Deliverable 2.1

Inventory of Neglected and Underutilized Species: NUS for the Sustainable Intensification of African Agriculture

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DISCLAIMER

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1. EXECUTIVE SUMMARY

FAO recently estimated that demand for food would increase by 70% by 2050, reflecting the effects of both population growth and rising per capita incomes. While almost one billion people suffer nowadays from inadequate diets and insecure food supplies, the challenge will rely both on increasing food supply, and on improving its nutritional value. A literature review suggests that 95% of published agricultural research is not relevant to the needs of small-scale farmers to reduce rural poverty and food insecurity (https://www.nature.com/articles/d41586-020- 02849-6). An alternative exists to supports economically-viable development and increased prosperity for small-scale farmers, while conserving agrobiodiversity and preserving the integrity of local ecosystems. Agriculture systems must diversify. At least 7,039 edible plant species have been used throughout human history (), while food security worldwide are nowadays reliant primarily on 12 species of cereals and 23 species of vegetables with wheat, rice, and maize alone accounting for almost half of the world's food calorie and nutrient intake (Reeves et al., 2016 ; Diazgranados et al., 2020, Ullian et al., 2020). By targeting key Neglected or Underutilised Species (NUS), the EWA-BELT project attempts to unlock NUS resources and explore the role that they could play along with the traditional knowledge and practices, to build a sustainable agriculture while ensuring the delivery of diversified ecosystem services. The exchange of practices and knowledge between East and West Africa will contribute to a better valorization of the NUS and their potential for the sustainable intensification of African agriculture.

2. Crop diversification in a changing world: mobilising underutilised crop genetic resources

At the crossroads of climate, biodiversity and food systems, agriculture plays a major role in the fight against climate change and its impacts as well as in the conservation and restoration of biodiversity while promoting its sustainable use (FAO, 2021). Agriculture, which occupies 40% of the land area (Foley et al., 2005) is a major driver of global changes. Indeed, it is responsible for 80% of deforestation and 29% of GHG emissions (Independent Group of Scientists Appointed by the Secretary-General, 2019).

Agriculture contributes to climate change but is also affected by it. Sub-Saharan Africa which is one of the most food-insecure regions in the world (*2019 – The State of Food Security and Nutrition in the World – SOFI –: Safeguarding against economic slowdowns and downturns | World Food Programme*, s. d.) will be particularly impacted (Defrance et al., 2020; Roudier et al., 2011; Sultan et al., 2014). Indeed, agricultural systems are dominated by rainfed crops. Changes over the past few decades have already resulted in yield reductions and crop losses associated with famines (Lobell et al., 2011; Sultan et al., 2019). Furthermore, agricultural productivity is expected to decrease in the near future, because of an increase in temperatures associated with an intensification of extreme events such as rainfall breaks, heat waves or heavy rains (Sylla et al., 2015; Taylor et al., 2017, 2013).

While millions of people are already facing both shortages (hunger) and excesses (obesity) of calorie and nutrient intakes (Gould, 2017), the FAO estimated that demand for food should be increased by 70% by 2050. The challenge will thus not only be on increasing the food supply but also ensuring nutritional security for populations under environmentally sustainable production systems while improving livelihoods of farming communities. To combat chronic food insecurity and achieve self-sufficiency, some governments have allocated or are allocating a large part of their budget to increase agricultural yields of dominant crops, such as rice or maize, by subsidising nitrogen fertilisers, irrigation, breeding, and dissemination of certified seeds (Snapp et al., 2010). These strategies follow the conventional narrative of agricultural development of increased specialisation at the farm level associated with enhanced market participation. An analysis of the Green Revolution in Europe and Asia shows that the intensification of agricultural practices through specialisation and homogenization of land and crop cover affects the stability of agricultural production. The use of agrochemicals in Africa has proven only marginally profitable (Morris et al., 2007) and hybrid varieties are not significantly more productive than local varieties when not fertilised (Snapp et al., 2010). Moreover, this strategy seems incompatible with many sustainable development goals.

Faced with these challenges, increasing attention is being paid to nature-based solutions such as crop diversity and agroecological practices in order to build a sustainable, fair and equitable agriculture (SDGs 2, 3, 12, 13, 15). Crop diversification strategies ranging from the cultivation of better adapted crop or varieties to the diversification of production systems are increasingly supported by research (Altieri, 1999; Beillouin et al., 2019; Isbell et al., 2015; Pironon et al., 2019; Renard & Tilman, 2019) and by international institutions such as the FAO (Bélanger et al., 2019), IPBES (Díaz et al., 2015), and the COP26. Indeed, greater crop diversity at the national level is associated with increased temporal stability of food supply over time (Renard & Tilman, 2019). Similar results are found at local scale (Bellon et al., 2020) and at the field level for forage crops in experimental stations (Prieto et al., 2015). These diversity-stability links are linked to an 'insurance effect' (Mahaut et al., 2021) where the responses of different crops to climatic or biotic disturbances can compensate each other.

Beyond productivity, crop diversity is also an asset supporting ecosystem services including provisioning services (food, medecine, freshwater, fibre, genetic resources, etc. s), regulating service (climate regulation, disease relation, water purification, pollination, etc.) and cultural services (spiritual and religious, aesthetic, educational, cultural heritage, ecotourism, etc.) (Bélanger et al., 2019). Finally, using crop diversity including landraces and crop wild relatives is viewed as an efficient short and medium-term strategy to adapt to rapid environmental changes (Pironon et al., 2019). For instance, a study on pearl millet showed how assisted migration could help mitigate the crop's vulnerability to future climate change (Rhoné et al., 2020).

However, the potential of crop diversity to support the resilience of agroecosystems remains undervalued, particularly in the South (Beillouin et al., 2019, 2021). It reflects the mismatch between the needs of populations in the South and current research. It is also illustrated in a literature review suggesting that 95% of the agricultural research published to date is not relevant to the needs of family farmers (https://www.nature.com/articles/d41586-020- 02849-6).

One approach to crop diversification is the promotion of neglected and underutilised species (NUS) also referred to as orphan crops, forgotten crops, minor crops, crop for the future, etc. At least 7,039 edible plant species have been used throughout human history, while food security worldwide are nowadays reliant primarily on 12 species of cereals and 23 species of vegetables with wheat, rice, and maize alone accounting for almost half of the world's food calorie and nutrient intake (Reeves et al., 2016 ; Diazgranados et al., 2020; Ullian et al., 2020). Subsequently, mainstream research has mainly concentrated on these few promoted species. The vast majority of edible species have been neglected. Indeed, over the past centuries, research focused on increasing the yields of major crops.

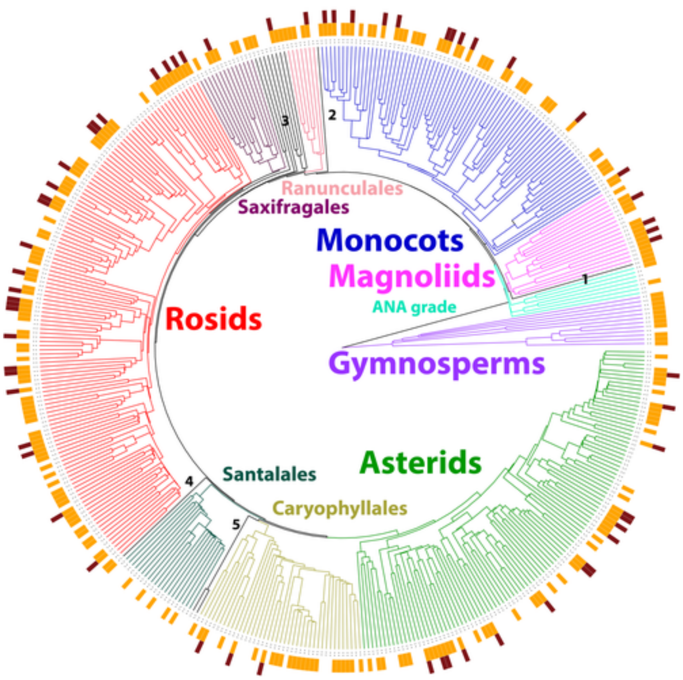

Figure 1 | Phylogenetic distribution of edible plants (Figure in Ulian et al. 2021). The orange rectangles refer to the presence of edible plants in each family, and the brown refers to the presence of major food crops.

