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Review

Expounding the Value of Grain Legumes in the Semi- and Arid Tropics

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Abstract: Approximately 70% of the population in the semi- and arid tropics reside in rural areas and depend on agriculture for their livelihood. Crop production is primarily focused on a few starchy staple crops. While this can ensure adequate calories, it inadvertently neglects the need for dietary diversity. Consequently, food and nutritional insecurity remains prevalent in the semi- and arid tropics. We reviewed the legume value chain with the aim to identify opportunities and challenges to unlocking their value and promoting them in the tropics. Several grain legumes are rich in proteins and micronutrients. They also possess adaptability to marginal environmental conditions such as drought and low input systems which typify rural landscapes. Adaptability to abiotic stresses such as drought makes them key to agriculture in areas that will receive less rainfall in the future. However, this potential was currently not being realized due to a range of challenges. Aspects related to their seed systems, production, post-harvest handling and marketing remain relatively under-researched. This was especially true for minor legumes. There is a need for trans-disciplinary research which will address the entire value chain, as has been done for major starchy crops. This could also unlock significant economic opportunities for marginalized groups such as women. This will unlock their value and allow them to contribute meaningfully to food and nutrition security as well as sustainable and resilient cropping systems.

Keywords: food and nutritional insecurity; South Asia; sub-Saharan Africa; value chain; water scarcity

1. Introduction

Water scarcity is increasing and this is exacerbated by population growth and ongoing climate change and variability [1]. Most of the regions categorized as 'water scarce' lie in the semi- and arid tropics. It is also in these regions that approximately 70% of the population depends on agriculture for their food and livelihood [2,3]. The prevalence of food and nutritional insecurity in semi- and arid tropics also remains high. South Asia and sub-Saharan Africa (SSA) have the highest estimated number of individuals experiencing some form of undernutrition (281 million and 224 million, respectively) [4]. This represents about 15% and 23% of the respective populations of South Asia and SSA. These figures are expected to increase due to population growth and climate change. The 2014/15 and 2015/16 drought that was experienced across SSA due to El Niño placed more than 30 million people at risk of hunger, with children being most vulnerable [5]. There is a need for a paradigm shift in terms of how we address challenges of food and nutrition security [6]]. Part of this includes identifying and promoting the cultivation of crops that are most suited to these environments. Such crops should also have the inherent capacity to contribute to the resilience of farming systems in these areas.

Across much of the semi- and arid tropics, cereals (rice (*Oryza sativa*)), maize (*Zea mays*) and wheat (*Triticum* spp.) and root and tuber crops (cassava (*Manihot esculenta*)), Irish potato (*Solanum tuberosum*) and sweet potato (*Ipomea batatas*) are the staple crops. These crops have been the subject of significant research and government attention [7]. This has led to breeding of high-yielding and drought-tolerant cultivars of common cereals and root and tuber crops. Cereals and root and tuber crops, which are starch rich, mainly provide calories to address energy requirements but lack dietary diversity to ensure adequate nutrition [8]. Dietary diversity is a strategy that involves including a variety of food groups to the diet such as fruit and vegetables, legumes, starch and animal products [9]. Meat, fruit and vegetables are the major sources of proteins and micronutrients, respectively, but they are not always accessible to the rural poor. Meat remains expensive while fruit and vegetables are generally affordable, only when in season, but unaffordable when out of season. In this regard, the use of grain legumes as alternative sources of protein and other micronutrients [10] could assist in improving dietary diversity of poor rural households.

The promotion of grain legumes has been mainly linked to them being rich sources of protein, low in saturated fat, as well as possessing certain important micronutrients (zinc, folate and calcium and tocopherols) [11–13]. In this regard, legumes could contribute significantly to diets of rural households if consumed as compliments to starch. While history shows that early Khoikhoi and Indian settlers in the semi- and arid tropics utilized indigenous legumes as a major component of their diets [14], this status has since changed. The "Green Revolution" shifted attention to cereal crops. While this resulted in improvements to crop production and energy supply, it inadvertently resulted in stagnation of production and crop improvement of legumes [15]. The promotion of legumes which are adapted to the semi- and arid tropics will contribute to the diversity of cropping systems and diets of people living in these areas. However, there is need to address critical knowledge gaps that will allow for the promotion and reinstatement of legumes within food systems.

To date, there has been separate attempts by crop scientists [16–22] and nutritionists [11–13] to address the knowledge gap on legumes. These efforts have been disciplinary and the information is yet to be consolidated so as to make meaningful impact on policy. The emerging interest on minor legumes, indigenous to semi- and arid tropics, should also be considered [23]. As the world celebrated the International Year of Pulses in 2016, there was a need to re-conceptualize the possible role that legumes can play in the post-2015 agenda. The aim of this review was to provide a holistic perspective on the potential of legumes. This was done through focusing on the legume value chain and identifying challenges and opportunities for unlocking the value of legumes.

A mixed-method review approach, which included combining quantitative and qualitative research or outcomes with process studies, was used to compile the review. Scientific journal articles, book chapters, technical reports and other forms of literature were used for the review. The review focused primarily on literature describing sub-Saharan Africa and South Asia; the two regions share similar development trajectories, challenges and opportunities, thus making them comparable. The review was then structured as follows; Section 2 provides an overview of water scarcity in SSA and SA and its effect on agricultural production. Furthermore, Section 2 also highlights food and nutritional security status in SSA and SA using selected indicators such as stunting, wasting, anemia and obesity. Section 3 discusses grain legumes, with a focus on their diversity and adaptability to the semi- and arid tropics. Section 4 discusses the progress and gaps in research on grain legumes. A value chain approach was used to categorize research into four components, namely, (i) breeding and crop improvement; (ii) agronomy; (iii) processing and utilization; and (iv) marketing. Lastly, Sections 5 and 6 present the challenges, opportunities and recommendations concerning promoting legumes in semi- and arid tropics.

2. Setting the Scene–South Asia and Sub-Saharan Africa

South Asia refers to the southern part of Asia which is dominated by the Indian tectonic plate which rises above sea level as Nepal and extends to the south of the Himalayas and the Hindu Kush. Sub-Saharan Africa refers to the regions that are fully or partially located south of the Sahara desert. The two regions are climatically alike according to the Köppen-Geiger climate classification.

They are described as semi- and arid climates due to actual precipitation being less than actual evapotranspiration [24]. These two regions are also considered the poorest regions in the world [25]. Approximately 70% of the population in these regions reside in rural areas and rely on agriculture for their food and livelihood [26]. However, agricultural activities are primarily challenged by water scarcity.

2.1. Water Scarcity

Most countries in South Asia and sub-Saharan Africa experience some form of water scarcity (Figure 1). Rainfed agriculture is the primary source of food production in the semi- and arid tropics. The amount of arable land under rainfed production ranges from 60% to 95% [27]; making water is the most limiting factor in crop production. The uncertainties in rainfall distribution and occurrences and the high frequency of dry spells and droughts [28] frequently result in significant yield losses and crop failure for rural farmers. Most of them are incapable of recovering from such disturbances. This alludes to the importance of promoting resilient cropping systems in these areas.

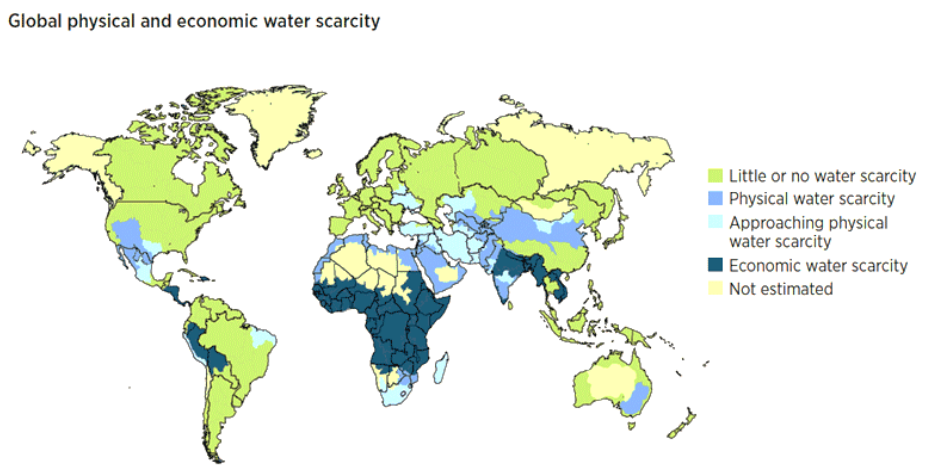

Figure 1. Areas of physical and economical water scarcity on a basin level in 2007 [29]. Most of the regions categorized as 'water scarce' fall in semi- and arid tropics.

2.2. Food and Nutritional Insecurity in Semi- and Arid Tropics

Agriculture is the major livelihood activity for 70% of people residing in the semi- and arid regions [3,28]. Food production is often inadequate to meet household food and nutrient requirements, hence people still have to buy food despite it being unaffordable [29]. This may in part explain the high prevalence of food and nutritional insecurity. South Asia and sub-Saharan Africa are faced with the highest prevalence of malnutrition (under- and overnutrition) in the world [30]. Undernutrition is commonly in the form of stunting (low height for age), wasting (low weight for age) and underweight in children under five years old [30]. It is estimated that one-half to two-thirds of stunted, wasted and underweight children reside in South Asia while one-third reside in sub-Saharan Africa [31]. This implies that 80% to 90% of the world's undernourished children reside in the semi- and arid tropics. In addition, prevalence of micronutrient deficiencies is high with anemia (a condition caused by lack of iron) having the highest prevalence affecting at least 50% of women in the reproductive age [30]. Conversely, being overweight and obesity affect at least 30% of the population [25]. These high levels of malnutrition are symptomatic of the poor dietary diversity in semi- and arid tropics. Based on these statistics, it is evident that nutrient intakes are not balanced [6] to meet the requirements for a healthy life—food and nutritional security.

Food security was defined as a 'situation when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life' [32]. This definition was not properly translated into regional agricultural policies which led to a prioritization of food production over nutrition agendas [6]. To emphasize the nutrition aspects and to clearly differentiate dietary quantity and quality, this review uses the term 'food and nutrition security' [33,34]. Agriculture, as the main source of food and livelihood in semi- and arid regions, provides an appropriate platform to tackle food and nutritional insecurity [3,34,35]. This can be achieved, in part, by increasing crop diversity and improving crop productivity which in turn strengthens the pillars of food and nutritional security. Furthermore, any such efforts should be defined and designed taking into consideration limitations posed by water scarcity i.e., recognizing the water-food-nutrition-health nexus [6]. This includes the promotion of crops that are adapted to dry areas and are nutrient dense [6] such as legumes [23].

Previous food security initiatives in semi- and arid regions had a narrow focus of increasing production of cereals and root and tuber staple crops. Consequently, such staple crops currently occupy 70% of arable crop area. Although these staples have a role to play in providing daily energy requirements, they are often poor sources of other nutrients. This poses concerns on dietary diversity and could be partly why semi- and arid regions are faced with the burden of malnutrition. There is need for a balance between starch-rich foods and other nutrient dense foods in order to improve dietary diversity. According to Alleyne et al. [36], one of the major concerns in diets of the rural poor is the issue of protein energy malnutrition. Legumes are a good source of protein and micronutrients and hence could be a good compliment to starchy diets [37].

Khan [38] reported daily per capita consumption of grain legumes to be 30 to 40 g in SSA and 40 to 60 g in SA. While in SA consumption is higher than in SSA, both regions are comparatively lower when compared to the world daily per capita consumption of 65 g [39]. This is exacerbated by the fact that consumption of animal-based protein in both SSA and SA is also lower (20 g daily per capita consumption) compared to the world (34 g daily per capita consumption) [39]. This highlights the poor protein diets in semi- and arid regions. Animal-based protein is expensive, hence there is more scope to increase protein in diets by increasing consumption levels of grain legumes.

