Role of Orphan Crops in Enhancing and Diversifying Food Production in Africa

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Abstract

Orphan- or understudied-crops are considered as the major staple food crops in many developing countries because of their particular role in food security, nutrition, and income generation to resource-poor farmers and consumers. Like other crops, orphan crops are also categorized under cereals, legumes, root crops, and fruit crops. Orphan crops are in general more adapted to the extreme soil and climatic conditions prevalent in Africa than the major crops of the world. However, due to lack of genetic improvement, orphan crops produce inferior yield in terms of both quality and quantity. The major bottlenecks affecting the productivity of orphan crops are low yield [for example, in finger millet (*Eleusine coracana*) and tef (*Eragrostis tef*)], poor in nutrition [cassava (*Manihot esculenta*), and enset (*Ensete ventricosum*)], and production of toxic substances [cassava and grass pea (*Lathyrus sativus*)]. Environmental factors such as drought, soil acidity and salinity, pests, diseases and weeds also contribute to large losses in yield. Hence, an agricultural revolution is required to increase food production for under-researched crops in order to feed the ever increasing population in Africa. Hence, modern crop breeding techniques developed for major crops of the world also need to be applied to orphan crops. The application of these techniques to the understudied crops is vital in order to boost productivity and feed the largely underfed and malnourished population of Africa.

Key words: orphan crops, understudied crops, Africa, agricultural revolution

Description of orphan crops

Different names are used interchangeably to describe the range of orphan crops. Some of these names are, underutilized crops [1], lost crops of Africa [2, 3, 4], minor crops [5], neglected crops [6], and crops for the future [7].

According to Wikipedia three criteria must meet in order for the plant to be considered underutilized or orphan crop, i) proven food or energy value, ii) the plant has been widely cultivated in the past, or the plant is currently cultivated, in a limited geographical area, and iii) currently cultivated less than other comparable plants [8]. According to Naylor *et al*. [9] twenty-seven orphan crops within developing countries are annually grown on about 250 million ha of land. **Table 1** shows the list of some orphan crops and their useful agronomic traits.

Although orphan crops are many in number, brief description is given below for the most important ones interms of the area they are grown and/or population they feed. These include cereals (e.g. millet, tef, fonio), legumes (cowpea, bambara groundnut, grass pea), and root crops (cassava, yam, enset).

Finger millet (*Eleusine coracana*) is the most important small millet in the tropics and is cultivated in more than 25 countries in Africa and Asia predominantly as a staple food grain [25]. The plant is tolerant to drought. The seed of finger millet contains valuable amino acid called methionine [2], which is lacking in the diets of hundreds of millions of the poor who live on starchy staples such as cassava. Finger millet is also a popular food among diabetic patients because of its slow digestion.

Tef (*Eragrostis tef)* is grown annually on over 2.5 million hectares of land mainly in Ethiopia. The plant is tolerant to abiotic stresses especially to poorly drained soils where other crops such as maize and wheat could not withstand. In addition, the seeds of tef produce healthy food because they do not contain gluten for which large portion of the population are allergic [24]. Unlike other cereals, the seeds of tef can be stored easily without losing viability under local storage conditions, since it is not attacked by storage pests [23].

Fonio (Acha, *Digitaria exilis* and *Digitaria iburua*) is an indigenous West African crop. It is grown mainly on small farms for home consumption. Fonio is not only tolerant to drought but also a very fast maturing crop. It is also nutritious because it is rich in methionine and cystine, the two amino acids vital to human health and deficient in major cereals such as wheat, rice and maize [26].

Cowpea (*Vigna unguiculata*) is a leguminous crop annually grown on about 10 million hectares of land mainly in Africa. The crop is tolerant to drought and heat. It also performs better than many other crops on sandy soils with low level of organic matter and phosphorus [27]. Since cowpea has quick growth and rapid ground cover, it is a useful crop in controlling erosion [28].