Suitable for a large variety of agro-ecosystems, neglected crops have recently regained interest for their utility to unlock marginal lands for agriculture. For instance, some of these NUS are receiving global interest such as teff (*Eragrostis tef*) and quinoa (*Chenopodium quinoa*) (Andreotti et al., 2022). NUS are locally adapted, culturally important and productive under the low-input production conditions widespread in smallholder farming systems. Finally, most of the neglected species have additional uses, the most common being medicines (70%), materials (59%), and environmental uses (40%) (Ulian et al., 2020). Those crops could thus be an asset for a more resilient, sustainable, and fair new 'green revolution' (Ulian et al., 2020).

3. Neglected and Underutilized Species to foster sustainable agriculture transition

3.1. To be or not to be a NUS

The common thread of NUS is the lack of scientific knowledge. Are they really species for the future? The first step in answering this question is to generate scientific knowledge. In the framework of the EWA-BELT project, we will focus on the species presented in Table 1. These species were chosen for their local importance, their nutritional properties and as a key to exploiting their potential and addressing food insecurity in Africa. Although species native to Africa have been favoured, species domesticated on other continents have not been excluded from the project as they may play a role in the sustainable intensification of African agriculture through the diversification of agrosystems. We choose the definition of the H2020 project Diversifood formulated as follows: a neglected and underutilised crop is 'a genetic resource with limited current use and potential to diversify and improve cropping systems and supply chains in a given context' (Chable et al., 2020). By highlighting key NUS, the EWA-BELT project attempts to unlock NUS resources and explore the role that they could play along with the traditional knowledge and practices, to build a sustainable agriculture while ensuring the delivery of diversified ecosystem services. The exchange of practices and knowledge between

East and West Africa within the framework of the EWA-BELT project will contribute to a better valorization of the NUS and their potential for the sustainable intensification of African agriculture.

Species	**Status**	**Origin**
Fonio (*Digitaria exilis*)	NUS	Native from Africa
Frafra Potato (*Solenostemon rotundifolius*)	NUS	Native from Africa
Groundnuts (*Arachis hypogaea*)	Locally Neglected	Introduced
Finger Millet (*Eleusine coracana*)	NUS	Native from Africa
Lablab Bean (*Lablab purpureus* L)	NUS	Native from Africa
Cocoa tree (*Theobroma cacao*)	Locally neglected	Introduced
Macadamia nuts (*Macadamia integrifolia* and *M. tetraphylla*)	Locally neglected	Introduced
Tef (*Eragrostis tef*)	NUS	Native from Africa
Lima bean (*Phaseolus lunatus L*)	Locally neglected	Introduced
Anchote (*Coccinia abyssinica*)	NUS	Native from Africa
Pearl millet (*Cenchrus americanus*)	Locally neglected	Native from Africa
Cowpea (*Vigna unguiculata*)	Locally neglected	Native from Africa
Bambara groundnut (*Vigna subterranea)*	NUS	Native from Africa
Sorghum *(Sorghum bicolor ssp. bicolor)*	Locally neglected	Native from Africa
Enset *(Ensete ventricosum)*	NUS	Native from Africa

Table 1 | NUS selected within the EWA-BELT Project

3.1.1. Fonio (*Digitaria exilis*)

The fonio, is an indigenous staple crop from Western Africa with great potential in for agriculture in marginal environments. In a region stretching from Senegal to Cameroun-Nigeria border, fonio is cultivated under a large range of environmental conditions. This level of adaptation is particularly relevant in the climate uncertainty context. Because of historical and contemporary shift toward high-yielding grain crops, its distribution has been reduced to relic and disjunct. Fonio is both drought-resistant and does not depend on external inputs, once again becomes a key crop to plant. Fonio has a local importance that provide reliable yields on marginal lands, and contribute significantly to food and nutritional security at local and regional levels. With its fast-maturing landraces, fonio is a key crop during food shortage. Furthermore, fonio is one of the most nutritious cereals thanks to its high levels of sulfur amino acids methionine and cystine (Jideani, 1999). It is regarded as a valuable source of income, especially for women and small-scale farmers. Indeed, the price of a kilo of fonio may be 1.5 to 2 times higher than that of a kilo of rice (Vodouhe et al., 2007). Furthermore, its cultivation requires few land works and is adapted to drought and low fertile soils (Vodouhe et al., 2007). Finally, fonio benefits from cultural embedding as it plays a key role in ritual systems in many African societies across West Africa, even where it is no longer the dominant crop in an agricultural system. Despite the promising nature of fonio to ensure food security for farmers and increase their income, fonio has received limited attention from mainstream research.

In Ghana, fonio is an important crop with immense potential to combat food and nutrition insecurity. However, its cultivation is limited to the north eastern part of the northern region of Ghana among the Anufo, Konkomba and Kabre tribes. Also, most of the farmers who cultivate the crop are aging and there is a potential threat of the crop getting extinct from the farming and food systems. Most of the youth in the growing areas are shifting to other cereals like rice and maize which they consider easier to work with and have several released varieties available with good agronomic packages. Fonio has received very little research attention by national government and other donor agencies and so there is no officially released fonio variety in Ghana. There is also limited information on the extent of genetic diversity (morphological and molecular) and nutritional profile among the fonio accessions cultivated in Ghana as well as good agronomic practices for fonio cultivation. There is the need to collect and genotype fonio landraces in Ghana for conservation and future breeding purposes. The EWA-BELT project thus provides a unique opportunity to conduct in-depth research on the genetic diversity among the fonio landraces to unearth the full potential of fonio to ensure food and nutrition security.

In Burkina Faso, it was a staple food before the loss of agrobiodiversity. In the areas of the West and East, local varieties are still present while it should be to reintroduce in the Central Plateau areas. It is fundamental for the diversification of crops as well as diets. In addition to its numerous nutritional properties, it was traditionally used in villages by people with diabetes for its glycaemic control and by pregnant women. It is usually cooked in grains (fonio couscous) with the gombo sauce or mixed with bean leaves (nièbe) in the form of meatballs.

Fonio is a key crop for food security in West Africa and potentially beyond. By focusing on this species, the EWA-BELT project will contribute significantly to the production of scientific knowledge and the valorisation of this NUS.

3.1.2. Frafra Potato (*Solenostemon rotundifolius*)

Frafra potato (*Solenostemon rotundifolius*) is one of the indigenous and resilient crops of Upper East and Upper West regions of the Guinea and Sudan savannah ecologies of Ghana. It is a good source of nourishment as it contains significant amounts of macro- and micronutrients. The tubers contain significant amounts of iron, calcium and betacarotene (vitamin A precursor). It is mainly used for preparing traditional dishes that may be fried, boiled or steamed. Additionally, its cultivation and utilization have been limited to some few communities in the growing areas. Less research studies have been done on the crop compared to other root and tuber crops like yam, cassava, sweet potato, cocoyam and Taro. However, CSIR-SARI released five improved varieties of the crop in 2017 which has seen slow dissemination rate as a result of low planting material multiplication rate of the crop (mostly by tubers). CSIR-SARI considers the EWA-BELT project as an opportunity to disseminate the improved varieties through the establishment of demonstrations in the farmer field research units. In addition, CSIR-SARI has fine-tuned a technology of propagating the crop using softwood stem cutting as planting material which would be showcased to farmers through capacity building training programmes. It is expected that this would promote largescale utilization of the crop through the development of new recipes and products from the crop to help combat food and nutrition insecurity.

3.1.3. Groundnuts (*Arachis hypogaea*)

Native to South America, groundnut (*Arachis hypogaea* L.), also known as peanut, is an annual legume crop and a complete food and ingredient. Indeed, it constitutes a rich source of heart-healthy monounsaturated oil. The seed contains 48-50% oil, 26-28% protein, 15% carbohydrates (energy) and is a rich source of minerals and vitamins. It is mainly grown by small-scale farmers in Africa to produce edible oil for human consumption. It also provides by-products for animal feeding. It was selected as it enhances soil fertility high, have market value and constitute a perfect choice for food & nutritional security as well an income generation. In the frame of the EWA-BELT project, the Kenyan team will evaluate of the performance of farmer preferred varieties accompanied by their associated agronomic principles.