3. Grain Legumes

3.1. Taxonomy

The word legume derives from the Latin word 'legere' which means 'to gather' [40]. Legume refers to the fruit of plants that are usually gathered by hand [40]. Legumes belong to the Fabaceae family and have an estimated 18,000 species in about 650 genera making them the third largest group of plant families after Orchidiacea and Compositae. The Fabaceae family comprises three sub-families Caesalpinioideae, Mimosoideae and Papilionoideae, depending on floral structure. The former two each comprise five tribes, which are mostly ornamental plants. The sub-family Papilionoideae comprises more than 32 tribes making it the biggest and most diverse sub-family; all grain legumes and major forage species belong to this sub-family. Of the 32 tribes, only seven tribes are edible [41] (Table 1); these form the focus of this review.

Table 1. Taxonomic affinities (tribe, subtribe, species and common names) of grain legumes (Adapted from [41] with some modifications).

Tribe	Sub-Tribe	Species	Common Name
Dalbergieae		*Arachis hypogaea* L.	groundnut
Cicerea		*Cicer arietum* L.	chickpea
Viciaea		*Lens culinaris* Med	lentil
		Pisum sativum L.	common pea
		Vicia faba L.	fababean
		Lathyrus sativus L.	grass pea
Genisteae	Lupininae	*Lupinus albus* L.	white lupine
		L lueus L.	yellow lupine
		L angustifolius L.	blue lupine
		L. mutabilis Sweet.	tarwi, chocho,

Table 1. *Cont.*

Tribe	Sub-Tribe	Species	Common Name
Phaseoleae	Erythrininae	*Mucana* spp. (velvet beans)	velvet beans
	Diocleinae	*Canavalia ensiformis* (L.) DC.	jackbean
		C. gladiata (Jacq.) DC.	swordbean
		Pachyrrhizus erosus (L.) Urban	yam bean
		P. tuberosis (Lam.) Spreng.	yam bean
		Calopogonium mucuniodes Desv	wild groundnut
	Glycininae	*Pueraria phaseoloides* (Roxb.) Benth.	puero, tropical kudzu
		Glycine max (L.) Merr.	soybean
	Clitoriinae	*Centrosema pubescens* Benth.	butterfly pea
		Clitoria ternatea L.	butterfly pea
	Phaseolinae	*Psophocarpus tetragonolobus* (L.) DC.	winged bean
		Lablab purpureus (L.) Sweet	lablab
		M. uniflorum (Lamb.) Verdc	horse gram, kulthi bean, hurali,
		Vigna aconitifolia (Jacq.) Marechal	moth bean
		V. angularis (Willd.)	azuki bean
		V. mungo (L.) Hepper	mung bean
		V. radiate (L.) Wilczek	mung bean
		V. subterranea (L.) Verdc.	bambara groundnut
		V. umbellate (Thunb.)	rice bean
		V. unguiculata (L.) Walp	cowpea
		Phaseolus acutifolus A.Gray	tepary bean
		P. coccineus L.	runner bean
		P. lunatis L.	lima bean
		P. polyanthus Greenm.	polyanthus bean
		P. vulgaris L.	common bean
	Cajaninae	*Cajanus cajan* (L.) Millsp.	pigeon pea
Indigoferae		*Cyamopsis tetragonoloba* (L.) Taubert	cluster-bean, siam-bean
Crotalariaea		*Crotalaria juncea* L.	indian hemp, sun hemp

3.2. Ecology

The highly diverse species of grain legumes are indigenous to various parts of the world. The ecology is, to a large extent, influenced by climate of its center of diversity [41,42]. The main centers of diversity are central America, South America, southwestern America, Africa and Europe. Owing to their wide diversity, grain legumes can be grown across different rainfall areas ranging from 200 mm to 1500 mm (Table 2). As such, some grain legumes are suited to the semi- and arid tropics that receive low annual rainfall. Although they grow well in environments similar to that of their center of diversity, they also adapt to other environments [43] implying that they have wide adaptability.

Depending on species as well as season and cultivar, grain legumes take between 60 to 200 days to mature, making them suitable crops for sequential cropping (Table 2). Semi- and arid tropics are faced with uncertainties in rainfall distribution and occurrences as well as high frequency of dry spells which short season crops may be able to escape. Grain legumes are not associated with tolerance to water-logging and frost. This poor adaptability can be attributed to the centers of diversity being mild environments. Several grain legumes are short-day plants, an attribute owing to their centers of diversity, with a few exceptions such as white lupine, chickpea, lentil and common pea being long-day plants (Table 2). There are, however, bred short-day cultivars of white lupine, chickpea, lentil and common pea.

Average grain yield ranges from 300 to 14,000 kg·ha^{-1} depending on season, crop species, cultivar and management practices (Table 2). The low yield in some grain legumes, relative to cereals and root and tuber crops, has been suggested as a possible reason for their decline in rural cropping systems. However, grain legumes can offer other ecological benefits that cereal crops cannot.

One distinct ecological function that makes grain legumes unique is their ability to fix atmospheric nitrogen [41]. While the Roman and Egyptian early settlers observed that in the presence of legume species soil was somewhat nutrient rich and plants were greener, it was only in 1888 when German scientists discovered that it was the legume root nodule that was responsible for this [44]. Since then, this made grain legume crops of particular interest in faming systems, especially under marginal conditions [45–47].

Table 2. Ecological characteristics (temperature, rainfall, growth cycle, photoperiod, soil type and yield) of selected grain legumes from the seven tribes of grain legumes.

Species	Min, Max Temp (°C)	Annual Rainfall (mm)	Growth Cycle (Days)	*Photoperiod	Soil Type	Grain Yield (kg/ha)	Source
Dry bean	10, 30	600–650	70–200	Short day	Sandy loam to heavy clays	500–2500	[48]
Groundnut	10, 30	500–600	125–150	Short day	Sandy loam	800–3500	[49]
Chickpea	5, 25	400–600	84–125	Long day	Sandy to silt loam	630–850	[50]
Soybean	10, 25	500–900	120–130	Short day	Clay loam	2000–4000	[51]
Lablab	10, 35	700–1500	60–120	Short day	Deep sands to heavy clays	1000–2500	[52]
Cowpea	8, 35	400–700	70–150	Short day	Sandy	1000–2000	[51]
Bambara groundnut	10, 35	400–600	90–180	Short day	Sandy loam	300–3000	[53]
Pigeon pea	–	–	100–200	Short day	Sandy to silt loam	718–1080	[54]
Tepary bean	20, 48	200–600	60–120	Short day	Sandy loam	1410–2239	[55]
Common Pea	5, 22	350–500	55–75	Day neutral	Sandy loam	1500–3120	[56]
Faba bean	−2, 25	700–1200	110–130	Short day	Clay loam	2000–14,000	[57]
White lupine	−7, 15	381–990	116–130	Long day	Sandy to silt loam	1570	[58]

*Photoperiod: Short day = 10 h or less; Day neutral = 10 to 12 h; Long Day = 12 h or more.

3.3. Major vs. Minor Grain Legumes

There is a wide diversity of grain legume species and there are concerns that some species are more prominent compared to others in terms of breeding efforts, socioeconomic importance, area under cultivation and utilization. This dichotomy is often referred to in the literature as major and minor grain legumes. Other terms also used to refer to minor grain legumes are underutilized, neglected, orphan, promising and future grain legumes. There still lacks a consensus definition of underutilized, neglected or minor grain legumes. The lack of a consensus definition of major vs. minor legumes creates challenges when attempting to categorize legumes. Congenial examples would be of chickpea and cowpea where their underutilization is geographically distributed. Cowpea used to be widely used but now it is only common in African diets and its use is slowly diminishing in other areas.

In this review we define major grain legumes as those species that are recognized internationally regardless of their centers of diversity, occupy significant crop area, have been subject to formal crop improvement and research and have common and established value chains internationally. Minor grain legumes are those that are only of regional importance, are neglected or underutilized in any dimension (geographic, social and economic) and have no common international and established value chain.

4. Legume Value Chain

Approximately 30 grain legumes are grown in the semi- and arid tropics across different ecological niches. Chickpea, dry bean, groundnut, pigeon pea, cowpea and soybean account for more than 90% of grain legume production (Table 3). The remainder of the grain legumes (e.g., fababean, bambara groundnut, common pea and lablab, lentil) account for less than 10% of legume production [59]. Singh and Singh [60] reported that in the last ten years there had been a significant upward trend (≈6%) in production of lentil in SA. Table 3 highlights the production trends of major and minor grain legumes where dry bean, groundnut and soybean are popular (each occupying > 5 million ha of land) across all regions and cowpea and chickpea are only popular in SSA and SA, respectively. In semi- and arid tropics more than 95% of grain legumes are produced under dryland conditions [61]. This implies that there is scope to increase grain legume production without increasing water withdrawals. This would be mostly through improvements in water productivity.

In semi- and arid tropics, legumes are planted on approximately 60 million hectares of land. This figure is minute when compared to starchy crops (cereals and root and tuber crops) that occupy over 250 million hectares in the same regions (Table 3). Starchy crops, as staple crops, have benefited from research related to their breeding, production, utilization and marketing. In this review, these components are referred to as a 'research value chain.' The 'research value chain' concept is used to describe the research activities and various stakeholders that products go through for them to be made available to consumers. The research value chain concept also extends to describe the value that products add to consumers and how they have been marketed and made available to consumers (Figure 2).

Starchy crops have established value chains and, owing to this high production, are widely available and utilized. If grain legumes are to be promoted, it is also imperative that research is carried out across the various points within a value chain. This review provides an overview of the grain legume research value chain to date. This will aid in identifying opportunities and constraints that exist for the promotion of grain legumes in rural farming systems of semi- and arid tropics.

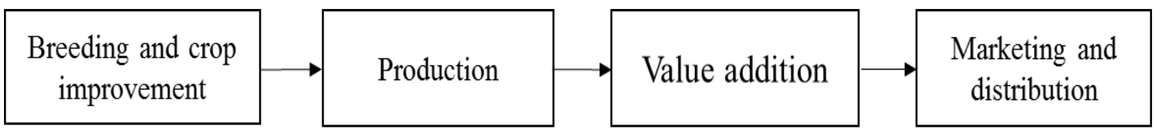

Figure 2. Research value chain from breeding and crop improvement to marketing and distribution.

Table 3. Production trends of selected grain legumes (chickpea, dry bean, groundnut, pigeon pea, soybean and cowpea) in the world and semi- and arid tropics (sub-Saharan Africa, and South Asia) for the period 2010–2012 (Adapted from Abate et al. [59] and Nedumaran et al. [62] with some minor modifications from faostat.fao.org).

	Area (1000 ha)	Yield (kg·ha^{-1})	Production (1000 Metric Ton)	% of World Production
World				
Chickpea	10,914	818	8929	-
Dry bean	27,232	723	19,705	-
Cowpea	14,500	454	6155	-
Groundnut	22,633	1607	36,379	-
Pigeon Pea	4655	885	3463	-
Soybean	92,622	2348	217,397	-
Lentil	3571	1904	2900	-
Sub-Saharan Africa				
Chickpea	398	769	315	3.5
Dry bean	5190	596	3045	16
Cowpea	11,440	450	5145	84
Groundnut	9057	1007	8942	40
Pigeon Pea	499	729	363	10
Soybean	1228	1060	1279	1.3
Lentil	100	1094	90	2
South Asia				
Chickpea	8334	855	6792	76
Dry bean	11,532	985	5908	30
Cowpea	159	975	154	3
Groundnut	7038	1122	8457	31
Pigeon Pea	4118	840	3068	88
Soybean	8490	1275	5735	9.2
Lentil	1700	633	1088	33

4.1. Breeding and Crop Improvement

Progress in breeding and crop improvement has been relatively slow, especially when compared to cereals such as maize, rice and wheat. Since the 1970s, grain legume breeding focused on disease resistance, growth habit and duration in relation to increasing yields [63]. It was only post-2000 that characteristics such as drought and heat-stress tolerance and environmental adaptability (genotype × environment) became topical [64,65]. Recently, pre-breeding of some minor grain legumes indigenous to semi- and arid tropics (e.g., cowpea, pigeon pea, and chickpea) has come into light for their adaptation to drought and heat stress.