Bambara groundnut (*Vigna subterranea*) is an annual legume crop grown for human consumption. The seeds of bambara groundnut are known as a complete food because they contain sufficient quantities of protein, carbohydrate and fat. The average composition of the seed is 63 percent carbohydrate, 19 percent protein, and 6.5 percent oil [3].

Grass pea (*Lathyrus sativus*) is another leguminous plant commonly grown for human consumption in Asia and Africa. The plant is extremely tolerant to drought and is considered as an insurance crop since it produces reliable yields when all other crops fail. Like other grain legumes grass pea is a source of protein particularly for resource poor farmers and consumers. However, the seeds of grass pea contain a neuron-toxic substance called ODAP [β-N-Oxalyl-L-α, β-diaminopropanoic acid [29].

Cassava (manioc; *Manihot esculenta)* is staple food for about a billion people [30]. The plant is tolerant to drought and also performs better than other crops on soils with poor nutrients. The major problems related to cassava are its very low protein content and the roots contain poisonous compounds called cyanogenic glycosides (CG) which liberate cyanide [31]. Konzo is a paralytic disease associated with consumption of insufficiently processed cassava.

Yam (*Dioscorea sp*) represents different species under genera Dioscorea. It is grown on about 5 million hectares of land world-wide [32] and staple food in west Africa. The roots are the edible part and looks like sweet potato (*Ipomoea batatas*) although they are not taxonomically related.

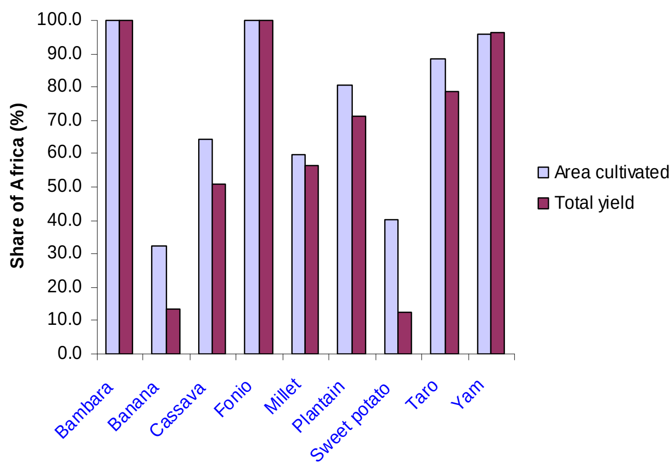
Enset (*Ensete ventricosum*) is commonly known as 'false banana' for its close resemblance to the domesticated banana plant. Unlike banana where the fruit is consumed, in enset the pseudostem and the underground corm are the edible parts. Enset is the major food for over 10 million people in densely populated regions of Ethiopia. The plant is considered as an extremely drought tolerant and adapts to different soil types [33]. Since enset flour is rich in starch but not in other essential nutrients enset-based diets need heavy supplementation.

Role of orphan crops in African economy and socio-economic conditions

Orphan crops play particular role in food security, nutrition, and income generation to resource-poor farmers and consumers in developing countries. These crops perform better than major crops of the world under extreme soil and climatic conditions prevalent in developing world particularly in Africa. Most of African orphan crops including finger millet and bambara groundnut are extremely drought tolerant while some others withstand water-logging for longer period than the major crops of the world (**Table 1**).

In general, orphan crops are extensively grown in Africa. The total global production of three orphan crops, namely bambara groundnut, fonio and yam comes from Africa (**Fig 1**). Africa also devotes large area of land for cassava, millet, plantain and taro cultivation. However, the total acreage and total production are not comparable for last four crops in Africa. For example, regarding cassava, Africa contributes for about 65 percent of the global area but produces only 50 percent of the total world production. This might be due to the use of unimproved planting materials and poor management practices.

Figure 1. Share of Africa in the world acreage and production for selected orphan crops in 2008.



Source: Adapted from FAOSAT [34].

