Abstract: Groundnut (Arachis hypogaea L.) is a major food and cash crop in Burkina Faso. Due to the growing demand for raw oilseeds, there is an increasing interest in groundnut production from traditional rain-fed areas to irrigated environments. However, despite implementation of many initiatives in the past to increase groundnut productivity and production, the groundnut industry still struggles to prosper due to the fact of several constraints including minimal development research and fluctuating markets. Yield penalty due to the presence of drought and biotic stresses continue to be a major drawback for groundnut production. This review traces progress in the groundnut breeding that started in Burkina Faso before the country’s political independence in 1960 through to present times. Up to the 1980s, groundnut improvement was led by international research institutions such as IRHO (Institute of Oils and Oleaginous Research) and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). However, international breeding initiatives were not sufficient to establish a robust domestic groundnut breeding programme. This review also provides essential information about opportunities and challenges for groundnut research in Burkina Faso, emphasising the need for institutional attention to genetic improvement of the crop.

Keywords: peanut; plant breeding; research; funding; genomics; INERA; cultivar; selection; Arachis hypogaea

1. Introduction: The Importance of Groundnut in Burkina Faso

Groundnut (Arachis hypogaea L.), also known as peanut, is a self-pollinated crop and allotetraploid (2n = 4x = 40) with a genome size of 2.54 Gb [1] and which belongs to the Fabaceae family [2,3]. Groundnut is an important food crop worldwide with an annual production of over 47 million tons on near 28 million hectares in 2017, according to the last statistics of Food and Agriculture Organisation (FAO) [4]. The crop’s cultivation, processing and trade significantly impacts the socio-economic development of a large number of developing and least developed countries [5]. Approximately 60% of the world’s production comes from Asia, whereas Africa accounts for 26%. In 2017, groundnut productivity was the lowest in Africa (839.6 kg/ha) compared to the rest of the world (1685.6 kg/ha) [4]. Burkina Faso (formerly known as Upper Volta) contributes 1–1.5% to the global groundnut production with approximately 400,000 tons per year [4].
In Burkina Faso, groundnut contributes significantly to both food security and poverty alleviation [6]. As in many low-income countries in Africa and Asia, the crop is primarily grown for subsistence by smallholder farmers [7], predominantly women [5,8,9], under rain-fed and low input conditions [10]. Groundnut can account for up to 50% of cash income while providing many benefits including a food rich in digestible proteins, high-quality oils, and many functional compounds and elements such as iron and zinc which are important to nutrition and health, especially in children [11–13]. As a legume crop, groundnut cultivation improves soil fertility and productivity by fixing atmospheric nitrogen [14]. Additionally, the plant’s haulm and by-products have value as a feed for livestock [15,16]. The groundnut value chain in Burkina Faso employs a significant number of people and contributes substantially to the economy [6,17] and to family wellbeing [5,18]. Clearly, groundnut improvement has a direct positive impact on the nutritional and economic status of smallholder farmers.

Despite the importance and benefits of groundnut for farmers and consumers in Burkina Faso, the production of this legume has been unsteady for the last 20 years or so [4]. Groundnut yields have remained low (~800 kg/ha) in sharp contrast with the crop’s potential which can provide up to 5000 kg/ha in intensive agriculture systems like in the USA [4,19,20]. This low level of productivity is attributable to several constraining factors including diseases and pests, erratic rainfall, drought, poor soils, market instability, and lack of locally adapted high-yielding varieties [19,21]. The highest production in Burkina Faso was 519,345 tonnes in 2016 [4], more due to the extension of cultivated land than to an increase in crop productivity (Figure 1). The stagnation of domestic production has been exacerbated by an unreliable seed supply system for groundnut [19] and weak organisation of the groundnut industry which has left a current gap in processing capacity.

![Groundnut production and area in Burkina Faso](image1)

![Groundnut yields in Burkina Faso](image2)

**Figure 1.** Evolution of groundnut (a) production (1000 tonnes; shelled) and area (1000 ha); (b) yield (kg/ha) in Burkina Faso between 1948 and 2017 [4,22,23].

Groundnut breeding in Burkina Faso has been tightly correlated with activities in the crop’s value chain which drive the whole groundnut industry including the research and development [6]. For more than a decade now, no major action plan has been established to develop the groundnut industry, especially after the 2008 food crisis [24]. To this extent, the focus of breeding efforts at INERA (Institute of Environment and Agriculture Research) was directed to the main staple food crops (i.e., maize, pearl millet, sorghum, rice) overlooking groundnut, which is often considered a cash crop, and thereby hampering groundnut cultivar development.

At present, information about progress and the current state of groundnut breeding in Burkina Faso is patchy. Most research results are confined to annual reports of individual projects with little published in international journals [25]. To our knowledge, publications in recent years have focused mainly on yield evaluation [26] and disease of local and exotic varieties for early leaf spot [27,28]. Earlier research activities involved the evaluation of resistance to foliar diseases in lines introduced from ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) or the USA through the Peanut CRSP (Peanut Collaborative Research Support Program) [29–31] and similar development programmes.

In this paper, research on groundnut improvement in Burkina Faso is reviewed with an outlook for future breeding strategies. It appears that groundnut research started under colonial projects...
before the country’s independence in 1960. However, it took nearly three decades before the national agriculture research programme emerged. Between 1980 and 2010, groundnut research was conducted by nationals with minimal access to technical and financial capacities. The most consistent support was from the USAID-funded Peanut CRSP. This was followed by years of resource scarcity, before groundnut research was rekindled with ICRISAT-led Gates-funded projects (Tropical Legumes) and local initiatives. Today, modern technologies offer the opportunity to advance and deliver improved groundnut varieties that meet farmer, consumer, processor, and export demands.

2. History of Groundnut Cultivation in Burkina Faso

Intensive groundnut production started in West Africa during the colonial period in the 1900s, providing raw material for the French oil factories as well a source of revenue [32], stimulating groundnut commercialization throughout the whole of Western Africa [33]. Subsequently, migrant groundnut farming arose as a labour system in West Africa associated with cash-cropping which drew thousands of young men from Burkina Faso and elsewhere (e.g., Mali, Guinea, Senegal, Mauritania) towards the Gambia River basin (Gambia), a hot-spot of groundnut cultivation at the time [32,33]. Although farmers had been growing the crop in many places in Burkina Faso, migrants returning home from the Gambia River basin were most likely the first to advance groundnut cultivation in the country. The swift widespread adoption of groundnut was probably due to the fact of its similarity to the West African native Bambara groundnut (Vigna subterranea) [33] to which farmers were already accustomed [23,33].

After successful promotion of groundnut cultivation in the region of Bobo-Dioulasso by the colonial administration in the early 1920s, crushing machines became operative in Ouagadougou and Banfora in 1922 and 1928, respectively [34]. Cultivation of groundnut extended rapidly around the country after 1936 [35,36], prompting the installation of the main factory for oil processing in 1941 in Bobo-Dioulasso [35]. Post-independence political unrest, drought waves, epidemics of groundnut rosette disease and groundnut price instability in global markets [22,32,33,37,38] resulted in low production levels through the early 1980s (Figure 1a). Production increased from 1985 due to the expanded acreage (Figure 1a) for cultivation of the crop [39] and significant governmental support to the groundnut sector by the SOFIVAR (Groundnut Funding and Extension Society) [37]. However, production has been erratic, and crop yields on average remained very low (<600 kg/ha) until the mid-1980s when, for the first time, yields reached >700 kg/ha (Figure 1b). The best yields (800–1000 kg/ha) were achieved between the mid-1990s and 2000, driven by market opportunities and national support provided to the groundnut sector [37,40]. Yields have fluctuated over the years since then (Figure 1b), highlighting the need for improved locally adapted varieties. The trend of an increase in groundnut production has been more due to the increase in area harvested than productivity improvement.

3. Groundnut Research in Burkina Faso

Groundnut research in Burkina Faso started before the country’s autonomy, with French projects targeting the crop production for export. The French National Institute for Colonial Agriculture (called CNRS post-1939) was created to conduct development research to increase revenues from agricultural production in the French colonies of Africa [41,42]. The hardship of World War II further prompted the creation of specialised research institutions, such as IRHO (Institute of Oils and Oleaginous Research), to increase food and oilseed production in Africa [42,43]. Subsequently, IRHO, having merged with GERDAT (Study and Research Group for the Development of Tropical Agriculture), has conducted research on groundnut with a focus in the main production area in southwestern regions of Burkina Faso [36]. The research objectives were to increase yields while developing resistance to rosette disease which could totally decimate production during years of disease outbreaks [36]. This prompted IRHO, based at Niangoloko, to undertake groundnut improvement research to develop cultivars resistant to rosette disease and adapted to southwestern regions of the country [36]. Resistant
cultivars were identified in 1952 around the Burkina/Côte-d’Ivoire border and used in breeding crosses at Bambey Agricultural Research Centre in Senegal [44]. By 1959, about 20 resistant cultivars with limited infection rate (≤6%) and better productivity (20–35% yield increase compared with local varieties) were introduced in Burkina Faso [36]. Additionally, experiments conducted between 1955 and 1963 resulted in some varieties with potential yields about three metric tonnes per hectare and showed that (1) groundnut densities between 111,100 and 133,300 plants/ha are optimal for top yields, and (2) phosphorus is the most limiting nutrient for groundnut in soils of western Burkina Faso [36]. The creation of ICRISAT in 1972 and nomination of groundnut as a mandate crop in 1976 [45] added momentum to research on groundnut [3,46]. Major constraints to production were identified [47], including pests [39,48], diseases [10,49], drought and aflatoxins [50–53].

Until the inception of PNRA in the mid-1980s, agricultural research was administered by the Ministry of Rural Development with little contribution of national scientists. Major research projects on groundnuts were implemented by international institutions [23,31,43,54] with the research station of IRHO at Niangoloko contributing somewhat but at a far lower level [32]. Varietal creation was limited at Niangoloko, as it was used primarily as a testing site, while breeding populations were developed at the research centre in Bambey, Senegal [44]. Apart from a few French agronomists, no Burkinabe conducted research in Niangoloko, probably because groundnut was not a priority for the government [54]. Government investment in agricultural extension prevailed over research even before technologies were developed to support food production as suggested by donors [23]. Then, progressive departure of international researchers and lack of resources, equipment, and trained scientists halted research activity and led to a loss of valuable germplasm and breeding records [32,55]. Restructuring in the 1980 to 1985 timeframe gave rise to INERA which initiated breeding programmes in 1988 [56].