Consultative Group on International Agricultural Research (CGIAR) institutes such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Institute of Tropical Agriculture (IITA), and the Centre for Agricultural Research in Dry Areas (ICARDA) have largely driven breeding and crop improvement of grain legumes for the semi- and arid tropics. This is with the exception of soybean breeding and crop improvement that has also been driven by private seed companies. Consultative Group on International Agricultural Research institutes are also responsible for germplasm conservation with ICRISAT and IITA maintaining the highest number of grain legume accessions. ICRISAT maintains 14,968 accessions of groundnut, 13,771 of pigeon pea and 81,000 of chickpea [66] while IITA maintains 15,115 accessions of cowpea, 1742 of soybean, 1815 of bambara groundnut and ≈2000 of other minor grain legumes combined [67]. It is interesting to note that despite the large germplasm collections, <1% has so far been utilized in breeding programs [66]. This highlights low utilization of genetic resources by breeders. According to Foyer et al. [68], the low utilization of genetic resources has led to stagnation of grain legume yields. In order to increase adoption of grain legumes, improved varieties that are drought- and heat-stress tolerant, nutrient dense and high yielding should be made available. This is still in its infancy and there is need for novel biotechnological techniques such as marker-assisted selection to speed up grain legume improvement. This should include whole-genome sequencing in the existing legume accessions including crop wild relatives to develop new molecular markers.

Seed Systems

In semi- and arid tropics, 80%–90% of grain legume seed systems are farmer-driven (farmer seed systems). This means that farmers use farm-saved seed from the previous harvest, acquire them from other farmers through barter or gifts or obtain them from informal local markets [69–76]. This seed is often in the form of landraces, which are open-pollinated varieties that are often the product of many years (>100 years) of natural and farmer selection [77]. In some instances, seed companies supply landraces of both major and minor grain legumes that are not certified or tested [71,73,75]. They take advantage of their strategic positioning in the agriculture sector to source seed of grain legumes and supply them to research institutions or farmers. Farmers have also been reported to purchase hybrid seed, which is the product (first-generation progeny) of a cross between two unrelated (genetic dissimilar) parents [78], and then recycle it similarly to how they recycle landraces [73,75]. However, unlike for landraces and other open-pollinated varieties, recycling hybrid seeds has negative implications on subsequent seed quality. In addition, most grain legumes that are grown in the semi- and arid tropics are self-pollinating plants, hence recycling seeds may result in loss of vigor, decrease in immunity to diseases and reduced adaptability to changing environments [75].

Adoption of improved seed will significantly increase productivity assuming that it is accompanied by the adoption of best management practices. Promoting hybrid seed may also come with increased dependency on other agricultural inputs such as chemicals, fertilizers and water [79,80]. This may create new challenges under low input agriculture systems that typify the semi- and arid tropics as farmers may not be able to afford the use of external inputs. In this regard, the use of improved open-pollinated varieties adapted to a range of environments would be more desirable. Thus, promoting grain legumes in cropping systems will require formulation of dynamic strategies that ensure availability and farmers' adoption of improved seed as well as adoption of best management practices that allow for yield maximization. This should be underpinned by viable and sustainable seed systems (formal and informal) that are beneficial to all role players (breeders, government and farmers).

Formal seed systems are discouraged by farmers' tendency to recycle seed, thereby decreasing the demand for certified seed [81]. However, farmers' tendency to recycle seeds is influenced by several factors such as high cost of purchasing hybrid seed every season and lack of formal seed suppliers in rural areas. In addition, use of hybrids also risks loss of benefits such as ease of exchanging or sharing seed as well as earning income from selling seeds on the informal market [81]. This highlights the need to integrate formal and informal seed systems when promoting grain legumes. Muigai et al. [81] suggested integrating informal seed channels into formal seed structures by providing foundation seed to selected rural farmer groups to multiply. This should be supported by extension advice on seed production, processing, treatment, storage and developing a legal framework that permits marketing of certified and uncertified seed of acceptable genetic purity and germination quality. This will provide resource-poor farmers with quality seeds of improved varieties at affordable prices. A similar strategy is underway in Nigeria aimed to "sustainably improve farmers' access to high quality and affordable cassava planting material through the development and promotion of models for seed provisions" [67]. Such models, if successful, could be adopted and restructured for grain legumes.

4.2. Production

4.2.1. Agronomy

Soil fertility is one of the major constraints in subsistence agriculture. Studies have shown that including grain legumes in cropping systems improves soil fertility [82–84]. This could be through relay cropping, intercropping, crop rotations or double cropping [82–84]. Legumes have also been successfully used as cover crops to improve soil fertility, control pests and suppress weeds [85–87]. While the role of grain legumes in increasing soil nitrogen cannot be denied, other macro- and micro-nutrients cannot be ignored. A deficiency of other nutrients such as phosphorous, boron and molybdenum may hinder nitrogen fixation [44,45,88]. In addition, subsistence farmers often do not use inoculants to stimulate the formation of nitrogen-fixing nodules. Studies on dry bean, groundnut, soybean and cowpea have shown that under marginal soils inoculating seed with Rhizobia improves nitrogen-fixation capacity and yield [89,90]. There should always be a balance of the essential soil nutrients that are required for growth and reproduction of grain legumes to get the maximum yield. Rural farmers should have access to soil analyses. This will aid in correcting soil fertility to maximize yield. While use of fertilizer may be limited due to affordability, options such as manure, compost and crop residues could be explored.

Another major agronomic component of grain legumes is weeding. According to Avola et al. [91], grain legumes are poor competitors with weeds. Without proper weed control, weeds can cause significant yield losses [92,93]. Groundnut, soybean and bambara groundnut have been observed to be among the poorest competitors with weeds and require constant weeding compared to other legumes such as cowpea and pigeon pea [94–97]. A study in Malawi showed that one of the factors influencing farmers' adoption of grain legumes in cropping systems was the high labor required due to constant weeding [97]. There is need for sustainable weed control strategies for poor rural farmers to increase adoption of grain legumes. This should include low-cost mechanical weeding machines and agronomic practices to reduce weed infestation. The latter includes research on the effects of mulching, spatial arrangements and critical periods for weed control in different grain legume species.

The adverse environmental conditions that typify most of the semi- and arid tropics suggest that currently grain legumes are being grown under sub-optimal conditions. This could explain the high incidences of aflatoxins reported in legumes, especially groundnut. Aflatoxins are a group of chemically similar toxic fungal metabolites (mycotoxins) produced by certain moulds of the genus *Aspergillus* growing on a number of raw food commodities [98]. Aflatoxins, notably *Aspergillus flavus*, are naturally abundant and often found when certain grain legumes are grown under stressful conditions such as drought [99]. Aflatoxin levels are high in groundnut (up to 11,865 μg/kg) [100]. This has become a concern for the production and export of groundnuts in semi- and arid tropics [101]. This is disconcerting; for the period 2000–2006, ≈80% of SSA's groundnut exports to the European Union were non-compliant with the Codex standard of aflatoxin levels (>50 ppb) [102]. Loss of markets therefore becomes a disincentive for farmers to continue production. Improved agronomic practices could lower the incidence of aflatoxins.

With the exception of major grain legumes, there is a lack of robust empirical information describing the agronomy of most grain legumes suitable for cultivation in the semi- and arid tropics. While this information may be available in few national agricultural research stations, it remains inaccessible to farmers. Rural farmers who still cultivate minor grain legumes mostly rely on indigenous knowledge and continue to get low yields, further marginalizing the continued production of minor grain legumes.

4.2.2. Water Use and Water Use Efficiency

In semi- and arid tropics, where water is the most limiting input to crop production, crop water requirement is an important factor. Crops that use less water are becoming increasingly important as one of the strategies to increase food production under conditions of water scarcity. Research on water use of grain legumes showed that cowpea and fababean had low water use ranging between 78 and 258 mm and 101 and 261 mm, respectively (Table 4). Lentils could also be considered low water users, especially when compared to major grain legumes such as dry bean, groundnut and soybean that had water use ranging from 318 to 463 mm, 697 to 809 mm and 598 to 690 mm, respectively (Table 4). The high water requirement of groundnuts could also explain the high incidence of aflatoxins as they are more prone to water-deficit stress. It could thus be inferred that cowpea, fababean, lentil, chickpea and common pea are suitable for growing in arid and semi-arid conditions where seasonal rainfall is low (200 to 400 mm) (Table 4).

However, low water use does not necessarily imply high water use efficiency (WUE). Water use efficiency of legumes ranges from 1.7 to 15.9 kg·ha^{-1}·mm^{-1} with various species showing noticeable differences in WUE (Table 4). These values are low when compared to WUE values reported for cereal and root and tuber crops. For maize and sorghum, the lowest reported WUE value was 4 kg·ha^{-1}·mm^{-1} [103] while the highest was up to 85 kg·ha^{-1}·mm^{-1} [104,105]. Potatoes on the other hand have WUE values as high as 195 kg·ha^{-1}·mm^{-1} [106]. It cannot be disputed that cereals and root and tuber crops are more water use efficient when compared to grain legumes. Values of water use and WUE are, however, wide-ranging and lack robustness as they were determined under different management and environmental conditions and are thus not conservative [107]. Water productivity (WP), which is the net benefits accrued per unit water consumed [108], offers greater spatial and temporal stability and is a true efficacy parameter of the crop production process [107].

Table 4. Water use and water use efficiency (WUE) of selected grain legumes.

Species	Water Use	Yield	WUE	Climate	Source
	mm	kg·ha^{-1}	kg Dry Matter ha^{-1} mm^{-1}		
Dry bean	318–463	1407–4031	1.7–10.9	Mediterranean	[18]
Groundnut	697–809	2080–4240	3.96–5.25	Semi-arid	[19]
Chickpea	150–340	358–1357	1.9–3.6	Mediterranean	[16]
Soybean	598–690	710–1910	1.16–2.80	Semi-arid	[20]
Cowpea	78–258	1020–1340	0.11–0.2	Semi-arid	[109]
Bambara groundnut	300–638	500–2400	0.1–0.12	Semi-arid	[21]
Pigeon pea	331–551	1816–2643	3.38–6.97	Semi-arid	[110]
Common pea	177–266	1040–2240	6–15.9	Mediterranean	[17]
Fababean	101–261	420–1920	1.7–12.5	Mediterranean	[17]
Lentil	160–308	339–1657	2.3–4.5	Mediterranean	[16]
White lupine	178–272	1570	2.1–8.5	Mediterranean	[17]

NB. Data were obtained from experiments conducted under varying environmental and management conditions.

4.3. Post-Harvest Handling, Storage and Value Addition

After harvesting, products go through some sort of transformation from their original state to a more valuable state. This is referred to as value addition. Value addition can be viewed as the benefits obtained from a product with respect to quality, form and functionality [111]. This includes the transformation of food to nutrients that are utilized by the body [112]. Value addition also includes agro-processing which describes the manufacturing processes involved to derive products from agricultural raw products [113].

4.3.1. Post-Harvest Handling and Storage

Subsistence farmers still harvest grain legumes manually. This can lead to splitting and significant yield losses (≈20%) [114]. In many parts of India, low-cost mechanical harvesting equipment has been designed for groundnut and dry bean to minimize labor and grain losses during harvesting [115]. There is also a need for similar low-cost technologies for other grain legumes coupled with suitable and appropriate maturity and harvest indices to aid farmers in correctly determining time of harvest; this will minimize grain losses during harvesting.