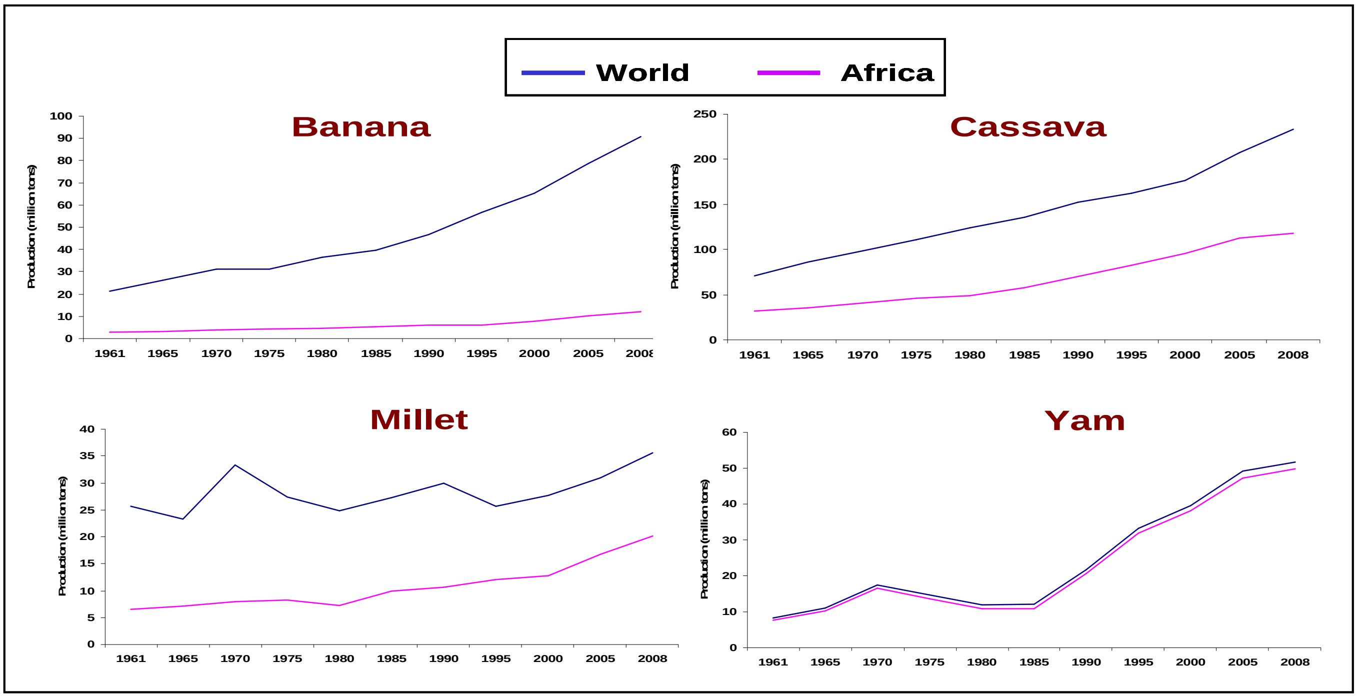
Fig 2 shows the trend of total production for four orphan crops in Africa as compared to the world production. Except for banana, the production of three other crops (cassava, millet and yam) has steadily increased over time in Africa. Yam is exclusively grown in Africa and the production of this crop has tripled in the last 25 years (**Fig 2**).

Orphan crops are also compatible to the agro-ecology and socio-economic conditions of the continent. However, when these crops are replaced by other newer crops for the locality, some problems were reported. The best example is from the study made in the Northwestern Ethiopia where the incidence of malaria has been elevated in the years when the cultivation of exotic crops specifically maize was increased at the expense of indigenous or orphan crops [36, 37, 38]. Malaria is the major health problem in the world particularly in Africa. In the year 2006, there were an estimated 247 million malaria cases causing nearly a million deaths, mostly of children under 5 years [39]. The study by McCann and colleagues [36, 37, 38] indicated that the pollen from maize facilitates optimum conditions for mosquito breeding. Mosquitoes carry *Plasmodium* parasites, the causal agent for malaria. Larvae of the mosquito had a survival rate of 93 percent when it fed on maize pollen, as opposed to a survival rate of about 13 percent when it fed on other possible food sources. As a result, the cumulative incidence of malaria in high maize cultivation areas was 9.5 times higher than in areas with less maize [36].

