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Increasing pulse agrobiodiversity to improve food security and sustainable agriculture in Sub-Saharan Africa

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Long-life cycle pulses have significant food security potential, however, there is little evidence to explain why they are not more widely produced and consumed in sub-Saharan Africa (SSA). This study aimed at exploring existing knowledge to inform on future research priorities in mainstreaming superior species. As staple food along with cereals, pulses are an important source of nutrients whose intake is often inadequate in SSA, however, pulse consumption remain inadequate in SSA. Depending on the crop's life cycle, pulses have multiple functions that can support food systems and ecosystem resilience. Compared to short-life cycle pulses, long-life cycle pulses rank higher in multipurpose role. However, prior research has focused primarily on short-life cycle pulses due to rapid grain production. Long-life cycle pulses remain underutilized and neglected despite showing steady but modest yield increases and adaptation to environments, suggesting that they are better positioned to respond to the diverse needs of smallholder farmers in SSA. In the context of climate change, rain-fed agriculture, depleted agricultural soils, and lack of subsidized fertilizers, there is need to transform existing food systems toward sustainable food production and improved resilience. Increasing pulse agrobiodiversity by integrating long-life cycle pulses in existing farming systems could not only contribute in alleviating malnutrition, but also poverty and inequalities. In addition, representative and accurate data are needed based on the correct use of accepted scientific names for all data across the food system. This is a prerequisite for assessing pulse consumption adequacy and quantifying production and consumption trends.

KEYWORDS

malnutrition, long-life cycle pulses, multi-function, consumption, resilience

Introduction

Malnutrition remains widespread in sub-Saharan Africa (SSA), disproportionally affecting children under 5 years and women of child bearing age. Anemia is the main burden of malnutrition in SSA, affecting 69% of households, followed by undernutrition (underweight, stunting, or wasting) and overweight/obesity at 45 and 25%, respectively (Christian and Dake, 2021). Local diets consist mainly of a few staple cereals and a low consumption of vegetables, fruits, pulses, and animal source foods. Households lack access to micronutrients, high quality protein, and fiber. Pulses have a diverse nutritional profile and are an important source of nutrients whose intake is often inadequate in SSA. As a staple food in the diet of rural populations across SSA, pulses could play a key role in alleviating nutrient deficiencies.

Pulses are crops of the Fabaceae or Leguminosae family, harvested exclusively as dry grains, such as bean, pigeon pea, and jack bean. This definition excludes legume grains such as soybean and groundnuts (leguminous oilseeds) that are used for oil extraction and those legumes harvested green that are classified by the FAO as vegetables [Food and Agriculture Organization (FAO), 1994, 2010]. Pulses are an important source of protein and fiber and micronutrients including folates, iron, and zinc (Kissinger, 2016). The protein content of pulses is high at 21%—25% compared to cereals at 10%—22% (Rajnincová et al., 2019). In addition, pulse protein has a digestibility of 69%—90% and is a rich source of essential amino acids, lysine and tryptophan, which are deficient in cereals (Sandberg, 2000; Pekmez, 2017). While, pulses contain several antinutritional compounds that reduce their digestibility and bioavailability of some nutrients, biological or thermal processing techniques can reduce antinutritional compounds and improve digestibility and bioavailability. In addition to food provision, pulse production can supplement household income, support ecosystem resilience and serve as feed for livestock production among other functions (De Jager et al., 2019).

While SSA has a rich biodiversity of long-life pulse crops, past research and promotion have only targeted two short-life cycle staple pulse crops. In the past, farmers were incentivized to exclusively produce the common bean (*Phaseolus vulgaris* L.) in East Africa and the cowpea (*Vigna unguiculata* (L.) *Walp.*) in West Africa (Hasanuzzaman, Filho, Fujita, and Nogueira, 2020). Of the area harvested of pulses, common bean and cowpea cover 58% in East Africa and 87% in West Africa (Hasanuzzaman, Filho, Fujita, and Nogueira, 2020). The Pan-Africa Bean Research Alliance (PABRA), a leader in bean research, prioritizes research related to drought and disease resistance, alongside improvements of grain quality including reduced cooking times and iron and zinc content [Mulambu et al., 2017; Pan-Africa Bean Research Alliance (PABRA), 2021]. Research focus on these short-life cycle species has centered mainly on rapid grain production. However, short-life cycle pulses rank low in terms of multi-functionality including in particular, ecosystem resilience *via* enhanced soil fertility. There is need to make use of the available large genetic variability of native pulses in SSA, particularly the long-life cycle species that have shown a steady, but modest yield increase over the last 50 years, without occupying more land [Food and Agriculture Organization (FAO), 2019; Hasanuzzaman, Filho, Fujita, and Nogueira, 2020].

