers, contributing to 74% of global production [4].

The grain of Bambara groundnut is regarded as a source of a complete and balanced diet. It contains carbohydrates (51–71%), crude protein (18–24%), oil (4–12%), fibre (3–12%), and ash (3–12%) [5]. Furthermore, it has essential and non-essential amino acids at 32.72% and 67.28%, respectively, per 100 g of grain [6]. Lysine is the major essential amino acid (10.3%) present in the grain. Due to higher protein and amino acid contents, Bambara groundnut is an ideal food to complement most cereal-based diets in SSA [7]. The total energy gains from Bambara groundnut grain consumption are the highest compared with other legumes such as cowpeas, pigeon peas (*Cajanus cajan* L.) and lentils (*Lens culinaris* L.) [8]. Bambara groundnut grain possesses some anti-nutritional factors (ANFs) that may limit bioavailability. Hence, a variety selection with low ANFs, grain soaking and cooking, and optimal consumption ensure nutritional benefits [9].

Bambara groundnut grain is consumed fresh or roasted and served as snack when young and immature. During maturity, the grain develops a hard seed coat, hence it has to be boiled prior to processing and consumption. In Benin, the grains are processed into flour to make bread, cakes and dumplings. In eastern African countries, the crushed grains are used to prepare soup. Moreover, Bambara groundnut flour is processed to make bread in Zambia [10]. In South Africa and Swaziland, the grains are utilized to add flavour in boiled cowpea grain [11]. It is also processed to produce milk similar to soybeans. The derived milk is used as a weaning food in several African countries. Bambara groundnut milk has a lighter colour compared with soybean milk [12]. The biomass (the stem, leaves, and haulm) has been extensively used for livestock feed. Additionally, the seed cake is used for livestock feed, while the grains are fed to pig and poultry. Young and succulent leaves contain essential mineral elements, including nitrogen and phosphorus, which are useful for animal health [13]. In Nigeria, tilapia fish are fed with Bambara groundnut leaf protein [14].

Bambara groundnut has been used to prepare traditional medicines. Reportedly, white grains are boiled with guinea fowl meat to treat diarrhea, while ground black grains are mixed with water to treat sick children. Also, Bambara groundnut flour is used to cure skin rashes, and grains are often chewed to relieve a swelling jaw [3].

Bambara groundnut is cultivated in altitudes ranging from 1100 m to 1600 m above sea level with mean temperatures between 20 and 28 °C [15]. The crop is relatively drought tolerant and requires limited agricultural inputs for production. It thrives with limited rainfall and under poor soil fertility conditions where many crop species would fail to be produced [16]. It requires from 110 to 150 days for growth and physiological maturity, depending on the genotype and environment. Bambara groundnut prefers well-drained soils. Sandy or loamy soils with a pH ranging from 5.0 to 6.5 are ideal for its establishment, for high pod yields, and for ease of harvest (Figure 2A). Unshelled yields of 500–800 kg ha^{-1} were reported under poor soil conditions with reduced nutrients and without the use of inorganic fertilizers. This is attributed to its ability to fix atmospheric nitrogen through a symbiotic association with Rhizobium bacteria [17]. Bambara groundnut is grown as a cover crop to protect the topsoil from erosion and to suppress weed infestations, making it significant for crop rotation with major cereal crops [15].

Bambara groundnut consists of a highly established tap root system and a highly branching stem bearing numerous horizontal branches where the leaves arise. The leaf consists of an extensive petiole with a green or purple base. It has irregularly developing flowers that arise from an elongated peduncle beneath the soil. The leaves with erect petioles are alternate and trifoliate. The peduncles are auxiliary, extending from the stem nodes and containing one to three flowers per peduncle (usually two). Pale yellow flowers appear on the freely branching stalks and, after fertilization, the stems extend towards the soil along with the growing seed with them. The harvestable yield of Bambara groundnut is a matured unshelled pod (Figure 2B) developed underground [17]. The pod is harvested after the plants are dug out of the soil. In plants with a bunched growth type, the pod remains attached to the root crown and is manually harvested. The growth cycle lasts between 90 and 170 days, while pod maturity takes about 120–150 days under ideal conditions. The flowers bloom 40–60 days after sowing and the pods matures 30 days after pollination. The seeds reach maturity after 55 days and continuous production of seeds occurs after every 30 days [18].

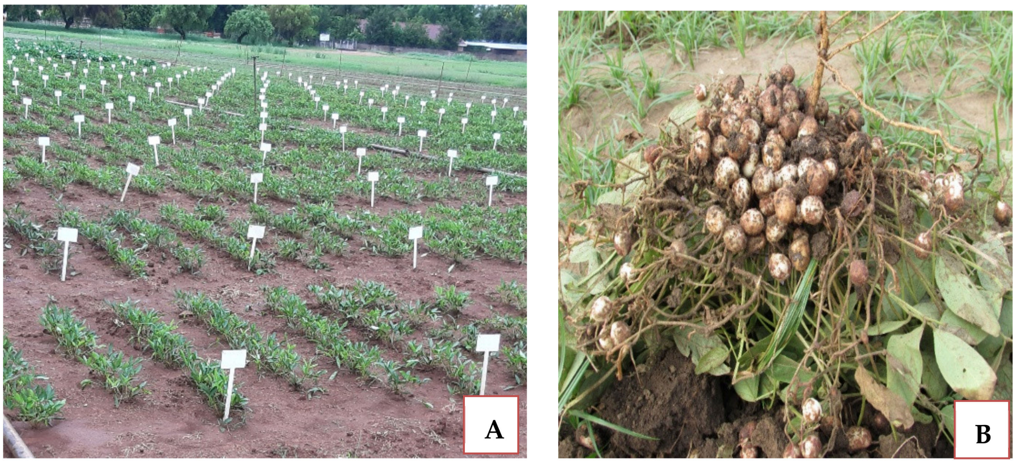

Figure 2. Bambara groundnut: (**A**) Field established crop stand at the Loskop site and (**B**) uprooted plant with matured pods at the Roodeplaat site in South Africa (Photo by AS Gerrano).

Bambara groundnut pods are formed underground spanning some 4 cm deep in the soil. Some Bambara groundnut genotypes bear a single seed per pod, while others can produce two to three seeds. The pods are formed in a clump (Figure 2B) and are yellow or dark red in colour. The grain colour is diverse and includes cream, yellow, brown, red, purple and black colours [18].

The International Institute of Tropical Agriculture (IITA) maintains the majority of Bambara groundnut germplasm accessions collected from various SSA countries [19]. In SSA, the crop is still cultivated using genetically unimproved landrace varieties. There is need for a concerted research effort on germplasm assembly, evaluation, product profiling, and variety design and development. The Bambara groundnut genome has not been fully explored, which is a key to utilizing the available genetic variation for breeding and cultivar development.

Despite the various nutritional and economic significances of the crop, Bambara groundnut is one of the most neglected and under researched plant genetic resources. Modern production technologies and value chains are yet to be developed in Africa to achieve economic gains from Bambara groundnut production, product development, and commercialization. There is limited research and development efforts globally on Bambara groundnut. The present grain yield of the crop is 0.85 t ha^{-1} despite a potential yield of over 3 t ha^{-1} [20]. The main yield limiting factors include a lack of improved cultivars with high yield and resistance to insect pests and diseases. In most SSA countries, the crop is cultivated using unimproved varieties or landraces that were developed through mass selection from wild relatives. There are no released cultivars emanated from modern breeding programs in SSA. Improving the production methods, yield levels, nutritional quality, processing and marketing of Bambara groundnut will enhance food and nutrition security, improve livelihoods, and contribute to economic development in SSA. In light of the above background, the aim of this paper was to document the progress made on Bambara groundnut production, utilization, and genetic improvement in SSA through highlighting the key production constraints, genetic resources and analysis, breeding methods, and gains on yield and nutrition. Information presented in this paper will guide production and genetic improvement of the crop to pursue food and nutrition security, and improved livelihoods from Bambara groundnut enterprises.

2. Production Status of Bambara Groundnut

Total global Bambara groundnut production was estimated at 0.2 million tonnes in the 2018 production year [4]. A larger quantity of Bambara groundnut is produced by West African countries, with a total production of 0.14 million tonnes in 2018 from an estimated area of 0.18 million hectares [4]. The top three global Bambara groundnut producing countries are Burkina Faso, Niger, and Cameroon. The top six Bambara groundnut producing countries in Africa include Burkina Faso, Niger, Cameroon, Mali, Togo and the Democratic Republic of the Congo with a total production of 0.06, 0.05, 0.04, 0.03, 0.02, and 0.01 million tonnes in 2018, respectively.