In this context, programmes supported by donors such as USAID (United States Agency for International Development), the European Union (EU) and the Bill and Melinda Gates Foundation (BMGF) were instrumental in re-establishing groundnut research and development in Burkina Faso [23]. The USAID-funded Collaborative Research Support Program (CRSP) stimulated and sustained research activities from 1975 to 2012 [29–31]. This Peanut CRSP network involved the Institute for the Sahel (INSAH), IRHO and ICRISAT. However, these activities focused primarily on pest and disease management and resistance to leaf spot diseases as well as testing of advanced lines for production efficiency [30]. These programmes resulted in improved groundnut varieties which still hold a large share of production in Burkina Faso today [22,25]. They enabled many works that would not be possible otherwise. In this research collaboration, cultivar development was conducted mainly by IRHO and ICRISAT [36,47,49,55], while work at INERA involved testing only. Such involvement of international research in national programmes has been at the core of crop breeding activities in West Africa [25]. The growing number of trained and qualified scientists in Burkina Faso and in the region opens opportunities for more research leadership within countries. However, breeding programmes continue to be handicapped by the lack of the resources needed to conduct research activities [25] and lack of research leadership to some extent. Consequently, most groundnut varieties cultivated in Burkina Faso today were developed before or shortly after 1960, some from Senegal as sharing cultivars has been common practice among countries in the sub-region [57–59]. Varieties such as 28–206, 59–426, 69–101 and Fleur 11 were introduced from Senegal to Burkina Faso [25]. To date, more than 20 varieties have been registered in the national catalogue of crop varieties. Some of these (e.g., TS 32-1, CN94 C, RMP 91, RMP 12, KH 241D) have been under cultivation for more than 50 years (Table 1). Cultivar development was stagnant in the country until 1990 when two varieties (SH 67A, SH 470P) were released (Table 1), and the average age of commercial groundnut varieties is about 30 years [55].
Table 1. Groundnut varieties released from the 1950s to date and registered in the national catalogue of plant varieties.

| Variety/Line | Pedigree | Botanical Type | Cycle (Days) | Year | Institution/Origin | Reference |
|--------------|----------|----------------|--------------|------|--------------------|-----------|
| CN 94C       | 90 Saria/Tougan 1) F₀       | Spanish        | 90           | 1966 | IRHO Saria, Burkina Faso | [10,60]   |
| Te. 3        | Local pop. Burkina          | Spanish        | 90           | 1958 |                     |           |
| TS 32-1      | Spanlex/Te. 3, F₀           | Spanish        | 90           | 1966 |                     |           |
| KH 149A      | GH 119-7-II-III/91 Saria    | Spanish        | 90           | 1964 |                     |           |
| KH 241D      | GH 11852 II/91 Saria        | Spanish        | 90           | 1964 |                     |           |
| QH 243 C     | KH 184 A/424 A, F₂          | Spanish        | 90           | 1971 |                     |           |
| RMP 91       | 48–37/Mani Pintar, F₀       | Virginia       | 135          | 1963 |                     |           |
| RMP 12       | 1036/Mani Pintar, F₉        | Virginia       | 135          | 1960 |                     |           |
| SH 67A       | QH 243C/ PI 1166            | Spanish        | 90           | 1990 |                     |           |
| SH 470P      | Flower 113/ QH 200A, F₂     | Spanish        | 90           | 1990 |                     |           |
| 69–101       | 55–455 14/28–206, F₂-B₃     | Virginia       | 120          | 1969 |                     |           |
| 59–426       | NA                        | Virginia       | 120          | 1959 |                     |           |
| ICGSE 104    | NA (Segregating material ICRISAT) | Valencia | 75–80     | 1990 |                     |           |
| Fleur 11     | Variety from China          | Spanish        | 90           | 1990 |                     |           |
| Nafa 1       | ICGV 92069/ICGV 93184      | Virginia       | 110          | 2018 |                     |           |
| Lekre (ICGV 93036) | J11/U4-7-5            | Spanish        | 90           | 2018 |                     |           |
| Misou Pale (ICGV 93036) | Var 27/U4-7-5 | Valencia       | 90           | 2018 |                     |           |
| Touinware (ICGV-IS 13806) | ICGV 86124/ICGV 7878 | Spanish        | 90           | 2018 |                     |           |
| Beeda (ICGV-IS 13830) | ICGV 86124/ICGV 7878 | Spanish        | 90           | 2018 |                     |           |
| Soukeba (ICGV-IS 13912) | ICGV 86124/ICGV 7878 | Spanish        | 90           | 2018 |                     |           |
| Kiema 1      | Local pop. Burkina          | Spanish        | 90           | 2018 |                     |           |

NA = not available; pop. = population.

The current increase in groundnut production has been almost entirely due to the fact of land expansion [4]. With the exhaustion of the country’s arable lands, a future increase in production must come from yield improvement based on genetic improvement and appropriate management practices. It has been estimated that less than 25% of approximately 460,000 hectares of land cultivated yearly in groundnut were occupied with improved varieties [55,63]. Replacement of popular groundnut varieties (TS 32-1, SH470-P, CN94 C, Fleur 11) with more productive ones is sought. Only recently, in 2018, have seven new varieties developed by ICRISAT been tested, registered in the national seed catalogue [62], and subsequently released for cultivation in Burkina Faso (Table 1). However, extension efforts are required to facilitate farmers’ awareness and adoption of these varieties.

4. Research Resources

In the early 2000s, Burkina Faso began investing more in agricultural research capacity. As of January 2019, more than 65% of scientists hold a doctorate degree (HRM, personal communication), compared to less than 50% before 2000. Currently, the number of scientists at INERA alone reaches over 300, not counting scientists at university-based agricultural research centres. However, the increase in the number of researchers did not go along with the increase in research capacity [64]. Lack of resources coupled with poor competitiveness of local salaries with that of international positions motivated the departure of many scientists to CGIARs, NGOs or Western countries. National research programs
struggle to keep up with evolving breeding methods and required infrastructures and equipment [64], limiting their effectiveness.

Furthermore, expenditures dedicated to research and development have been irregular [38] or reduced, sometimes due to the fact of political turmoil [23]. Since transitioning from PNRA, INERA has been chiefly financed through World Bank loans supporting three main projects [38,65,66]. What is more, of the proportion of funding dedicated to agriculture research, little goes to groundnut, making this crop less attractive to researchers. The consequence of resource limitation was attenuated by regional research initiatives through WECARD (West and Central African Council for Agricultural Research and Development) and ICRISAT. Regional efforts essentially guard against unnecessary replication of research in countries with similar agro-ecologies in the region and have the advantage of mobilising more donors [64]. International initiatives such as the Peanut CRSP enabled the implementation of many research activities on groundnut in the country for over three decades in collaboration with the University of Ouagadougou [23,31]. With the close of the World Bank-funded project PNDSA (National Project for Development of Agricultural Sector) in 2003, there was no funding at all for groundnut research at INERA until 2012, when groundnut development research started almost afresh with the second phase of Tropical Legumes project sponsored by the Gates Foundation. This project provided substantial support to the breeding programme in Burkina Faso, allowing INERA to reflect on product targets, breeding objectives to achieve these targets, and breeding process modernisation [67]. This funding had the merit of rekindling groundnut breeding in Burkina Faso, although there is still a need to develop clear and specific improvement goals, build technical capacity, and secure long-term funding.

In a nutshell, public sector groundnut breeding has not made satisfactory progress in Burkina Faso as in most sub-Saharan countries; no increase in genetic gain has been recorded in the last 30 years [68,69]. While technology can be accessed, especially through outsourcing, the primary challenge for groundnut improvement in Burkina Faso is the capacity to assemble relevant technological options to create an optimized varietal development pipeline for groundnut [68]. The national breeding programme needs to keep up with the evolving breeding methods through improved research leadership and technical expertise [68,70]. Therefore, a workforce of researchers able to apply advances in breeding methods, approaches and tools for cultivar development is needed. In West Africa, the University of Ghana/West Africa Centre for Crop Improvement has stepped up to provide such training at the postgraduate level with support from AGRA (Alliance for a Green Revolution in Africa) and others [71]. Other universities in Africa are also rising to meet this challenge of training the next generation of plant breeders. Furthermore, professional development programs, such as the African Plant Breeding Academy, coordinated by the University of California at Davis in the USA, offer continuing education to African plant breeders in the use of genomics-assisted selection and ways to optimize the breeding pipeline [72]. However, the question is, “Will these programs be enough to create the workforce needed for Burkina Faso?”

5. Production Environment

Groundnut was the top cash crop in Burkina Faso before cotton until 1977 [73]. Since then, groundnut production has primarily served domestic needs as a food crop [22,73]. Of the yearly production of more than 350,000 tonnes [4], only about 2% on average is exported [71] and this to other countries in West Africa [6]. A sharp increase in groundnut prices in early 1990s boosted production and exports towards Europe, at least for a few years [37,74]. However, the increased production and export levels were not sustained due to the decline in groundnut demand in Europe [73,75] and lack of adequate support to farmers [74]. Nevertheless, domestic demand for groundnut has been increasing in recent years to complement cotton seed for an increase of oil production which covers only approximately 30% of needs at the moment [76]. Currently, although groundnut production meets the demand for household consumption as food, little surplus is available for the processing
market [22,23,73]. The development of productive cultivars for the farming system upstream is necessary to meet growing demands and sustain a stable value chain.

The distribution of groundnut cultivation in Burkina Faso (Figure 2) indicates Centre-Ouest as the top groundnut producing region, followed by the Boucle du Mouhoun region. Production is mid-level in Hauts-Bassins, Centre-Sud, Centre-Est and Est regions. This distribution has remained consistent since the 1960s [36], reflecting minimal efforts to expand groundnut to new areas. Nevertheless, Burkina Faso is among the top ten groundnut producing countries in Africa, based on area harvested (Table 2). Moreover, an estimation of country production proportionally to the population size shows that the importance of groundnut production in Burkina Faso is similar to that of Nigeria, the top producer in Africa [4]. Groundnut has great economic potential for the country [74], if only more political support were provided to increase investment in the sector.

![Map of groundnut production per administrative region in Burkina Faso](map.png)

**Figure 2.** Map of groundnut production per administrative region in Burkina Faso, adapted based on the average of the last five years (2013–2017) [4]. 1: Boucle-du-Mouhoun; 2: Cascades; 3: Centre; 4: Centre-Est; 5: Centre-Nord; 6: Centre-Ouest; 7: Centre-Sud; 8: Est; 9: Hauts-Bassins; 10: Nord; 11: Plateau-Central; 12: Sahel; 13: Sud-Ouest. The choropleth map was drawn using R package GADMTools with breaks option “sd” (standard deviation).

**Table 2.** Top 10 groundnut producing countries based on average area harvested in the last five years (2013–2017) [4].

| Rank | Country          | Area (ha)   | Production (Tonnes) | Yield (kg/ha) |
|------|-----------------|-------------|---------------------|---------------|
| 1    | Nigeria         | 2,766,845.8 | 3,068,586.8         | 1110.4        |
| 2    | Sudan           | 2,027,954.4 | 1,629,402.2         | 797.8         |
| 3    | UR * Tanzania   | 1,208,903.0 | 1,285,027.0         | 1052.8        |
| 4    | Senegal         | 950,149.6   | 806,165.4           | 843.2         |
| 5    | Niger           | 779,283.6   | 417,776.0           | 537.4         |
| 6    | Chad            | 760,472.6   | 843,546.2           | 1117.1        |
| 7    | Guinea          | 553,012.0   | 469,918.2           | 887.5         |
| 8    | DRC *           | 492,000.0   | 370,447.4           | 753.6         |
| 9    | Burkina Faso    | 480,635.4   | 380,894.2           | 799.8         |
| 10   | Cameroon        | 439,308.4   | 610,196.2           | 1386.4        |

* UR Tanzania = United Republic of Tanzania; DRC = Democratic Republic of the Congo.

### 6. Constraints to Groundnut Productivity

The difference between groundnut potential yield and actual yields in farmer fields, referred to as yield gap [77,78], reaches over 50% Burkina Faso [4,62], due to the fact of several biotic and abiotic constraints [10,14,28,39,57]. With rain-fed systems, up to 50% of the yield potential can be compromised by moisture stress due to the fact of inconsistent rainfall [78]. Identifying ways to manage...
constraints that undermine the crop productivity and widen yield gap is key to developing an effective groundnut improvement programme. Desmae et al. [47] summarized the main traits of breeding interest identified in recent years: drought tolerance; resistance to rosette, foliar diseases (leaf spots and rust) and aflatoxin; and quality traits such as high oil content, especially with high proportion of high oleic acid. Potential sources were highlighted to improve groundnut varieties for these traits [47]. Not discounting the effects of G × E (interactions between genotype and environment), which can lead to inconsistent trait expression, these resources could be important assets to the groundnut improvement programme in Burkina Faso.

6.1. Abiotic Constraints

In Burkina Faso where rain-fed agriculture is predominant, rainfall patterns represent the most significant climatic factor affecting groundnut production. Low, erratic rainfall and increasing periods among rains render groundnut cultivation subject to substantial yield losses [79,80]. A strategy to cope with drought stress is to develop short-duration varieties to escape end-of-season drought as well as drought tolerant varieties that hold up under conditions of low soil moisture [81].