One of the major advantages of grain legumes is their long shelf life hence availability throughout the year. However, this is largely determined by storage conditions. Once the grain legumes have been threshed, the seeds must be stored at ≈12% moisture content and temperatures below 15 °C to avoid discoloration, mould and fungi. Some grain legumes are very sensitive during storage and, if care is not taken, up to 50% of storage losses can be incurred [116]. For example, when chickpea seed is harvested, its outside seed coat usually has a lower moisture level than the inside of the seed. If left to sit in storage, the moisture level can balance out (tempering/sweating), causing the overall moisture level to rise. In this way, chickpeas that are harvested at a safe moisture level can, after a week, exceed the recommended 14%. Left untreated, the harvest can spoil. For this reason, chickpea producers often store the crop in a hopper-bottomed bin that has aeration, which can help bring down the moisture level [117]. This information may not be available to subsistence farmers and they may not have access to specialized storage containers. This is one of the reasons why there is a shift towards promoting value chain research; if chickpeas are promoted to farmers, this has to be accompanied by knowledge of chickpea post-harvest handling and storage as well as provision of specialized storage containers to avoid detrimental post-harvest losses.

Under proper storage conditions, grain legumes can be stored for up to three years [118]. Considering the predicted increase in drought occurrences, this is an important attribute as stored grain can be consumed during drought and when there is a shortage of food. However, weevils, rats, bruchids and other storage pests can be a problem in storage and proper chemicals need to be used to control them [118]. Poor storage environment can result in color loss, moisture absorption, and desorption as well as hardness or case hardness issues [119]. In semi- and arid tropics, such storage challenges are frequently experienced by subsistence farmers and this could be partly why they are discouraged from producing large quantities. If there are no markets to sell the surplus grain to, this acts as a further disincentive to farmers and they subsequently only produce grain they can consume in the short term. Poor storage conditions may also have an effect on the seed quality (viability and vigor) reserved for the next season. While grain legumes may have a longer shelf life compared to vegetables, dairy products, fruits, and meat products, currently this advantage has not been fully explored due to farmers' lack of appropriate storage conditions. This ultimately compromises the potential of grain legume availability all year round.

4.3.2. Nutritional Quality

Grain legumes contain 5% to 39% protein with white lupine and soybean being the highest protein sources (Table 5) [120,121]. By comparison, vegetables and cereals contain 2% and 8% to 12% protein, respectively [117]. This makes grain legumes the best source of proteins among all the food crops. In the absence of meat, grain legumes offer the best protein supplement to meet the recommended daily allowance (RDA) of 56 g (Table 5). Soybean contains the most protein compared to other grain legumes; this could explain why it has been widely accepted. In addition to being good sources of protein, some grain legumes such as bambara groundnut, soybean and cowpea contain reasonable amounts of carbohydrates (up to 56%) (Table 5). Soybean and tepary bean contain sufficient iron to meet the RDA for an adult male and almost enough to meet the RDA of an adult female (Table 5). This implies that incorporating these crops in diets could alleviate the high prevalence of anemia in semi- and arid tropics. Soybean, dry beans, bambara groundnut and tepary bean contain >160 mg of calcium which is higher than the same serving of milk (125 mg per 100 g milk) (Table 5) [122].

Cereals are the major source of carbohydrates but are poor sources of proteins and micronutrients providing ≈12 g protein, 10 to 140 mg calcium, 0.5 to 3.9 mg iron, and 0.6 to 3.3 mg zinc per 100 g serving [123]. This is comparatively lower than grain legumes and justifies the need to promote grain legumes to compliment cereals in diets. However, these values are for raw seeds and it will be impetuous to not consider how nutritional value is affected by the different processes that the grain legumes go through before they are consumed. The presence of anti-nutritional factors (ANFs) and aflatoxins should also be considered as they pose an impediment to utilization of grain legumes.

Table 5. Average nutrient content of selected grain legumes per 100 g raw mature seeds.

Species	Energy	Protein	Carbohydrates	Fat	Vit A	Iron	Zinc	Calcium	Source
	Kcal		g		µg		mg		
*RDA		56.0; 46.0	130.0	20.0–35.0	900.0; 700.0	8.0; 18.0	11; 8	1000.0	[124]
Dry bean	333.0	21.8	2.5	2.5	–	4.7	–	183.0	[125]
Groundnut	570.0	25.0	21.0	48.0	–	2.0	3.3	62.0	[126]
Chickpea	164.0	8.9	27.0	2.6	1.0	2.89	1.5	49.0	[10]
Soybean	446.0	36.5	30.2	19.9	1.0	15.7	4.9	277.0	[127]
Lablab	50.0	2.9	9.2	0.3	–	0.76	0.4	41.0	[128]
Cowpea	116.0	7.8	20.8	0.5	–	2.51	1.3	24.0	[10]
Bambara groundnut	367.0	20.6	56.0	6.6	–	5.96	7.9	219.0	[129]
Pigeon pea	136.0	7.2	28.9	1.6	–	1.6	1.0	42.0	[130]
Tepary bean	–	–	–	–	–	12.6	5.0	165.0	[131]
Common pea	81.0	5.4	14.0	0.4	38.0	1.47	1.2	25.0	[10]
Fababean	341.0	8.0	18.0	0.7	–	6.7	3.1	103.0	[132]
Lentil	353.0	26.0	60.0	1.0	–	7.54	4.8	56.0	[10]
White lupine	1741.0	39	11.5	5.8	–	3.1	4.5	0.68	[120]

*RDA = Recommended Dietary Allowance (Male; Female); Nutritional values may vary from one variety to the other.

Anti-Nutrient Factors

Anti-nutrient factors (ANFs) are chemical compounds synthesized by plants for their own defense. Metabolically, synthesis of anti-nutrients is a favorable attribute as it is an adaptive mechanism. However, synthesis of anti-nutrients is through inactivation of some nutrients that are important to humans [133]. This ultimately decreases nutritive value of foods. Common ANFs in legumes include tannins, phytates, oxalates, saponins, lectins, alkaloids, protease inhibitors cynogenic glucosides and oligosaccharides. They occur in small quantities ranging from 0.2% to 4%. Some ANFs cause undesirable effects to humans when consumed in excess [134]. Phytic acid impairs the absorption of iron, zinc and calcium. Lectins are difficult to digest and may affect the cells lining the intestinal tract. Saponins increase intestinal permeability also known as leaky gut [121]. Oligosaccharides occur in large quantities (≈20–50 mg/g) and are responsible for the flatulence associated with consuming legumes [121]. However, ANFs are not all undesirable; they have some benefits. For example, phytates and saponins are believed to lower the risk of colon and breast cancer [135]. Despite the latter, generally anti-nutrients are not desirable. Minimizing ANFs in grain legumes is linked to improving agronomic practices and minimizing stress during production.

4.3.3. Processing and Utilization

In rural communities, the processing and utilization of grain legumes has a long history that is intimately linked to women and their traditional livelihood tasks [136,137]. This will be an advantage for promoting grain legumes for improved household nutrition in semi- and arid tropics where women have greater influence over household food choices, child nutrition and ultimately health [138]. Grain legumes can play an increasingly important role as a source of income in rural communities, especially those near towns and cities. The money could be used towards other household needs and children's education [138].

Depending on the type of grain legume and the intended use, the various processes may differ. One of the initial steps (primary processes) is to further dry the harvested pods. Drying is done under the sun and, depending on resources, grains are spread on the ground or on a raised platform.

After sun drying comes two processes that are considered time consuming and laborious when done manually. This includes (i) dehusking which is the process of removing the husks; and (ii) winnowing which involves separating the husks from the seed [139]. Resource-poor farmers use manual methods (mortar with pestles and wooden or stone shellers). These processes require manual labor and this could also partly explain the low cultivated areas for grain legumes in rural households. Labor is limited due to rural to urban migration of the economically active age group [140]. In this regard, the development of low-cost technologies for processing the harvest could go some way in encouraging farmers to allocate more land to grain legumes.

Secondary processes include, but are not limited to, soaking, cooking, fermenting and germinating [139]. Cooking improves appeal, nutrition and digestibility of grain legumes. In several grain legumes, cooking time (boiling) of pods and/or grains is comparatively lengthy (three to five hours). This could be a disincentive in rural areas where fuelwood and water for cooking are scarce [141]. Soaking and cooking time of grain legumes have also been shown to affect nutritional quality of some grain legumes [142]. It was observed that proteins, minerals and carbohydrate content in seeds decreased by 16% to 20%, 30% and 18% to 40%, respectively, following cooking [143–145]. This raises the challenge of developing appropriate cooking methods that maximize nutrient retention. Although the challenges related to cooking time and nutrient retention have been raised, research still lags in providing solutions. Such solutions could be useful in unlocking their value.

While legumes have mainly been considered for their grains, young tender leaves and flowers of some grain legumes can also be consumed as vegetables [146,147]. Leaves and flowers are rich in vitamins and minerals [146,147]. Tapping into this potential could contribute to dietary diversity through unlocking a useful source of vitamins and minerals. This could be explored when other leafy vegetables are not available as well as to increase the leafy vegetable basket. However, there are scant studies reporting on the nutritional status of young tender leaves and flowers of legumes as well as harvest times.

Animal Feed

In addition to human consumption, grain legumes can be used for fodder. The value of grain legumes in livestock production has been explored for forage legumes such as *Medicago sativa* (alfafa), clover (*Trifolium* spp.) and vetch (*Vicia sativa*). This is mainly targeted for commercial livestock production and is unaffordable for subsistence farmers. Subsistence farmers can utilize grain legume residues for fodder but this remains underutilized and poorly documented in the semi- and arid tropics [148]. After harvesting pods, leaves of grain legumes such as chickpea, lentil, cowpea, common pea, soybean, fababean and lablab can be left in the field for animal grazing. Grain, leaves and husks of soybean, common pea, fababean, lupine, cowpea, bambara groundnut, velvet bean, chickpea, lentils and lablab can be ground and used as animal feed [132,149–151]. They form an important plant-based protein source that can be fed directly or mixed with cereals to form complete meals [145,152]. The fact that most grain legumes have a dual purpose (i.e., human and animal feed) makes them ideal for inclusion in crop–livestock systems that characterize smallholder and subsistence agriculture.

Agro-Processing

Agro-processing enables conversion of farm produce to various commodities that can attract different markets. Agro-processing increases shelf life, reduces wastage and has the potential to increase income of subsistence farmers [113]. Due to rising incomes and change in lifestyles, the demand for processed foods is increasing, creating opportunities for the agro-processing industry [153,154].

Agro-processing in various countries has been biased towards cereals, fruits, vegetables, oil, textiles and beverages. In semi- and arid tropics, grain legume agro-processing is dominated by the major grain legumes. Dry beans are commonly tinned or are sold raw with proper packaging and branding. Groundnuts are commonly sold roasted with proper packaging and branding or are processed into peanut butter. Soybean is the most versatile among all the grain legumes and can be processed to milk, curd, sauce, cheese and chunks. These products are common amongst vegetarians and those who are allergic to cow milk. In addition to the above products, groundnuts and soybean are processed to produce oil. The multiple uses make soybean and groundnut the most economically important grain legumes.

On the contrary, minor grain legumes have received less attention in terms of agro-processing. This inadvertently reduces their utilization and subsequent demand; this may explain why seed companies tend to not focus on them. Despite the lack of research, several minor grain legumes have potential for processing into various products. For example, bambara groundnut seed can be used to produce vegetable milk although this potential is currently underexplored [155,156]. India has made a significant milestone on agro-processing of minor grain legumes (chickpeas and lentils). Promoting agro-processing of minor grain legumes could open up new value chains and opportunities for rural farmers to participate in these value chains. Agro-processing would also increase demand for minor grain legumes thus necessitating increased production and availability of seed. Increasing opportunities for rural farmers to earn incomes and exit poverty is key to sustainable development in the semi- and arid tropics.