Despite the rich biodiversity of cultivated and wild pulses in SSA, there is limited documentation of the potential role of long-life cycle species, in particular, their multiple benefits and potential to offer diversify to both agricultural production, dietary consumption, and strengthening of natural environments. In addition, the available data is poorly managed and highly fragmented, scattered in various publications and reports or in inaccessible databases to policy makers and practitioners. This study aimed at exploring existing indigenous and scientific knowledge. The goal is to inform on future research priorities in mainstreaming superior long-life cycle species for nutrition and income, in transforming food systems in SSA.

Inadequate pulse consumption

The average per capita availability of pulses for human consumption slightly increased in low- and middle-income countries since the 1990s from 7.30 kg in 1995 to 7.94 kg in 2007; representing a growth rate of 0.8% per year (Akibode and Maredia, 2012). The demand for pulses continues to increase in line with the growing population and rising per capita incomes (Sharasia et al., 2017; Li and Siddique, 2018). The contribution of pulses to total protein consumption in SSA is high, estimated at 10%—40% (Sharasia et al., 2017), hence, pulses play an important role in SSA diets. However, despite positive growth in pulse production area in SSA (Koroma et al., 2016), the consumption of pulses and legumes in general (pulses, soy foods, groundnut) is far below the recommended intake (Global Nutrition Report, 2021). As shown in Figure 1, the estimated consumption of legumes in SSA is only a quarter (25 g/day/capita) of the recommended 100 g/day by the EAT-Lancet Commission of which, half of the recommended intake (50 g/day or 18 kg/year) comprises of pulses (Willett et al., 2019). Considering the key role of pulses in SSA diet, inadequate or decline in availability and consumption could further exacerbate malnutrition, poverty, and inequality in the region.

Constraints and barriers in pulse production and consumption

Multiple drivers directly or indirectly contribute to low pulse production and consumption in SSA. For example, the focus

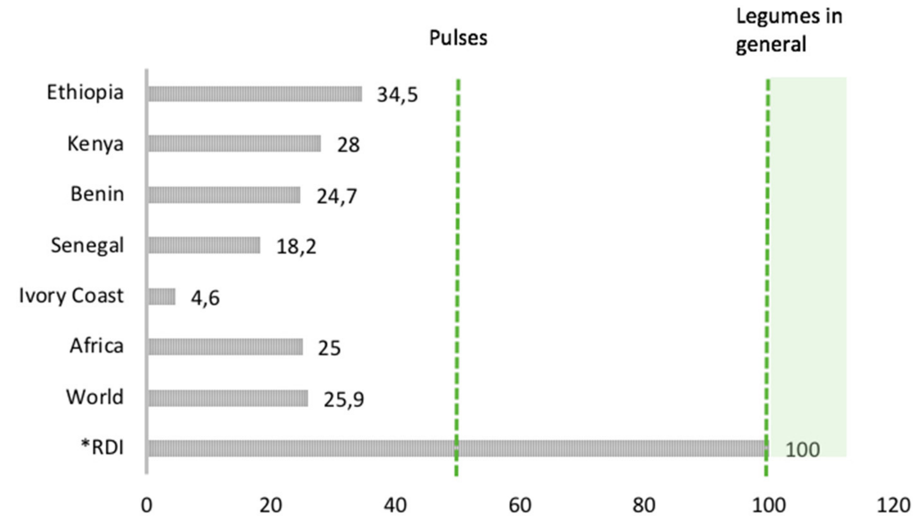

FIGURE 1
Legume intake (g/day/capita) in adults aged >20 years. Data source: Global Dietary Database (2019), *TMREF: Theoretical minimum risk of exposure level; the optimal dietary intake that minimizes risk from all causes of deaths combined. For legume intake, TMREF is 100 g/day including 50 g pulses, 25 g soy foods, 25 g peanut (Willett et al., 2019).