Another constraint to realize yield potential is low levels of inputs in managing the crop. In Burkina Faso, groundnut is grown mostly under subsistence agriculture by smallholder farmers [74]. Fertiliser use for all crops since 2000 has averaged 11.1 kg/ha which is shockingly inadequate [64]. Appropriate use of fertilisers can lead to a 45% increase in groundnut yields [37]. However, farmers are incentivised to apply fertilisers and improve soil conditions only when there are market prospects [40]. Yet, critical elements, such as phosphorus and calcium, prove to be the top limiting nutrients for groundnut production, especially in the western regions of the country [36]. Although this issue can be overcome by applying appropriate chemical fertilisers, these are often out of reach for most smallholder farmers. Only 4% and 16% of farmers use chemical fertilisers or compost, respectively, in groundnut production, resulting in very low yields [37,74]. Therefore, it is advisable to develop cultivars that withstand the deficiency of both calcium and P to keep a good level of crop productivity. Soils in Burkina Faso present optimum pH between 6.0 and 6.5 for groundnut growth [82] which typically results in adequate availability of calcium and manganese [83]. Nevertheless, acidic pH should be taken into consideration in the breeding programme to anticipate the growing soil acidification in some areas in the country [84].

6.2. Biotic Constraints

As in most tropical regions of the world, diseases are major constraints to groundnut production in Burkina Faso [25]. Problems with foliar diseases including rust have been longstanding [85] with persistent occurrence in Burkina Faso [28]. Rosette disease, which affects the leaves and stem, is common in Western Burkina Faso [57,86,87] and is transmitted by the vector *Aphis craccivora* Koch [88] in a persistent manner [89]. Also, peanut clump disease, common in West Africa [90], has been reported in the country [57,86] and needs to be monitored. These diseases can cause important losses in groundnut production if not controlled [90]. Often foliar diseases occur simultaneously and collectively can cause from 24% up to 70% yield loss, following severe defoliation [10,25].

Groundnut productivity can also be reduced by soil pests [91]. Taxa associated with groundnut damage with high economic impact include termites (Isoptera), millipedes (Diplopoda) and scarabaeid larvae (Coleoptera) usually referred to as white grubs [39]. Species *Trochulus* sp., *Microtermes lepidus* Sjöstedt and *M. parvulus* Sjöstedt have been reported in Burkina Faso [92]; however, little is known about the economic importance of these pests at present. Additionally, the current erratic weather pattern can cause pests profiles to change thereby necessitating frequent nationwide surveys to document key pests associated with groundnut productivity. Studies at ICRISAT identified sources of resistance to these pests which hold promise for improving crop productivity [39,48]. Genetic resistance could be a key element of a broader strategy for effective pest control and control of pest-induced diseases, integrating use of pest-resistant varieties, cultural practices to minimize insect populations and bio-insecticides.
7. Suggested Foci for Groundnut Improvement in Burkina Faso

In principle, the target traits for groundnut improvement depend on farmers’ needs, consumer and market demands and processing requirements [70]. The most pressing need in Burkina Faso is for groundnut varieties with high yield potential that also possess tolerance to major biotic and abiotic yield-reducing factors. Closing the yield gap is the main focus besides improving yield per se as in most of the developing countries [93]. Improved varieties must be able to thrive under minimal management conditions as farmers often simply cannot afford inputs such as pesticides and chemical fertilizers [85]. Furthermore, improved varieties must be developed to meet demands of the value chain [94], based on regular consultations with key stakeholders including both women and men farmers, marketers, processors and consumers [68,95].

7.1. Elements to Consider in Cultivar Development

In Burkina Faso as elsewhere in West Africa, market desirable traits in groundnut include high seed yield, high oil/high oleic oil content in the seeds and resistance to aflatoxins for food safety [75,96]. There is now a call for groundnuts specifically developed for end-use application: cooking oil, confectionary and peanut butter [47,97,98]. High oil content groundnut varieties are currently in high demand to supply oil-crushing factories. Recent studies have demonstrated the possibility to raise oil content to as much as 55% of seed composition, presenting up to 80% oleic [99,100]. Oil quality in terms of high proportion of oleic acid is desirable to increase product shelf life [101] and provide many health benefits to consumers [102–104]. The challenge is to build on these advances in groundnut improvement for oil content and quality [105] to put these traits together with other desirable agronomic traits (i.e., yield and disease resistance) in an ideal cultivar for stakeholders of the value chain [95].

The cornerstone and highest priority trait in crop breeding is the yield. Pod number per plant, shelling percentage, proportion of mature kernels per pod and seed weight are important parameters contributing to groundnut yield [70]. Other traits to consider include early maturity, ease in harvesting (peg strength) and shelling, kernel size, shape and colour, fresh seed dormancy and blanching ability [3,47,70]. Additionally, reticulation (venation and ridging visible on the pod), beak (appendage of the tip of the indehiscent pod) and constriction of pods are traits that provide not only varietal specifications, but also reflect market preferences [106]. For instance, slight pod constriction is preferred in the market, as it prevents flattened kernels, whereas pods with prominent reticulation or deep constriction tend to carry soil on them, thus reducing the market value [106].

To sustain productivity, groundnut resistance to biotic and abiotic stresses must be improved. To this end, ICRISAT has identified and developed sources of key traits, including resistance to early leaf spot (caused by *Cercospora arachidicola*), late leaf spot (caused by *Phaeoisariopsis personata*), rust (caused by *Puccinia arachidis*) and aflatoxins [10,27,28,30,47,53]. Additionally, significant progress has been achieved at ICRISAT in developing drought tolerant [107,108] and early maturing cultivars [47]. These sources can be utilised by Burkina-based breeding programmes to develop improved locally adapted germplasm.

7.2. Exploring Novel Industrial Uses of Groundnuts

Groundnut is considered as a “smart food”, that is, a food that is highly nutritious, resilient to climate change with relatively low carbon and water footprints; as such, it has the potential to alleviate poverty [109]. Having high protein content and a healthy oil profile and serving as a source of key micronutrients including magnesium, groundnut has been used to make ready-to-use therapeutic food [110], used by UNICEF to treat acute malnutrition among children, women and men in developing countries [111,112]. Acute malnutrition affects near 500,000 children in Burkina Faso [112], resulting in 24.4% underweight and 10.2% mortality among children under five [113]. More generally, 25% of the population (~5 million people) are affected by hidden hunger [114,115]. To add more to the health
benefit of groundnut, improvement for nutritional traits, i.e., bio-fortification, such as iron and zinc, must be on the breeding agenda [109,116]. This is important to reduce the prevalence of anaemia (>40%) among preschool-age children [113].

Besides, groundnut haulms can be used for livestock feed [117] thus giving additional value to the crop. Groundnut haulms are protein-rich and easy for animals to digest [16]. The need for feed has been increasing in recent years due to the drastic reduction of pastureland and the development of suburban farming in towns [118]. Therefore, animal feed production and market are promising sector of domestic economy [119], especially during the dry season when fresh grazing is not available [17]. However, livestock feed is rarely a production objective per se in subsistence farming. The development of dual-purpose varieties offering both high kernel yield and aboveground biomass could offer new opportunities to expand the groundnut value chain.

7.3. Broadening Genetic Base of Breeding Population

Cultivated groundnut is said to have a relatively narrow genetic base globally [1,120,121], perhaps due to the polyploidisation [122]. Therefore, useful genetic variability must be created through judicious choice of parents in creating new breeding populations for crop improvement [123]. The nature and magnitude of genetic variability present in the breeding population and the extent to which the trait is heritable are key to success of the crop improvement programme [123]. Pre-breeding activities deploying strategic crossing among cultivated varieties and also between cultivars and wild groundnuts [122,124–126] has enlarged the crop base genetic diversity. Interestingly, accessions and advanced breeding lines which are stored in gene banks across the globe [93] are abundant and accessible through appropriate legal procedures [127]. These resources constitute invaluable material for national and international breeding programmes.

8. Modernization Is Needed to Maximise Genetic Gain in Developing Varieties that Meet Stakeholder Demands

In principle, plant breeding is implemented through three basic steps, viz. (1) crossing choice individuals with traits of interest to create breeding populations with useful genetic variation, (2) identification and selection of progeny from the breeding crosses having outstanding performance aligned with the product target, and (3) development of stable new cultivars from selected progeny [128]. The success of this process can be measured by estimating the rate of genetic gain over time, using the so-called breeder’s equation [129,130]: \( \Delta G = \left( h^2 \sigma_p i \right)/L \). The estimate of the rate of genetic gain (\( \Delta G \)) is a product of the narrow sense heritability for the trait under selection (\( h^2 \)), the standard deviation of the phenotypic variance of the trait (\( \sigma_p \)), and the selection intensity (\( i \)), divided by the length of time to complete a full breeding cycle (\( L \)). As such, it is also a function of selection accuracy (\( h \); the square root of narrow sense heritability) and the additive genetic variation within the population (\( \sigma_a^2 \); a component of \( h^2 \)). Each of these parameters can and should be manipulated in the breeding programme to maximise genetic gain in achieving the product target [68]. Such a strategy implies increasing heritability, selection accuracy, selection intensity and the speed of the breeding cycle and effectively exploiting genetic variation [128]. Modern breeding approaches, technologies and tools offer the means to increase the rate of genetic gain to effectively and efficiently reach product targets and thus get improved varieties out to farmers faster.

8.1. Modern Approaches, Technologies and Tools to Benefit Choice of Parents and Creation of Breeding Populations

Choice of parents is one of the most critical decisions to achieving success in cultivar development. Firstly, parental lines must represent viable sources of the suite of traits defined in the product target. Crossing of parents offers the opportunity for genetic recombination to result in new combinations of favourable alleles in the offspring. Ultimately, a potential new cultivar must contain favourable alleles for all the traits of interest. Genomics can aid in identifying lines with favourable alleles to
employ as parents. For example, GWAS (genome-wide association studies) can be conducted to characterize germplasm, identify new sources of favourable alleles, and tag genes to be tracked through the breeding process. Genomic approaches using GEBV (genomic estimated breeding values) can be used to leverage genetic information as well as phenotypic information collected from prospective parent lines and their relatives to guide the breeder in choosing parents. Once crosses are made, mating designs and tailored breeding approaches can be deployed to maximize seed returns and accelerate progress to homozygosity [131]. Technologies such as doubled haploidy has been used to create “instant inbreeds” in some crops, including groundnut [132,133] which offers advantages in testing by cutting “noise” due to the segregation that is present in early generations.

To create useful genetic variation, technologies such as mutation, transformation, and gene editing can be deployed. Mutation breeding involves irradiating seed with gamma rays or using chemical mutagens like ethyl methane sulphonate, diethylsulfate or sodium azide [134–136] to evoke changes in the DNA. Successful cases of mutation breeding have been reported extensively for the improvement of important traits including groundnut yield [137,138], allergen reduction [135], and oleic acid content in the oil profile [139]. Therefore, mutation breeding can be a useful breeding approach, especially with genetic improvement of crops having narrow genetic base such as groundnut [135,140].

Groundnut improvement for tolerance to some of the biotic and abiotic stresses can be difficult, either due to the complex genetic control of that trait or absence of resistant sources. For instance, it has been difficult to develop resistance to *Aspergillus flavus* infection and aflatoxin production in groundnut in a sustainable manner [141,142]. Similar issues observed with groundnut response to other stress contexts such as drought and virus attacks have warranted alternative approaches to conventional breeding. In such conditions, genetic transformation presents great potential in groundnut improvement to utilize genes from other species [45,70,143,144]. Likewise, the difficulties of plant regeneration by tissue culture techniques and selection of transgenic events [144–146] are being overcome by recent advances in groundnut transformation process [147]. To date, at least a dozen of successful groundnut transformations have been reported in the literature [69]. Recently, agrobacterium-mediated transformation and groundnut tissue culture techniques were refined for optimum use which enabled development of genetically modified groundnut that was near-immune to aflatoxin contamination [147].