3.1.4. Finger Millet (*Eleusine coracana*)

Finger millet (*Eleusine coracana* Gaertn L*)* is native to East Africa where it has been cultivated since the Bronze Age. It is now cultivated on more than 2.5 million hectares in South Asia and East Africa where it is an important cereal, with nutraceutical properties as well as ensuring food security in these areas even during harsh environment (Chandra et al., 2016). Indeed, finger millet grain is rich in calcium, fiber, iron, and methionine, tryptophan, and other essential amino acids, making the crop a reservoir of health-giving nutrients (Chandra et al., 2016). Furthermore, finger millet earned the popular name of 'famine crop' as its seeds can resist storage pests for as long as 10 years, ensuring food supply even during a crop failure (Mgonja et al., 2007). Despite the fact that it is a staple in the diets of millions of people, finger millet is still referred to as neglected crop. In the framework of the EWA-BELT project, finger millet will be studied jointly in Ethiopia, Kenya and Tanzania. Indeed, its ability to tolerate various abiotic stresses and pathogens make it an excellent NUS for developing strategies for sustainable intensification of African agriculture.

3.1.5. Lablab Bean (*Lablab purpureus L*)

Likely domesticated in Eastern and/or Southern Africa, Lablab is considered as one of diverse and drought-tolerant legume species. It can grow in arid, semi-arid, subtropical, warm and humid areas, with a temperature ranging from 18 ^{0}C to 30 ^{0}C. The crop may also thrive in a wide range of soils, from sandy to clay, with a pH of 5 to 7.5. Even with less than 650mm of rainfall per year, lablab can produce good harvests, making it ideal for drought-prone areas (Guretzki and Papen. B, 2013).

Lablab beans are the major source of nutritious food for both humans and livestock, females from Kenya's Kikuyu region use them ceremonially, spiritually and nutritionally. Cooked lablab beans were given to women to eat during their reproductive stages, particularly after pregnancy, because it is a unique and nourishing diet that keeps women well during and after pregnancy.

According to research, lablab has a variety of applications that benefit smallholder farmers who produce it (Maass et al., 2010). Findings show how multifunctional crops benefit customers by providing household income, food security, animal fodder and soil cover to prevent soil erosion. The lablab crop is critical to people's food security and health, as well as the national economy. However, the crop is neglected and underutilized (Maass et al. 2010); due to less demand as it is replaced by other legumes. A recent study revealed that lablab is a potentially important crop for smallholder farmers in Tanzania to improve farmers livelihoods and food security (Forsythe, 2019). Therefore, in EWA-BELT project, this crop was seen as potentially underutilized and will be assessed to improve the contribution of its yields to the lives of communities as well as stakeholders or participants across the value addition and value chain in a different way.

3.1.6. Cocoa tree (*Theobroma cacao*)

Although Cocoa (*Theobroma cacao*) is not a neglected crop at global scale, cocoa is one of the underutilized crops in Tanzania. Faced with challenges of pests, diseases, and insects, lack of improved varieties, inadequate extension services, land tenure issues, inadequate family labor, theft, lack of national cocoa production policy, unreliable markets, and poor farming systems, it needs more research. Indeed, cocoa could play a major role in improving livelihoods and reducing poverty, as it was contributing more to household income than any other crop (Nyamora & Kanyeka, 2012). In Tanzania the demand of cocoa in the market is higher but the productivity is low as farmers have adopted local cocoa landraces because there are no improved varieties as there is no registered cocoa variety in Tanzania (Sudjud et al., 2020). In addition, in Tanzania there is no well-defined cocoa farming system, which also hinder cocoa production as no cocoa farming system research has yet done in Tanzania. Also, poor marketing systems as the cocoa growers are particularly exposed to market price fluctuations, farmers sell unprocessed cocoa beans to the buyers and no common markets for cocoa (Nyomora *et al.,* 2012). Cocoa farmers rarely formed cooperatives, which gave them little bargaining power. Customers, rather than growers, set the prices. The majority of buyers (80%) went to the orchards of the producers and purchased directly from them. Despite its convenience, farmers were denied the benefits of more centralized and systematized market venues. The current value chain marketing structure (and worldwide demand for low-quality/low-cost beans) do not provide appropriate incentives for quality improvement, as a result, cocoa growers are particularly exposed to market price fluctuations (Nyomora *et al*., 2012). Tanzania exports the majority of its cocoa as raw materials, and in this case as a crucial ingredient in the confectionery and chocolate industries. Cocoa processing generates more income than raw exports; it is relatively underdeveloped among Tanzanians (Nguyen, *et al,* 2014). However, no studies that have been done in Tanzania and other countries have given the answers to problems facing the cocoa industry, the lack of improved cocoa planting materials, unknown cocoa farming systems, and price fluctuations in Tanzania.

Therefore, under the EWA-BELT project, the Nelson Mandela African Institution of Science and Technology (NM-AIST) and TARI will assess Cocoa farms in the growing areas of Tanzania with a focus on genetic diversity and value chain analysis. This study will provide an important contribution to morphological and genetic characterization of *Theobroma cacao L.* species in Tanzania, which can help breeders in the future for interspecific crossing attempts and come with cocoa superior ones for cultivation hence will increase productivity. Also, this study will lead into documentation of cocoa farming system used which will improve efficiency in farm production (Krauss & Soberanis, 2001) and diagnose points of ineffectiveness in cocoa value chain for corrective action.

3.1.7. Macadamia nuts (*Macadamia integrifolia* and *M. tetraphylla*)

Macadamia has recently become an upcoming crop in eastern Africa with high economic returns. Macadamia nut is most important crop with numerous uses that are beneficial to human healthy, environmental and to other living organisms (Mbora et al., 2008). The main inspiration for farmers to cultivate macadamia nuts is to improve income. Additionally, macadamia nuts is a source of food rich in vitamins, minerals and essential oils for human consumption, alternative source of energy for cooking, livestock feeds, environmental friendly it protects soil from erosion and it attract beneficial organisms (Nagao, 2011). In Tanzania macadamia farming is faced with several challenges including; pests and diseases, poor farming lack of knowledge and skills and unreliable markets. Pests and lack of market information all donate to low macadamia harvests (Nagao, 2011). Furthermore, absence of clear macadamia farming systems in Tanzania also hinders macadamia production, and there are no studies on macadamia farming systems that have been done yet (Mbora at el., 2008). EWA-BELT Project will assess macadamia farming systems in the macadamia growing areas of the Tanzania, in terms of farming systems and value chain analysis.

3.1.8. Tef (*Eragrostis tef*)

Tef [*Eragrostis tef* (zucc) Trotter] is an important Ethiopian cereal crop. It could be a good alternative for the primary cereal crops because it is resistant to climate variability and change. Tef has been cultivated and used for human consumption in Ethiopia for centuries. It is one of Ethiopia's most important crops, being at the center of the country's rapidly expanding agricultural output markets (Minten et al., 2014). It is predominantly cultivated for human use in Ethiopia. It has been eaten in a variety of forms; including flatbread called 'Injera,' porridge, and fermented alcoholic beverages (Krauss & Soberanis, 2001). It has high nutritional content, free of gluten, and long storability of grains (Zhu, 2018); its quality makes the crop one of the world's most unique but underutilized crops (Cheng et al., 2017; Lee, 2018). Tef grain is high in iron, calcium, and fiber, as well as having a low glycemic index, making it suitable for individuals with diabetics and allergies to gluten (Abadi et al., 2020). Furthermore, its straw is quite precious, as it is preferred by cattle, and its price is higher than that of other cereals' straw. It is a major cereal crop grown next to sorghum and maize for food and market purpose in Ethiopia (Gemechu & Alemu, 2016).

Tef has the largest share of area (22.56%, 2.93 million hectares) of the grain crops and second (after maize) in terms of grain production (19.46%, 5.02 million tons) in Ethiopia (CSA, 2020/21). Depending on the cultivar and altitude, tef takes 90 to 130 days to grow (Gebretsadik et al., 2009). It is also suited to a variety of agroecological conditions ranging from drought stress to waterlogged soil conditions and varied soil types.

Tef has many cultivars and most of them can survive in both wet and drought conditions (Assefa et al., 2011). Even though tef is a major crop in Ethiopia, its production is still low due to variability in rainfall in the lowlands and poor soil fertility in the humid highlands.

About 70 million people in Ethiopia are dependent for their diet on tef, a cereal crop rich in nutrition but largely neglected from scientific research. Its promotion, popularization and development of value-added products out of teff will enhance the sustainable food system of Ethiopia and beyond.