In Thailand, agro-processing reduced poverty in rural areas through (i) the purchase of agricultural products by the agro-processing industry; and (ii) establishing agro-processing industries near rural areas in-order to employ poor farmers [157]. This provides a successful case study for governments in developing countries to establish grain legume agro-processing facilities for rural farmers. India, in its efforts to encourage grain legume production, made available more than 10,000 small-scale grain legume mills [158]. Though this is incomparable to cereal hullers and mills (>200,000), it served as a starting point [158]. Developing countries should embark on similar projects to facilitate agro-processing in rural areas and make grain legume products more available at low cost. To realize this, research, development and innovation should support the development of acceptable standards, branding and marketing. Promotion of agro-processing could create business opportunities for rural farmers [159].

4.4. Marketing

Ultimately, within the value chain, there must be a market to consume the grain legume products. Marketing structures are divided into three levels—(i) the traditional/local market; (ii) wholesaler/processor market; and (iii) the retailer market. For grain legumes in the rural areas of semi- and arid tropics, the traditional market is the dominant market level. Major grain legumes are available on both the traditional and retail market while minor grain legumes are only found on the traditional market [160]. On the traditional market, grain legumes are sold whole with minimum value addition. As a result, they do not fetch a high price and products move slowly due to limited utilization. This discourages farmers from producing surplus grain legumes hence resorting to growing cereals. Cereals have a higher demand on all market levels hence they sell fast. This makes it attractive for subsistence farmers as they are guaranteed to sell their product.

Cereals have also enjoyed much innovation with regards to their agro-processing. There is a wide variety of cereal products thus attracting a wider market and ultimately increasing utilization. The number of grain legume products are only one-third of the number of cereal products [161]. This is further evidence that cereals are more utilized than grain legumes. To increase grain legume utilization, the same strategy of product diversification could be employed. This will broaden the grain legume market and ultimately increase utilization. However, product diversification is highly dependent on agro-processing. Currently, agro-processing has only focused on a few major grain legumes. Effective product diversification will require inclusion of minor grain legumes. Minor grain legumes are currently being manually processed by farmers in rural areas implying that there is scope for agro-processing in these grain legumes. There is need for investments in research, development and innovation in order to establish successful and sustainable large- and small-scale grain legume agro-processing facilities. However, such development should pay attention not to exclude rural farmers.

Rural farmers are the primary producers of grain legumes. The majority of them continue to live in poverty and are the most vulnerable to food and nutrition insecurity [138]. The current marketing and distribution channels for value-added grain legumes have not benefitted rural farmers. Value added products are expensive in retail stores and the traditional market offers limited utilization. Thus, promotion of grain legume agro-processing as a strategy to market grain legumes should include rural farmers as they are the main target of strategies to alleviate food and nutrition security. This will benefit rural farmers through (i) product diversification which will ultimately increase utilization and subsequently improve protein intake in households; and (ii) provide value added products that will attract a wider market and that will sell faster, thereby translating to increased household income.

4.5. Grain Legumes: Opportunities and Constraints

The grain legume research value chain has largely focused on grain legumes of regional economic importance. With approximately 30 grain legume species being grown in the semi- and arid tropics, only less than 50% of these have received significant research attention. This is mainly because research funding has favored a few major grain legumes (chickpea, dry bean, cowpea, fababean, groundnut, lentil, pigeon pea and soybean). These grain legumes are also part of the CGIAR's mandate crops, hence they have received significant research attention compared to other minor grain legumes [162,163]. There is an opportunity to increase the grain legume basket by tapping into the potential of other minor grain legumes. Thus far, there is scant documented information on these crops due to lack of funding to support research, development and innovation on these crops.

Breeding and crop improvement of grain legumes has been limited by the poor demand of seed. In semi- and arid tropics, farmers continue to recycle their own seed. Failure by breeders to improve farmers' varieties and tap into certain beneficial traits has confined the production of minor grain legumes to the ecological niches where they have been conserved. The semi- and arid tropics are rich in grain legume biodiversity which is currently underutilized. With increased promotion of grain legumes there is an opportunity to exploit these genetic resources. This could result in development of high-yielding cultivars that are suitable for growing in water scarce environments. The reported low yields of grain legumes have made them unattractive for farming. The low yields could also be as a result of lack of improved cultivars and farmers' agronomic knowledge which is mostly based on indigenous knowledge.

Soil fertility is one of the major challenges in rural cropping systems [164]. Grain legumes fix nitrogen, a unique feature that makes them important under marginal conditions. While nitrogen fixation is a key point for the promotion of grain legumes, there is poor understanding that nitrogen fixation is influenced by other factors such as presence of nitrogen fixing bacteria, lack of other soil nutrients and abiotic stresses [45,165]. Also, as previously alluded to, nitrogen fixation is often limited by the lack of inoculants in rural cropping systems. Water is the most limiting resource in agriculture; this has led to crop failures, poor yields, and high levels of aflatoxins and ANFs in major grain legumes. Several minor grain legumes are more drought tolerant and water use efficient than major grain legumes and offer opportunities for cultivation in dry areas where water is most limited. This would imply that their ability to fix nitrogen would be less sensitive to water stress as well; however, there is a need to test such a hypothesis. In this regard, they also offer opportunities for addressing food and nutrition insecurity in marginal agricultural production areas where most major crops may fail.

Grain legumes are nutritious and have the potential to improve nutritional status of the rural poor. However, most published nutrition values are derived from raw seeds. There is need for research that assesses the nutritional profile of grain legumes after processing as this would be more informative to dietary intake. Most grain legumes are characterized by long cooking time and are processed differently by cultures of semi- and arid tropics. Long cooking time often creates challenges as it means more water and energy are required to prepare them—resources that are equally scarce in rural areas. This suggests that there are opportunities for breeders, agronomists and nutritionists to work together to unlock such challenges. This would lead to improved utilization of grain legumes.

Owing to their long shelf life, legumes are available throughout the year thus offering a more sustainable protein source for poor rural farmers. However, even with this characteristic, given the reported challenges with post-harvest handling and storage, grain legumes are not reaching their potential shelf life. There are opportunities for agricultural engineers to develop low-cost post-harvest technologies for use in rural areas. Improving storage could serve as incentive for farmers to produce more of a crop as they know they can store it for longer periods.

The market for grain legumes, in particular minor grain legumes, remains underdeveloped. This confines their utilization to the niche areas in which they are produced. Consequently, grain legumes have become a poor and slow income-generating source for rural farmers, acting as a disincentive to their continued production despite the benefits associated with them. Opportunities that exist in agro-processing could lead to the opening of new markets through value addition and product diversification. Improved income realized from agro-processing could promote autonomous pathways out of poverty for poor rural households.

5. Recommendations

There is a large diversity of grain legumes that fit into various agro-ecologies. This implies that grain legumes can be grown in various environments. Focusing on a few specific grain legumes leaves farmers with limited choices and forces farmers to grow them in unsuitable environments and risk crop failure. If grain legumes are to be promoted to increase dietary diversity, then there is need to broaden the grain legume basket by increasing research, development and innovation on other minor grain legumes. While regionally important grain legumes have received breeding attention compared to other minor grain legumes, there is still need for pre-breeding to develop new gene pools for all grain legumes. This will be followed by breeding and commercialization of cultivars that are nutrient dense and well-adapted to semi- and arid conditions. Breeding efforts and subsequent commercialization of minor grain legumes should recognize the role played by farmers in rural areas and create opportunities for meaningful access and beneficiation.

There should be more integration of indigenous and scientific knowledge to allow rural farmers to improve grain yield and quality. It has been realized that soil fertility is a constraint in rural cropping systems and that grain legumes have the ability to improve soil fertility. To improve soil fertility, legumes should be incorporated into cropping systems through relay cropping, intercropping, crop rotations or double cropping. Researchers need to make practical recommendations based on water use and water productivity of grain legumes and focus on improving crop water productivity. This should include minor grain legumes that are indigenous to semi- and arid conditions as they have been observed to be more drought tolerant when compared to major grain legumes.

6. Conclusions

There is a high prevalence of food and nutrition insecurity in semi- and arid tropics. Measures to increase food production should create a balance between increasing productivity, water scarcity and nutrition. The fact that grain legumes are rich sources of proteins and micronutrients suggests that they have a role to play in contributing to food and nutrition security in poor rural communities. Use of grain legumes for both human and animal consumption provides an opportunity to improve sustainability of crop-livestock systems in the semi- and arid tropics. The large diversity of grain legumes makes them adaptable to a range of environments, especially marginal agriculture production areas. However, a poorly developed and understood value chain currently limits the realization of this potential. Aspects of their breeding, seed systems, production, marketing and utilization are not well explained. This is mostly the case for minor legumes which incidentally hold the most potential for improving food and nutrition security in semi- and arid areas. Focusing on the value chain could aid researchers to identify and unlock barriers for the promotion of legumes in semi- and arid tropics. Despite the large diversity of grain legumes, research has been biased towards major grain legumes. Ironically, the minor grain legumes are the ones indigenous to semi- and arid tropics and hence are more adaptable to water-scarce conditions. There is need to increase the legume basket by adding minor grain legumes. This will also act as a buffer when major grain legumes are not successful due to drought.

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References

1. Conway, D.; Persechino, A.; Ardoin-Bardin, S.; Hamandawana, H.; Dieulin, C.; Mahé, G. Rainfall and water resources variability in sub-Saharan Africa during the twentieth century. *J. Hydrometeorol.* **2009**, *10*, 41–59. [CrossRef]
2. Alliance for a Green Revolution in Africa (AGRA). *Africa Agriculture Status Report: Focus on Staple Crops*; AGRA: Nairobi, Kenya, 2013.
3. Graeub, B.; Chappell, M.; Wittman, H.; Ledermann, S.; Kerr, R.; Gemmill-Herre, B. The State of Family Farms in the World. *World Dev.* **2016**, *87*, 1–15. [CrossRef]
4. Food and Agriculture Organization; International Fund for Agricultural Development; World Food Programme. *The State of Food Insecurity in the World: Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress*; FAO: Rome, Italy, 2015.
5. United Nations Children's Fund (UNICEF). *A Wake-up Call: El Niño's Impact on Children. Briefing Note*; UNICEF: New York, NY, USA, 2015.
6. Mabhaudhi, T.; Chibarabada, T.; Modi, A. Water-Food-Nutrition-Health Nexus: Linking Water to Improving Food, Nutrition and Health in Sub-Saharan Africa. *Int. J. Environ. Res. Public Health* **2016**, *13*, 107. [CrossRef] [PubMed]
7. Organisation for Economic Co-operation and Development (OECD); Food and Agriculture Organization (FAO). *OECD-FAO Agricultural Outlook 2015*; OECD: Paris, France, 2015.
8. Kearney, J. Food consumption trends and drivers. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2010**, *365*, 2793–2807. [CrossRef] [PubMed]
9. Faber, M.; Venter, S.L.; Benadé, A.J.S. Increased vitamin A intake in children aged 2–5 years through targeted home-gardens in a rural South African community. *Public Health Nutr.* **2002**, *5*, 11–16. [CrossRef] [PubMed]
10. Iqbal, A.; Khalil, I.A.; Ateeq, N.; Khan, M.S. Nutritional quality of important food legumes. *Food Chem.* **2006**, *97*, 331–335. [CrossRef]
11. Seena, S.; Sridhar, K.R. Physicochemical, functional and cooking properties of under explored legumes, Canavalia of the southwest coast of India. *Food Res. Int.* **2005**, *38*, 803–814. [CrossRef]
12. Boschin, G.; Arnoldi, A. Legumes are valuable sources of tocopherols. *Food Chem.* **2011**, *127*, 1199–1203. [CrossRef] [PubMed]
13. Akinyele, I.O.; Shokunbi, O.S. Concentrations of Mn, Fe, Cu, Zn, Cr, Cd, Pb, Ni in selected Nigerian tubers, legumes and cereals and estimates of the adult daily intakes. *Food Chem.* **2015**, *173*, 702–708. [CrossRef] [PubMed]
14. Mooney, H.; Drake, J. *Ecology of Biological Invasions of North America and Hawaii*; Springer Science & Business Media: Berlin, Germany, 2012.
15. Pingali, P.L. Green revolution: Impacts, limits, and the path ahead. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 12302–12308. [CrossRef] [PubMed]
16. Zhang, H.; Pala, M.; Oweis, T.; Harris, H. Water use and water-use efficiency of chickpea and lentil in a Mediterranean environment. *Aust. J. Agric. Res.* **2000**, *51*, 295–304. [CrossRef]
17. Siddique, K.H.M.; Regan, K.L.; Tennant, D.; Thomson, B.D. Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. *Eur. J. Agron.* **2001**, *15*, 267–280. [CrossRef]