Furthermore, gene editing has shown great promise in creating new allelic variants using various technologies such as zinc finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs) and clustered regularly interspaced short palindromic repeats (CRISPR) [148–151]. Gene editing can result in gene modification (e.g., single base change), gene silencing (i.e., knockout), or gene insertion (i.e., knock-in) [150]. Recent studies have shown that multiple genetic changes can be performed in concert [152], suggesting the potential to utilize CRISPR to generate new genetic diversity for quantitative traits. For example, work by Campa et al. [153] demonstrated, in mammalians, simultaneous editing of up to 25 target sites using CRISPR in conjunction with nuclease Cas12A. Thus, genetic engineering is a powerful tool to achieve groundnut improvement for difficult traits, but also any other traits of interest [144,145,154]. However, public reluctance to consume food made from genetically modified plants [155–157] and complex regulation processes [150,158–160] could preclude the application of genetic engineering approaches in groundnut breeding. Although genetically modified crops and those derived from any gene editing pipelines are not banned per se in Burkina Faso, they are subject to stringent regulatory law before experimentation, trials and commercial release [161]. Public education and government support for appropriate review and regulation of genetically engineered products is key to overcoming potential obstacles.

8.2. Modern Approaches, Technologies and Tools to Benefit Evaluation and Selection

The rate of genetic gain toward product targets can be increased by increasing selection intensity. However, this can cripple progress if the selection intensity is so high as to effectively eliminate genetic variation. This potentially negative effect can be managed by increasing population size, that is,
creating more progeny from each breeding cross. To deal with a larger number of individuals to test for each trait specified in the product target, technologies that can screen more individuals in less time with fewer resources are needed. Mechanization can help to manage activities such as planting, harvesting and threshing. In addition, technologies to facilitate high-throughput phenotyping can be used to increase efficiency in screening. Thus, the near infrared spectroscopy (NIRS) provides a robust, quick, cost-effective and non-destructive phenotyping for groundnut seed oil content and fatty acid profile [162,163]. Additionally, modern phenotyping facilities such as that at ICRISAT offer the possibility to dissect physiological factors with tight correlation with traits of interest (transpiration efficiency and drought tolerance, for instance) [164]. Likewise, advanced experimental designs, including randomised blocks, variable incomplete blocks, factorial, lattice, row-column and partial replicated designs [165] are useful in effectively partitioning genetic variation from environmental variation, G × E and error which can increase the accuracy of selection. Here again, technologies can come into play. For example, laser levelling of fields has been used to create more uniform fields for testing [166] which has been shown to result in more precise data upon which to make selection decisions [167,168]. However, cost may be a limitation for the use of this technology in resource poor breeding programmes [168].

To reduce the length of the breeding cycle, various approaches and technologies are available. Off-season nurseries offer the opportunity for more generations per year, cutting the overall time to complete the breeding cycle [68,163]. The term “speed breeding” has been coined to describe approaches and technologies to shorten the life cycle of the plant in generations where selection is not exercised [169,170]. For example, O’Connor et al. [171] were able to cycle 145 day groundnut lines at the rate of three generations per year to advance inbreeding from F2 to F4 based on controlled greenhouse conditions of optimal temperature and continuous light. In addition, marker-assisted selection, involving “tagged” genes of interest, can be utilized to cut the length of the breeding cycle. Individuals can be evaluated and selected based on genotype alone, eliminating wait times until the trait is manifested phenotypically and, in many cases, reducing field and labour resources required for phenotypic evaluation.

Advanced molecular approaches such as genomic selection utilize dense genome marker coverage to estimate genetic potential. Genomic selection facilitates faster identification of lines to serve as parents in the next breeding cycle, shortening cycle time [131]. In addition, genomic selection can be used to “predict” performance, replacing preliminary testing, as a means to advance progeny with greater genetic promise to advanced testing stages [131,172]. Furthermore, it can offer higher predictive ability when associated with modelling G × E interaction [173]. Estimated gain from genomic selection can be as much as 5 fold that of conventional breeding [174–176]. Although uptake of genomics-assisted breeding in Burkina Faso has been extremely low, as in many developing countries [69], due to the lack of human and infrastructure resources [70], nevertheless, opportunity for breeding programmes to embrace genomics-assisted breeding exists, using, where applicable, data available in partner institutions like ICRISAT where historical data on the performance of about 340 advanced breeding lines have been compiled [70].

8.3. Modern Approaches, Technologies and Tools to Support Commercialization and Release of Improved Cultivars

Modern approaches and technologies are available to support production of volumes of quality seed for distribution of new improved groundnut cultivars to farmers. DNA fingerprinting technologies ensure seed authenticity and purity [177]. Seed quality can be preserved using seed storage technologies, along with monitoring of relative humidity and seed moisture content with electronic meters or indicator papers [178]. Preserving seed quality is crucial for both the cultivar development process and the conservation of germplasm.

Data management tools that track materials through the entire breeding process facilitate traceability and document pedigree information. For example, the Breeding Management System
(BMS) [179] provides a comprehensive suite of mutually compatible software applications that work together to help breeders manage germplasm and collect, store and analyse their research data [180]. The BMS manages breeding data across all phases of the crop improvement cycle, keeping a safe, standardized and centralized record of data from one generation to the next in order to facilitate more economical and accelerated cultivar development. Such a system is not only crucial and foundational to breeding teams in their quest for selection accuracy, it supports breeding operations, resource allocation and data analyses [181], and provides support services at every step of the breeding process, all the way through to cultivar release. Such tools are essential to integrate and support all aspects of the breeding pipeline and to integrating efforts across team members.

A number of analytical and decision support tools for genomics-assisted breeding are freely available [182]. For example, CIMMYT offers several software options to facilitate various specialized analyses [183]. Other resources are available in the scientific literature to facilitate bioinformatics aspects of managing DNA-sequence data (e.g., GAPIT; Genome Association and Prediction Integrated Tool [184]). Use of publicly available tools such as these satisfies needs while avoiding license fees.

9. Research Challenges in Burkina Faso

Important breeding programmes are conducted across the world to improve groundnut as a multipurpose oilseed legume crop. Achievements in groundnut genomic research will affect cultivar development worldwide [105,185]. Collegial initiatives, such as the International Peanut Genome Consortium, resulted in major knowledge about the groundnut genome, which aided the deployment of molecular markers in breeding projects [1,70,99,163,182]. In addition to yield increase, cultivar development was geared towards traits as resistance to drought, aflatoxin resistance and foliar diseases, and seed quality and nutrient content [105,186,187]. The ICRISAT Headquarters (India) and its derivative research centres in Africa have been leading groundnut research programmes for decades, based on consumer and farmer preferences in semi-arid regions [186], thus providing some of the most significant impact on the crop production in Africa and Asia [186]. ICRISAT together with national partners have released near 200 improved ICRISAT-bred cultivars in 36 countries since 1986 [105]. In China, the world leading groundnut producer country, the breeding efforts using conventional and advanced methods, resulted in the release of more than 400 varieties in about 70 years [105]. In the USA, several university-based research teams (Georgia, Texas, and Auburn) conduct state-of-the-art research and breeding for traits of commercial importance [135,154,188,189]. Some of these research programmes overlap with breeding activities in national agricultural research systems (NARS) across Africa.

Although noticeable progress has been recorded in recent years [186], groundnut research has been comparatively trivial in many African NARS [69]. In Burkina Faso and other countries in West Africa, groundnut breeding operates to satisfy uneven environments and diverse stakeholders with low uptake of agricultural technologies [55,190]. To succeed cultivar development in such a context, design and implementation of trials must take into consideration the huge gap that often exists between optimum on-station conditions and irregular farmer field settings. This may result in increased costs due to the need for high numbers of field trials.

Additionally, the implementation of a modern breeding programme requires expertise, infrastructure, equipment, all of which requires a higher level of investment. To assess the benefit and ultimate value of implementing a new approach, technology, or tool, a cost-benefit analysis can be performed to provide justification for the additional expenditures. Furthermore, with or without further investment, other factors can go a long way to build in greater efficiencies in cultivar development: outsourcing some activities requiring special equipment or expertise (e.g., genotyping), establishing research networks to better leverage available resources and data, and forging partnerships with the private sector.

The lack of sustained funding and over-dependency on donors [64] restraints possibilities to implement long term view and renders the programme vulnerable to funding inconsistencies and abrupt changes in research agenda and vision. Therefore, efforts must be put into igniting government
commitment to research for food and nutritional security in the country. Policy makers and those in the groundnut value chain must be made aware of possibilities and challenges if groundnut production is to impact national nutrition and trade and draw support from the private sector.

Ultimately, private sector intervention is probably the way forward to dependably invest substantial funding in the crop breeding and bring better governance in the breeding programme. The groundnut industry could be inspired by successful examples of private agricultural research in Burkina Faso and elsewhere, driven by cash crops such as cotton, banana and oil palm [64,191,192].

10. Conclusions

Groundnut production and genetic improvement in Burkina Faso has stagnated for too long. In the absence of a strong national program, research in the country has centred on evaluations of lines developed at international research institutes and programmes such as IRHO, ICRISAT and Peanut CRSP. However, lines from international institutions may have limited alignment with domestic product targets and fail to deliver adaptation under local conditions required for high yield. For best adaptability of cultivars to local conditions and national stakeholder needs, a strong national breeding programme built on the foundation of local germplasm collection must be the driver.

Most of the issues discussed in this review are applicable to many other national agricultural research programmes in sub-Saharan or West Africa. The scientific strength of breeding programmes requires expertise in plant breeding and genetics (i.e., at least two full-time PhD scientists per crop species [55]) as well as support in related disciplines important for groundnut improvement, viz. entomology, agronomy, weed science, pathology [55,69]. We contend that it is possible to significantly increase groundnut production and productivity through dedication of a strong local breeding programme which takes advantage of improved lines from international research institutions and modern breeding approaches, technologies and tools to develop locally adapted, high-yielding varieties with desirable traits. To this extent, strategies to accelerate genetic gain need to be adopted, along with gender integration in the entire crop development and value chain. Building technical and infrastructure capacities of the national breeding programme is needed to achieve such a research level and to expedite delivery of improved groundnut varieties to modern and smallholder farmers.

Author Contributions: M.K. wrote the first draft and incorporated the inputs from the co-authors and comments of editors. J.S., A.M., D.K.O., H.D., P.J. and R.H.M. reviewed the first draft and made inputs to improve the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding and the APC was funded by authors.

Acknowledgments: This review was facilitated by INERA (Institute of Environment and Agriculture Research, Burkina Faso), AIPPA-AOCC (African Plant Breeding Academy and African Orphan Crops Consortium) and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics).

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

References

1. Bertioli, D.J.; Jenkins, J.; Clevenger, J.; Dudchenko, O.; Gao, D.; Seijo, G.; Leal-Bertioli, S.C.M.; Ren, L.; Farmer, A.D.; Pandey, M.K.; et al. The genome sequence of segmental allotetraploid peanut arachis hypogaea. Nat. Genet. 2019, 51, 877–884. [CrossRef] [PubMed]
2. Valls, J.F.; Simpson, C.E. New species of arachis (leguminosae) from brazil, paraguay and bolivia. Bonplandia 2005, 14, 35–63. [CrossRef]
3. Stalker, H.T. Peanut (Arachis hypogaea L.). Field Crops Res. 1997, 53, 205–217. [CrossRef]
4. FAO Food and Agricultural Commodities Production. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 30 March 2020).
5. Tyroler, C. Gender Considerations for Researchers Working in Groundnuts; USAID—Feed The Future: Washington, DC, USA, 2018; p. 32.
6. Santara, I.; Mas Aparisi, A.; Balié, J. Analyse des Incitations et Pénalisations Pour L’arachide au Burkina Faso; FAO: Rome, Italy, 2013; p. 37.
7. Varshney, R.K.; Ribaut, J.-M.; Buckler, E.S.; Tuberosa, R.; Rafalski, J.A.; Langridge, P. Can genomics boost productivity of orphan crops? *Nat. Biotechnol.* 2012, 30, 1172–1176. [CrossRef]

8. Ndjeunga, J.; Ibro, A.; Cisse, Y.; Ben Ahmed, M.I.; Moutari, A.; Kodio, O.; Echekwu, C. Characterizing Village Economies in Major Groundnut Producing Countries in West Africa: Cases of Mali, Niger and Nigeria; ICRISAT: Hyderabad, India, 2010; p. 89.