3.1.9. Lima bean (*Phaseolus lunatus L*)

Lima bean is a diploid (2n=22), predominantly autogamous, annual and pluriannual crop originated in the Neotropics. Neotropical in origin, lima bean is naturally distributed from the southern United States to northern Argentina, from sea level to over 2700 m in the Andes (Abadi et al., 2020). The early European explorers introduced it to the other parts of the world and according to Mackie (1943), the Spaniards took it to Asia and through the slave trade, and was conveyed from Brazil to Africa. Though there are no definite times regarding when the lima bean was introduced to Ethiopia, Engels et al. (1991) stated that it was introduced, fairly, recently, and distributed in the southwestern parts. However, Westphal (1974) collected specimens from areas including Shoa, Wellega, Illubabor, Kefa, Gamo Gofa, Sidamo and Hararge.

Lima bean is mainly used as a food legume for its fresh and dry seeds (Fig 1) and widely available in the local markets as sources of protein. It can also be used as a green manure and as animal feed (Nwokolo, 1996). In Ethiopia, it used for making stew solely and/or mixed with other vegetables as well as the boiled lima bean and/or mixed with cereals like maize can be consumed. It is high value crop that the price of 1 kg of fresh lima bean is more than Birr 100 (~USD 2), in several local markets (Fig 2). Lima beans grains are rich in nutritious components, containing approximately 63% carbohydrates, 25% proteins, 6% fibbers and 4% ash (Yellavila et al., 2015). It is, therefore, one of the crops of consideration for nutrition sensitive agriculture and sustainable intensification of smallholder cropping systems as it is grown on fence-lines and in home-gardens. Moreover, it has a potential to support bean production in the hot and humid environments, due to its traditional varieties that have been noted to have robust disease tolerance (Snapp et al., 2018).

Lima beans are well studied and documented in Americas and in the Eurasia, but not in Africa, particularly in Ethiopia. Report indicates that lima bean is the second most cultivated in the *Phaseolus* species, globally (Camacho-Pérez et al., 2018). Despite its wider and common production, potential productivity and diversity, it is considered as a minor and categorized under neglected and underutilized crop species (Popoola et al., 2019) across the world. In fact, its production statistics are commonly combined with the production statistics of other dry beans, may be due to its so low production in several countries and it is not included in the largest global crop production database of FAOSTAT. Some of the reasons for low production and limited research attention in Ethiopia might be related to either of its recent introduction or unsuitability for research due to its voluminous growth, indeterminate perennial growth habit and requiring mandatory staking (Popoola *et al.,* 2019). Anyhow, since 1972 there have been only two varieties (Calico Pole and California baby lima bean) which were recommended for production (Gashawbeza, 2019) and recently two varieties were released by Melkassa Agricultural Research Center.

As the research and improvement of lima bean is at its very infant stage in Ethiopia, identifying the different types of lima bean landraces that are found in the hands of farmers, investigating their importance, morphological and molecular diversity is very important considering nutritional and economic values the crop has and its many aforesaid importance. This helps to determine proper utilization and conservation of lima bean landraces and provides an opportunity for participatory variety selection based on farmers' preferences and utilization for future hybridization programs for the genetic improvement of the crop. Therefore, in-depth research on this crop is crucial to develop high yielding, climate-smart and nutrient dense varieties so as to realize sustainable intensification of small holder cropping systems.

3.1.10. Anchote (*Coccinia abyssinica*)

Anchote (*Coccinia abyssinica* [Lam.] Cogn) is an endemic tuber crop originated in Ethiopia , (Dohle, 2017). Its distribution is limited to only in Ethiopia. It is widely grown throughout the south and south western parts of Ethiopia for centuries (Abera, 1995). It grows in altitudes ranging from 1300 to over 2800 meters above sea level. The crop requires a total annual rainfall of 762-1016 mm with a mean minimum and maximum temperature of 12 and 28 °C, respectively. It prefers soil pH in the range of 4.5 to 7.5. It grows well in the major soil groups (such as nitisols, oxisols, ultisols) of western and south western Ethiopia (Duresso, 2018). Anchote is annual trailing vine belonging to the family of cucurbitacea and grown mainly for its root as food. *Coccinia abyssinica* is the only species cultivated for its edible tuberous roots and young shoots, which are used as leafy vegetables (Fekadu et al., 2013).

Anchote has both nutritional and medicinal values and economic and socio-cultural importance. Tubers of anchote are regarded as valuable food sources. They are rich in Ca and Mg compared to other root crops. This could be due to the high calcium and protein content of tubers (Parmar et al., 2017). According to Ayalew *et al.* (2017) anchote leaves are even more nutritious (higher protein and amino acids) than other root and tuber crops.

Anchote dish is known for its cultural food in south western and Western region of Ethiopia. On holidays like Ethiopian Meskel, anchote food is the first to be served with high respect in the towns and rural communities of the south and south western regions of Ethiopia. Anchote dish is considered as unique and cultural food which popular in Wollega region of Ethiopia. In this region, it is served as a prestige dish in Oromo Culture during special ceremonies and on holidays. *Anchote* tuber is used as as part of the traditional medication by traditional practitioners. In addition, Anchote is documented in the list of medicinal plans of Ethiopia. Red fleshed anchote tuber is more valued among the local population for its medicinal properties.

Despite all these values of anchote, it is largely neglected from scientific research. Its promotion and popularization will enhance the sustainable food system of rural communities.

3.1.11. Pearl millet (*Cenchrus americanus*)

Pearl millet (*Cenchrus americanus* – L. – Morrone syn. *Pennisetum glaucum* – L. – R. Br.) domesticated in West Africa is the main staple food for communities in sub-Saharan Africa (FAOStat 2013) due to its high tolerance to extreme climate conditions. Although not really considered neglected, the crop is locally being phased out by producers due to the difficulty in obtaining adequate yields and varieties adapted to climate change. Indeed, its production remains low, with an average grain yield of just 900 kg/ha (Pucher et al., 2015). However, it is considered a nutritious staple cereal grown in arid, low-fertility soils in sub-Saharan Africa. At the agronomic level, it is traditionally used in rotation and intercropped with cowpea and can adapt to different stress conditions. Recovering and evaluating indigenous varieties that showed higher protein concentration than improved varieties and hybrids and higher fat concentrations and micronutrient density (P, K, Ca, Mg, Zn, Cu). Aware that recovering genetic diversity as a climate mitigation strategy in West Africa will therefore require collaboration and experience sharing between project states and FFRUs working in the same region. In traditional cooking, it is cooked as couscous, also in combination with ground peas (see the local name above). The flour is used in the preparation of a traditional drink in welcoming rituals.

3.1.12. Cowpea (*Vigna unguiculata*)

Cowpea [Vigna unguiculata (L.) Walp.] is a legume crop key to food safety and the livelihoods West Africa. The seeds are an important source of plant protein and vitamins for humans, animal feed and a source of cash income. The young leaves and unripe pods are eaten as vegetables. With varieties harvested in as little as 60–80 days, this crop is essential for food security. Harvest occurs during the 'hungry season' when grain reserves from the previous cereal harvests have been depleted and current crops are not ready for harvest. At the agronomic level, as a legume, it plays an important role as a soil-improving crop, providing nitrogen, especially in areas where soil fertility is low and access to fertilisers, even of animal origin, is limited. For this reason, it is among the most widely used crops in rotations and in intercrops with other crops (this has the advantage of providing nitrogen to the grain, reducing evapotranspiration, and improving weed control). It is drought tolerant and adapts well to sandy and poor soils. However, Cowpea cultivation is mainly under traditional systems and it remains a low-yielding crop, often due to the lack of pest and pathogen control.

In the frame of the EWA-BELT, the study of alternative methods of pest management and an appropriate cropping system could improve famers livelihoods and preserve its diversity.

3.1.13. Bambara groundnut (*Vigna subterranea*)

Bambara groundnut, in local language – *voandzou*, was cultivated throughout West Africa in pre-colonial times; after which it was gradually replaced by the groundnut, a leguminous plant with similar fruits. It's a leguminous crop cultivated in sandy soils, mostly in the south-western areas of Burkina Faso. Resistant to drought, high temperatures, and pathogens. It stores well and is therefore consumed during the rainy season when the cereals harvested the previous year begin to decline. The starch levels (up to 53% of the seed), the amylose content of the starch (15.7-35.3% of the starch) and the dietary fiber content (up to 10.3% of the seed) make this crop a desirable food to include in diets for the management of diabetes and high cholesterol. There is a wide variation in crude protein concentration within the genetic background of the species, reported as 9.6-30.7% of the seed. Through varietal assessment within the FFRUs, the aim is to select cultivars that can combine suitable agronomic characteristics and high protein content or possibly develop new ones. Furthermore, it can be included in diets to supplement phosphorus, potassium, magnesium, and zinc requirements and serve as a source of omega-3 and omega-6 essential fatty acids along with other legumes. In traditional cooking, it is usually associated with millet (the dish is called 'Suma ni pigri' – *mòoré* or 'Tiguen nankourou ni pigue' – *dyula* in the local language).