In SSA Bambara groundnut is mainly produced by small-scale farmers across fragmented and remote farm lands. Most production areas are inaccessible to collect production and productivity data. This makes it challenging to accurately assess the total production and size of production areas in SSA. The yield level of Bambara groundnut in Africa varies from 0.6^{-1} t ha^{-1}, depending on variety and production conditions. However, unshelled mean yields of up to 3 t ha^{-1} were reported when cultivating some landraces in the transition agro-ecological zone in Nigeria [21]. A low mean yield of 0.85 t ha^{-1} was reported in Ghana under good management practices close to yield levels of other legumes such as cowpeas (0.80 t ha^{-1}) and pigeon peas (0.78 t ha^{-1}) [22]. There is an emerging need for Bambara food due to population growth, urbanization, and life style changes in SSA. Presently, there is limited market supply of Bambara groundnut, unlike other legumes such as groundnut [23].

Figure 3 presents Bambara groundnut production status. The productivity of the crop in SSA has remained stagnant and low and ranged from 0.65 t ha^{-1} to 0.78 t ha^{-1} from 1999 to 2018. This was mainly due to low yield gains associated with the use of low-yielding varieties and the use of poor-quality seeds. Higher productivity (0.9 t ha$^{-1)}$ was achieved in 1999 (Figure 3), notably through use of better management practices [24]. The production trend exhibited a significant improvement with a 10% increase in the area harvested and 8% increase in yield from 2012 to 2018 (Figure 3). This was mostly attributed to an increased area of production. The area of production has increased owing to its wide acceptance by the farmers and the market place, signaling a higher scope for the expansion of Bambara groundnut production in SSA [4].

Bambara groundnut is popularly cultivated and marketed in southern Africa. The most suitable agro-ecologies for Bambara groundnut production in the region include Swaziland, Botswana, Zimbabwe, Uganda, Zambia, and South Africa (Figure 1) [25]. Hillock et al. [26] estimated a market supply of 1500–4000 tons in 2005 in South Africa, with a substantial amount imported from Zimbabwe. In southern Africa, Zimbabwe is the largest exporter of Bambara groundnut, contributing to about 2000–3000 tons per year to the southern African countries. Bambara groundnut is relatively the prominent legume crop in Botswana, cultivated over an estimated area of 1500 ha with a total grain production of about 400 tons since 2006 [26]. In South Africa, the main Bambara groundnut producing provinces include Limpopo, Mpumalanga, North West, Gauteng, and KwaZulu-Natal. Most production is undertaken by smallholder farmers for food and income generation [27].

2.1. Constraints to Bambara Groundnut Production

Productivity of Bambara groundnut is affected by a number of production challenges [7]. The leading production constraints include biotic stresses (e.g., diseases caused by fungi, bacteria, and viruses, insect pests, and nematodes), abiotic stress (e.g., drought, extreme temperatures, and poor soil fertility) and socio-economic factors [28]. The key production constraints of the crop are outlined below.

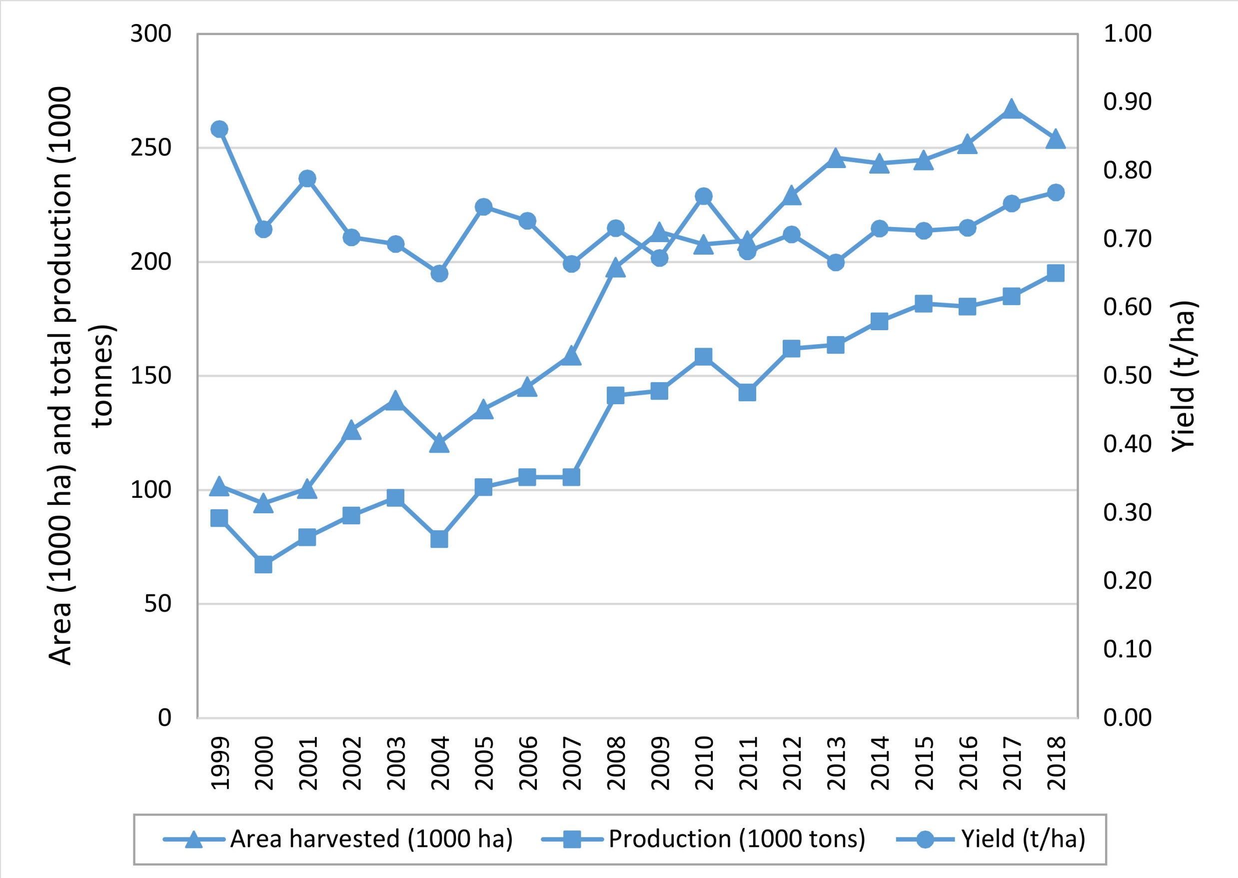

Figure 3. Total production (1000 tonnes), area of production (1000 ha), and yield (t/ha) of Bambara groundnut in sub-Saharan Africa from 1999 to 2018 (Adapted from [4]).

2.1.1. Biotic Stresses

Field insect pests and diseases affect Bambara groundnut production. Bambara groundnut pods are developed in the soil (Figure 2). Hence, it is self-protected from aerial insect pests and diseases when compared with other common legumes. Pathogenic fungi, viruses, insect pests, nematodes, and weeds inflict yield loss in Bambara groundnut [29].

Pathogenic Fungi

Several fungal pathogens attack Bambara groundnut crops under dry and humid conditions. Fungal diseases of the crop in SSA comprises of the leaf spot caused by *Cercospora canescens* (Ellis and Martin), Fusarium wilt (*Fusarium oxysporum* Schlechtend f.sp. *voandzeia*), rust (*Puccinia graminis* f.sp. Tritici) and leaf blight (*Colletotrichum graminicola* [Ces.] G.W. Wils) [18]. Leaf blotch caused by the *Phomopsis sp*. and powdery mildew (*Erysiphe sp*) are key diseases reported in Zimbabwe, attacking mainly immature leaves [30]. In Malaysia, Bambara groundnut is reportedly affected by the dieback disease (*Lasiodiplodia theobromae* [Pat.] Griff. & Maubl). Asiwe [31] reported Aspergillus genera as the main fungus causing seed borne diseases on both Bambara groundnut and cowpea. *Sclerotium rolfsii* (Sacc.) in South Africa [32] and powdery mildew (*Erysiphe polygony*) in Ghana are other key pathogens of the crop [33]. Fungal pathogens reduce seed germination, seed quality, and lead to mycotoxin production, which is harmful to both humans and livestock.