Limitations or negative characteristics of orphan crops

Although orphan crops perform better than major crop under extreme environmental conditions and fit to the

Figure 2 The trend of production for four orphan crops from 1961 to 2008.



Source: Adapted from FAOSAT [35].

socio-economic conditions of the developing countries especially in Africa, they have also a number of limitations. The major bottleneck is related to the little genetic investigation made on these crops. Almost all orphan crops are studied by poorly funded researchers based in the developing nations where resources for conducting research are limiting. The majority of these researchers have little chance to establish partnerships with the scientific community especially with those in the developed countries. Some of the outstanding bottlenecks related to orphan crops are indicated below:

- **Poor grain yield:** most orphan crops particularly cereals such as tef, millet and fonio produce extremely low seed yield.

- **Poor in nutrient content:** although root and tuber crops such as cassava and enset produce high yield, the products are largely starchy materials that are deficient in other essential nutrients particularly in protein. Although these crops are staple food crops for large number of Africans, supplementation with other nutrients is required.

- **Unfavorable agronomic characters**: Some of the negative features associated with the African rice (*Oryza glaberrima)* unlike the Asian rice (O. *sativa) are rapid shattering of the* seeds, difficulty of milling the grain, and lower seed yield (Linares 2002).

- **Abiotic stresses:** Since most fertile lands are used to grow other crops than the orphan crops, the productivity of orphan crops under the less fertile and moisture deficit soils is extremely low.

- **Hazardous or toxic products:** The following orphan crops produce a variety of toxic substances that affect the health of human.

⇒ **Cassava.** The roots of cassava contain poisonous compounds called cyanogenic glycosides (CG) which liberate cyanide [31]. Konzo is a paralytic disease associated with consumption of insufficiently processed cassava.

⇒ **Hyacinth bean** *(Lablab purpureus).* The pods and seed of hyacinth bean can be poisonous due to high concentrations of cyanogenic glycosides and can only be eaten after prolonged boiling [1].

⇒ **African yam bean** *(Sphenostylis stenocarpa).* The seeds of African yam bean contain anti-nutritional factors such as cyanogenic glycosides and trypsin inhibitors. Cooking is required to reduce toxins to safe levels, though this also decreases the level of nutrients in seed [1].

⇒ **Grass pea.** the seeds of grass pea contain a neuron-toxic substance called ODAP [β-N-Oxalyl-L-α, β-diaminopropanoic acid [29]. ODAP is the cause of the disease known as neurolathyrism, a neurodegenerative disease that causes paralysis of the lower body. Serious neurolathyrism epidemics have been reported during famines when grass pea is the only food source [40].

Genetic improvement of orphan crops: lessons from major crops

Crop production could be increased by either expanding the arable area or through intensification, i.e., using improved seed, fertilizer, fungicides, herbicides, irrigation, etc. According to Food and Agriculture Organization, agricultural intensification represents about 80 percent of future increases in crop production in developing countries [41]. Based on this goal, crop breeders are focusing towards achieving improved cultivars that produce higher yields and at the same time tolerate to the sub-optimal soil and climatic conditions.

Among plant characters or traits that contributed for higher productivity in the last century, those which alter the architecture of the plant rank first. Architectural changes include alteration in branching pattern and reduction in plant height. The major achievement of Green Revolution in 1960's was due to the introduction of semi-dwarf crop varieties of wheat and rice along with proper crop production packages. These broadly adapted semi-dwarf cultivars were responding to fertilizer application; which led to tremendous increase in productivity. Currently, a number of genes affecting plant height are identified from major cereal crops including wheat, rice and maize [42]. According to the International Food Policy Research Institute, Green Revolution represented the successful adaptation and transfer of scientific revolution in agriculture [43]. However, since this agricultural revolution did not occur in Africa, crop productivity remains very low.