3.1.14. Sorghum *(Sorghum bicolor ssp. bicolor)*

Domesticated in East Africa, sorghum (*Sorghum bicolor (L.) Moench*), is a main crop throughout semi-arid regions of Africa and Asia. It is is an annual erect grass that can grow as tall as up to 5 m high, and follows the C4 photosynthetic pathway. Its leaves are broad, very similar to maize but shorter and broader. Inflorescence is a panicle of around 60 cm long, bearing up to 6000 spikelets. Sorghum is a climate smart crop with the inherent ability to adapt to future climate change. Sorghum is an important food crop for millions of people in Africa. There are dual purpose varieties can be directly used as fodder, silage or livestock can feed on the straws after the grain has been harvested.

In the frame of the EWA-BELT project, the Kenyan team will evaluate of the performance of farmer preferred varieties accompanied by their associated agronomic principles.

3.1.15. **Enset *(Ensete ventricosum)***

Enset (*Ensete ventricosum* (welw.) Cheesman) is a perennial multipurpose diploid (2n=18) herbaceous plant related to the banana plant that belongs to the family Musaceae (Cheesman, 1947; Vavilov, 1951). Enset is also monocarpic and fruits only once in its life cycle 8/6/22 8:21:00 AM. It is indigenous to Ethiopia, where diverse clones are grown. Although the crop can be found in different parts of Africa, it is currently cultivated only in Ethiopia, where it supports the lives of more than 20 million people. Enset has the following uses: food and feed crop, medicinal value, source of fiber and protection from soil erosion. However, enset is considered as one the orphan/understudied crops. Many studies reported the existence of high levels of enset clonal diversity in Ethiopia. Farmers distinguish landraces on the basis of phenotypic characteristics such as petiole, midrib and leaf sheath color, angle of leaf orientation, size and color of leaves, and circumference and length of the pseudostem. They also tend to base their enset clone identification on use function. In practice functional groups from the same landraces might have different vernacular names, and also same name might be given to different landraces or clones by different ethnic or linguistic groups and agroecological zones (Yemataw et al., 2018). As a result, the diversity of functional groups of enset is not well understood (Tsedeke Abate *et al.,* 1996; Tsegaye, 2002; Teshome, 2016). Therefore, within the EWA-BELT project, we will identify enset functional groups in southern Ethiopia and assess its genetic diversity.

3.2. Enhancing neglected and underutilised crop with genomics

Over the last two decades, the development of novel DNA sequencing technologies has transformed the genetic ‘moving from genotyping to genome typing’ (Luikart et al., 2003). The decrease in costs of next generation sequencing technologies combined with better expertise leading to automatic analysis of increasing data directly benefited underutilised crops. The generation of high-quality genomic resources will streamline basic and applied research, trait discovery, and breeding, including statistical methods supporting genomic and environment-based selection. Such innovation has effectively removed barriers, thus greatly increasing the genomic research of NUS. Several of them now benefit from high quality genomic resources

(Abrouk et al., 2020; Chang et al., 2019; Jamnadass et al., 2020). Taking advantage of this NUS genomics revolution, the EWA-BELT project will tackle the challenge of increased knowledge of genomic diversity and its related environment-based selection. The research strategy for the target species was discussed in a dedicated workshop. During this meeting, six species among those presented above were selected for genomic diversity analysis. The selection criteria were: 1) potential of the species for sustainable intensification and its local importance, 2) lack of knowledge on genetic diversity for these species, 3) absence of ongoing work on this topic, 4) availability of genetic resource collections or the possibility of building them, 5) capacity-building needs of the partners' teams in population genomics and breeding.

Neglected and Underutilized Genomic Workshop

Organized by A. Barnaud (IRD) and C. Billot (Cirad)

14–16 March 2022 in Montpellier, France

Participants (alphabetical order): Joseph Adjebeng-Danquah[1], Richard Yaw Agyare[1], Truphosa Amakhobe[2], Xavier Argout[3], Adeline Barnaud[4], Claire Billot[3], Sisay Buta[5], Alemayehu Chala[5], Sandrine Causse[3], Daniel Fonceka[3], Christophe Jenny[3], Thomas Kaczmarek[3], Deodatus Kiriba[6], James Kombiok[7], Brice Nicodème Koudougou[8], Christian Leclerc[3], Thierry Leroy[3], Maïa Lejbowicz[4], Goldwin Maro[9], Julius Missanga[9], Kelvin Mtei[9], Loise Mumbi[2], Amsalu Nebiyu[10], Temesgen Olango[5], Sheila Okoth[2], Doris Puozaa[1], Jean-François Rami[3], Bénédicte Rhoné [3], Nora Scarcelli[4], Rachele Stentella[8], Theophilus Kwabla Tengey[1], Pavrthravani Venkataramana[9], Noel Makete[11].

Participant Affiliations:

1 CSIR-SARI, Ghana

2 University of Nairobi, Kenya

3 CIRAD – AGAP, France

4 IRD-DIADE, France

5 Hawassa University Ethiopia

6 TARI, Tanzania

7 KDC, Ghana

8 ACRA, Italy

9 NM-AIST, Tanzania

10 Jimma University, Ethiopia

11 KALRO, Kenya

Objectives

The objectives of the workshop were to 1) plan in detail the genomic activities planned in the frame of the WP2.1.1, 2) create synergies between the NUS teams and especially between the PhD students from different countries, 3) define the expectations of the training courses planned in the project on population genomics, 4) Visit ARCAD Gene Bank dedicated to the conservation of tropical genetic resources and the Cirad genotyping and sequencing platform, 5) Develop NUS researcher network and common protocols.

Program

Monday, 14 March 2022

- Introduction to the workshop
- Presentation of ongoing and planned activities on each NUS (All partners),
- New sequencing technologies applied to NUS in EWA-BELT
- Visit of the Cirad genotyping and sequencing platform
- Nagoya? The regulatory issues of the project on genetic resources

Tuesday, 15 March 2022

- Parallel meeting on targeted crop

Wednesday, 16 March 2022

- Restitution and collective discussion on the research matrix proposed for each crop
- Selection of the targeted NUS
- Roadmap for the genomic activities planned in the WP2.1.1