Viral Diseases

Bambara groundnut is affected by viral diseases, especially in regions where other grain legumes such as cowpeas are grown. Thottappilly and Rossel [34] reported some common viral diseases ravaging Bambara groundnut production in Nigeria including cowpea aphid-borne mosaic virus (CABMV), black-eye cowpea mosaic virus (BECMV), peanut mottle potyvirus (PMV), cowpea mottle comovirus (CMV), and cowpea yellow mosaic virus (CYMV). Rosette virus disease has also been reported in Tanzania, although no drastic yield damages have occurred [35]. There is no yield loss data recorded due to diseases on Bambara production [36]. However, disease severity is dependent on genotype, the environment, and genotype–environment interaction [36].

Insect Pests and Nematodes

Bambara groundnut is less affected by field insect pests compared with other legumes such as cowpeas. However, storage pests such as the cowpea weevil (*Callosobruchus maculatus* F.) can cause severe damage on stored grains [37]. The cowpea weevil is classified as the main postharvest insect pest affecting major legumes [38]. This pest reportedly caused 99% losses on pulse crops during storage. Bruchids (*Callosobruchus maculatus* Boh.) are the most devastating insect pests of Bambara groundnut stored grains [39]. Akpalu et al. [3] reported field crop losses due to leafhoppers [*Hilda patruelis* (Stal) and *Empoasca facialis* (Jacobi). Aphids led to a 65% yield damage under high rainfall conditions [40]. Other insect pests of the crop include groundnut jassid (*Empoasca kerri* Pruthi) and brown leaf beetles *(Ootheca mutabilis* Schönherr) [41].

The root-knot nematode [Meloidogynae javanica Treub] is among the main field pests leading to low yield gains on Bambara groundnut [42]. Severe damages by the root knot nematode leads to leave chlorosis, slow growth, restricted root systems, and reduced pod weight, thus inflicting yield loss. Nematode infestations have been reported in several African countries including Botswana, Zimbabwe, and South Africa [43].

Management of Disease and Insect Pests in Bambara Groundnut Production

Bambara groundnut producers in SSA do not use crop protection chemicals due to limited access and prohibitive costs. Instead, cultural practices such as crop rotation, burning of previous season debris, and the application of ash on storage seeds are practiced as preventative measures against several diseases and pests [13]. Earthing up after the development of flowers had a positive effect on yield and facilitated easy harvesting. The use and effectiveness of biological control agents has not been reported against Bambara groundnut pests and diseases. Resistance breeding is the most economic and sustainable approach to control common diseases and pests of legume crops including Bambara groundnut. There is need to exploit the existing genetic variation to develop disease and pest resistant cultivars [44].

2.1.2. Abiotic Stress

Bambara groundnut has become the favoured drought-tolerant crop. It has a unique ability to grow in a wide range of agro-ecological zones that differ in soil conditions. It has the ability to produce a significant amount of yield under moderate or extreme drought stress. However, research has shown that drought stress on the crop leads to reductions in pod dry matter and, ultimately, reduced grain yield especially if it occurs during the flowering stage [45]. Feldman et al. [36] reported that groundnut and other traditional legumes failed during dry spells, while Bambara groundnut produced relatively acceptable yields. Despite the lack of detailed comparisons between legume species under drought conditions, Bambara groundnut has unique drought adaptation, scoping the opportunity for improvement programs. Jørgensen et al. [21] reported that the stress tolerance index (STI) had a significant positive correlation with grain yield in both stressed and non-stressed conditions when evaluating 28 Bambara groundnut genotypes. Thus, STI can be used as a selection criterion for drought tolerance breeding in Bambara groundnut. There is limited research that has documented the degree of drought response on crop development, yield response, and adaptation in Bambara groundnut.

The total minimum rainfall requirement of the crop is estimated to be 300 mm [15]. However, excessive rainfall conditions, especially during harvest, results in drastic yield losses. Production is most suitable in regions with temperatures between 19 °C and 30 °C. Singh and Basu [17] reported the highest seedling emergence at 30 °C. Temperatures above 30 °C result in heat stress.

Bambara groundnut grows well on well-drained soils such as sandy and sandy loam soils. Some reports suggest that phosphorus mineral elements are crucial for the growth and yield performance of the crop [46]. The use of superphosphate fertilizer was reported to increase pod yields under poor soil conditions in Nigeria [47]. Bambara groundnut fixes 32 to 81 kg of nitrogen per ha−1, which is a sufficient amount for good pod set and grain production. Several studies have shown that temperature, humidity, and day length have variable effects on the vegetative, phenological, and reproductive developmental stages of Bambara groundnut [36].

2.1.3. Socio-Economic Constraints

Bambara groundnut is yet a minor crop widely grown by women smallholder farmers in SSA. The crop has not received research support on breeding, seed systems and agronomic management methods. Bambara groundnut breeding projects are required to develop farmer and market-preferred and superior cultivars for food security, enhanced livelihoods, and for good return on investment [48]. Furthermore, farmers have limited access to finances for expanding production through the use of new seed varieties, crop inputs such as irrigation systems, fertilizers and crop protection resources, effective harvesting systems, and postharvest storage facilities. Also, smallholder farmers should have the access to regional markets for economic gains from Bambara groundnut production [10,49].

2.1.4. Lack of Coordinated Seed System and Market

Bambara groundnut farmers use farm saved and poor-quality seeds of low yielding landraces [50] acquired from the informal sector via farmer-to-farmer seed exchange or from local markets. This demonstrates the intricacy of the Bambara groundnut supply chain, as well as the necessity to establish trading networks. Unlike the traditional legume crops, there is limited formal Bambara groundnut breeding and improved seed delivery systems in SSA hindering production and productivity of the crop [51,52]. Value-added products are yet to be developed from Bambara groundnut. This will enhance human nutritional benefits, and market and investment opportunities from Bambara groundnut enterprises.

2.1.5. Postharvest Constraints

Bambara groundnut has been overlooked by the research community both in Africa and globally. Hence, the crop has several postharvest constraints such as a lack of modern processing technology and storage and transportation problems. Due to the hard seed coat of Bambara groundnut, its cooking time is relatively longer. Also, there are no modern processing methods to separate the hard pod and grains. Mubaiwa et al. [11] reported that several processing technologies were recommended for other major crops that could be adapted to Bambara groundnut. However, most technologies were not adopted due to limited application to rural communities who have poor access to electricity, alternative power generators, and other resources. Hence, there is need to develop processing, storage and transport methods that are compatible with the social needs and preferences of local communities.

3. Genetic Resources and Genetic Analysis in Bambara Groundnut

Demand-driven variety development and product profiles are required for Bambara groundnut breeding and product development. Bambara groundnut is an important source of food products and cash income along the value chains. Genetic variation, germplasm acquisition and evaluation, new progeny development, and maintenance are critical components required to design and release farmer-preferred varieties. The effective selection of target traits and enhanced response to selection is dependent on genetic variation [53]. Also, adequate generation variation is required to select parental lines with complementary traits for breeding. The key traits required in Bambara groundnut breeding include grain yield and quality gains, disease resistance, heat and drought tolerance, early cooking time, and low levels of antinutritional components such as phenolics, tannins, and phytates to enhance digestion and bioavailability [54].

Genetically diverse Bambara groundnut collections are available in SSA for pre-breeding and breeding programs. For instance, wild relatives of the crop have been reported in north eastern Nigeria and northern Cameroon, which are regarded as the centers of diversity for the crop. The International Institute of Tropical Agriculture (IITA) has a large number of accessions collected from countries across sub-Saharan Africa. In Nigeria, IITA maintained about 1815 accessions of Bambara groundnut. These were largely sourced from farmers' fields across various SSA countries (Table 1). Furthermore, other accessions are maintained by various national gene banks of the Southern Africa Development Community (SADC) member countries [55].

Table 1. Number of Bambara groundnut accessions collected from various countries or institutions in Africa (Data from [27]).