18. Muñoz-Perea, C.G.; Allen, R.G.; Westermann, D.T.; Wright, J.L.; Singh, S.P. Water use efficiency among dry bean landraces and cultivars in drought-stressed and non-stressed environments. *Euphytica* **2007**, *155*, 393–402. [CrossRef]
19. Patel, G.N.; Patel, P.T.; Patel, P.H. Yield, Water Use Efficiency and Moisture Extraction Pattern of Summe. Available online: http://ejournal.icrisat.org/Volume6/Groundnut/GN_Patel.pdf (accessed on 22 December 2016).
20. Obalum, S.E.; Igwe, C.A.; Obi, M.E.; Wakatsuki, T. Water use and grain yield response of rainfed soybean to tillage-mulch practices in southeastern Nigeria. *Sci. Agric.* **2011**, *68*, 554–561.
21. Mabhaudhi, T.; Modi, A.; Beletse, Y. Growth, phenological and yield responses of a bambara groundnut (*Vigna subterránea* L. Verdc) landrace to imposed water stress: II. Rain shelter conditions. *Water SA* **2013**, *39*, 191–198. [CrossRef]
22. Chibarabada, T.P.; Modi, A.T.; Mabhaudhi, T. Water use characteristics of a bambara groundnut (*Vigna subterranea* L. Verdc) landrace during seedling establishment. *Water SA* **2015**, *41*, 472–482. [CrossRef]
23. Chivenge, P.; Mabhaudhi, T.; Modi, A.T.; Mafongoya, P. The Potential Role of Neglected and Underutilised Crop Species as Future Crops under Water Scarce Conditions in Sub-Saharan Africa. *Int. J. Environ. Res. Public Health* **2015**, *12*, 5685–5711. [CrossRef] [PubMed]
24. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci. Discuss.* **2007**, *4*, 439–473. [CrossRef]
25. Wojcicki, J.M. The double burden household in sub-Saharan Africa: Maternal overweight and obesity and childhood undernutrition from the year 2000: Results from World Health Organization Data (WHO) and Demographic Health Surveys (DHS). *BMC Public Health* **2014**, *14*, 1124. [CrossRef] [PubMed]
26. World Bank Open Data. Available online: http://data.worldbank.org (accessed on 10 July 2015).
27. Rockström, J.; Karlberg, L.; Wani, S.P.; Barron, J.; Hatibu, N.; Oweis, T.; Bruggeman, A.; Farahani, J.; Qiang, Z. Managing water in rainfed agriculture—The need for a paradigm shift. *Agric. Water Manag.* **2010**, *97*, 543–550. [CrossRef]
28. Rockström, J. Water for food and nature in drought–prone tropics: Vapour shift in rain–fed agriculture. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2003**, *358*, 1997–2009. [CrossRef] [PubMed]
29. Molden, D. Water for Food, Water for Life—A Comprehensive Assessment of Water Management in Agriculture. Available online: http://link.springer.com/article/10.1007%2Fs10795-008-9044-8?LI=true (accessed on 22 December 2016).
30. International Food Policy Research Institute (IFPRI). *Global Nutrition Report 2014: Actions and Accountability to Accelerate the World's Progress on Nutrition*; IFPRI: Washington, DC, USA, 2014.
31. United Nations Children's Fund (UNICEF); World Health Organization (WHO); World Bank. Child Malnutrition Indicators (Stunting, Wasting, Severe Wasting, Overweight and Underweight) and New Global & Regional Estimates for 2013. Available online: http://www.who.int/nutgrowthdb/jme_2012_summary_note_v2.pdf (accessed on 22 December 2016).
32. Food and Agriculture Organisation (FAO). The Rome declaration on world food security. *Popul. Dev. Rev.* **1996**, *22*, 14–17.
33. Thompson, B.; Amoroso, L.; Meerman, J. *Promoting the Expression "Food and Nutrition Security (FNS)"*; A Strategy Note from the Nutrition and Consumer Protection Division—AGN. Available online: http://www.fao.org/ag/agn/nutrition/docs/Food_and_Nutrition_Security-Strategy_Note.pdf (accessed on 22 December 2016).
34. Shetty, P. From food security to food and nutrition security: Role of agriculture and farming systems for nutrition. *Curr. Sci.* **2015**, *109*, 456–461.
35. McDermott, J.; Johnson, N.; Kadiyala, S.; Kennedy, G.; Wyatt, A.J. Agricultural research for nutrition outcomes–rethinking the agenda. *Food Secur.* **2015**, *7*, 593–607. [CrossRef]
36. Alleyne, G.A.O.; Hay, R.W.; Picou, D.I.; Stanfield, J.P.; Whitehead, R.G. *Protein-Energy Malnutrition*; Edward Arnold (Publishers): London, UK, 1977.
37. Abberton, M. Enhancing the role of legumes: Potential and obstacles. *Grassl. Carbon Seq. Manag. Policy Econ.* **2010**, *11*, 177.
38. Khan, M.A. Nutritional attributes of food legumes. *Progress. Farming* **1987**, *7*, 36–40.
39. Singh, U.; Singh, B. Tropical grain legumes as important human foods. *Econ. Bot.* **1992**, *46*, 310–321. [CrossRef]
40. Hatcher, P.; Battey, N. *Biological Diversity: Exploiters and Exploited*; John Wiley & Sons: Hoboken, NJ, USA, 2011.

41. Allen, O.N.; Allen, E.K. *The Leguminosae. A Source Book of Characteristics, Uses and Nodulation*; University of Wisconsin Press, Madison & Macmillan Publishers: London, UK, 1981.
42. Smartt, J. *Grain Legumes: Evolution and Genetic Resources*; Cambridge University Press: Cambridge, UK, 1990.
43. Smartt, J. *Tropical Pulses*; Longman: London, UK, 1976; p. 348.
44. Sur, S.; Bothra, A.K.; Sen, A. Symbiotic Nitrogen Fixation-A Bioinformatics Perspective. *Biotechnology* **2010**, *9*, 257–273. [CrossRef]
45. Zahran, H.H. Rhizobium-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. *Microbiol. Mol. Biol. Rev.* **1999**, *63*, 968–989. [PubMed]
46. Crews, T.E.; Peoples, M.B. Legume versus fertilizer sources of nitrogen: Ecological tradeoffs and human needs. *Agric. Ecosyst. Environ.* **2004**, *102*, 279–297. [CrossRef]
47. Hutchinson, J. *Evolution and Phylogeny of Flowering Plants*; Academic Press: London, UK; New York, NY, USA, 1969.
48. Dry Beans Production Guideline. Available online: http://www.nda.agric.za/docs/Brochures/Dry-beans.pdf (accessed on 10 May 2015).
49. Smartt, J. *The Groundnut Crop: A Scientific Basis for Improvement*; Smartt, J., Ed.; Chapman and Hall: London, UK, 1994.
50. Chickpea. Available online: http://www.nda.agric.za/docs/Brochures/Chickpea.pdf (accessed on 10 May 2015).
51. Dugje, I.Y.; Omoigui, L.O.; Ekeleme, F.; Bandyopadhyay, R.; Kumar, P.L.; Kamara, A.Y. *Farmers' Guide to Soybean Production in Northern Nigeria*; IITA: Ibadan, Nigeria, 2009.
52. Valenzuela, H.; Smith, J. Lablab. Available online: http://www.ctahr.hawaii.edu/oc/freepubs/pdf/GreenManureCrops/lablab.pdf (accessed on 22 December 2016).
53. Swanevelder, C.J. Bambara Groundnuts—Food for Africa. Available online: http://www.nda.agric.za/docs/brochures/bambara.pdf (accessed on 22 December 2016).
54. Odeny, D.A.; Jayashree, B.; Ferguson, M.; Hoisington, D.; Crouch, J.; Gebhardt, C. Development, characterization and utilization of microsatellite markers in pigeonpea. *Plant Breed.* **2007**, *126*, 130–136. [CrossRef]
55. Hamama, A.A.; Bhardwaj, H.L. Tepary bean: A short duration summer crop in Virginia. In *Trends New Crop. New Uses*; ASHS Press: Alexandria, VA, USA, 2002; pp. 429–431.
56. Boswell, V.G. The influence of temperature upon the growth and yield of garden peas. *Proc. Am. Soc. Hort. Sci.* **1926**, *23*, 162–168.
57. Faba Bean. Available online: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/157729/faba-bean-pt1.pdf (accessed on 22 December 2016).
58. White Lupine, *Lupinus albus L.* (USDA NRCS Big Flats Plant Materials Center). Available online: https://plants.usda.gov/plantguide/pdf/pg_lual22.pdf (accessed on 29 October 2016).
59. Abate, T.; Alene, A.D.; Bergvinson, D.; Shiferaw, B.; Silim, S.; Orr, A.; Asfaw, S. *Tropical Grain Legumes in Africa and South Asia: Knowledge and Opportunities*; International Crops Research Institute for the Semi-Arid Tropics: Patancheru, India, 2012.
60. Singh, K.M.; Singh, A.K. *Lentil in India: An Overview*; Available SSRN 2510906; Military Police Regimental Association: Fort Leonard Wood, MO, USA, 2014.
61. Oweis, T. *Supplemental Irrigation: A Highly Efficient Water-Use Practice*; ICARDA: Aleppo, Syria, 1997.
62. Nedumaran, S.; Abinaya, P.; Jyosthnaa, P.; Shraavya, B.; Rao, P.; Bantilan, C. Grain Legumes Production, Consumption and Trade Trends in Developing Countries. Available online: http://oar.icrisat.org/6428/ (accessed on 22 December 2016).
63. Von Oppen, M. *Prospects for Grain Legume Production in Asia*; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT): Kurnool, India, 1981.
64. Sharma, S.; Upadhyaya, H.D.; Varshney, R.K.; Gowda, C.L.L. Pre-breeding for diversification of primary gene pool and genetic enhancement of grain legumes. *Front. Plant Sci.* **2013**, *4*, 309. [CrossRef] [PubMed]
65. Duc, G.; Agrama, H.; Bao, S.; Berger, J.; Bourion, V.; De Ron, A.M.; Gowda, C.L.L.; Mikic, A.; Millot, D.; Singh, K.B. Breeding annual grain legumes for sustainable agriculture: New methods to approach complex traits and target new cultivar ideotypes. *CRC. Crit. Rev. Plant Sci.* **2015**, *34*, 381–411. [CrossRef]
66. Germplasm resources. Available online: http://exploreit.icrisat.org/page/projects/708 (accessed on 10 July 2015).
67. Genetic Resources Center. Available online: http://www.iita.org/geneticresources;jsessionid=DACC1285D353484D2DA69BA9F2CEB4DB (accessed on 14 September 2015).