List of the selected crop for genomic work

—Fonio (*Digitaria exilis*), Ghana, West Africa

—Ensete (*Ensete ventricosum*), Ethiopia

—Lablab bean (*Lablab purpureus*), Tanzania

—Cocoa (*Theobroma cacao*), Tanzania

—Lima Bean (*Phaseolus lunatus*), Ethiopia

—Finger millet (*Eleusine coracana*), Ethiopia, Kenya and Tanzania, East Africa

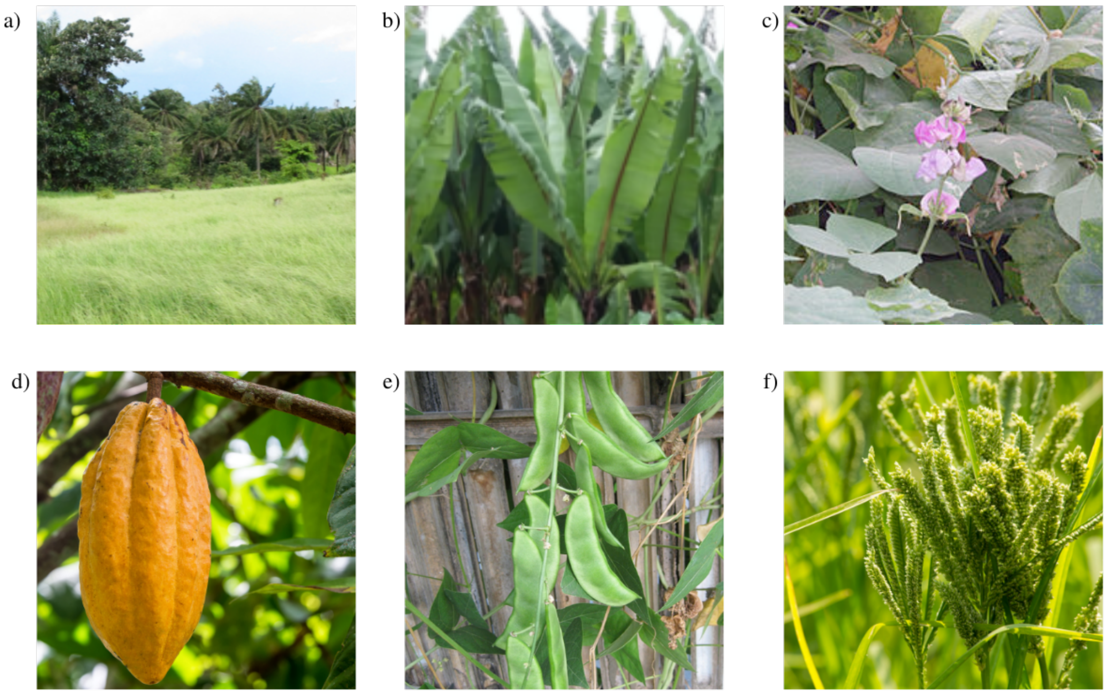

Figure 2 | Neglected and underutilised crops considered priorities by the EWA-BELT project. a) Fonio (*Digitaria exilis*) © IRD, b) Ensete (*Ensete ventricosum*) © Hawassa University, c) Lablab bean (Lablab purpureus) CC BY-SA 2.0, d) Cocoa (*Theobroma cacao*) © Canva, e)

Lima Bean (*Phaseolus lunatus*) CC BY-SA 2.0, f) Finger millet (*Eleusine coracana*) © Canva.

4. Challenges and prospects of NUS research strategies

Investing in research will help realise the full potential of the targeted NUS. But do we really want to replicate the research and development programs of major crops that have focused primarily on improving productivity?

To collectively discuss the research strategies to be deployed on NUS, we organized a 2 hours dedicated webinar on the 14 of December 2021 'Neglected and Underutilized Species to Build for Sustainable Intensification of African Agriculture: Challenges and Perspectives'. In the seminar, three internationally recognized keynote speakers from different disciplinary backgrounds (crop geneticist, social scientist, etc.) shared the latest scientific advances on NUS and their visions for the NUS of research strategies:

—'Agrobiodiversity and resilience' Delphine Renard, CNRS-CEFE

—'Unlocking NUS resources to support food security and promote sustainable agriculture' Samuel Pironon, Royal Botanical Gardens Kew

—'The quinoa boom: a controversial success' Didier Bazile, Biodiversity Advisor and Senior Researcher at CIRAD

These presentations were followed by a panel discussion where participants were invited to collectively reflect on research avenues on neglected and underutilised crops for a transition towards more sustainable and equitable agricultural systems in the light of global change. Several points were highlighted including the questions of conservation, harvesting technologies and breeding strategies.

4.1. Conservation and Sustainable use of NUS

Setting up global NUS research programs will need to strengthen conservation and access to this diversity. Indeed, while the need to access NUS genetic resources for farmers and scientific communities is growing, this diversity is under erosion threat in situ (Díaz et al., 2015) while insufficiently conserved ex situ. Indeed, half of the 7.4 million accessions in Genebank are advanced varieties, and only one third is landraces or old varieties (Commission on Genetic

Resources for Food and Agriculture, 2010). Furthermore, conservation efforts are unevenly distributed across the world. In Africa for example, national genebanks conserving over 10,000 accessions, more dedicated to local genetic resources than international centres, are only located in eastern Africa (Commission on Genetic Resources for Food and Agriculture, 2010). Hence, assessment, collection and conservation of existing NUS diversity is crucial.

4.2.NUS breeding strategies need to go beyond the Green Revolution model

Breeding strategies for NUS should go beyond the agronomic traits' selection and yield increase. Indeed, in the context of family farming systems, there are two main issues: (i) adapting the NUS to accelerating rates of environmental changes; and (ii) optimizing the multifunctionality of NUS. To reach these objectives, the breeding strategy for NUS could be inspired by a new framework, derived from ecological theory that enables diversity to be incorporated into plant-breeding programs (Litrico & Violle, 2015). This approach combined with participatory breeding schemes could help to meet farmers' needs for varietal adaptation to a combination function: climate change adaptation, biotic and abiotic resistance, cultural and culinary needs. This requires better consideration of farmers' perceptions, knowledge and practices through their involvement together with other stakeholders in research projects and the promotion of participatory and intergenerational dialogue from farmers to farmers. Furthermore, in order to incorporate diversity into participatory and in-situ breeding programmes, it is important to recognise informal seed systems (and vegetative propagation). Through these systems, with the help of researchers, farmers can return to selecting, multiplying, selecting, improving and conserving crop genetic diversity (Goïta and Frison, 2020).

4.3.NUS, from the shade to the light for a sustainable future

NUS have the potential to 'end hunger, achieve food security and improve nutrition and promote sustainable agriculture' as articulated in the UN SDG 2 and have a key role to play in advancing agricultural development beyond the Green Revolution model. Considering that little funds are invested in the underutilised crops because their financial attractiveness is not obvious and most of the time, they are unknown by the majority, we need to be innovative to promote these species. NUS will greatly benefit from a collective effort from the scientific community. Future actions will not only need to bring together all the scientific expertise at a disciplinary (biology, agronomy, climate science, social sciences, etc.) and an interdisciplinary level but will require the development of a strong network of partnerships with research institutions, and stakeholders – from smallholder farmers to policymakers like the one implemented in EWA-BELT through the FFRUs (Farmers Field Research Units).

5. References

2019 – The State of Food Security and Nutrition in the World (SOFI) : Safeguarding against economic slowdowns and downturns | World Food Programme. (s. d.). Consulted on february 23, 2021, at https://www.wfp.org/publications/2019-state-food-security-and-nutrition-world-sofi-safeguarding-against-economic

Abadi, T., Eyasu, A., Zemeda, D., & Hadush, H. (2020). Enhancement of tef production through popularization of improved Quncho tef variety at Northwestern Zone of Tigray, Ethiopia. *Journal of Agricultural Biotechnology and Sustainable Development*, *12*(2), 34-38.

Abera, H. (1995). *Anchote : An endemic tuber crop*. Jimma College of Agriculture, Oromia, ET. http://hdl.handle.net/10625/13577

Abrouk, M., Ahmed, H. I., Cubry, P., Šimoníková, D., Cauet, S., Pailles, Y., Bettgenhaeuser, J., Gapa, L., Scarcelli, N., & Couderc, M. (2020). Fonio millet genome unlocks African orphan crop diversity for agriculture in a changing climate. Nature communications, 11(1), 1-13.

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. In M. G. Paoletti (Éd.), Invertebrate Biodiversity as Bioindicators of Sustainable Landscapes (p. 19-31). Elsevier. https://doi.org/10.1016/B978-0-444-50019-9.50005-4

Andreotti, F., Bazile, D., Biaggi, C., Callo-Concha, D., Jacquet, J., Jemal, O. M., King, O. I., Mbosso, C., Padulosi, S., Speelman, E. N., & van Noordwijk, M. (2022). When neglected species gain global interest : Lessons learned from quinoa's boom and bust for teff and minor millet. Global Food Security, 32, 100613. https://doi.org/10.1016/j.gfs.2022.100613

Assefa, K., Yu, J.-K., Zeid, M., Belay, G., Tefera, H., & Sorrells, M. E. (2011). Breeding tef [Eragrostis tef (Zucc.) trotter] : Conventional and molecular approaches. *Plant breeding*, *130*(1), 1-9.

Beillouin, D., Ben-Ari, T., & Makowski, D. (2019). Evidence map of crop diversification strategies at the global scale. Environmental Research Letters, 14(12), 123001. https://doi.org/10.1088/1748-9326/ab4449

Beillouin, D., Ben-Ari, T., Malézieux, E., Seufert, V., & Makowski, D. (2021). Positive but variable effects of crop diversification on biodiversity and ecosystem services. Global Change Biology, 27(19), 4697-4710. https://doi.org/10.1111/gcb.15747

Bélanger, J., Pilling, D., FAO, & Commission on Genetic Resources for Food and Agriculture. (2019). The state of the world's biodiversity for food and agriculture. http://www.fao.org/3/CA3129EN/CA3129EN.pdf

Bellon, M. R., Kotu, B. H., Azzarri, C., & Caracciolo, F. (2020). To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. World Development, 125, 104682. https://doi.org/10.1016/j.worlddev.2019.104682

Camacho-Pérez, L., Martínez-Castillo, J., Mijangos-Cortés, J. O., Ferrer-Ortega, M. M., Baudoin, J. P., & Andueza-Noh, R. H. (2018). Genetic structure of Lima bean (Phaseolus lunatus L.) landraces grown in the Mayan area. *Genetic resources and crop evolution*, *65*(1), 229-241.