Country/Institution	Number of Accessions
International Institute of Tropical Agriculture (IITA)/Nigeria	1815
National Plant Genetic Resource Centre (NPGRC)/Zambia	284
Genetic Resources and Biotechnology Institute (GRBI)/Zimbabwe	129
International Plant Genetic Resource Institute (IPGRI)/Cameroon	207
Information Centre for Genetic/Togo	139
Plant Genetic Resource Research Institute (PGRRI)/Ghana	120
National Plant Genetic Resources Centre (NPGRC)/Central African Republic	103
International Plant Genetic Resources Institute (IPGRI)/Burkina Faso	97
National Gene Bank of Agricultural Research Centre/Chad	70
Plant Genetic Resource Centre (PGRC)/Malawi	59
National Plant Genetic Resources Centers (NPGRC)/Congo	42
National Plant Genetic Resources Centers/Madagascar	49
National Research Laboratory on Plant Production/Senegal	36
National Centre for Genetic Resources and Biotechnology (NACGRAB)/Niger	33
National Plant Genetic Resource of Tanzania (NPGRT)	28
Bioversity International and International Center for Tropical Agriculture/Mali	28
National Agricultural Research Institute (INRAB)/Benin	27
National Plant Genetic Resources Centre (NPGRC)/Swaziland	11
Agricultural Plant Genetic Resources Conservation and Research Centre (APGRC)/Sudan	5
National Genetic Resource Centre (NGRC)/Botswana	5
National Centre for Agricultural Research (CNRA)/Côte d' Ivoire	4
National Genebank of Kenya/Kenya	2
Agricultural Research Council (ARC)/South Africa	1
Ethiopian Biodiversity Institute (EBI)/Ethiopia	1

Various national and international research programs in Africa and southeast Asia have been actively involved in the breeding, selection and, genetic advancements of novel Bambara groundnut lines. This has resulted in the release of few varieties such as 'Mana' and 'Kazuma' in Zimbabwe in 2004 [5]. Bambara groundnut populations derived from the Kazuma variety as a founder parent enabled the development of a draft Bambara groundnut genomic sequence [20]. Several Kazuma derived varieties were under evaluation for future variety release and commercialization [56].

Well-characterized germplasm collection is a pre-requisite for plant-breeding programmes. Bonny et al. [57] reported two genetic clusters when investigating the genetic diversity among 101 Bambara groundnut accessions in Côte d'Ivoire using 13 morphological traits. The authors reported significant differences for days to 50% flowering, days to 50% maturity, 100-seed weight, and seed yield. Phenotypic traits and molecular markers have become complementary tools in genotype selection programs [58]. Several molecular markers have been used to examine the genetic diversity in Bambara groundnut [59–62]. The key markers system reported were Random Amplified Polymorphic DNA (RAPD) [63–65], Restriction Fragment Length Polymorphism (RFLP) [63,66–68], Simple Sequence Repeats (SSR) [60,69,70], Single Nucleotide Polymorphism (SNP) [60,71,72] and diversity array technology (DArT) [8]. These studies reported the presence of high genetic variability and distinct genetic groups for marker-assisted selection. There are limited reports on genetic analysis using SNP markers for Genome Wide Associations (GWAS) studies on Bambara groundnut in Africa. Genetic linkage maps have been constructed for Bambara groundnut based on wild and domesticated accessions [73]. The genomic sequence of the crop has been recently published [74].

Bambara groundnut is one of the preferred research crops in the African Orphan Crop Consortium (AOCC) which ensures effective research and development of the crop. The AOCC comprises 101 traditional food crops with multiple economic traits and enhanced nutrition [15]. Various studies reported nutrient compositions of Bambara groundnut [75–79]. Figure 4 summarizes key macronutrients present in the root, leaf, and seed of Bambara groundnut. These included nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca). The seed is a rich source of N, K, and P compared with leaf and root. Bambara groundnut also contains micronutrients such as zinc, iron, calcium, and potassium. These are vital for a balanced diet and to combat malnutrition prevalent in SSA.

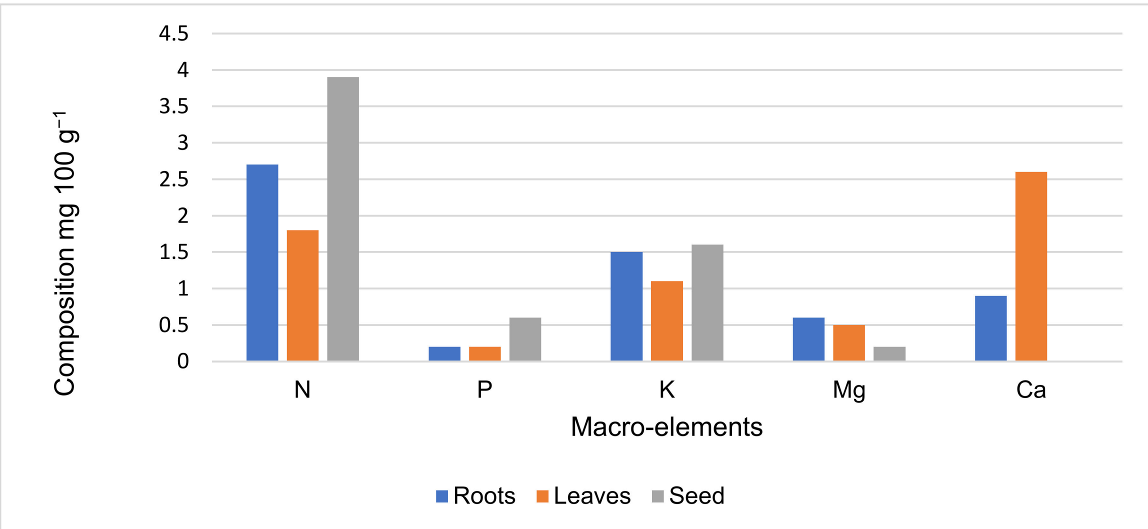

Figure 4. Macro-nutrient composition of Bambara groundnut (Adapted from [79]).

4. Importance of Landraces and Traditional Varieties

Landraces are the majority of Bambara groundnut germplasm used by farmers in SSA. Farmers benefit from the genetic variation present among landraces such as for food quality, stable and reasonable yields, tolerance to biotic and abiotic stresses, and local adaptation. The genetic diversity present among Bambara groundnut landraces signifies its potential for effective breeding [78]. Farmers harvest acceptable yields during drought stress when other major crops would fail. The majority of the presently grown traditional varieties are landraces which were developed through mass selection. Small-holder farmers cultivate landrace varieties of Bambara groundnut as a monoculture, intercropped with other staple crops such as maize for effective resource use and continuous household food supply. Yield stability exhibited by landraces is viewed as a key farmer-preferred trait for grain production and food supply. Furthermore, landraces are an ideal source of genetic variation for high protein quality and quantity. There is high genetic variation amongst landrace varieties in SSA useful for genetic improvement and analyses for diverse economic traits [69].

5. Opportunity for Bambara Groundnut Breeding

Limited achievements are made on genetic advancement and gains on yield and nutritional traits in Bambara groundnut [80]. The hitherto limited progress includes breeding for yield potential [81], nutritional composition [82], drought tolerance [83], adaptations to marginal soils [84], and N-fixation ability [85]. Breeding progress and genetic gain on the crop is relatively slow when compared to other traditional legumes. This is attributable to various challenges such as a lack of adequate genetic variation, poorly coordinated or non-existent seed systems, complex flowering biology and pod formation, a lack of value additions, and poor market systems of the crop.

The primary goal of Bambara improvement programs is to focus on seed yield and nutritional quality traits. Oyeyinka et al. [86] compared nutrition and the functional and phytochemical properties of different selections. The results exhibited high protein content among the test genotypes. Similarly, high levels of essential fatty acids, thiamine, ribovin, and vitamin K were recorded [87]. Moreover, Halimi et al. [88] examined the chemical properties of starches in Bambara groundnut. The results revealed that seed source/origin and crop management practices affected chemical composition [89]. Food fortification, the use of artificial supplements, and food imports are among the strategies used to overcome the problem of malnutrition in Africa. The adoption of traditional plant breeding methods to enhance nutritional benefits of orphan food crops such as Bambara groundnut is an economic and affordable strategy to decrease malnutrition in Africa [90].

Integrating conventional breeding with molecular breeding techniques can fast track cultivar development and deployment, including for orphan crops. This could significantly reduce the breeding cycles and enable varieties to be released rapidly. Rajendrakumar [91] reported that morphological markers have been successfully used to select the best parents in Bambara for the development of early maturing varieties. Morphological markers are not expensive, less technologically demanding, and easy to analyse. Therefore, they can be successfully used in Bambara groundnut breeding. However, phenotypic traits are subject to genotype–environment interaction, limiting the reproducibility of selection gains [92].