9. Feldstein, H.S.; Butler Flora, C.; Poats, S.V. *Gender Variable in Agricultural Research*; International Development Research Centre: Ottawa, ON, Canada, 1989.

10. Subrahmanyam, P.; Bosc, J.P.; Hassane, H.; Smith, D.H.; Mounkaila, A.; Ndunguru, B.J.; Sankara, P. Les maladies de l’arachide au niger et au burkina faso. *Oéagineux* 1992, 47, 119–133.

11. Alper, C.M.; Mattes, R.D. Peanut consumption improves indices of cardiovascular disease risk in healthy adults. *J. Am. Coll. Nutr.* 2003, 22, 133–141. [CrossRef]

12. Francisco, M.L.D.L.; Resurreccion, A.V. *Functional components in peanuts.* *Crit. Rev. Food Sci. Nutr.* 2008, 48, 715–746. [CrossRef]

13. Jibrin, M.; Habu, S.; Echekwu, C.; Abdullahi, U.; Usman, I. Phenotypic and genotypic variance and heritability estimates for oil content and other agronomic traits in groundnut (*Arachis hypogaea* L.). *Int. J. Sci. Res. Eng. Stud.* 2016, 3, 29–32.

14. Hamidou, F.; Harou, A.; Achiou, B.; Halilou, O.; Bakasso, Y. Nitrogen fixation by groundnut and cowpea for productivity improvement in drought conditions in the sahel. *Tropicultura* 2018, 36, 63–79.

15. Ranganayakulu, G.S.; Chandraobulreddy, P.; Thippeswamy, M.; Veeranagamallaiah, G.; Sudhakar, C. Identification of drought stress-responsive genes from drought-tolerant groundnut cultivar (*Arachis hypogaea* L. Cv k-134) through analysis of subtracted expressed sequence tags. *Acta Physiol. Plant.* 2012, 34, 361–377. [CrossRef]

16. Blummel, M.; Ratnakumar, P.; Vadez, V. Opportunities for exploiting variations in haulm fodder traits of intermittent drought tolerant lines in a reference collection of groundnut (*Arachis hypogaea L.*). *Field Crop. Res.* 2012, 126, 200–206. [CrossRef]

17. Desmae, H.; Sones, K. *Groundnut Cropping Guide*; Africa Soil Health Consortium: Nairobi, Kenya, 2017.

18. Njuki, J.; Kaaria, S.; Chamunorwa, A.; Chiuri, W. Linking smallholder farmers to markets, gender and intra-household dynamics: Does the choice of commodity matter? *Eur. J. Dev. Res.* 2011, 23, 426–443. [CrossRef]

19. Narh, S.; Boote, K.J.; Naab, J.B.; Abudulai, M.; M’Bi Bertin, Z.; Sankara, P.; Burow, M.D.; Tillman, B.L.; Brandenburg, R.L.; Jordan, D.L. Yield improvement and genotype x environment analyses of peanut cultivars in multislocation trials in west africa. *Crop Sci.* 2014, 54, 2413–2422. [CrossRef]

20. USDA. *Quick Stats*; US Department of Agriculture: Washington, DC, USA, 2019.

21. Zongo, A.; Khera, P.; Sawadogo, M.; Shasidhar, Y.; Sriswathi, M.; Vishwakarma, M.K.; Sankara, P.; Ntare, B.R.; Varshney, R.K.; Pandey, M.K.; et al. Ssr markers associated to early leaf spot disease resistance through selective genotyping and single marker analysis in groundnut (*Arachis hypogaea L.*). *Biotechnol. Rep.* 2017, 15, 132–137. [CrossRef]

22. Anonymous. Development of rainfed agriculture in the sahel: Overview and prospects. In Proceedings of the Fifth Conference of the Club du Sahel, Brussels, Belgium, 26–28 October 1983; Sahel, C.D., Ed.; CILSS: Ouagadougou, Burkina Faso, 1983.

23. Morris, W.H.M. *Production, commercialisation et exportation de l’arachide: Senegal, gambie, mali, burkina faso et niger*; Peanut CRSP: Griffins, GA, USA, 2020. Available online: https://pdf.usaid.gov/pdf_docs/PNABM077.pdf (accessed on 13 May 2020).

24. MAFAP. *Revue des Politiques Agricoles et Alimentaires au Burkina Faso*; SPAAA, Ed.; FAO: Rome, Italy, 2013.

25. Islesb, T.; Wynne, J.; Nigam, S. Groundnut breeding. In *The Groundnut Crop*; Springer: Berlin/Heidelberg, Germany, 1994; pp. 552–623.

26. Neya, F.B.; Sanon, E.; Koita, K.; Zagre, B.M.b.; Sankara, P. Diallel analysis of pod yield and 100 seeds weight in peanut (*Arachis hypogaea L.*) using griffing and hayman methods. *J. Appl. Biosci.* 2017, 116, 11619–11627. [CrossRef]

27. Zongo, A.; Konate, A.K.; Koita, K.; Sawadogo, M.; Sankara, P.; Ntare, B.R.; Desmae, H. Diallel analysis of early leaf spot (cercospora arachidicola hori) disease resistance in groundnut. *Agronomy* 2019, 9, 15. [CrossRef]
28. Zongo, A.; Nana, A.; Sawadogo, M.; Konate, A.; Sankara, P.; Ntare, B.; Desmae, H. Variability and correlations among groundnut populations for early leaf spot, pod yield, and agronomic traits. *Agronomy* 2017, 7, 52. [CrossRef]

29. CRSP, P. Annual Report of the Peanut Collaborative Research Support Program (Crsp); University of Georgia: Athens, GA, USA, 1983; p. 231.

30. Gapasin, D.; Cherry, J.; Gilbert, J.; Gibbons, R.; Hildebrand, G.; Nelson, D.; Valentine, H.; Williamson, H. The Peanut Collaborative Research Support Program (Crsp); University of Georgia: Athens, GA, USA, 2005; p. 359.

31. Dalton, T.J.; Cardwell, K.; Katsvairo, T. The Peanut Collaborative Research Support Program: A Report Submitted to the Bureau of Food Security, Usaid; USAID: Washington, DC, USA, 2012; p. 56.

32. Swindell, K. Serawoollies, tillibunkas and strange farmers: The development of migrant groundnut farming along the gambia river, 1848–1895. *J. Afr. Hist.* 1980, 21, 93–104. [CrossRef]

33. Brooks, G.E. Peanuts and colonialism: Consequences of the commercialization of peanuts in west africa, 1830–1870. *J. Afr. Hist.* 1975, 16, 29–54. [CrossRef]

34. Anonymous. L’ économie de la Haute Volta. Available online: https://clubjosephkizerbo.blog4ever.com/l-economie-de-la-haute-volta (accessed on 17 July 2019).

35. Anonymous. *Histoire du Burkina du 19e Siècle à Nos Jours*; Eurêka: Brussels, Belgium, 1996; p. 20.

36. IRHO. *L’arachide: Principaux Resultats Obtenus en Experimentation*; Institut de Recherches Pour les Huiles et Oleagineux (IRHO): Station de Niangoloko, Haute-Volta, 1964; p. 13.

37. Gbikpi, P. *L’agriculture Burkinabe*; Ministère de L’agriculture et des Ressources Animales: Luanda, Angola, 1996.

38. Stads, G.-J.; Boro, S.I. Indicateurs relatifs aux sciences et technologies agricoles, Burkina Faso. In *Abrégé l’ASTI*; INERA-IFPRI, Ed.; IFPRI: Washington, DC, USA, 2004; p. 10.

39. Umeh, V.; Youm, O.; Waliyar, F. Soil pests of groundnut in sub-Saharan Africa—A review. *Int. J. Trop. Insect Sci.* 2001, 21, 23–32. [CrossRef]

40. Barandao, A. Étude de Faisabilité Technico-Economique Pour L’implantation D’une Unité de Production de Plumpy’nut à Kongoussi. Ph.D. Thesis, EIER-ETSHER, Ouagadougou, Burkina Faso, 2006.

41. Volper, S.; Bichat, H. Des jardins d’essai au cirad: Une épopée scientifique française. In *Un Parcours Dans les Mondes de la Recherche Agronomique. L’Inra et le Cirad*; CNRS: Paris, France, 2014; Volume 3, pp. 113–124.

42. Tourte, R. *Histoire de la Recherche Agricole en Afrique Tropicale Francophone*; Organisation des Nations Unies pour L’alimentation et L’agriculture: Rome, Italy, 2005.

43. Surre, C. *L’institut de Recherches Pour les Huiles et Oleagineux: 1942–1984*; CIRAD: Paris, France, 1993.

44. Sauger, L.; Catherinet, M.; Durand, Y. Contribution a l’étude de la rosette chlorotique de l’arachide. *Bull. Agron. Minist. Fr. Outremer* 1954, 13, 163–180.

45. Nigam, S.; Dwivedi, S.; Gibbons, R. Groundnut breeding: Constraints, achievements and future possibilities. In *Plant Breeding Abstracts*; CAB International: Wallingford, UK, 1991; pp. 1127–1136.

46. Matlon, P.; Cantrell, R.; King, D.; Benoit-Cattin, M. *Coming Full Circle: Farmers’ Participation in the Development of Technology*; IDRC: Ottawa, ON, Canada, 1984.

47. Desmae, H.; Janila, P.; Okori, P.; Pandey, M.K.; Motagi, B.N.; Monyo, E.; Mponda, O.; Okello, D.; Sako, D.; Echeckwui, C.; et al. Genetics, genomics and breeding of groundnut (*Arachis hypogaea L*). *Plant Breed.* 2019, 138, 425–444. [CrossRef] [PubMed]

48. Amin, P.; Singh, K.; Dwivedi, S.; Rao, V. Sources of resistance to the jassid (empoasca kerri pruthi), thrips (frankliniella schultzei (trybom)) and termites (odontotermes sp.) in groundnut (*Arachis hypogaea L*). *Peanut Sci.* 1985, 12, 58–60. [CrossRef]

49. ICRISAT. Resistance to Soil-borne Diseases of Legumes. In Proceedings of the Consultants’ Group Discussion on the Resistance to Soil-Borne Diseases of Legumes, Patancheru, India, 8–11 January 1979; Nene, Y.L., Ed.; ICRISAT: Patancheru, India, 1979; p. 180.

50. Upadhyaya, H.D.; Nigam, S.N.; Mehan, V.K.; Lenne, J.M. Aflatoxin contamination of groundnut: Prospects for a genetic solution through conventional breeding. In *Proceedings of the First Asia Working Group Meeting*, Hanoi, Vietnam, 27–29 May 1996; Mehan, V.K., Gowda, C.L.L., Eds.; International Crops Research Institute for the Semi-Arid Tropics: Hanoi, Vietnam, 1997; pp. 81–85.
51. Upadhyaya, H.; Nigam, S.; Thakur, R. Genetic Enhancement for Resistance to Aflatoxin Contamination in Groundnut. In *Summary proceedings of the Seventh ICRISAT Regional Groundnut Meeting for Western and Central Africa*; ICRISAT: Cotonou, Benin, 2002; pp. 29–36.

52. Waliyar, F.; Bockeelé-Morvan, A. Resistance of groundnut varieties to aspergillus flavus in senegal. In *International Workshop on Aflatoxin Contamination of Groundnut, Patancheru, Andhra Pradesh, India, 1989*; Hall, S.D., Ed.; ICRISAT: Andhra Pradesh, India, 1989; p. 426.