68. Foyer, C.H.; Lam, H.-M.; Nguyen, H.T.; Siddique, K.H.M.; Varshney, R.K.; Colmer, T.D.; Cowling, W.; Bramley, H.; Mori, T.A.; Hodgson, J.M. Neglecting legumes has compromised human health and sustainable food production. *Nat. Plants* **2016**, *2*, 16112. [CrossRef]
69. Almekinders, C.J.M.; Louwaars, N.P.; de Bruijn, G.H. Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* **1994**, *78*, 207–216. [CrossRef]
70. Coomes, O.T.; McGuire, S.J.; Garine, E.; Caillon, S.; McKey, D.; Demeulenaere, E.; Jarvis, D.; Aistara, G.; Barnaud, A.; Clouvel, P. Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy* **2015**, *56*, 41–50. [CrossRef]
71. Almekinders, C.J.M.; Louwaars, N.P. The Importance of the Farmers' Seed Systems in a Functional National Seed Sector. *J. New Seeds* **2002**, *4*, 15–33. [CrossRef]
72. Jones, R.B.; Audi, P.A.; Tripp, R. The Role of Informal Seed Systems in Disseminating Modern Varieties. The Example of Pigeonpea From a Semi-Arid Area of Kenya. *Exp. Agric.* **2001**, *37*, 539–548. [CrossRef]
73. Reddy, R.; Nigam, S.N.; Parthasarthy, R.; Ahmed, S.; Ratnakar, R.; Alur, S.; Ashok, K.A. *Village Seed Banks: An Integrated Seed System for Improved Seed Production and Supply—A Case Study*; International Crops Research Institute for the Semi-Arid Tropics: Patancheru, India, 2010.
74. United States Agency for International Development (USAID). *Burundi Legume/Bean Value Chain Rapid Analysis*; USAID: Washington, DC, USA, 2012.
75. Wekundah, J.M. *Why Informal Seed Sector Is Important in Food Security*; African Technology Policy Studies Network: Nairobi, Kenya, 2012; Volume 43, pp. 1–20.
76. Bèye, A.M.; Wopereis, M.C.S. Cultivating knowledge on seed systems and seed strategies: Case of the rice crop. *Net J. Agric. Sci.* **2014**, *2*, 11–29.
77. Zeven, A.C. Landraces: A review of definitions and classifications. *Euphytica* **1998**, *104*, 127–139. [CrossRef]
78. Saxena, K.B.; Kumar, R.V.; Tikle, A.N.; Saxena, M.K.; Gautam, V.S.; Rao, S.K.; Khare, D.K.; Chauhan, Y.S.; Saxena, R.K.; Reddy, B.V.S.; et al. ICPH 2671—The world's first commercial food legume hybrid. *Plant Breed.* **2013**, *132*, 479–485. [CrossRef]
79. Bezner Kerr, R. Seed struggles and food sovereignty in northern Malawi. *J. Peasant Stud.* **2013**, *40*, 867–897. [CrossRef]
80. Kerr, R.B. Lessons from the old Green Revolution for the new: Social, environmental and nutritional issues for agricultural change in Africa. *Prog. Dev. Stud.* **2012**, *12*, 213–229. [CrossRef]
81. Muigai, C.; Ogana, F.; Shiferaw, B.; Simtowe, F.; Asfaw, S. Integrated Innovations for Improving Legume Productivity, Market Linkages and Risk Management in Eastern and Southern Africa. Seed Production and Marketing: A Handbook for Farmer Organizations and Agro-Enterprises. Available online: http://ongoing-research.cgiar.org/factsheets/integrated-innovations-for-improving-legume-productivity-market-linkages-and-risk-management-in-eastern-and-southern-africa (accessed on 22 December 2016).
82. Karpenstein-Machan, M.; Stuelpnagel, R. Biomass yield and nitrogen fixation of legumes monocropped and intercropped with rye and rotation effects on a subsequent maize crop. *Plant Soil* **2000**, *218*, 215–232. [CrossRef]
83. Smith, A.; Snapp, S.; Dimes, J.; Gwenambira, C.; Chikowo, R. Doubled-up legume rotations improve soil fertility and maintain productivity under variable conditions in maize-based cropping systems in Malawi. *Agric. Syst.* **2016**, *145*, 139–149. [CrossRef]
84. Reckling, M.; Hecker, J.-M.; Bergkvist, G.; Watson, C.A.; Zander, P.; Schläfke, N.; Stoddard, F.L.; Eory, V.; Topp, C.F.E.; Maire, J. A cropping system assessment framework—evaluating effects of introducing legumes into crop rotations. *Eur. J. Agron.* **2015**, *76*, 186–197. [CrossRef]
85. Blevins, R.L.; Herbek, J.H.; Frye, W.W. Legume cover crops as a nitrogen source for no-till corn and grain sorghum. *Agron. J.* **1990**, *82*, 769–772. [CrossRef]
86. Chabi-Olaye, A.; Nolte, C.; Schulthess, F.; Borgemeister, C. Effects of grain legumes and cover crops on maize yield and plant damage by Busseola fusca (Fuller)(*Lepidoptera: Noctuidae*) in the humid forest of southern Cameroon. *Agric. Ecosyst. Environ.* **2005**, *108*, 17–28. [CrossRef]
87. Rühlemann, L.; Schmidtke, K. Evaluation of monocropped and intercropped grain legumes for cover cropping in no-tillage and reduced tillage organic agriculture. *Eur. J. Agron.* **2015**, *65*, 83–94. [CrossRef]
88. Divito, G.A.; Sadras, V.O. How do phosphorus, potassium and sulphur affect plant growth and biological nitrogen fixation in crop and pasture legumes? A meta-analysis. *Field Crop Res.* **2014**, *156*, 161–171. [CrossRef]

89. Cheruiyot, R.C.; Gicharu, G.K.; Gitonga, N.M.; Boga, H.; Maingi, J.M. Effect of Inoculating Selected Climbing Bean Cultivars with Different Rhizobia Strains on Nitrogen Fixation. Available online: http://etd-library.ku.ac.ke/handle/123456789/7861 (accessed on 22 December 2016).
90. Mweetwa, A.M.; Mulenga, M.; Mulilo, X.; Ngulube, M.; Banda, J.S.K.; Kapulu, N.; N'gandu, S.H. Response of Cowpea, Soya Beans and Groundnuts to Non-Indigenous Legume Inoculants. *Sustain. Agric. Res.* **2014**, *3*, 84. [CrossRef]
91. Avola, G.; Cavallaro, V.; Patanè, C.; Riggi, E. Gas exchange and photosynthetic water use efficiency in response to light, CO 2 concentration and temperature in Vicia faba. *J. Plant Physiol.* **2008**, *165*, 796–804. [CrossRef] [PubMed]
92. Olorunmaiye, P.M. Weed control potential of five legume cover crops in maize/cassava intercrop in a Southern Guinea savanna ecosystem of Nigeria. *Aust. J. Crop Sci.* **2010**, *4*, 324.
93. Rubiales, D.; Fernández-Aparicio, M. Innovations in parasitic weeds management in legume crops. A review. *Agron. Sustain. Dev.* **2011**, *32*, 433–449. [CrossRef]
94. Martin, S.G.; Van Acker, R.C.; Friesen, L.F. Critical period of weed control in spring canola. *Weed Sci.* **2009**, *49*, 326–333. [CrossRef]
95. Abdelhamid, M.T.; El-Metwally, I.M. Growth, nodulation, and yield of soybean and associated weeds as affected by weed management. *Planta Daninha* **2008**, *26*, 855–863. [CrossRef]
96. Bhale, V.M.; Karmore, J.V.; Patil, Y.R.; Krishi, P.D. Integrated weed management in groundnut (Arachis hypogea). *Pakistan J. Weed Sci. Res.* **2012**, *18*, 733–739.
97. Mhango, W.G.; Snapp, S.S.; Phiri, G.Y.K. Opportunities and constraints to legume diversification for sustainable maize production on smallholder farms in Malawi. *Renew. Agric. Food Syst.* **2013**, *28*, 234–244. [CrossRef]
98. Luchese, R.H.; Harrigan, W.F. Biosynthesis of aflatoxin—the role of nutritional factors. *J. Appl. Bacteriol.* **1993**, *74*, 5–14. [CrossRef] [PubMed]
99. Heathcote, J.G.; Hibbert, J.R. *Aflatoxins: Chemical and Biological Aspects*; Elsevier Scientific Pub. Co.: Amsterdam, The Netherlands, 1978.
100. Chala, A.; Mohammed, A.; Ayalew, A.; Skinnes, H. Natural occurrence of aflatoxins in groundnut (Arachis hypogaea L.) from eastern Ethiopia. *Food Control.* **2013**, *30*, 602–605. [CrossRef]
101. Exporting Groundnuts. Available online: http://www.tradeforum.org/exporting-groundnuts (accessed on 20 September 2015).
102. Diaz Rios, L. *Barrier, Catalyst, or Distraction? Standards, Competitiveness, and Africa's Groundnut Exports to Europe*; Agriculture and Rural Development Discussion Paper 39; World Bank: Washington, DC, USA, 2008.
103. Igbadun, H.E.; Mahoo, H.F.; Tarimo, A.K.P.R.; Salim, B.A. Crop water productivity of an irrigated maize crop in Mkoji sub-catchment of the Great Ruaha River Basin, Tanzania. *Agric. Water Manag.* **2006**, *85*, 141–150. [CrossRef]
104. Saeed, I.A.M.; El-Nadi, A.H. Forage sorghum yield and water use efficiency under variable irrigation. *Irrig. Sci.* **1998**, *18*, 67–71. [CrossRef]
105. Tijani, F.O.; Oyedele, D.J.; Aina, P.O. Soil moisture storage and water-use efficiency of maize planted in succession to different fallow treatments. *Int. Agrophys.* **2008**, *22*, 81.
106. Badr, M.A.; El-Tohamy, W.A.; Zaghloul, A.M. Yield and water use efficiency of potato grown under different irrigation and nitrogen levels in an arid region. *Agric. Water Manag.* **2012**, *110*, 9–15. [CrossRef]
107. Van Halsema, G.E.; Vincent, L. Efficiency and productivity terms for water management: A matter of contextual relativism versus general absolutism. *Agric. Water Manag.* **2012**, *108*, 9–15. [CrossRef]
108. Molden, D.; Murray-Rust, H.; Sakthivadivel, R.; Makin, I. A water-productivity framework for understanding and action. In *Water Productivity in Agriculture: Limits and Opportunities for Improvement*; Kijne, J.W., Barker, R., Molden, D., Eds.; CAB International: Oxfordshire, UK, 2003.
109. Abayomi, Y.A.; Ajibade, T.V.; Sammuel, O.F.; Saadudeen, B.F. Growth and yield responses of cowpea (Vigna unguiculata (L.) Walp) genotypes to nitrogen fertilizer (NPK) application in the Southern Guinea Savanna zone of Nigeria. *Asian J. Plant Sci.* **2008**, *7*, 170–176. [CrossRef]
110. Vimalendran, L.; Latha, K.R. Yield, water use and water use efficiency of pigeonpea [Cajanus cajan (L.) Millsp.] under drip fertigation system. *J. Appl. Nat. Sci.* **2014**, *6*, 457–462.
111. Anderson, D.P.; Hanselka, D. Adding Value to Agricultural Products. Available online: http://agecoext.tamu.edu/files/2013/10/rm1-8.pdf (accessed on 22 December 2016).