The use of molecular markers and the development of genetic resources has improved the understanding of genetic control of agricultural traits, leading to quality control, marker-assisted selection, and genomics-enabled breeding [5]. Genetic linkage maps based on the diversity arrays technology (DArT), simple sequence repeats (SSR), and single nucleotide polymorphisms (SNP) markers have been designed for Bambara groundnut. Four founder populations, including wild type and domesticated Bambara groundnut genotypes, were used to develop progenies segregating for growth habit, drought resistance, and genomic analysis [20,56,60,93].

Molecular markers overcome the majority of the limitations of biochemical and morphological markers [94]. Some microsatellites markers were used to evaluate a population of 80 Bambara groundnut landraces from Ghana [95]. Moreover, 32 Bambara genotypes were genotyped using SNP markers in Burkina Faso. From this study, a total of 186 alleles were detected with a mean of two alleles per locus and an average genetic similarity of 75.8% [96].

Diverse Bambara groundnut genotypes were finger printed to establish their genetic purity and for estimation of residual heterozygosity using 20 selected SSR markers [60]. Ho et al. [56] reported quantitative trait loci (QTL) analysis and construction of linkage map of Bambara groundnut using DArT and SSR markers. This has been regarded as a significant milestone for integrated breeding of the crop [5]. Molecular markers complement phenotypic selection and reduce selection generation cycles. Marker-assisted breeding is well recognized on traditional legume crops such as soybean, groundnut, and common beans. Recent research interest has shifted to deal orphan crops such as Bambara groundnut due to its potential to cope with climate change and provide nutritional security [18]. Adaptation to local growing conditions, crop phenology, and market preferences are the drivers of Bambara groundnut breeding and adoption in SSA [97,98]. The growing demand for new cultivars of Bambara groundnut can be met using the conventional breeding and genomic selection methods [99].

6. Conclusions

There is extensive genetic variation of Bambara groundnut in Africa for several agronomic attributes including breeding, value adding product development, and marketing. However, the crop is under-researched and under-utilized in SSA. The present review has summarised progress on Bambara groundnut production and uses, breeding methods, genetic resources to guide cultivar development, and germplasm conservation. There is need for a concerted research on Bambara groundnut involving plant breeders, agronomists, and food scientists in both African regions and globally. This will enable knowledge and germplasm sharing and innovative research and product development. New generations of Bambara groundnut cultivars should comprise of market preferred product profiles including desirable agronomic, nutritional, and processing qualities that benefit the food and feed industry.

7. Outlook and Recommendation

- There is a limited research progress on Bambara groundnut improvement and product development in Africa. Furthermore, modern crop management, production technologies, and value chains are yet to be developed in SSA to achieve significant economic gains from Bambara groundnut production and marketing.
- A lack of improved and commercial seeds represents a major set-back in Bambara groundnut production, product development, and commercialization. Therefore, establishing pre-breeding programs using the available genetic and genomic resources is an initial step towards the genetic improvement of the crop. Information on the genetic diversity, drought tolerance, and nutrient contents of diverse collections of Bambara groundnut is crucial for strategic production and recommendation to growers, the food and feed industry, and to government or non-government scientists.
- Research into processing techniques should be established to optimize the cooking time, to prepare various food products, and for effective and durable postharvest handling.
- The unique nutritional and health benefits and resilience of the crop in performing under unfavorable environmental and growing conditions in Africa provides an opportunity for policy and investment support and for large scale production of the crop compared with other major traditional legumes.
- Improved crop management and post handling technologies, modern varieties with high yield and nutritional quality, and value addition and market access are among the key research and development drivers of Bambara groundnut for improving food security and to support the food systems in Africa or internationally.

Author Contributions: Conceptualization, N.G.M.; A.S.G. and H.S. investigation, resources, N.G.M.; writing—original draft preparation, A.S.G. and H.S.; writing—review and editing, A.S.G. and H.S.; supervision, A.S.G. and H.S.; funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Research Foundation, grant number UID: 118509 and the APC was funded by University of KwaZulu-Natal African Center for Crop Improvement and Agricultural Research Council—Vegetables Industrial and Medicinal Plant Institute.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data and information associated with the current review are presented in the manuscript.

Acknowledgments: Agricultural Research Council, National Research Foundation and University of Kwa-Zulu Natal, South Africa are sincerely thanked for the overall research support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Oerke, E.-C.; Dehne, H.-W.; Schönbeck, F.; Weber, A. *Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops*; Elsevier: Amsterdam, The Netherlands, 2012.
2. Alhassan, G.A.; Egbe, M.O. Participatory rural appraisal of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) production in Southern Guinea Savanna of Nigeria. *Agric. Sci.* **2013**, *1*, 18–31. [CrossRef]
3. Akpalu, M.; Atubilla, I.; Oppong-Sekyere, D. Assessing the level of cultivation and utilization of bambara groundnut (*Vigna subterranea* (L.) Verdc.) in the Sumbrungu community of Bolgatanga, Upper East Region, Ghana. *Int. J. Plant Anim. Environ. Sci.* **2015**, *3*, 68–75.
4. FAOSTAT—Food and Agriculture Organization of the United Nations. *Statistical Databases*; FAOSTAT: Rome, Italy, 2020.
5. Mayes, S.; Ho, W.K.; Chai, H.H.; Song, B.; Chang, Y.; Massawe, F. *Bambara Groundnut (Vigna subterranea (L) Verdc.)—A Climate Smart Crop for Food and Nutrition Security. Genomic Designing of Climate-Smart Pulse Crops*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 397–424.
6. Gonné, S.; Félix-Alain, W.; Benoît, K.B. Assessment of twenty Bambara groundnut (*Vigna subterranea* (L.) Verd court) landraces using quantitative morphological traits. *Int. J. Plant Res.* **2013**, *3*, 39–45.
7. Alake, O.C.; Ayo-Vaughan, M.A. Genotypic variation and correlations between yield system traits and yield components in African landraces of Bambara groundnut. *S. Afr. J. Plant Soil.* **2017**, *34*, 125–137. [CrossRef]
8. Haleegoah, J.; Asafu-Agyei, J.; Addo, J. Practices and constraints in Bambara groundnuts production, marketing and consumption in the brong ahafo and upper-East Regions of Ghana. *J. Agron.* **2015**, *9*, 111–118.
9. Unigwe, A.E.; Doria, E.; Adebola, P.; Gerrano, A.S.; Pillay, M. Anti-nutrient analysis of 30 Bambara groundnut (*Vigna subterranea*) accessions in South Africa. *J. Crop Improv.* **2018**, *32*, 208–224. [CrossRef]
10. Cook, D. *Small Scale Farmers Utilization and Perceptions of Bambara Groundnut Production in South Africa: A Case Study in a Semi-Arid Region of Limpopo*; University of Cape Town: Cape Town, South Africa, 2017.
11. Mubaiwa, J.; Fogliano, V.; Chidewe, C.; Linnemann, A.R. Hard-to-cook phenomenon in bambara groundnut (*Vigna subterranea* (L.) Verdc.) processing: Options to improve its role in providing food security. *Food Rev. Int.* **2017**, *33*, 167–194. [CrossRef]
12. Yao, D.N.; Kouassi, K.N.; Erba, D.; Scazzina, F.; Pellegrini, N.; Casiraghi, M.C. Nutritive Evaluation of the Bambara Groundnut Ci12 Landrace [*Vigna subterranea* (L.) Verdc. (Fabaceae)] Produced in Côte d'Ivoire. *Int. J. Mol. Sci.* **2015**, *16*, 21428–21441. [CrossRef]
13. Keller, G. African nightshade, eggplant, spider flower et al.—Production and consumption of traditional vegetables in Tanzania from the farmers point of view. *J. Crop Sci.* **2014**, *6*, 368–390.
14. Mazahib, A.; Nuha, M.; Salawa, I.; Babiker, E. Some nutritional attributes of Bambara groundnut as influenced by domestic processing. *Int. Food Res. J.* **2013**, *20*, 1165.
15. Azam-Ali, S.; Sesay, A.; Karikari, S.; Massawe, F.; Aguilar-Manjarrez, J.; Bannayan, M. Assessing the potential of an underutilized crop–a case study using Bambara groundnut. *Exp. Agric.* **2014**, *37*, 433–472. [CrossRef]
16. Dansi, A.; Vodouhè, R.; Azokpota, P.; Yedomonhan, H.; Assogba, P.; Adjati, A. Diversity of the neglected and underutilized crop species of importance in Benin. *Sci. World J.* **2012**, *1*, 32–63. [CrossRef]
17. Singh, A.; Basu, M. Bambara Groundnut: Its Physiology and Introduction in India. In *Advances in Plant Physiology*; I.K. International Publishing House: New Delhi, India, 2006; pp. 235–249.
18. Shrestha, J.; Kunwar, C.B.; Bhandari, B. Response of mass selection in maize (*Zea mays* L.). *Our Nat.* **2018**, *16*, 35–42. [CrossRef]
19. Mkandawire, C.H. Review of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) production in Sub-Sahara Africa. *Agric. J.* **2017**, *2*, 464–470.
20. Smýkal, P.; Coyne, C.; Redden, R.; Maxted, N. *Genetic and Genomic Resources of Grain Legume Improvement*; Elsevier: Amsterdam, The Netherlands, 2013; pp. 41–80.
21. Smýkal, P.; Coyne, C.J.; Ambrose, M.J.; Maxted, N.; Schaefer, H.; Blair, M.W. Legume crops phylogeny and genetic diversity for science and breeding. *Crit. Rev. Plant Sci.* **2015**, *34*, 43–104. [CrossRef]
22. Mayes, S.; Ho, W.K.; Chai, H.H.; Gao, X.; Kundy, A.C.; Mateva, K.I.; Zahrulakmal, M.; Hahiree, M.K.; Kendabie, P.; Licea, L.C.; et al. Bambara groundnut: An exemplar underutilised legume for resilience under climate change. *Planta.* **2019**, *250*, 803–820. [CrossRef]
23. Jørgensen, S.T.; Liu, F.; Ouédraogo, M.; Ntundu, W.; Sarrazin, J.; Christiansen, J.L. Drought responses of two bambara groundnut (*Vigna subterranea* L. Verdc.) landraces collected from a dry and a humid area of Africa. *J. Agron. Crop Sci.* **2010**, *196*, 412–422. [CrossRef]