Modern improvement techniques are not yet employed in orphan crops. Breeders of orphan crops are mostly dependent on the conventional techniques such as selection and hybridization. Only limited numbers of breeders implement modern techniques such as marker-assisted breeding and transgenics. Genomic information such as whole-genome sequencing are not yet available for orphan crops. In order to feed the ever-increasing population of Africa, agricultural revolution is needed to boost productivity of orphan crops through the implementation of modern technologies proved to be effective for major crops of the world.

Application of modern improvement techniques to the orphan crops

A number of molecular markers are implemented in modern plant breeding. These include Restriction Fragment Length Polymorphisms (RFLPs), Random Amplified Polymorphic DNAs (RAPDs), Amplified Fragment Length Polymorphisms (AFLPs) and microsatellites (Simple Sequence Repeats, SSR). Marker assisted selection (MAS) is the identification of DNA sequences located near genes that can be tracked to breed for traits that are difficult to observe. According to Collard and Mackill [44] the following factors should be considered before selecting what type of DNA marker to be used in MAS: reliability; quantity and quality of DNA required; technical procedure for marker assay; level of polymorphism; and cost. Comparative mapping studies have revealed that the genomes of plant species within families are conserved for chromosomal regions [45]. Hence, orthologous genes from orphan crops could be identified and isolated based on information from major crops.

Conventional breeding technologies including selection, hybridization and mutation breeding are all considered as non-transgenic methods. From modern techniques, marker-assisted breeding and TILLING are also non-transgenic. TILLING (Targeting Induced Local Lesion IN Genomes) is a high-throughput and low cost method for the discovery of induced mutations. Transgenic and a modified form known as cisgenesis are widely applied to major crops such as rice and maize. Only few orphan crops have so far benefited from the techniques. Transgenic is considered as other advancement towards boosting crop yields and improving nutritional quality of crops. Due to high adoption rate, the global area under transgenic crops is tremendously increased from just 1.7 million ha in 1996 to about 134 million ha in 2009 [46].

Future perspectives and recommendations

In order to boost productivity and diversify the food system in Africa orphan crops should be given due attention. The following points need to be considered in order to promote orphan crops research:

- Apply modern improvement techniques to orphan crops research. These include MAS, TILLING, tissue culture and transgenic techniques. The goals and techniques to be employed might vary for different orphan crops. However, the majority of research on orphan crops focuses on four areas, i) improving productivity per unit area, ii) breeding for tolerance against biotic and abiotic stresses, iii) enhancing nutritional quality through biofortification, and iv) removing toxic substances from some plant species.

- Financial and technical supports for researchers and institutions involved in orphan crops research since research on these crops are mostly underfunded and dependent on locally available meagre resources. These supports could be invested in training African scientists and developing infrastructure for African research institutes.

- Establish partnerships with public and private institutions. The partnerships could be made within and between research institutes, universities and private organizations.

- Create a network of orphan crops researchers at different levels: national, regional and international. The network will be an effective information exchange mechanism either among orphan crops researchers or with those working on major crops. This can be facilitated, for example, by forming internet discussion forum.

- Organize conferences, workshops or trainings related to orphan crops research and development.

The First International Conference on African Orphan Crops was held in September 2007, in Bern, Switzerland in order, i) to address the major crop productivity problems related to orphan crops in Africa; ii) to propose the strategy of implementing modern techniques to orphan crops; and iii) to discuss the prospects and feasibility of modern crop biotechnology in African agriculture in general and orphan crops in particular through round-table discussions involving prominent scientists. About 80 researchers from four continents participated in the conference. The Proceedings of the conference has been recently published [47]. The second conference on African orphan crops is expected to take place in Africa in near future.

Conclusion

Orphan- or Understudied-crops provide food for resource poor farmers and consumers in Africa. They also grow under extreme environmental conditions, many of them poorly suited to major crops of the world. Since Green Revolution did not occur in Africa, the continent did not benefit from the positive effects of this agricultural revolution that boosted the productivity of food crops in other parts of the world. The next Green Revolution for Africa needs to also include these locally adapted crops that are mostly known as orphan- or understudied-crops. Although these crops are largely unimproved, the implementation of modern improvement techniques on these crops has many advantages.