Chable, V., Nuijten, E., Costanzo, A., Goldringer, I., Bocci, R., Oehen, B., Rey, F., Fasoula, D., Feher, J., Keskitalo, M., Koller, B., Omirou, M., Mendes-Moreira, P., van Frank, G., Naino Jika, A. K., Thomas, M., & Rossi, A. (2020). Embedding Cultivated Diversity in Society for Agro-Ecological Transition. Sustainability, 12(3), 784. https://doi.org/10.3390/su12030784

Chandra, D., Chandra, S., Pallavi, & Sharma, A. K. (2016). Review of Finger millet (Eleusine coracana (L.) Gaertn) : A power house of health benefiting nutrients. *Food Science and Human Wellness*, *5*(3), 149-155. https://doi.org/10.1016/j.fshw.2016.05.004

Chang, Y., Liu, H., Liu, M., Liao, X., Sahu, S. K., Fu, Y., Song, B., Cheng, S., Kariba, R., Muthemba, S., Hendre, P. S., Mayes, S., Ho, W. K., Yssel, A. E. J., Kendabie, P., Wang, S., Li, L., Muchugi, A., Jamnadass, R., … Liu, X. (2019). The draft genomes of five agriculturally important African orphan crops. GigaScience, 8(3). https://doi.org/10.1093/gigascience/giy152

Cheng, A., Mayes, S., Dalle, G., Demissew, S., & Massawe, F. (2017). Diversifying crops for food and nutrition security – a case of teff. *Biological Reviews*, *92*(1), 188-198. https://doi.org/10.1111/brv.12225

Commission on Genetic Resources for Food and Agriculture (Éd.). (2010). The second report on the state of the world's plant genetic resources for food and agriculture. Commission on Genetic Resources for Food and Agriculture, Food and Agriculture Organization of the United Nations.

CSA (Central Statistical Agency), 2021. Agricultural Sample Survey 2020/21 Report on area and production of major crops. Central Statistical Agency, Addis Ababa.

Defrance, D., Sultan, B., Castets, M., Famien, A. M., & Baron, C. (2020). Impact of Climate Change in West Africa on Cereal Production Per Capita in 2050. Sustainability, 12(18), 7585. https://doi.org/10.3390/su12187585

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J. R., Arico, S., Báldi, A., Bartuska, A., Baste, I. A., Bilgin, A., Brondizio, E., Chan, K. M., Figueroa, V. E., Duraiappah, A., Fischer, M., Hill, R., … Zlatanova, D. (2015). The IPBES Conceptual Framework – Connecting nature and people. Current Opinion in Environmental Sustainability, 14, 1-16. (Yemataw et al., 2018)

Diazgranados, M., Allkin, R., Black, N., Cámara-Leret, R., Canteiro, C., Carretero, J., Eastwood, R., Hargreaves, S., Hudson, A., Milliken, W., Nesbitt, M., Ondo, I., Patmore, K., Pironon, S., Turner, R., Ulian, T., & Díaz-Rueda, D. (2020). World Checklist of Useful Plant Species. https://doi.org/10.5063/F1CV4G34

Dohle, S. (2017). *Development of Resources for Lima Bean (Phaseolus lunatus) Breeding and Genetics Research* [Ph.D., University of California, Davis]. https://www.proquest.com/docview/1970028347/abstract/586DAD7155EA47F4PQ/1

Duresso, M. E. (2018). Study on ethnobotany and phenotypic diversity in anchote (Coccinia abyssinica (Lam.)Cogn.) Landraces in Western Ethiopia. *International Journal of Agricultural Sciences*, *8*(2), 1404-1427.

Ending hunger : Science must stop neglecting smallholder farmers. (2020). Nature, 586(7829), 336-336. https://doi.org/10.1038/d41586-020-02849-6

FAO. (2021). Climate change, biodiversity and nutrition nexus : In brief. FAO. https://www.fao.org/publications/card/fr/c/CB6087EN/

Fekadu, H., Beyene, F., & Desse, G. (2013). Effect of Traditional Processing Methods on Nutritional Composition and Anti-nutritional Factors of Anchote (Coccinia Abyssinica (lam.) Cogn) Tubers Grown in Western Ethiopia. *Journal of Food Processing & Technology*, *4*(7), 1-8. https://doi.org/10.4172/2157-7110.1000249

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N., & Snyder, P. K. (2005). Global Consequences of Land Use. Science, 309(5734), 570-574. https://doi.org/10.1126/science.1111772

Forsythe, C. (2019, novembre 26). *Exploring the viability of re-introducing Lablab purpureus (L.) Sweet as a multifunctional legume in northern Tanzania* [Second cycle, A2E]. SLU, Department of Biosystems and Technology (from 130101). https://stud.epsilon.slu.se/15228/

Gebremariam, M. M., Zarnkow, M., & Becker, T. (2013). Effect of teff (Eragrostis tef) variety and storage on malt quality attributes. *Journal of the Institute of Brewing*, *119*(1-2), 64-70.

Gebretsadik, H., Haile, M., & Yamoah, C. F. (2009). Tillage frequency, soil compaction and N-fertilizer rate effects on yield of teff (Eragrostis tef (Zucc) Trotter) in central zone of Tigray, Northern Ethiopia. *Momona Ethiopian journal of science*, *1*(1).

Gemechu, F., & Alemu, G. (2016). Participatory demonstration of improved Teff variety in Habro and Oda Bultum districts of west Hararghe Zone, Oromia regional national state, Ethiopia. *International Journal of Agricultural Education and Extension*, *2*, 44-47.

Goïta Mamadou and Frison Emile, IPES-Food, 2020. The added value(s) of agroecology: Unlocking the potential for transition in West Africa.

Gould, J. (2017). Nutrition : A world of insecurity. Nature, 544(7651), S6-S7. https://doi.org/10.1038/544S6a

Harrison, J., Moore, K. A., Paszkiewicz, K., Jones, T., Grant, M. R., Ambacheew, D., Muzemil, S., & Studholme, D. J. (2014). A draft genome sequence for Ensete ventricosum, the drought-tolerant "tree against hunger". *Agronomy*, *4*(1), 13-33.

Independent Group of Scientists appointed by the Secretary-General. (2019). Global Sustainable Development Report 2019 : The Future is Now – Science for Achieving Sustainable Development,. United Nations.

Isbell, F., Craven, D., Connolly, J., Loreau, M., Schmid, B., Beierkuhnlein, C., Bezemer, T. M., Bonin, C., Bruelheide, H., de Luca, E., Ebeling, A., Griffin, J. N., Guo, Q., Hautier, Y., Hector, A., Jentsch, A., Kreyling, J., Lanta, V., Manning, P., … Eisenhauer, N. (2015). Biodiversity increases the resistance of ecosystem productivity to climate extremes. Nature, 526(7574), 574-577. https://doi.org/10.1038/nature15374

Jamnadass, R., Mumm, R. H., Hale, I., Hendre, P., Muchugi, A., Dawson, I. K., Powell, W., Graudal, L., Yana-Shapiro, H., Simons, A. J., & Van Deynze, A. (2020). Enhancing African orphan crops with genomics. Nature Genetics, 52(4), 356-360. https://doi.org/10.1038/s41588-020-0601-x

Jideani, I. A. (1999). Traditional and possible technological uses of Digitaria exilis (acha) and Digitaria iburua (iburu) : A review. *Plant Foods for Human Nutrition (Dordrecht, Netherlands)*, *54*(4), 363-374.

Krauss, U., & Soberanis, W. (2001). Biocontrol of Cocoa Pod Diseases with Mycoparasite Mixtures. *Biological Control*, *22*(2), 149-158. https://doi.org/10.1006/bcon.2001.0956

Lee, H. (2018). Teff, a rising global crop : Current status of teff production and value chain. *The Open Agriculture Journal*, *12*(1).