24. Ayamdoo, A.; Demuyakor, B.; Badii, K.B.; Sowley, E. Storage systems for Bambara groundnut (*Vigna subterranean*) and their implications for bruchid pest management in Talensi-Nabdam District, Upper East Region, Ghana. *Agric. Sci.* **2013**, *9*, 32.
25. Keller, G.; Mndiga, H.; Maass, B.L. Diversity and genetic erosion of traditional vegetables in Tanzania from the farmer's point of view. *Plant Genet. Res.* **2005**, *3*, 400–413. [CrossRef]
26. Karunaratne, A.S.; Walker, S.; Ruane, A.C. Modelling Bambara groundnut yield in Southern Africa: Towards a climate-resilient future. *Clim. Res.* **2015**, *65*, 193–203. [CrossRef]
27. Hillocks, R.J.; Bennett, C.; Mponda, O.M. Bambara nut: A review of utilization, market potential and crop improvement. *Afr. Crop Sci. J.* **2012**, *20*, 1–16.
28. Khan, M.M.H.; Rafii, M.Y.; Ramlee, S.I.; Jusoh, M.; Al-Mamun, M. Genetic Inconsistency Assessment and Selection Criteria of Bambara groundnut (*Vigna subterranea* L. Verdc.) Landraces for High Yield Revealed by Qualitative and Quantitative traits. *Bangladesh Agric. Res. Inst.* **2020**, *3*, 45–50.
29. Gbaguidi, A.; Dansi, A.; Dossou-Aminon, I.; Gbemavo, D.; Orobiyi, A.; Sanoussi, F. Agromorphological diversity of local Bambara groundnut (*Vigna subterranea* (L.) Verdc.) collected in Benin. *Genet. Resour. Crop Evol.* **2018**, *65*, 1159–1171. [CrossRef]
30. Sesay, A.; Magagula, C.; Mansuetus, A. Influence of sowing date and environmental factors on the development and yield of Bambara groundnut (*Vigna subterranea*) landraces in a sub-tropical region. *Exp. Agric.* **2018**, *44*, 167–183. [CrossRef]
31. Zongo, E.; Néya, B.J.; Traoré, V.S.E.; Palanga, E.; Zabré, J.; Barro, N. Impact of Cowpea mottle virus on the Growth and Yield of Bambara Groundnut (*Vigna subterranean* (L.) Verdc.). *Am. J. Plant Sci.* **2018**, *9*, 2053. [CrossRef]
32. Obagwu, J. Control of brown blotch of Bambara groundnut with garlic extract and benomyl. *Phytoparasitica* **2013**, *31*, 207. [CrossRef]
33. Asiwe, J. Needs assessment of cowpea production practices, constraints and utilization in South Africa. *Afr. J. Biotechnol.* **2019**, *8*, 20.
34. Cilliers, A.J.; Pretorius, Z.A.; Van Wyk, P.S. Integrated Control of Sclerotium rolfsii on Groundnut in South Africa. *J. Phytopathol.* **2003**, *151*, 249–258. [CrossRef]
35. Mkandawire, F.L.; Sibuga, K.P.; Mkandawire, F.L.; Sibuga, K.P. Yield response of Bambara groundnut to plant population and seedbed type. *Afr. Crop. Sci. J.* **2002**, *10*, 39–49. [CrossRef]
36. Thottappilly, G.; Rossel, H.W. Identification and characterization of viruses infecting bambara groundnut (*Vigna subter-ranea*) in Nigeria. *Int. J. Pest Manag.* **1997**, *43*, 177–185. [CrossRef]
37. Jonah, P.M.; Aliyu, B.; Jibung, G.G. and Abimiku, O.E. Phenotypic and genotypic variance and heritability estimates in Bam-bara groundnut (*Vigna subterranea* [L.] Verdc) in Mubi, Adamawa State, Nigeria. *Int. J. IT Eng. Appl. Sci. Res.* **2013**, *2*, 66–71.
38. Feldman, A.; Ho, W.K.; Massawe, F.; Mayes, S. Bambara Groundnut Is a Climate-Resilient Crop: How Could a Drought-Tolerant and Nutritious Legume Improve Community Resilience in the Face of Climate Change? In *Sustainable Solutions for Food Security*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 151–167.
39. Hasan, M.; Uddin, K.; Mohamed, M.T.M.; Zuan, A.T.K. Nitrogen and phosphorus management for Bambara groundnut (*Vigna subterranea)* production-A review. *Legum. Res. Int. J.* **2018**, *41*, 483–489. [CrossRef]
40. Tlankka, N.S.; Mbega, E.R.; Ndakidemi, P.A. Potential of Indigenous Pesticidal Plants in the Control of Field and Post-Harvest Arthropod Pests in Bambara Groundnuts (*Vigna subterranea* (L.) Verdc.) in Africa: A Review. *Am. J. Plant Sci.* **2020**, *11*, 745–772. [CrossRef]
41. Duodu, K.G.; Apea-Bah, F.B. African Legumes: Nutritional and Health-Promoting Attributes. In *Gluten Free Ancient Grains*; Woodhead Publishing: Sawston, UK, 2017; pp. 223–269. [CrossRef]
42. Alozie:, Y.E.; Iyam, M.A.; Lawal, O.; Udofia, U.; Ani, I.F. Utilization of Bambara Groundnut Flour blends in bread production. *J. Food Technol.* **2009**, *7*, 111–114.
43. Adu-Dapaah, H.; Asibuo, J.; Danquah, O.; Akyaw, M.O.; Haleegoah, J.; Amoatey, H. Genetic improvement of under-utilized and neglected crops in low income food deficit countries through irradiation and related techniques. *Agric. Sci.* **2014**, *37*, 143–154.
44. Lusser, M.; Parisi, C.; Plan, D.; Rodríguez-Cerezo, E. Deployment of new biotechnologies in plant breeding. *Nat. Biotechnol.* **2012**, *30*, 231–239. [CrossRef] [PubMed]
45. Olayide, O.E.; Donkoh, S.A.; Ansah, I.G.K.; Adzawla, W.; O'Reilly, P.J.; Mayes, S.; Feldman, A.; Halimi, R.A.; Nyarko, G.; Ilori, C.O.; et al. Assessing socioeconomic factors influencing production and commercialization of Bambara groundnut as an indigenous climate resilient crop in Nigeria. *Sci. Rev. Nat.* **2018**, *9*, 2–10.
46. Nyau, V.; Prakash, S.; Rodrigues, J.; Farrant, J. Antioxidant activities of Bambara groundnuts as assessed by FRAP and DPPH assays. *J. Food Nutr. Disord.* **2015**, *3*, 7–11.
47. Abu-Muriefah, S.S. Effect of chitosan on common bean (*Phaseolus vulgaris* L.) plants grown under water stress conditions. *Int. Res. J. Agric. Sci. Soil Sci.* **2013**, *3*, 192–199.
48. Mitran, T.; Meena, R.S.; Lal, R.; Layek, J.; Kumar, S.; Datta, R. Role of Soil Phosphorus on Legume Production. In *Legumes for Soil Health and Sustainable Management*; Springer: Singapore, 2018; pp. 487–510. [CrossRef]
49. Toungos, M.; Babayola, M.; Shehu, H.; Kwaga, Y.; Bamai, N. Effects of Nitrogen Fertilizer on the Growth of Vegetable Amaranths (*Amaranthus cruensis.* L) in Mubi, Adamawa State Nigeria. *Asian J. Adv. Agric. Res.* **2018**, *6*, 1–12. [CrossRef]
50. Baoua, I.; Amadou, L.; Abdourahmane, M.; Bakoye, O.; Baributsa, D.; Murdock, L. Grain storage and insect pests of stored grain in rural Niger. *J. Stored Prod. Res.* **2015**, *64*, 8–12. [CrossRef]
51. Shimelis, H.; Shiringani, R. Variance components and heritabilities of yield and agronomic traits among cowpea genotypes. *Euphytica* **2010**, *176*, 383–389. [CrossRef]