of agricultural research on a few staple crops increased the availability of cereal grains that are less dense in protein and micronutrients (Beal et al., 2017), largely at the expense of pulse production and improvement (Pingali, 2012). For instance, maize, wheat, and rice had cumulative production gains of 200% to 800% during 1961–2012 period, while pulses only gained 59% (FAO, 2016). Pulse production is often restricted to marginal areas while fertile lands are reserved for cereal crops. Pulses are therefore mostly sidelined by agricultural policies (Snapp et al., 2018) and new technology in terms of improved cultivars (Abate et al., 2012). Although short-life cycle pulses have received research attention in SSA, hybrid varieties depend on the use of high-cost inputs such as inorganic fertilizers, which remain very expensive due to a lack of fertilizer production capacity (Snapp et al., 2018). Without governmental support through subsidies, production of short-life cycle pulses is unprofitable. Pulse crops often yield less and demand more labor than cereal crops due to labor-intensive manual harvesting, threshing, weeding and sowing practices (Franke et al., 2017). Smallholder farmers are often discouraged from producing large quantities to avoid losses (Chibarabada et al., 2017). Consequently, smallholder farmers revert to traditional common bean and cowpea varieties with low to no market value (Hasanuzzaman, Filho, Fujita, and Nogueira, 2020).

As agricultural livelihoods in SSA become more uncertain, regardless of farming system or crop type (Masih et al., 2014), rural communities abandon unprofitable agriculture and migrate to urban areas (Djurfeldt and Jirström, 2013). The FAO estimates that by 2050, about 50% of population in SSA will be urban [Food and Agriculture Organization (FAO), 2019]. Increased urbanization and higher incomes provide an increased access to food outlets, such as supermarkets, restaurants, and fast food chains (Khoury et al., 2014). Retailers increasingly drive the food value chain and influence what is grown and consumed (Anand et al., 2015), with consumer preferences changing as few efforts to protect or promote traditional foods exist (Kissinger, 2016). As a shift from foods traditionally sold in fresh or open public markets takes place (Tilman and Clark, 2014), the consumption of processed foods, which are convenient and available, become *de facto* choice (Ranganathan et al., 2016; Baker et al., 2020; Reardon et al., 2021).

Pulses that require long cooking times are less convenient, more energy consuming, and, therefore, less desirable for consumers and processors (Wood, 2016). This is recognized to have implication for gender equity and nutritional value of diets (Snapp et al., 2018). Research on improved bean seeds with shorter cooking time is underway (Cichy et al., 2019), and it is one of PABRA's top research priority. In this regard, PABRA has supported the establishment of private enterprises at scale for processing and canning precooked beans, which directly impact consumer pulse consumption. Moreover, hard-to-cook (HTC) defect caused by high temperature (>25°C) and/or relative humidity (>65°C) during storage can be prevented through correct storage in dark, dry, airtight containers (Wainaina et al., 2021).

Moreover, consumers particularly children do not easily digest pulses, and make them uneasy. Generally, pulses are perceived as not well tolerated and cause digestive discomforts caused by bacterial fermentation of indigestible oligosaccharides in the gut. Prior research suggests that children do not digest pulses as well as adults (De Jager et al., 2019). However, techniques such as soaking, discarding water before cooking, and pulse protein isolate from wet processing, can reduce oligosaccharide content. Additional barriers to promoting pulse consumption include an overall lack of access to post-harvest facilities (i.e., storage) and processing equipment in SSA (Abdoulaye et al., 2016). Given these constraints and barriers, increasing yields or competitiveness of the pulse sector in SSA remains a major challenge.

The role of pulses in sustainable agriculture

Pulse crops respond to stress by developing defense mechanisms against pests and adaptation to marginal environments (Cullis and Kunert, 2016), which benefit accompanying crops the farming systems. Unlike cereals, pulses disrupt parasitic weed, pest and disease infestation cycles, particularly in monoculture systems (Kabambe and Mloza-Banda, 2000; Bagayoko et al., 2012; Rusinamhodzi et al., 2012). Moreover, their adaptation to marginal environments can improve soil fertility, particularly the long-life cycle pulses (De Jager et al., 2019).

Increasing pulse agrobiodiversity for sustainable agriculture and resilience

To achieve food security, stability is needed in food access, availability and quality, which largely depends upon the resilience of the food system (Béné, 2020). In SSA, food systems are largely unstable and rank low in resilience. This is primarily due to high exposure and vulnerability to crisis or shocks and hence, are unable to recover (FAO et al., 2021). As a consequence, the prevalence of food insecurity and undernourishment is widespread in SSA. In this regard, local food systems need to be transformed toward more sustainable food production and improved resilience. As agricultural research focuses on increasing the yield and biotic/abiotic resistance of staple short-life cycle pulses, pulse agrobiodiversity can be increased by integrating long-life cycle pulses in existing farming systems (Snapp et al., 2018). This strategy would not only help tackle the burden of malnutrition, but could also reduce its underlying structural causes, such as poverty and inequality, thus linking food security and nutritional outcomes (FAO et al., 2021).