Litrico, I., & Violle, C. (2015). Diversity in Plant Breeding: A New Conceptual Framework. Trends in Plant Science, 20(10), 604-613. https://doi.org/10.1016/j.tplants.2015.07.007

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate Trends and Global Crop Production Since 1980. Science, 333(6042), 616-620. https://doi.org/10.1126/science.1204531

Lobell, D. B., & Tebaldi, C. (2014). Getting caught with our plants down : The risks of a global crop yield slowdown from climate trends in the next two decades. Environmental Research Letters, 9(7), 074003. https://doi.org/10.1088/1748-9326/9/7/074003

Luikart, G., England, P. R., Tallmon, D., Jordan, S., & Taberlet, P. (2003). The power and promise of population genomics : From genotyping to genome typing. Nat Rev Genet, 4(12), 981-994. https://doi.org/10.1038/nrg1226

Mahaut, L., Pironon, S., Barnagaud, J.-Y., Bretagnolle, F., Khoury, C. K., Mehrabi, Z., Milla, R., Phillips, C., Renard, D., Rieseberg, L. H., & Violle, C. (2021). Global mismatches between crop distributions and climate suitability. BioRxiv, 2021.04.15.439966. https://doi.org/10.1101/2021.04.15.439966

Maass, B. L., Knox, M. R., Venkatesha, S. C., Angessa, T. T., Ramme, S., & Pengelly, B. C. (2010). Lablab purpureus—A Crop Lost for Africa? *Tropical Plant Biology*, *3*(3), 123-135. https://doi.org/10.1007/s12042-010-9046-1

Mbora, A., Jamnadass, R., & Lillesø, J. -p B. (2008). *Growing high priority fruits and nuts in Kenya : Uses and management*. World Agroforestry Centre.

Minten, B., Stifel, D., & Tamru, S. (2014). Structural transformation of cereal markets in Ethiopia. *Journal of Development Studies*, *50*(5), 611-629.

Morris, M., Kelly, V. A., Kopicki, R. J., & Byerlee, D. (2007). Fertilizer Use in African Agriculture : Lessons Learned and Good Practice Guidelines. The World Bank. https://doi.org/10.1596/978-0-8213-6880-0

Nagao, M. A. (2011). Farm and forestry production and marketing profile for macadamia nut (Macadamia integrifolia and M. tetraphylla). *Specialty crops for pacific island agroforestry. Holualoa, Hawaii: Permanent Agriculture Resources*.

Nwokolo, E. (1996). Lima bean (Phaseolus lunatus L.). In *Food and feed from legumes and Oilseeds* (p. 144-158). Springer.

Nyamora, A., & Kanyeka, Z. (2012, janvier 1). *Supporting Tanzania's Cocoa Farmers*. Africa Portal; Research on Poverty Alleviation (REPOA). https://www.africaportal.org/publications/supporting-tanzanias-cocoa-farmers/

Parmar, A., Gebre, B. A., Legesse, A., Demelash, Y., Fladung, K., & Hensel, O. (2017). Nutritional Comparison of White and Red Coccinia Abyssinica (Lam.) Cong. Accessions : An Under-Utilised Edible Tuber of the Ethiopian Highlands. *Foods (Basel, Switzerland)*, *6*(8), E71. https://doi.org/10.3390/foods6080071

Pironon, S., Etherington, T. R., Borrell, J. S., Kühn, N., Macias-Fauria, M., Ondo, I., Tovar, C., Wilkin, P., & Willis, K. J. (2019). Potential adaptive strategies for 29 sub-Saharan crops under future climate change. Nature Climate Change, 9(10), 758-763. https://doi.org/10.1038/s41558-019-0585-7

Prieto, I., Violle, C., Barre, P., Durand, J.-L., Ghesquiere, M., & Litrico, I. (2015). Complementary effects of species and genetic diversity on productivity and stability of sown grasslands. Nature Plants, 1(4), 1-5. https://doi.org/10.1038/nplants.2015.33

Popoola, J., Ojuederie, O., Omonhinmin, C., & Adegbite, A. (2019). Neglected and underutilized legume crops : Improvement and future prospects. In *Recent advances in grain crops research*. IntechOpen.

Pucher, A., Sy, O., Angarawai, I. I., Gondah, J., Zangre, R., Ouedraogo, M., Sanogo, M. D., Boureima, S., Hash, C. T., & Haussmann, B. I. (2015). Agro-morphological characterization of west and central African pearl millet accessions. *Crop Science*, *55*(2), 737-748.

Renard, D., & Tilman, D. (2019). National food production stabilized by crop diversity. Nature, 571(7764), 257-260. https://doi.org/10.1038/s41586-019-1316-y

Reeves, T. G., Thomas, G., & Ramsay, G. (2016). Save and grow in practice: Maize, rice, wheat–a guide to sustainable cereal production. Rome, Italy, UN Food and Agriculture Organization. Retrieved from http://www. fao.org/3/a-i4009e.pdf

Rhoné, B., Defrance, D., Berthouly-Salazar, C., Mariac, C., Cubry, P., Couderc, M., Dequincey, A., Assoumanne, A., Kane, N. A., Sultan, B., Barnaud, A., & Vigouroux, Y. (2020). Pearl millet genomic vulnerability to climate change in West Africa highlights the need for regional collaboration. Nature Communications, 11(1), 5274. https://doi.org/10.1038/s41467-020-19066-4

Rojas, M., Lambert, F., Ramirez-Villegas, J., & Challinor, A. J. (2019). Emergence of robust precipitation changes across crop production areas in the 21st century. Proceedings of the National Academy of Sciences of the United States of America, 116(14), 6673-6678. https://doi.org/10.1073/pnas.1811463116

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields : What does the recent literature say? Global Environmental Change, 21(3), 1073-1083. https://doi.org/10.1016/j.gloenvcha.2011.04.007

secretariat. (2019, mai 17). Global Assessment Report on Biodiversity and Ecosystem Services. IPBES. http://www.ipbes.net/global-assessment

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., & Kanyama-Phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. Proceedings of the National Academy of Sciences, 107(48), 20840-20845. https://doi.org/10.1073/pnas.1007199107

Snapp, S., Rahmanian, M., & Batello, C. (2018). *Pulse crops for sustainable farms in sub-Saharan Africa*. United Nations.

Sudjud, S., Mahmud, S. A., & Djafar, C. A. (2020). *Exploration of Morphological Diversity of Cacao Plant (Theobroma cacao L.) in Bacan Island*. 89-93. https://doi.org/10.2991/aer.k.200325.018

Sultan, B., Defrance, D., & Iizumi, T. (2019). Evidence of crop production losses in West Africa due to historical global warming in two crop models. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-019-49167-0

Sultan, B., Guan, K., Kouressy, M., Biasutti, M., Piani, C., Hammer, G. L., McLean, G., & Lobell, D. B. (2014). Robust features of future climate change impacts on sorghum yields in West Africa. Environmental Research Letters, 9(10), 104006. https://doi.org/10.1088/1748-9326/9/10/104006

Ulian, T., Diazgranados, M., Pironon, S., Padulosi, S., Liu, U., Davies, L., Howes, M.-J. R., Borrell, J. S., Ondo, I., Pérez-Escobar, O. A., Sharrock, S., Ryan, P., Hunter, D., Lee, M. A., Barstow, C., Łuczaj, Ł., Pieroni, A., Cámara-Leret, R., Noorani, A., … Mattana, E. (2020). Unlocking plant resources to support food security and promote sustainable agriculture. PLANTS, PEOPLE, PLANET, 2(5), 421-445. https://doi.org/10.1002/ppp3.10145

Vodouhe, R. S., Dako, G. E. A., Dansi, A., & Adoukonou-Sagbadja, H. (2007). Fonio : A treasure for West Africa. *Plant Genetic Resources and Food Security in West and Central Africa. Regional Conference, Ibadan, Nigeria, 26-30 April, 2004*, 219-222.

Yellavila, S. B., Agbenorhevi, J. K., Asibuo, J. Y., & Sampson, G. O. (2015). *Proximate composition, minerals content and functional properties of five lima bean accessions*.

Yemataw, Z., Bekele, A., Blomme, G., Muzemil, S., Tesfaye, K., & Jacobsen, K. (2018). A review of enset [Ensete ventricosum (Welw.) Cheesman] diversity and its use in Ethiopia. *Fruits*.

Zhu, F. (2018). Chemical composition and food uses of teff (Eragrostis tef). *Food chemistry*, *239*, 402-415.