52. Sidibé, A.; Meldrum, G.; Coulibaly, H.; Padulosi, S.; Traore, I.; Diawara, G.; Sangaré, A.R.; Mbosso, C. Revitalizing cultivation and strengthening the seed systems of fonio and Bambara groundnut in Mali through a community biodiversity management approach. *Plant Genet. Resour.* **2020**, *18*, 31–48. [CrossRef]
53. Ibrahim, A.R.; Dansi, A.; Salifou, M.; Ousmane, A.; Alzouma, A.; Alou, W. Farmers' practices, utilization, conservation and marketing of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Dosso Region, Western Niger. *Genet. Resour. Crop. Evol.* **2018**, *65*, 1907–1914. [CrossRef]
54. Agyeman, K.; Asante, B.O.; Berchie, J.N.; Sarkodie-Addo, J.; Marno, P.; Adabah, R. Farmers' perceptions, constraints and preferences for improved Bambara groundnut varieties in Ghana. *J. Agric. Food Res.* **2021**, *3*, 100097. [CrossRef]
55. Smýkal, P.; Vernoud, V.; Blair, M.W.; Soukup, A.; Thompson, R.D. The role of the testa during development and in establishment of dormancy of the legume seed. *Front. Plant Sci.* **2014**, *5*, 351. [PubMed]
56. Qaku, X.W.; Adetunji, A.; Dlamini, B.C. Fermentability and nutritional characteristics of sorghum Mahewu supplemented with Bambara groundnut. *J. Food Sci.* **2020**, *85*, 1661–1667. [CrossRef]
57. Saka, J.O.; Ajibade, S.R.; Adeniyan, O.N.; Olowoyo, R.B.; Ogunbodede, B.A. Survey of Underutilized Grain Legume Production Systems in the Southwest Agricultural Zone of Nigeria. *J. Agric. Food Inf.* **2004**, *6*, 93–108. [CrossRef]
58. Ho, W.K.; Chai, H.H.; Kendabie, P.; Ahmad, N.S.; Jani, J.; Massawe, F.; Kilian, A.; Mayes, S. Integrating genetic maps in bambara groundnut [*Vigna subterranea* (L) Verdc.] and their syntenic relationships among closely related legumes. *BMC Genom.* **2017**, *18*, 1–9. [CrossRef]
59. Bonny, B.S.; Dagou, S.E.K.A.; Ajoumani, K.; Koffi, K.G.; Kouonon, L.C.; Sie, R.S. Evaluation of the diversity in qualitative traits of Bambara groundnut germplasm (*Vigna subterranea* (L.) Verdc.) of Côte d'Ivoire. *Afr. J. Biotechnol.* **2019**, *18*, 23–36.
60. Abberton, M.T.; Marshall, A.H. Progress in breeding perennial clovers for temperate agriculture. *J. Agric. Sci.* **2005**, *143*, 117–135. [CrossRef]
61. Forrester, O.O.; Maurice, E.; Victor, W.; James, O.O.; Laura, K.; Paul, K.; Odongo, F.O.; Wasike, V.; Owuoche, J.O.; Karanja, L.; et al. Genetic diversity of Bambara groundnut (*Vigna subterranea* (L.) verdc.) landraces in Kenya using microsatellite markers. *Afr. J. Biotechnol.* **2015**, *14*, 283–291. [CrossRef]
62. Ahmad, N.S.; Redjeki, E.S.; Ho, W.K.; Aliyu, S.; Mayes, K.; Massawe, F.; Kilian, A.; Mayes, S. Construction of a genetic linkage map and QTL analysis in bambara groundnut. *Genome* **2016**, *59*, 459–472. [CrossRef]
63. Fatimah, S.; Ardiarini, N. Genetic diversity of Madurese bambara groundnut (*Vigna subterranea* L. Verdc.) lines based on morphological and RAPD markers. *Sabrao J. Breed. Genet.* **2018**, *50*, 2–6.
64. Redjeki, E.S.; Ho, W.; Shah, N.; Molosiwa, O.; Ardiarini, N.; Kuswanto; Mayes, S. Understanding the genetic relationships between In-donesian Bambara groundnut landraces and investigating their origins. *Genome* **2020**, *63*, 319–327. [CrossRef]
65. Mukakalisa, C.; Kandawa-Schulz, M.; Mapaure, I. Effect of sowing seasons on growth and development of bambara groundnut (*Vigna subterranean* L.). *Acta Hortic.* **2013**, *979*, 689–693. [CrossRef]
66. Rungnoi, O.; Suwanprasert, J.; Somta, P.; Srinives, P. Molecular genetic diversity of Bambara groundnut (*Vigna subterranea* L. Verdc.) revealed by RAPD and ISSR marker analysis. *Sabrao J. Breed. Genet.* **2012**, *44*, 1–4.
67. Amadou, H.; Bebeli, P.; Kaltsikes, P. Genetic diversity in Bambara groundnut (*Vigna subterranea* L.) germplasm revealed by RAPD markers. *Genome* **2001**, *44*, 995–999. [CrossRef]
68. Benson, O.; Anyango, B.; Nyunja, R.A.; Koech, P.K.; Skilton, R.A.; Francesca, S. Morphological, genetic and symbiotic characterization of root nodule bacteria isolated from Bambara groundnuts (*Vigna subterranean* L. Verdc) from soils of Lake Victoria basin, western Kenya. *Agric. Sci.* **2015**, *9*, 32.
69. Puozaa, D.K.; Jaiswal, S.K.; Dakora, F.D. African origin of Bradyrhizobium populations nodulating Bambara groundnut (*Vigna subterranea* L. Verdc) in Ghanaian and South African soils. *PLoS ONE* **2017**, *12*, e0184943. [CrossRef] [PubMed]
70. Massawe, F.; Roberts, J.; Azam-Ali, S.; Davey, M. Genetic diversity in bambara groundnut (*Vigna subterranea* (L.) Verdc) landraces assessed by Random Amplified Polymorphic DNA (RAPD) markers. *Genet. Resour. Crop. Evol.* **2003**, *50*, 737–741. [CrossRef]
71. Somta, P.; Chankaew, S.; Rungnoi, O.; Srinives, P. Genetic diversity of the Bambara groundnut (*Vigna subterranea* (L.) Verdc.) as assessed by SSR markers. *Genome* **2011**, *54*, 898–910. [CrossRef]
72. Molosiwa, O.O. *Genetic Diversity and Population Structure Analysis of Bambara Groundnuts (Vigna Subterranea (L.) Verdc.) Landraces Using Morpho-Agronomic Characters and SSR Markers*; University of Nottingham: Nottingham, UK, 2012; Volume 2, pp. 40–48.
73. Absattar, T.; Absattarova, A.; Fillipova, N.; Otemissova, A.; Shavrukov, Y. Diversity array technology (DArT) 56K analysis, confirmed by SNP markers, distinguishes one crested wheat grass Agropyron species from two others found in Kazakhstan. *Mol. Breed.* **2018**, *38*, 1–11. [CrossRef]
74. Oludare, A.; Kioko, J.; Akeem, A.; Olumide, A.; Justina, K.; Adejoke, I. Genetic diversity in Bambara groundnut (Vigna subter-ranean) as revealed by molecular weights of the seeds 'proteins. *Bangladesh J. Plant Breed. Genet.* **2017**, *30*, 19–28. [CrossRef]
75. Bhanu, A.; Singh, M.; Srivastava, K.; Hemantaranjan, A. Molecular mapping and breeding of physiological traits. *Adv. Plants Agric. Res.* **2016**, *3*, 193–206. [CrossRef]
76. Chang, Y.; Liu, H.; Liu, M.; Liao, X.; Sahu, S.K.; Fu, Y.; Song, B.; Cheng, S.; Kariba, R.; Muthemba, S.; et al. The draft genomes of five agriculturally important African orphan crops. *Giga Sci.* **2019**, *8*, 3–152. [CrossRef] [PubMed]
77. Pahane, M.M.; Tatsadjieu, L.N.; Bernard, C.; Njintang, N.Y. Production, nutritional and biological value of bambara groundnut (Vigna subterranea) milk and yoghurt. *J. Food Meas. Charact.* **2017**, *11*, 1613–1622. [CrossRef]