53. Nigam, S.N.; Waliyar, F.; Aruna, R.; Reddy, S.V.; Kumar, P.L.; Craufurd, P.Q.; Diallo, A.T.; Ndabar, B.R.; Upadhyaya, H.D. Breeding peanut for resistance to aflatoxin contamination at icrisat. *Peasant Sci.* 2009, 36, 42–49. [CrossRef]

54. World-Bank. *Upper Volta—Agricultural Issues Study*; 3296; World Bank: Washington, DC, USA, 1982; p. 267.

55. Ndjeunga, J.; Manusch, K.; Simtowe, F. Assessing the effectiveness of agricultural r&d for groundnut, pearl millet, pigeonpea, and sorghum in west and central africa and east and southern africa. In *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*; Walker, T.S., Alwang, J., Eds.; CGIAR and CAB international: Wallingford, UK, 2015; chapter 7; pp. 123–147.

56. INERA. *Productions Scientifiques et Techniques des Chercheurs de L’inera (1990–2012)*; INERA: Ouagadougou, Burkina Faso, 2012; p. 97.

57. Germani, G. *Etude Nématologique de Deux Affections de L’arachide en Haute-Volta: La Chlorose et le Clump*; Office de la Recherche Scientifique et Technique D’outre—Mer (ORSTOM): Abidjan, Adiopodoumé, 1973; p. 31.

58. Picasso, C. *Evolution des rendements et de ses composantes pour l’arachide et quelques cultures en rotation dans le sud du burkina faso*. *Oléagineux* 1987, 42, 469–474.

59. Gillier, P.; Silvestre, P. *L’arachide*; Maisonnuvee et Larose: Paris, France, 1969.

60. CNS. *Catalogue National des Especes et Varietes Agricoles du Burkina Faso*; Semences, C.N.S., Ed.; CNS: Ouagadougou, Burkina Faso, 2014; p. 81.

61. Mayeux, A.H.; F, W.; R, N.B. *Groundnut Germplasm Project*; ICRISAT: Andhra Pradesh, India, 2003; p. 78.

62. Anonymous. *Catalogue Régional des Espèces et Variétés Végétales Cedeao-Uemoa-Cilss: Variétés Homologuées 2016–2018*; CORAF, Ed.; CORAF: Dakar, Senegal, 2019.

63. ASTI. *Cgiar’s Diiva Project*; A Consolidated Database of Crop Varietal Releases, Adoption, and Research Capacity in Africa South of the Sahara; CGIAR: Montpellier, France, 2017.

64. Hollinger, F.; Staatz, J.M. *Croissance Agricole en Afrique de L’ouest: Facteurs Déterminants de Marché et de Politique; L’organisation des Nations Unies Pour L’alimentation et L’agriculture*; Rome, Italy, 2015.

65. Stads, G.-J.; Kabore, S.S. *Burkina Faso: Évaluation de la Recherche Agricole*; IFPRI: Roma, Italy, 2010.

66. INERA. *Institut de L’environement et de Recherches Agricoles: Bilan de 10 Annees de Recherche 1988–1998*; CNRST/INERA: Stockholm, Sweden, 2006; p. 122.

67. Miningou, A.; Sawadogo, E.; Barry, S.; Traore, S.A. *Final Narrative Report on Groundnut 2018 TL III/Burkina Faso*; INERA: Stockholm, Sweden, 2019; p. 28.

68. Cobb, J.N.; Juma, R.U.; Biswas, P.S.; Arbelaez, J.D.; Rutkoski, J.; Atlin, G.; Hagen, T.; Quinn, M.; Ng, E.H. Enhancing the rate of genetic gain in public-sector plant breeding programs: Lessons from the breeder’s equation. *Theor. Appl. Genet.* 2019, 132, 627–645. [CrossRef]

69. Abady, S.; Shimelis, H.; Janila, P.; Mashilo, J. *Groundnut (Arachis hypogaea L.) improvement in sub-saharan africa: A review*. *Acta Agric. Scand. Sect. B Soil Plant Sci.* 2019, 69, 528–545. [CrossRef]

70. Janila, P.; Variath, M.T.; Pandey, M.K.; Motagi, B.N.; Okori, P.; Manohar, S.S.; Rathnakumar, A.L.; Radhakrishnan, T.; Liao, B.; et al. Genomic tools in groundnut breeding program: Status and perspectives. *Front. Plant Sci.* 2016, 7, 289. [CrossRef]

71. Mumm, R.; Danquah, E. The state of soybean in africa: The african plant breeders of tomorrow. *Farmdoc Daily* 2019, 9, 15116–15120.

72. Mumm, R.H.; Howard-Yana, S.; Danquah, E.Y.; Van Deyneze, A.; Edema, R.; Achigan-Dako, E.G.; Suza, W.P.; Madakadze, R.M. Aiming for excellence in training and sustaining african plant breeders. In *Crop Improvement and Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*; Walker, T.S., Alwang, J., Eds.; CGIAR and CAB international: Wallingford, UK, 2015; chapter 7; pp. 123–147.
75. FAO. *Worldwide Regulations for Mycotoxins in Food and Feed in 2003;* 92-5-105162-3; Food and Agriculture Organisation of the United Nations: Rome, Italy, 2004.

76. CCIB. *Donnees Ceb 2018;* Chambre de Commerce et d’Industrie du Burkina Faso: Ouagadougou, Burkina Faso, 2018.

77. van Ittersum, M.K.; Cassman, K.G.; Grassini, P.; Wolf, J.; Tittonell, P.; Hochman, Z. Yield gap analysis with local to global relevance—A review. *Field Crop. Res.* 2013, 143, 4–17. [CrossRef]

78. Lobell, D.B.; Cassman, K.G.; Field, C.B. Crop yield gaps: Their importance, magnitudes, and causes. *Annu. Rev. Environ. Resour.* 2009, 34, 179–204. [CrossRef]

79. KPR, V.; Sankar, G.M.; HP, S.; Balaguravaiah, D.; Padmalatha, Y. Modeling sustainability of crop yield in rainfed groundnut based on rainfall and land degradation. *Indian J. Dryland Agric. Res. Dev.* 2003, 13, 7–13.

80. Camberlin, P.; Diop, M. Inter-relationships between groundnut yield in Senegal, interannual rainfall variability and sea-surface temperatures. *Theor. Appl. Climatol.* 1999, 63, 163–181. [CrossRef]

81. Janila, P.; Nigam, S.N. Phenotyping for groundnut (*Arachis hypogaea* L.) improvement. In *Phenotyping for Plant Breeding: Applications of Phenotyping Methods for Crop Improvement*; Panguluri, S.K., Kumar, A.A., Eds.; Springer: New York, NY, USA, 2013; pp. 129–167.

82. Stoop, W.A. Variations in soil properties along three toposequences in Burkina Faso and implications for the development of improved cropping systems. *Agric. Ecosyst. Environ.* 1987, 19, 241–264. [CrossRef]

83. Parker, M.B.; Walker, M.E. Soil ph and manganese effects on manganese nutrition of peanut. *Agron. J.* 1986, 78, 614–620. [CrossRef]

84. Coulibaly, P.J.d.A.; Okae-anti, D.; Ouattara, B.; Sawadogo, J.; Sedogo, M.P. Effect of Dry Cropping Season of Sorghum on Selected Physico-Chemical Properties in West Africa. *Int. J. Agric. Innov. Res.* 2018, 7, 192–196.

85. Gibbons, R.; Mertin, J. *Abstracts in English and French of the International Workshop on Groundnuts 13-17 October 1980;* ICRISAT: Andhra Pradesh, India, 1981.

86. Bonkoungou, S. Distribution Géographique et Quelques Aspects Ecologiques des Virus du Clump et de la Rosette de L’arachide au Burkina Faso. Ph.D. Thesis, Universite de Dschang, Dschang, Cameroun, 2001.

87. De Berchoux, C. La rosette de l’arachide en haute-volta comportement des lignées résistantes. *Oléagineux* 1960, 15, 229–233.

88. Dubern, J. *La Rosette Chlorotique de L’arachide: Contribution à L’étude de la Transmission Par Aphis Craccivora Koch;* ORSTOM: Adiopodoume, Cote d’Ivoire, 1977; p. 16.

89. Naidu, R.; Kimmins, F.; Deom, C.; Subrahmanyam, P.; Chiyembekeza, A.; Van der Merwe, P. Groundnut rossette: A virus disease affecting groundnut production in sub-saharan africa. *Plant Dis.* 1999, 83, 700–709.

90. Nigam, S.; Prasada Rao, R.; Bhatnagar-Mathur, P.; Sharma, K. Genetic management of virus diseases in peanut. *Plant Breed. Rev.* 2012, 36, 293.

91. Wightman, J.; Rao, G.R. Groundnut pests. In *The Groundnut Crop*; Springer: Berlin/Heidelberg, Germany, 1994; pp. 395–479.

92. Janila, P.; Nigam, S.N.; Pandey, M.K.; Nagesh, P.; Varshney, R. Groundnut improvement: Use of genetic and genomic tools. *Front. Plant Sci.* 2013, 4, 23. [CrossRef] [PubMed]

93. Janila, P.; Nigam, S.N.; Pandey, M.K.; Nagesh, P.; Varshney, R. Groundnut improvement: Use of genetic and genomic tools. *Front. Plant Sci.* 2013, 4, 23. [CrossRef] [PubMed]

94. Persley, G.J.; Anthony, V.M. *The Business of Plant Breeding: Market-Led Approaches to New Variety Design in Africa;* CABI: Wallingford, UK, 2017.

95. Persley, G.J.; Anthony, V.M. *The Business of Plant Breeding: Market-Led Approaches to New Variety Design in Africa;* CABI: Wallingford, UK, 2017.

96. Dorner, J.W. Management and prevention of mycotoxins in peanuts. *Food Addit. Contam. Part A* 2008, 25, 203–208. [CrossRef] [PubMed]

97. Christèle, I-V.; Laurencia, O.; Sylvie, A.; Hounhouigan, J.; Polycarpe, K.; Waliou, A.; Hama, F.B. *Traditional Recipes of Millet, Sorghum-and Maize-Based Dishes and Related Sauces Frequently Consumed by Young Children in Burkina Faso and Benin;* Wageningen University Publisher: Wageningen, The Netherlands, 2010.

98. Ayensu, D.A. *The Art of West African Cooking,* 1st ed.; Doubleday: New York, NY, USA, 1972; p. 145.

99. Chen, X.; Lu, Q.; Liu, H.; Zhang, J.; Hong, Y.; Lan, H.; Li, H.; Wang, J.; Liu, H.; Li, S.; et al. Sequencing of cultivated peanut, arachis hypogaea, yields insights into genome evolution and oil improvement. *Mol. Plant* 2019, 12, 920–934. [CrossRef]
100. Varshney, R.K. Exciting journey of 10 years from genomes to fields and markets: Some success stories of genomics-assisted breeding in chickpea, pigeonpea and groundnut. *Plant Sci.* 2016, 242, 98–107. [CrossRef]

101. Bolton, G.E.; Sanders, T.H. Effect of roasting oil composition on the stability of roasted high-oleic peanuts. *J. Am. Oil Chem. Soc.* 2002, 79, 129–132. [CrossRef]

102. Vassiliou, E.K.; Gonzalez, A.; Garcia, C.; Tadros, J.H.; Chakraborty, G.; Toney, J.H. Oleic acid and peanut oil high in oleic acid reverse the inhibitory effect of insulin production of the inflammatory cytokine tnf-α both in vitro and in vivo systems. *Lipids Health Dis.* 2009, 8, 25. [CrossRef]

103. O’Byrne, D.J.; Knauf, D.A.; Shireman, R.B. Low fat-monounsaturated rich diets containing high-oleic peanuts improve serum lipoprotein profiles. *Lipids 1997*, 32, 687–695. [CrossRef]

104. Rizzo, W.B.; Watkins, P.A.; Phillips, M.W.; Cranin, D.; Campbell, B.; Avigan, J. Adrenoleukodystrophy: Oleic acid lowers fibroblast saturated c22–26 fatty acids. *Neurology 1986*, 36, 357–361. [CrossRef]

105. Holbrook, C.C.; Burow, M.D.; Chen, C.Y.; Pandey, M.K.; Liu, L.; Chagoya, J.C.; Chu, Y.; Ozias-Akins, P. Chapter 4—Recent advances in peanut breeding and genetics. In *Peanuts*; Stalker, H.T., Wilson, R., Eds.; AOCS Press: Urbana, IL, USA, 2016; pp. 111–145.