112. Boland, M.A. Leadership Development in Agricultural Economics: Challenges for Academic Units. *J. Agric. Resour. Econ.* **2009**, *34*, 367–382.
113. Food and Agriculture Organization. *The State of Food and Agriculture*; FAO: Rome, Italy, 1997.
114. Williams, B. Grain Legume Harvesting File. Available online: http://C:/Users/212512302/Downloads/grain_legume_harvesting_1994.pdf (accessed on 5 August 2015).
115. Mothander, B.; Kjærby, F.; Havnevik, K.J. *Farm Implements for Small-Scale Farmers in Tanzania*; Nordic Africa Institute: Uppsala, Sweden, 1989.
116. Kat, J.; Diop, A.; Gergeley, N. *Guidelines for the Establishment, Operation, and Management of Cereal Banks*; Issues 83-88; FAO: Rome, Italy, 1992.
117. USA Dry Pea, Lentil & Chickpea Production. Available online: http://www.pea-lentil.com/core/files/pealentil/uploads/files/Chapter3.pdf (accessed on 15 October 2015).
118. Summerfield, J. *World Crops: Cool Season Food Legumes: A Global Perspective of the Problems and Prospects for Crop Improvement in Pea, Lentil, Faba Bean and Chickpea*; Springer Science & Business Media: Berlin, Germany, 2012.
119. McCormack, J.H. *Seed Processing and Storage Principles and Practices of Seed Harvesting, Processing, and Storage: An Organic Seed Production Manual for Seed Growers in the Mid-Atlantic and Southern US*; Carolina Farm Stewardship Association: Pittsboro, NC, USA; Garden Medicinals and Culinaries: Earlysville, VA, USA, 2004.
120. Večerek, V.; Suchý, P.; Straková, E.; Macháček, M.; Palta, J.A.; Berger, J.D. Nutritive composition of seeds of the lupin varieties registered in the Czech Republic. In *Lupins for Health and Wealth, Proceedings of the 12th International Lupin Conference, Fremantle, Australia, 14–18 September 2008*; International Lupin Association: Canterberry, New Zealand, 2008; pp. 14–18.
121. Messina, M.J. Legumes and soybeans: Overview of their nutritional profiles and health effects. *Am. J. Clin. Nutr.* **1999**, *70*, 439–450.
122. Smith, T.M.; Kolars, J.C.; Savaiano, D.A.; Levitt, M.D. Absorption of calcium from milk and yogurt. *Am. J. Clin. Nutr.* **1985**, *42*, 1197–1200. [PubMed]
123. McKevith, B. Nutritional aspects of cereals. *Nutr. Bull.* **2004**, *29*, 111–142. [CrossRef]
124. Food and Agricultural Organization; World Health Organization. Vitamin and Mineral Requirements in Human Nutrition. Available online: http://apps.who.int/iris/bitstream/10665/42716/1/9241546123.pdf (accessed on 22 December 2016).
125. Geil, P.B.; Anderson, J.W. Nutrition and health implications of dry beans: A review. *J. Am. Coll. Nutr.* **1994**, *13*, 549–558. [CrossRef] [PubMed]
126. Atasie, V.N.; Akinhanmi, T.F.; Ojiodu, C.C. Proximate analysis and physico-chemical properties of groundnut (*Arachis hypogaea* L.). *Pak. J. Nutr.* **2009**, *8*, 194–197. [CrossRef]
127. Liu, K. Chemistry and nutritional value of soybean components. In *Soybeans*; Springer: Berlin, Germany, 1997; pp. 25–113.
128. Deka, R.K.; Sarkar, C.R. Nutrient composition and antinutritional factors of *Dolichos lablab* L. seeds. *Food Chem.* **1990**, *38*, 239–246. [CrossRef]
129. Yao, D.N.; Kouassi, K.N.; Erba, D.; Scazzina, F.; Pellegrini, N.; Casiraghi, M.C. Nutritive Evaluation of the Bambara Groundnut Ci12 Landrace [*Vigna subterranea* (L.) Verdc.(Fabaceae)] Produced in Côte d'Ivoire. *Int. J. Mol. Sci.* **2015**, *16*, 21428–21441. [CrossRef] [PubMed]
130. Singh, U.; Jain, K.C.; Jambunathan, R.; Faris, D.G. Nutritional quality of vegetable pigeonpeas [*Cajanus cajan* (L.) Mill sp.]: Mineral and trace elements. *J. Food Sci.* **1984**, *49*, 645–646. [CrossRef]
131. Sheerens, J.C.; Tinsley, A.M.; Abbas, I.R.; Weber, C.W.; Berry, J.W. The nutritional significance of tepary bean consumption. *Desert Plants* **1983**, *5*, 11–56.
132. Crépon, K.; Marget, P.; Peyronnet, C.; Carrouée, B.; Arese, P.; Duc, G. Nutritional value of faba bean (*Vicia faba* L.) seeds for feed and food. *Field Crops Res.* **2010**, *115*, 329–339. [CrossRef]
133. Gemede, H.F.; Ratta, N. Antinutritional factors in plant foods: Potential health benefits and adverse effects. *Glob. Adv. Res. J. Food Sci. Technol.* **2014**, *3*, 103–117.
134. Gilani, G.S.; Xiao, C.W.; Cockell, K.A. Impact of antinutritional factors in food proteins on the digestibility of protein and the bioavailability of amino acids and on protein quality. *Br. J. Nutr.* **2012**, *108*, 315–332. [CrossRef] [PubMed]
135. Bennink, M.R. Consumption of black beans and navy beans *(Phaseolus vulgaris)* reduced azoxymethane-induced colon cancer in rats. *Nutr. Cancer* **2002**, *44*, 60–65. [CrossRef] [PubMed]

136. Ezumah, N.N.; Di Domenico, C.M. Enhancing the role of women in crop production: A case study of Igbo women in Nigeria. *World Dev.* **1995**, *23*, 1731–1744. [CrossRef]
137. Modi, M.; Modi, A.; Hendriks, S. Potential role for wild vegetables in household food security: A preliminary case study in Kwazulu-Natal, South Africa. *Afr. J. Food Agric. Nutr. Dev.* **2006**, *6*, 1–13. [CrossRef]
138. Food and Agriculture Organization (FAO). Social Protection and Agriculture: Breaking the Cycle of Rural Poverty. In *The State of Food and Agriculture 2015*; FAO: Rome, Italy, 2015; p. 151.
139. Subuola, F.; Widodo, Y.; Kehinde, T. Processing and Utilization of Legumes in the Tropics. Available online: http://cdn.intechopen.com/pdfs/35126/intech-processing_and_utilization_of_legumes_in_the_tropics.pdf (accessed on 22 December 2016).
140. De Haan, A. Rural-Urban Migration and Poverty: The Case of India. *IDS Bull.* **1997**, *28*, 35–47. [CrossRef]
141. Deshpande, S.S. *Fermented Grain Legumes, Seeds and Nuts: A Global Perspective*; Issue 142; Food and Agriculture Organization: Rome, Italy, 2000.
142. Güzel, D.; Sayar, S. Effect of cooking methods on selected physicochemical and nutritional properties of barlotto bean, chickpea, faba bean, and white kidney bean. *J. Food Sci. Technol.* **2012**, *49*, 89–95. [CrossRef] [PubMed]
143. Meiners, C.R.; Derise, N.L.; Lau, H.C.; Crews, M.G.; Ritchey, S.J.; Murphy, E.W. The content of nine mineral elements in raw and cooked mature dry legumes. *J. Agric. Food Chem.* **1976**, *24*, 1126–1130. [CrossRef] [PubMed]
144. Mahadevamma, S.; Tharanathan, R.N. Processing of Legumes: Resistant Starch And Dietary Fiber Contents. *J. Food Qual.* **2004**, *27*, 289–303. [CrossRef]
145. Siddhuraju, P.; Becker, K.; Makkar, H.P.S. Studies on the nutritional composition and antinutritional factors of three different germplasm seed materials of an under-utilized tropical legume, Mucuna pruriens var. Utilis. *J. Agric. Food Chem.* **2000**, *48*, 6048–6060. [CrossRef] [PubMed]
146. Manay, N.; Swamy, S. *Food: Facts and Principles*, 2nd ed.; New Age International: New Delhi, India, 2001.
147. Toensmeier, E. *Perennial Vegetables: From Artichokes to Zuiki Taro, A Gardener's Guide to over 100 Delicious and Easy to Grow Edibles*; Chelsea Green Publishing: White River Junction, VT, USA, 2007.
148. Sumberg, J. The logic of fodder legumes in Africa. *Food Policy* **2002**, *27*, 285–300. [CrossRef]
149. Dixon, R.M.; Hosking, B.J. Nutritional value of grain legumes for ruminants. *Nutr. Res. Rev.* **1992**, *5*, 19–43. [CrossRef] [PubMed]
150. Huisman, J.; Van der Poel, A.F.B. Aspects of the nutritional quality and use of cool season food legumes in animal feed. In *Expanding the Production and Use of Cool Season Food Legumes*; Springer: Berlin, Germany, 1994; pp. 53–76.
151. Jezierny, D.; Mosenthin, R.; Bauer, E. The use of grain legumes as a protein source in pig nutrition: A review. *Anim. Feed Sci. Technol.* **2010**, *157*, 111–128. [CrossRef]
152. Nji, F.F.; Niess, E.; Pfeffer, E. Nutrient content of Bambara groundnut (Vigna subterranea) and the effects of its inclusion on the performance of growing broiler chickens and on egg production and quality. *J. Anim. Feed Sci.* **2004**, *13*, 497–507.
153. Timmer, C.P. Getting agriculture moving: Do markets provide the right signals? *Food Policy* **1995**, *20*, 455–472. [CrossRef]
154. International Monetary Fund. *The Gambia: Poverty Reduction Strategy Paper—Progress Report*; International Monetary Fund: Washington, DC, USA, 2014.
155. Brough, S.H.; Azam-Ali, S.N.; Taylor, A.J. The potential of bambara groundnut (*Vigna subterranea*) in vegetable milk production and basic protein functionality systems. *Food Chem.* **1993**, *47*, 277–283. [CrossRef]
156. Agunbiade, S.O.; Amosu, A.M.; Degun, A.M.; Omeonu, P.E. The physio-chemical and organoleptic properties of milk fabricated from *Glycine max, Vigna subterranea* and *Sphenostylis stenocarpa*. *J. Chem. Pharm. Res.* **2011**, *3*, 918–924.
157. Watanabe, M.; Jinji, N.; Kurihara, M. Is the development of the agro-processing industry pro-poor? The case of Thailand. *J. Asian Econ.* **2009**, *20*, 443–455. [CrossRef]
158. Chengappa, P.G. Emerging trends in agro-processing in India. *Indian J. Agric. Econ.* **2004**, *59*, 55–74.
159. Singh, K.P.; Srivastva, A.K.; Srinivas, K.; Singh, S.R.K.; Gupta, H.S. *Entrepreneurship Development in Agriculture through Agro Processing Centre: A Case Study of Almora District in NW Himalaya*; International Commission of Agricultural Engineering: Liège, Belgium, 2007; Volume 4, pp. 1–14.
160. Giller, K.E.; Murwira, M.S.; Dhliwayo, D.K.C.; Mafongoya, P.L.; Mpepereki, S. Soyabeans and sustainable agriculture in southern Africa. *Int. J. Agric. Sustain.* **2011**, *9*, 50–58. [CrossRef]

161. Kachru, R.P. Agro-processing industries in India—Growth, status and prospects. *J. Indones. Agroind.* **2010**, *13*, 114–126.
162. Gepts, P.; Beavis, W.D.; Brummer, E.C.; Shoemaker, R.C.; Stalker, H.T.; Weeden, N.F.; Young, N.D. Legumes as a model plant family. Genomics for food and feed report of the Cross-Legume Advances Through Genomics Conference. *Plant Physiol.* **2005**, *137*, 1228–1235. [CrossRef] [PubMed]
163. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); International Center for Tropical Agriculture (CIAT); International Center for Agricultural Research in the Dry Areas (ICARDA); International Institute of Tropical Agriculture (IITA). Grain Legumes: Leveraging Legumes to Combat Poverty, Hunger, Malnutrition and Environmental Degradation. Available online: http://legumelab.msu.edu/uploads/files/BeebeS_CRP_5-14.pdf (accessed on 22 December 2016).
164. Sanchez, P.A. Soil fertility and hunger in Africa. *Science* **2002**, *295*, 2019–2020. [CrossRef] [PubMed]
165. Carranca, C.; De Varennes, A.; Rolston, D. Biological nitrogen fixation by fababean, pea and chickpea, under field conditions, estimated by the 15N isotope dilution technique. *Eur. J. Agron.* **1999**, *10*, 49–56. [CrossRef]