Since long-life cycle pulses largely remain underutilized or neglected in SSA, scaled up resilience of the food system could be achieved through their multi-functional attributes such as climate and ecosystem resilience, economic viability, intercropping potential, resistance to pest and diseases, weed control, provision of food, feeds and fuel, among other functions. Compared to short-life cycle pulses, longer-life cycle pulses are better positioned to respond to the diverse needs of smallholder farmers in SSA (Table 1). In addition, increasing pulse agrobiodiversity could strengthen resilience of population groups that are most vulnerable to economic adversity, particularly women. Women play a central role in the pulse sector (Snapp et al., 2018), yet their leadership in food policy decision-making and food systems needs to be strengthened. Importantly, policies and investments should aim to realize efficiency gains and cut food and waste losses from production to consumption. This calls for the integration of small and medium-sized enterprises aimed at maintaining community-based food systems and ensuring an adequate supply of safe and nutritious foods (Béné, 2020).

In spite of the significant potential of neglected and underutilized long-life cycle pulses, there is little evidence to explain why they are not more widely produced and consumed in SSA. To promote superior species (Table 1) and in line of answering to a common research call, future research will focus on collecting value chain characteristics data including; best practices for production, storage, handling and processing, marketing, nutritional value, consumer perceptions and the potential for value added products. Multi-site ethnobotanical surveys will study the diversity and role of long-life cycle pulses on farm, with respect to their establishment and management, location and arrangement, market opportunities, uses and functions in farmer fields. Participatory rural appraisal will incorporate the knowledge and opinions of rural people in the planning and management of integrating the long-life cycle pulses. Quantitative descriptors of variation in potential long-life cycle pulses will be used to select superior species.

Discussion

In SSA, pulses remain a staple food alongside cereals and are an important source of protein and fiber in the diet. As the demand for pulses increases in line with the population growth and market demand, existing farming systems are under enormous pressure to meet domestic and international needs. In SSA, pulses are mainly produced by smallholder farmers and are largely sidelined by subsidies, agricultural policies, and new technology. Pulse production is therefore faced with numerous constraints and barriers that hider efforts to increase pulse yields and competitiveness of the pulse sector. To alleviate this problem, pulse agrobiodiversity can be increased by integrating long-life cycle pulses in existing farming systems. Long-life cycle pulses have the potential to withstand conditions under rainfed agriculture, highly deleted agricultural soils, and inaccessibility to organic or inorganic fertilizers. Compared to short-life cycle pulses, long-life cycle pulses can respond better to the diverse needs of the smallholder farmers.

Agricultural soils in SSA are largely depleted following decades of continuous cropping without organic or inorganic nutrient replenishment, resulting in poor crop growth and

TABLE 1 Comparison of multipurpose potential between short- and long-life cycle pulses.

Pulse	Growth type[1] (days)		Yield[2] (kg/ha)	N fixation[3] (kg/ha)	Biomass[4] (kg/ha)	Multipurpose services[5]	Cropping systems[6]	Biotic and abiotic resilience[7]
	Short-life	Long-life						
Common bean	70–120		500–2,600	46		a	i,	1
Cowpea	60–120		200–7,000	12–50		a	i, ii, iii	2
Lima bean	115–180		200–5,000	40–60		a, b, f, i	v, vi, x	3, 7, 8
Pigeon pea		100–365	200–10,000	20–235		a, b, c, d, e, f, i, k	v, vi	6
African yam bean		150–240	2,000–3,000			a, f, g		5, 7
Velvet bean		120–330	240–6,000	34–348	1,600–17,400	a, b, c, d, f, h	i, iv, vi, vii	3, 7, 8
Lablab bean		54–220	600–4,500	20–170	2,520–3,200	a, b, c, d, f, h	i, ii, iii, vi	4, 7
Jack bean		90–300	800–4,600	240	8,000–50,000	a, b, c, d, f, g, h, i, j, k	i, viii, ix, x	3, 7, 8