106. Rao, V.R.; Murty, U. Botany—Morphology and anatomy. In *The Groundnut Crop*; Springer: Berlin/Heidelberg, Germany, 1994; pp. 43–95.

107. Nigam, S.N.; Chandra, S.; Sridevi, K.R.; Bhukta, M.; Reddy, A.G.S.; Rachaputi, N.R.; Wright, G.C.; Reddy, P.V.; Deshmukh, M.P.; Mathur, R.K.; et al. Efficiency of physiological trait-based and empirical selection approaches for drought tolerance in groundnut. *Ann. Appl. Biol.* 2005, 146, 433–439. [CrossRef]

108. Ntare, B.R.; Williams, J.H.; Dougbedji, F. Evaluation of groundnut genotypes for heat tolerance under field conditions in a sahelian environment using a simple physiological model for yield. *J. Agric. Sci.* 2001, 136, 81–88. [CrossRef]

109. ICRISAT. Smart Food. Available online: https://www.smartfood.org/why-smartfood-2/ (accessed on 25 August 2019).

110. Nutriset Plumpy’nut® et le Modèle Cmam: Comment la r&d de Nutriset a Contribué à Transformer le Traitement de la Malnutrition Aiguë Sévère. Available online: https://www.nutriset.fr/articles/fr/plumpynut-et-le-modele-cmam-contribution-de-la-recherche-et-developpement-de-nutriset (accessed on 25 July 2019).

111. Tidey, C. *Teaming up to Turn the Tide against Malnutrition in Niger*; UNICEF: New York, NY, USA, 2012.

112. Bloemen, S. *Des Solutions Locales Pour Répondre à Une Crise Alimentaire Régionale*; UNICEF: New York, NY, USA, 2013.

113. WHO. *Worldwide Prevalence of Anaemia 1993-2005: World Global Database of Anaemia*; World Health Organization: Geneva, Switzerland, 2008; p. 51.

114. Gödecke, T.; Stein, A.J.; Quim, M. The global burden of chronic and hidden hunger: Trends and determinants. *Glob. Food Secur.* 2018, 17, 21–29. [CrossRef]

115. von Grebmer, K.; Saltzman, A.; Birol, E.; Wiesman, D.; Prasai, N.; Yohannes, Y.; Menon, P.; Thompson, J.; Sonntag, A. 2014 *Global Hunger Index: The Challenge of Hidden Hunger*; Welthungerhilfe, IFPRI, Concern Worldwide: Washington, DC, USA, 2014; p. 56.

116. Janila, P.; Nigam, S.N.; Abhishek, R.; Anil Kumar, V.; Manohar, S.S.; Venuprasad, R. Iron and zinc concentrations in peanut (*Arachis hypogaea* L.) seeds and their relationship with other nutritional and yield parameters. *J. Agric. Sci.* 2014, 153, 975–994. [CrossRef]

117. Cook, B.; Crosswhaite, I. Utilization of arachis species as forage. In *The Groundnut Crop*; Springer: Berlin/Heidelberg, Germany, 1994; pp. 624–663.

118. Orsini, F.; Kahane, R.; Nono-Womdim, R.; Gianquinto, G. Urban agriculture in the developing world: A review. *Agron. Sustain. Dev.* 2013, 33, 695–720. [CrossRef]

119. Ayantunde, A.A.; Blummel, M.; Grings, E.; Duncan, A.J. Price and quality of livestock feeds in urban markets of west africa’s sahel: Case study from bamako, mali. *Revue D’élevage Medecine Veterinaire Pays Tropicaux 2014*, 67, 13–21. [CrossRef]

120. Moretzsohn, M.C.; Gouvea, E.G.; Inglis, P.W.; Leal-Bertioli, S.C.; Valls, J.F.; Bertioli, D.J. A study of the relationships of cultivated peanut (*Arachis hypogaea*) and its most closely related wild species using intron sequences and microsatellite markers. *Ann. Bot.* 2012, 111, 113–126. [CrossRef]

121. Stalker, H.T.; Tallury, S.P.; Seijo, G.R.; Leal-Bertioli, S.C. Chapter 2—Biology, speciation, and utilization of peanut species. In *Peanuts*; Stalker, H.T., Wilson, R., Eds.; AOCS Press: Urbana, IL, USA, 2016; pp. 27–66.
122. Foncêka, D.; Hodo-Abalo, T.; Rivallan, R.; Faye, I.; Sall, M.N.; Ndoye, O.; Fávero, A.P.; Bertioli, D.J.; Glassmann, J.-C.; Courtois, B.; et al. Genetic mapping of wild introgressions into cultivated peanut: A way toward enlarging the genetic basis of a recent allotetraploid. *BMC Plant Biol.* 2009, 9, 103. [CrossRef]

123. Knauft, D.A.; Wynne, J.C. Peanut breeding and genetics. In *Advances in Agronomy*; Sparks, D.L., Ed.; Academic Press: Cambridge, MA, USA, 1995; Volume 55, pp. 393–445.

124. Abdou, Y.A.-M.; Gregory, W.C.; Cooper, W.E. Sources and nature of resistance to cercospora arachidicola hori and cercosporidium personatum (beek & curtis) deighton in arachis species. *Peanut Sci.* 1974, 1, 6–11.

125. Mallikarjuna, N.; Senthilvel, S.; Hoisington, D. Development of new sources of tetraploid arachis to broaden the genetic base of cultivated groundnut (*Arachis hypogaea L.*). *Genet. Resour. Crop Evol.* 2011, 58, 889–907. [CrossRef]

126. Janila, P.; Ramaiah, V.; Rathore, A.; Rupakula, A.; Reddy, R.K.; Waliyar, F.; Nigam, S.N. Genetic analysis of resistance to late leaf spot in interspecific groundnuts. *Euphytica* 2013, 193, 13–25.

127. Correa, C.M. Considerations on the standard material transfer agreement under the fao treaty on plant genetic resources for food and agriculture. *J. World Intellect. Prop.* 2006, 9, 137–165. [CrossRef]

128. Moose, S.P.; Mumm, R.H. Molecular plant breeding as the foundation for 21st century crop improvement. *Plant Physiol.* 2008, 147, 969–977. [CrossRef]

129. Lush, J.L. Animal Breeding Plans; Read Books Ltd.: Redditch, UK, 1937.

130. Eberhart, S. Factors effecting efficiencies of breeding methods. *Afr. Soils Sci.* 1970, 15, 655–680.

131. Heffner, E.L.; Lorenz, A.J.; Jannink, J.-L.; Sorrells, M.E. Plant breeding with genomic selection: Gain per unit time and cost. *Crop Sci.* 2010, 50, 1681–1690. [CrossRef]

132. Bera, S.; Bhattacharya, A.; Bhatt, O. In vitro callogenesis and plant regeneration from anther culture in groundnut (*Arachis hypogaea L.*). *J. Plant Genet. Resour.* 2007, 20, 118–121.

133. Maluszynski, M.; Kashu, K.J.; Szarejko, I. Published doubled haploid protocols in plant species. In *Doubled Haploid Production in Crop Plants: A Manual*; Maluszynski, M., Kashu, K.J., Forster, B.P., Szarejko, I., Eds.; Springer: Dordrecht, The Netherlands, 2003; pp. 309–335.

134. Gunasekaran, A.; Pavadai, P. Studies on induced physical and chemical mutagenesis in groundnut (*Arachis hypogaea*). *Int. Lett. Nat. Sci.* 2015, 8, 25–35. [CrossRef]

135. Knoll, J.E.; Ramos, M.L.; Zeng, Y.; Holbrook, C.C.; Chow, M.; Chen, S.; Maleki, S.; Bhattacharya, A.; Ozias-Akins, P. Tilling for allergen reduction and improvement of quality traits in peanut (*Arachis hypogaea L.*). *BMC Plant Biol.* 2011, 11, 81. [CrossRef]

136. Mensah, J.; Obadoni, B. Effects of sodium azide on yield parameters of groundnut (*Arachis hypogaea L.*). *Afr. J. Biotechnol.* 2007, 6, 668–671.

137. Busolo-Bulafu, C.M. *Mutation Breeding of Groundnuts (Arachis hypogaea L.) in Uganda*; IAEA: Vienna, Austria, 1991.

138. Tshilenge-Lukanda, L.; Mukendi-Tshibingu, R.; Kalonji-Mbuyi, A.; Nkongolo, K.; Kizungu, R.E. Radio-sensitivity of some groundnut (*Arachis hypogaea L.*) genotypes to gamma irradiation: Indices for use as improvement. *Br. J. Biotechnol.* 2012, 3, 169–178. [CrossRef]

139. Tshilenge-Lukanda, L.; Funny-Biola, C.; Tshiyouyi-Mpunga, A.; Mudibu, J.; Ngoie-Lubwika, M.; Mukendi-Tshibingu, R.; Kalonji-Mbuyi, A. Radio-sensitivity of some groundnut (*Arachis hypogaea L.*) genotypes to gamma irradiation: Indices for use as improvement. *Br. J. Biotechnol.* 2012, 3, 169–178. [CrossRef]

140. Tshilenge-Lukanda, L.; Funny-Biola, C.; Tshiyouyi-Mpunga, A.; Mudibu, J.; Ngoie-Lubwika, M.; Mukendi-Tshibingu, R.; Kalonji-Mbuyi, A. Radio-sensitivity of some groundnut (*Arachis hypogaea L.*) genotypes to gamma irradiation: Indices for use as improvement. *Br. J. Biotechnol.* 2012, 3, 169–178. [CrossRef]

141. Fountain, J.C.; Khera, D.; Yang, L.; Nayak, S.N.; Scully, B.T.; Lee, R.D.; Chen, Z.-Y.; Kemerait, R.C.; Varshney, R.K.; Guo, B. Resistance to aspergillus flavus in maize and peanut: Molecular biology, breeding, environmental stress, and future perspectives. *Crop J.* 2015, 3, 229–237. [CrossRef]

142. Torres, A.M.; Barros, G.G.; Palacios, S.A.; Chulze, S.N.; Battilani, P. Review on pre and post-harvest management of peanuts to minimize aflatoxin contamination. *Food Res. Int.* 2014, 62, 11–19. [CrossRef]

143. Ozias-Akins, P.; Yang, H.; Gill, R.; Fan, H.; Lynch, R.E. Reduction of aflatoxin contamination in peanut: A genetic engineering approach. In *Crop Biotechnology*; American Chemical Society: New York, NY, USA, 2002; Volume 829, pp. 151–160.

144. Holbrook, C.C.; Ozias-Akins, P.; Chu, Y.; Guo, B. Impact of molecular genetic research on peanut cultivar development. *Agronomy* 2011, 1, 3–17. [CrossRef]
145. Bhatnagar-Mathur, P.; Sunkara, S.; Bhatnagar-Panwar, M.; Waliyar, F.; Sharma, K.K. Biotechnological advances for combating aspergillus flavus and aflatoxin contamination in crops. Plant Sci. 2015, 234, 119–132. [CrossRef]

146. Higgins, C.M.; Dietzgen, R.G. Genetic Transformation, Regeneration and Analysis of Transgenic Peanut; Australian Centre for International Agricultural Research: Canberra, Australia, 2000; p. 90.