78. Adebiyi, J.A.; Njobeh, P.B.; Kayitesi, E. Assessment of nutritional and phytochemical quality of Dawadawa (an African fermented condiment) produced from Bambara groundnut (*Vigna subterranea*). *Microchem. J.* **2019**, *149*, 104034. [CrossRef]
79. Hussin, H.; Gregory, P.J.; Julkifle, A.L.; Sethuraman, G.; Tan, X.L.; Razi, F.; Azam-Ali, S.N. Enhancing the Nutritional Profile of Noodles with Bambara Groundnut (*Vigna subterranea*) and Moringa (*Moringa oleifera*): A Food System Approach. *Front. Sustain. Food Syst.* **2020**, *4*, 59. [CrossRef]
80. Hardy, Z.; Jideani, V.A. Functional characteristics and microbiological viability of foam-mat dried Bambara groundnut (*Vigna subterranea*) yogurt from reconstituted Bambara groundnut milk powder. *Food Sci. Nutr.* **2020**, *8*, 5238–5248. [CrossRef] [PubMed]
81. Tan, X.L.; Azam-Ali, S.; Von Goh, E.; Mustafa, M.; Chai, H.H.; Ho, W.K.; Mayes, S.; Mabhaudhi, T.; Azam-Ali, S.; Massawe, F. Bambara Groundnut: An Underutilized Leguminous Crop for Global Food Security and Nutrition. *Front. Nutr.* **2020**, *7*, 276. [CrossRef]
82. Uma, M.; Hittalamani, S.; Murthy, B.K.; Viswanatha, K. Microsatellite DNA marker aided diversity analysis in cowpea. *Indian J. Genet.* **2009**, *69*, 35–43.
83. Dwivedi, S.L.; Crouch, J.H.; Mackill, D.J.; Xu, Y.; Blair, M.W.; Ragot, M.; Upadhyaya, H.D.; Ortiz, R. The Molecularization of Public Sector Crop Breeding: Progress, Problems, and Prospects. *Adv. Agron.* **2007**, *95*, 163–318. [CrossRef]
84. Ijarotimi, O.S.; Esho, T.R. Comparison of nutritional composition and anti-nutrient status of fermented, germinated and roasted bambara groundnut seeds (*Vigna Subterranea*). *Br. Food J.* **2009**, *111*, 376–386. [CrossRef]
85. Berchie, J.; Opoku, M.; Adu-Dapaah, H.; Agyemang, A.; Sarkodie-Addo, J. Evaluation of five bambara groundnut (*Vigna subterranea* (L.) Verdc.) landraces to heat and drought stress at Tono-Navrongo, Upper East Region of Ghana. *Afr. J. Agric. Res.* **2012**, *7*, 250–256. [CrossRef]
86. Kendabie, P.; Jorgensen, S.T.; Massawe, F.; Azam-Ali, S.; Mayes, S. Day length effects on growth and seed production efficiency in Bambara groundnut (*Vigna subterranea* L.). In Proceedings of the 3rd International Conference on Neglected and Underutilized Species, Accra, Ghana, 25 September 2016; p. 28.
87. Taffouo, V.; Wamba, O.; Yombi, E.; Nono, G.; Akoe, A. Growth, yield, water status and ionic distribution response of three Bambara groundnut (*Vigna subterranean* (L.) verdc.) landraces grown under saline conditions. *Int. J. Bot.* **2010**, *6*, 53–58. [CrossRef]
88. Oyeyinka, S.A.; Singh, S.; Adebola, P.O.; Gerrano, A.S.; Amonsou, E.O. Physicochemical properties of starches with variable amylose contents extracted from bambara groundnut genotypes. *Carbohydr. Polym.* **2015**, *133*, 171–178. [CrossRef]
89. Tsamo, A.T.; Ndibewu, P.P.; Dakora, F.D. Phytochemical profile of seeds from 21 Bambara groundnut landraces via UPLC-qTOF-MS. *Food Res. Int.* **2018**, *112*, 160–168. [CrossRef] [PubMed]
90. Halimi, R.A.; Barkla, B.J.; Mayes, S.; King, G.J. The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security. *J. Food Compos. Anal.* **2019**, *77*, 47–59. [CrossRef]
91. Olaleye, A.; Adeyeye, E.; Adesina, A. Chemical composition of bambara groundnut (*Vigna subterranea* L. Verdc) seed parts. *Bangladesh J. Sci. Ind. Res.* **2013**, *48*, 167–178. [CrossRef]
92. Harris, T.; Jideani, V.; Le Roes-Hill, M. Flavonoids and tannin composition of Bambara groundnut (*Vigna subterranea*) of Mpumalanga, South Africa. *Heliyon* **2018**, *4*, e00833. [CrossRef]
93. Rajendrakumar, P.; Patil, J.V. Molecular Markers for the Genetic Improvement of Millets. *Millets Sorghum* **2017**, 341–394. [CrossRef]
94. Nti, C.A. Effects of bambara groundnut (Vigna subterranea) variety and processing on the quality and consumer appeal for its products. *Int. J. Food Sci. Technol.* **2009**, *44*, 2234–2242. [CrossRef]
95. Basu, S.; Roberts, J.; Azam-Ali, S.; Mayes, S. Development of microsatellite markers for Bambara groundnut (*Vigna subterranea* L. Verdc.)—An underutilized African legume crop species. *Mol. Ecol. Notes* **2017**, *7*, 1326–1328. [CrossRef]
96. Kumar, P.; Gupta, V.; Misra, A.; Modi, D.; Pandey, B. Potential of molecular markers in plant biotechnology. *Plant Omics* **2009**, *2*, 141.
97. Mafakheri, K.; Bihamta, M.R.; Abbasi, A.R. Assessment of genetic diversity in cowpea (*Vigna unguiculata* L.) germplasm using morphological and molecular characterisation. *Cogent Food Agric.* **2017**, *3*, 1327092. [CrossRef]
98. Vidigal, P.; Romeiras, M.; Monteiro, F. Crops Diversification and the Role of Orphan Legumes to Improve the Sub-Saharan Africa Farming Systems. In *Sustainable Crop Production*; InTech: London, UK, 2020; Volume 65, pp. 45–60.
99. Hendre, P.S.; Muthemba, S.; Kariba, R.; Muchugi, A.; Fu, Y.; Chang, Y.; Song, B.; Liu, H.; Liu, M.; Liao, X.; et al. African Orphan Crops Consortium (AOCC): Status of developing genomic resources for African orphan crops. *Planta* **2019**, *250*, 989–1003. [CrossRef]