[1] Growth type from shortest to longest. [2] Dry grain yield from lowest to highest. [3] Nitrogen contribution from lowest to highest. [4] Biomass linked to soil organic matter. [5] Multipurpose services: a) food, b) fodder/feed, c) soil fertility, d) cover/alley crop, e) fuel, f) medicinal value, g) pesticidal potential, h) weed control, i) nematode control, j) disease control, k) control Striga spp. [6] Intercroped with: i) maize, ii) sorghum, iii) millet, iv) wheat, v) cereals, vi) other legumes, vii) hay/silage viii), banana, xi) coffee, x) tubers. [7] Natural biotic and abiotic resilience: 1) impacted by drought, 2) not very resistant to drought, 3) good drought tolerant, 4) Drought tolerant than common bean and cowpea, 5) high levels of draft tolerance, 6) most draft tolerant legume, 7) resistance to pests, 8) resistance to diseases.

productivity (Stewart et al., 2020). Moreover, the rainfed agricultural systems are vulnerable to climate change characterized by extreme heat, increased aridity and changes in rainfall pattern. Unlike short-life cycle pulses, long-life cycle pulses have a well-developed deep root system and a large symbiotic apparatus that supports biological nitrogen fixation and phosphorus mobilization over many months. This potentially facilitates ecosystem resilience (soil fertility) and recovery from intermittent stresses such as drought or pest pressure (Snapp et al., 2018). In addition, long-life cycle pulses are able to maintain vegetative growth during consecutive dry months and hence, produce lots of biomass above ground for soil fertility (organic matter) as well as for food, fodder, income, and fuel. By maintaining vegetative growth beyond the life cycle of other accompanying crops, long-life cycle pulses contribute toward filling food shortage gaps during postharvest dry months. Therefore, long-life cycle pulses have the potential to contribute toward agricultural sustainability and resilience of the food systems through increasing cropping intensity, annual productivity, agrobiodiversity, and a reduction in overall risk caused by the reliance of few staple pulse, cereal and tuber crops (Foyer et al., 2016). In addition, pulses can provide economic advantages by boosting crop yields, reducing input requirements, and diversifying crop and income stream portfolio of smallholder farmers (Calles et al., 2019).

The estimation of pulse production and consumption status in SSA is difficult due to low availability of production data, and unavailable or unrepresentative national consumption data. First, the diversity of pulse species in SSA is enormous and spans mixed and intercropped farming systems, including wild species. Second, pulses are often overlooked in agricultural statistics as they tend to be a secondary crop to cereal crops. Third, many pulse species and varieties are either misidentified or reported in an aggregated manner as composite data of very different species or interchangeably applying names to completely different species. As a result, there is a considerable nomenclatural confusion across the food system, both locally and internationally.

The inability to correctly identify pulses spans throughout the food system, from field to market and among consumers. This confusion may explain the challenge in interpreting the data presented in Figure 1, based on Global Dietary Database 2019. In this database, beans and legumes are categorized under a single dietary factor (or Global Dietary Database (GDD) factor). Although beans themselves are pulses and hence forms part of legumes, comparison of such mixed and generalized consumption data between countries and regions or with recommended intake is potentially misleading. This is because the consumption of different legume fractions (pulses, soy foods, and groundnut) largely vary across different countries and world regions. For instance, while data for East Africa may largely represent pulse consumption, data from other regions may include soy foods and groundnut in addition to pulses. This knowledge gap lags behind that of other staple food crops, calling for improved documentation of pulse distribution in SSA, including which pulse species and varieties are grown and consumed, and where (Pachico, 2014).

Conclusion

This study aimed at exploring existing knowledge to inform on future research priorities in mainstreaming superior species. From a perspective of food security and sustainable food systems, integrating long-life cycle pulses into existing farming systems in developing world could significantly contribute to agriculture sustainability and food system resilience. Increased long-life cycle pulse production and consumption could help reduce malnutrition, poverty and inequalities. This change could also potentially contribute to targeted Sustainable Development Goals 2: zero hunger, 3: good health and well-being, 8: decent work and economic growth 12: responsible consumption and production 13: climate action. There is also a need for accurate pulse production and consumption data, based on the correct use of accepted scientific names for all data across the food system. Long-life cycle pulses should be the focus for future research plans that integrate contributions of various food systems actors for better nutrition, good health, livelihoods, and sustainable agriculture practices in SSA and beyond.

Data availability statement

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

Author contributions

PN wrote the first draft of the manuscript. All authors contributed to conception, design of the study, manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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