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Table 1. Major orphan crops of Africa and their important traits

Common Name	Botanical name	Other names	Type of crop	Country or region of importance in	Important trait	Reference
African eggplant	*Solanum aethiopicum*	Mock Tomato, Ethiopian eggplant	Leafy vegetable	All regions	High yielding	[3]
African rice	*Oryza glaberrima*		cereal	Western	resistant to diseases and pests	[10]
African yam bean	*Sphenostylis stenocarpa*		Root crop	All regions	High protein content	[3]
Amaranth	*Amaranthus spp.*		Leafy vegetable	All regions	Fast growing	[3]
Bambara groundnut	*Vigna subterranea*		legume	All regions	Rich in protein, drought tolerant	[3]
Banana	Musa spp.		fruit	All regions	High yield	[11]
Baobab	*Adansonia digitata*		Leafy vegetable/fruit	All regions	Drought tolerant	[3]
Barbados cherry	*Malpighia glabra*		fruit	All regions	Rich in vitamin	[1]
Cassava	*Manihot esculentum*	manioc	Root crop	All regions	Drought tolerant	[13]

Common Name	Botanical name	Other names	Type of crop	Country or region of importance in Africa	Important trait	Reference
Celosia	*Celosia argentea*		Leafy vegetable	Western	High productivity	[3,12]
Chickpea	*Cicer arietinum*		legume	Southern & Eastern	Protein source	[14]
Cowpea	*Vigna unguiculata*		legume	All regions	Drought tolerant	[3]
Dika	*Irvingia gabonensis, I. wombolu*		fruit	western	oil-rich	[3]
Enset	*Ensete ventricosum*		Trunk/root	Ethiopia	Drought tolerant	[15]
Ethiopian Mustard	*Brassica carinata*	Ethiopian kale, gomen zer	Leafy vegetable & oil crop	All egions	Resistant to blackleg pathogen	[16]
Finger millet	*Eleusine coracana*	African millet, Ragi	cereal	All regions	Rich in iron, protein; low in glycaemic index	[1, 12]
Fonio	*Digitaria exilis*	Acha	cereal	Western	Fast maturing	[2,12]
Foxtail millet	*Setaria italica*	*Italian millet*	cereal		Drought tolerant	[17]
Grass pea	*Lathyrus sativus*	Indian vetch, guaya	legume	Eastern	Extremely drought tolerant	[18]
Kodo millet	*Paspalum scrobiculatum*		cereal	western	tolerant to flooding	[17]
Little millet	*Panicum sumatrense*		cereal		Drought tolerant	[17]
Noug	*Guizotia abyssinica*	Niger seed	oil seed	Eastern & southern	High oil content	[19]
Okra	*Abelmoschus esculentus*		Leafy vegetable	West Africa	Tolerant to biotic stresses, fast growing	[20]
Pearl millet	*Pennisetum glaucum*		cereal	All regions	Drought tolerant	[21]
Plantain	Musa spp.		fruit	Eastern & western		[11]
Proso millet	*Panicum miliaceum*	Common millet	cereal		Drought tolerant	[17]
Quinoa	*Chenopodium quinoa*		cereal		High in protein content	[1]
Sesame	*Sesamum indicum*		Oil seed	All regions	oxidatively stable oil	[1]
Sweet potato	*Ipomoea batatas*		Root	All regions	rich in riboflavin and calcium	[1]
Tamarind	*Tamarindus indica*		fruit		Long storage time	[4]
Taro	*Colocasia esculenta*		Root and leaf vegetable	western		[22]
Tef	*Eragrostis tef*	teff	cereal	Horn of Africa	Tolerant to abiotic stresses; free of gluten	[23,24]
Vernonia	*Vernonia galamensis*	ironweed	industrial oilseed	East Africa	High oil content	[12]
Yam	*Dioscorea spp*		Root crop	Western and Eastern	Drought tolerant	[12]

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