147. Sharma, K.K.; Pothana, A.; Prasad, K.; Shah, D.; Kaur, J.; Bhatnagar, D.; Chen, Z.-Y.; Raruang, Y.; Cary, J.W.; Rajasekaran, K.; et al. Peanuts that keep aflatoxin at bay: A threshold that matters. Plant Biotechnol. J. 2018, 16, 1024–1033. [CrossRef]

148. van de Wiel, C.C.M.; Schaart, J.G.; Lotz, L.A.P.; Smulders, M.J.M. New traits in crops produced by genome editing techniques based on deletions. Plant Biotechnol. Rep. 2017, 11, 1–8. [CrossRef]

149. Mishra, R.; Zhao, K. Genome editing technologies and their applications in crop improvement. Plant Biotechnol. Rep. 2018, 12, 57–68. [CrossRef]

150. Kleter, G.A.; Kuiper, H.A.; Kok, E.J. Gene-edited crops: Towards a harmonized safety assessment. Trends Biotechnol. 2019, 37, 443–447. [CrossRef]

151. Subburaj, S.; Tu, L.; Jin, Y.-T.; Bae, S.; Seo, P.J.; Jung, Y.J.; Lee, G.-J. Targeted genome editing, an alternative tool for trait improvement in horticultural crops. Hortic. Environ. Biotechnol. 2016, 57, 531–543. [CrossRef]

152. Wolter, F.; Schindele, P.; Puchta, H. Plant breeding at the speed of light: The power of crispr/cas to generate directed genetic diversity at multiple sites. BMC Plant Biol. 2019, 19, 176. [CrossRef] [PubMed]

153. Campa, C.C.; Weisbach, N.R.; Santinha, A.J.; Incarnato, D.; Platt, R.J. Multiplexed genome engineering by cas12a and crispr arrays encoded on single transcripts. Nat. Methods 2019, 16, 887–893. [CrossRef] [PubMed]

154. Yuan, M.; Zhu, J.; Gong, L.; He, L.; Lee, C.; Han, S.; Chen, C.; He, G. Mutagenesis of FAD2 genes in peanut with CRISPR/Cas9 based gene editing. BMC Biotechnol. 2019, 19, 24. [CrossRef] [PubMed]

155. Ezezika, O.; Thomas, F.; Lavery, J.; Daar, A.; Singer, P. A social audit model for agro-biotechnology initiatives in developing countries: Accounting for ethical, social, cultural and commercialization issues. J. Technol. Manag. Innov. 2009, 4, 24–33. [CrossRef]

156. Savadori, L.; Savio, S.; Nicotra, E.; Rumiani, R.; Finucane, M.; Slovic, A.P. Expert and public perception of risk from biotechnology. Risk Anal. 2004, 24, 1289–1299. [CrossRef]

157. Assemblée-Nationale, A. Régime de sécurité en matière de biotechnologie au burkina faso; Assemblée-Nationale: Ouagadougou, Burkina Faso, 2006; p. 40.

158. Hill, R.A. Conceptualizing risk assessment methodology for genetically modified organisms. Environ. Biosaf. Res. 2005, 4, 67–70. [CrossRef]

159. Johnson, K.L.; Raybould, A.F.; Hudson, M.D.; Poppy, G.M. How does scientific risk assessment of GM crops fit within the wider risk analysis? Trends Plant Sci. 2007, 12, 1–5. [CrossRef]

160. Potrykus, I. Regulation must be revolutionized. Nature 2010, 466, 561. [CrossRef]

161. Assemblee Nationale, B.F. Loi no 064–2012ûn du 20 Décembre 2012 Portant Régime de Sécurité en Matière de Biotechnologie; Presidence: Ouagadougou, Burkina Faso, 2012.

162. Sundaram, J.; Kandala, C.V.; Holser, R.A.; Butts, C.L.; Windham, W.R. Determination of in-shell peanut oil and fatty acid composition using near-infrared reflectance spectroscopy. J. Am. Oil Chem. Soc. 2010, 87, 1103–1114. [CrossRef]

163. Janila, P.; Pandey, M.K.; Shasidhar, Y.; Variath, M.T.; Sriswathi, M.; Khera, P.; Manohar, S.S.; Nagesh, P.; Vishwakarma, M.K.; Mishra, G.P.; et al. Molecular breeding for introgression of fatty acid desaturase mutant alleles (AHFAD2A and AHFAD2B) enhances oil quality in high and low oil containing peanut genotypes. Plant Sci. 2016, 242, 203–213. [CrossRef]

164. ICRISAT. Why G.E.M.S? Available online: http://gems.icrisat.org/ (accessed on 27 February 2020).

165. Hinkelmann, K.; Kemphorone, O. Design and Analysis of Experiments Volume 2: Advanced Experimental Design; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2005.

166. Naresh, R.; Singh, S.; Misra, A.; Tomar, S.; Kumar, P.; Kumar, V.; Kumar, S. Evaluation of the laser leveled land leveling technology on crop yield and water use productivity in western uttar pradesh. Afr. J. Agric. Res. 2014, 9, 473–478.

167. Al-Naggar, A.; Abdalla, A.; Gohar, A.; Hafez, E. Breeding values of 254 maize (Zea mays L.) doubled haploid lines under drought conditions at flowering and grain filling. J. Adv. Biol. Biotechnol. 2016, 1–15. [CrossRef]

168. Yost, M.; Sorensen, B.; Creech, E.; Allen, N.; Larsen, R.; Ramirez, R.; Ransom, C.; Reid, C.; Gale, J.; Kitchen, B. Defense against Drought; Utah State University Extension: Salt Lake City, UT, USA, 2019; p. 8.
169. Watson, A.; Ghosh, S.; Williams, M.J.; Cuddy, W.S.; Simmonds, J.; Rey, M.-D.; Asyraf Md Hatta, M.; Hinchliffe, A.; Steed, A.; Reynolds, D.; et al. Speed breeding is a powerful tool to accelerate crop research and breeding. *Nat. Plants* 2018, 4, 23–29. [CrossRef] [PubMed]

170. Chiurugwi, T.; Kemp, S.; Powell, W.; Hickey, L.T. Speed breeding orphan crops. *Theor. Appl. Genet.* 2019, 132, 607–616. [CrossRef]

171. O’Connor, D.J.; Wright, G.C.; Dieters, M.J.; George, D.L.; Hunter, M.N.; Tatnell, J.; Fleischfresser, D.B. Development and application of speed breeding technologies in a commercial peanut breeding program. *Peaunt Sci.* 2013, 40, 107–114. [CrossRef]

172. Larkin, D.L.; Lozada, D.N.; Mason, R.E. Genomic selection—Considerations for successful implementation in wheat breeding programs. *Agronomy* 2019, 9, 479. [CrossRef]

173. Lado, B.; Barrios, P.G.; Quincke, M.; Silva, P.; Gutiérrez, L. Modeling genotype environment interaction for genomic selection with unbalanced data from a wheat breeding program. *Crop Sci.* 2016, 56, 2165–2179. [CrossRef]

174. Bassi, F.M.; Bentley, A.R.; Charmet, G.; Ortiz, R.; Crossa, J. Breeding schemes for the implementation of genomic selection in wheat (*Triticum* spp.). *Plant Sci.* 2016, 242, 23–36. [CrossRef]

175. Ben Hassen, M.; Bartholomé, J.; Valé, G.; Cao, T.-V.; Ahmadi, N. Genomic prediction accounting for genotype by environment interaction offers an effective framework for breeding simultaneously for adaptation to an abiotic stress and performance under normal cropping conditions in rice. *G3* 2018, 8, 2319–2332. [CrossRef]

176. Robertsen, C.D.; Hjortshøj, R.L.; Janss, L.L. Genomic selection in cereal breeding. *Agronomy* 2019, 9, 95. [CrossRef]

177. Mumm, R.H.; Walters, D.S. Quality control in the development of transgenic crop seed products research supported in part by exygen research, 30158 research drive, state college, PA 16801. *Crop Sci.* 2001, 41, 1381–1389. [CrossRef]

178. Bradford, K.J.; Dahal, P.; Bello, P. Using relative humidity indicator paper to measure seed and commodity moisture contents. *Agric. Environ. Lett.* 2016, 1. [CrossRef]

179. IBP. Your Partner for Modern Plant Breeding. Available online: [https://www.integratedbreeding.net/](https://www.integratedbreeding.net/) (accessed on 27 February 2020).

180. Rathore, A.; Singh, V.K.; Pandey, S.K.; Rao, C.S.; Thakur, V.; Pandey, M.K.; Anil Kumar, V.; Das, R.R. Current status and future prospects of next-generation data management and analytical decision support tools for enhancing genetic gains in crops. In *Plant Genetics and Molecular Biology*; Varshney, R.K., Pandey, M.K., Chitikineni, A., Eds.; Springer: Cham, Switzerland, 2018; pp. 277–292.

181. Cobb, J.N.; Biswas, P.S.; Platten, J.D. Back to the future: Revisiting mas as a tool for modern plant breeding. *Theor. Appl. Genet.* 2019, 132, 647–667. [CrossRef] [PubMed]

182. Varshney, R.K.; Singh, V.K.; Hickey, J.M.; Xun, X.; Marshall, D.F.; Wang, J.; Edwards, D.; Ribaut, J.-M. Analytical and decision support tools for genomics-assisted breeding. *Trends Plant Sci.* 2016, 21, 354–363. [CrossRef] [PubMed]

183. CYMMIT. CIMMYT Research Software. Available online: [https://data.cimmyt.org/dataverse/cimmytswdv](https://data.cimmyt.org/dataverse/cimmytswdv) (accessed on 27 February 2020).

184. Lipka, A.E.; Tian, F.; Wang, Q.; Peiffer, J.; Li, M.; Bradbury, P.J.; Gore, M.A.; Buckler, E.S.; Zhang, Z. Gapit: Genome association and prediction integrated tool. *Bioinformatics* 2012, 28, 2397–2399. [CrossRef] [PubMed]

185. Pandey, M.K.; Monyo, E.; Ozias-Akins, P.; Liang, X.; Guimarães, P.; Niqam, S.N.; Upadhyaya, H.D.; Janila, P.; Zhang, X.; Guo, B.; et al. Advances in arachis genomics for peanut improvement. *Biotechnol. Adv.* 2012, 30, 639–651. [CrossRef]

186. Ojewoo, C.O.; Janila, P.; Bhatnagar-Mathur, P.; Pandey, M.K.; Desmoe, H.; Okori, P.; Mwololo, J.; Ajeigbe, H.; Njuguna-Mungai, E.; Muricho, G.; et al. Advances in crop improvement and delivery research for nutritional quality and health benefits of groundnut (*Arachis hypogaea* L.). *Front. Plant Sci.* 2020, 11, 29. [CrossRef]

187. Akram, N.A.; Shafiq, F.; Ashraf, M. Peanut (*Arachis hypogaea* L.): A prospective legume crop to offer multiple health benefits under changing climate. *Compr. Rev. Food Sci. Food Saf.* 2018, 17, 1325–1338. [CrossRef]

188. Chu, Y.; Wu, C.L.; Holbrook, C.C.; Tillman, B.L.; Person, G.; Ozias-Akins, P. Marker-assisted selection to pyramid nematode resistance and the high oleic trait in peanut. *Plant Genome* 2011, 4, 110–117. [CrossRef]

189. Wilson, J.N.; Chopra, R.; Baring, M.R.; Selvaraj, M.G.; Simpson, C.E.; Chagoya, J.; Burow, M.D. Advanced backcross quantitative trait loci (qtl) analysis of oil concentration and oil quality traits in peanut (*Arachis hypogaea* L.). *Trop. Plant Biol.* 2017, 10, 1–17. [CrossRef]
190. Ndjeunga, J.; Bantilan, M.C.S. Uptake of improved technologies in the semi-arid tropics of west africa: Why is agricultural transformation lagging behind? *Electron. J. Agric. Dev. Econ.* 2005, 2, 85–102.
191. Ruttan, V.W. Changing role of public and private sectors in agricultural research. *Science* 1982, 216, 23–29. [CrossRef] [PubMed]
192. Naseem, A.; Spielman, D.J.; Omamo, S.W. Private-sector investment in r&d: A review of policy options to promote its growth in developing-country agriculture. *Agribusiness* 2010, 26, 143–173.

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).