Food and nutritional security impact of exploiting opportunities and developing strategies in increase yam (Dioscorea spp.) production in Ethiopia

Demilew Deres Andualem (demilewbiot@yahoo.com)
EIAR: Ethiopian Institute of Agricultural Research https://orcid.org/0000-0002-9960-8758

Research Article

Keywords: yam production in Ethiopia, yam seed tuber production technologies, orphan crops in Ethiopia, biotech techniques for large-scale production of yam planting materials, women and youth cooperatives for yam production

Posted Date: April 5th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1501836/v1

Abstract

To feed the world's exponentially growing population, agriculture needs to use "every arrow in its quiver." Agricultural research efforts must go beyond corn, wheat, and rice, and take a second look at "orphan crops," those that tend to get less attention, such as yams. Yams (genus *Dioscorea*, family *Dioscoreaceae)* are an economically, nutritionally, and medicinally valuable crop for over 300 million people all over the world. Africa produces approximately 96.5 percent of the world's yams. In Ethiopia, it is mostly grown in the western and southern regions, but despite its potential to offset malnutrition and food insecurity, yam production in the country has declined from 200,000 tons in 1993 to 45,000 tons in 2020 due mainly to biotic and abiotic pressures. The availability of a widely diverse landraces, large tracts of arable land, and newly released cultivars hold much promise for Ethiopia's yam production. This review proposes that (1) expanding the yam land cover; (2) more research investments in seed tuber production technologies and the development of varieties resistant to biotic and abiotic stress; and (3) more cooperatives for seed tuber production of farmer-preferred varieties, will considerably enhance yam production in Ethiopia.

1 Introduction

Millions of people worldwide suffer from food insecurity and various forms of malnutrition as a result of the high cost of healthy diets. In Ethiopia, several factors contribute to this scenario, including climate change, lack of technology and/or access to it, sociocultural problems, biotic and abiotic factors, and the dearth of skilled labor (Semahegn 2021). According to Anderson (2012), climate change alone could reduce maize and wheat production by 3.8 percent and 5.5 percent, respectively. In addition, new and emerging fungal and oomycete pathogens constantly threaten staples and other economically important commodity crops (Fones et al. 2020).

In 2020, international development agencies report that approximately 811 million people worldwide faced hunger (FAO, IFAD, UNICEF, WFP, and WHO, 2021). Ethiopia, for one, has a population that is growing at 1.4 percent per year on average, a rate that will double the current number of people to 205 million by 2050. Small-scale farmers, threatened with fragmented farmlands, recurring droughts, and lack of rainfall are unlikely to produce harvests that will meet this growing demand (Agidew and Singh 2018). Already, despite Ethiopia's abundance of natural resources, more than five million live in poverty. As (Deressa and Hassan 2009) posit, the number of people living in poverty increases as crop net revenue per hectare decreases over time due to climate change.

Scientists have long advocated that feeding the world's population in the face of dwindling resources necessitates appropriate policy and research investments. For the developing world, some solutions hold great promise. Biotechnology, for example, can be applied to boost cereal crops production. Farms can be diversified to grow fruits and vegetables (Islam et al., 2018). More specifically, farmers can take advantage of the benefits that can be derived from orphan (underutilized) crops.

Orphan crops are those that have been understudied and underexploited despite their potential to provide low-income families with employment, revenues, and a more diverse diet (Massawe et al., 2015). Among them are yams (*Dioscorea spp.*), whose nutritional and pharmacological properties can combat hidden hunger caused by micronutrient deficiency (Padhan &Panda, 2020; Epping & Laibach 2020). Yam production in Ethiopia, therefore, deserves a second look.

The present article highlights opportunities and suggests strategies to improve yam production in Ethiopia using evidence from experiences in West and Central Africa.

1.1 Yams in Ethiopia

Yams are plants in the *Dioscoreaceae* family's largest genus, *Dioscorea*, under which falls over 600 species. They are monocotyledonous herbaceous vines with starchy underground or aerial tubers that climb. Yam tubers, formed by the activity of ground meristems, are more similar anatomically to the stem than to the roots. The aerial stems of yams are frequently long and twining, with alternate or opposite leaves, but are less commonly short and erect, with a single leaf subtending it (Caddick et al., 2002).

There are over 600 yam species in the tropics and subtropics. Martin and Ortiz (1963) report the geographical origins and domestication, distribution, botanical classification, morphology, and cytology of yam species. Various edible yam species have been domesticated independently in America, Africa, Madagascar, South and Southeast Asia, Australia, and Melanesia. The origins of various yam species vary geographically. However, according to Coursey (1967), yam species found throughout the tropics originated from three distinct geographical centers— West Africa, Southeast Asia, and tropical America. Ethiopia's yams differ from the species commonly cultivated in West Africa (Tamiru et al., 2007). Coursey (1967) confirmed that *D. abyssinica* originated in Ethiopia, although its cultivation is limited within the country.

2 Importance Of Yams

2.1 Yam for global food security

Grown primarily for its tubers that are rich in carbohydrates, proteins, lipids, fibers, and minerals, yams are a major food source; its foliage is used to make pharmaceutical products (Bhandari et al., 2003; Padhan et al., 2018). It provides a living for over 300 million people in the tropics and subtropics (Mignouna et al., 2008), but its potential for food, employment, income, and nutrition, remains untapped (Beckford, Campbell, & Barker, 2011; Adigoun-Akotegnon et al., 2019).

Yam farmers sell the tubers and bulbils as food. They also extract bioactive compounds from the peel and use it to feed farm animals and fish (Epping & Laibach, 2020). In India, many yam species are eaten and used to treat various ailments (Dutta, 2015). The greater yam, *Dioscorea alata*, is grown in India and is known for its high tuber yield (Sheela et al., 2016). *Dioscorea bulbifera* is one of the species that grow in southern Ethiopia that has high levels of carbohydrates (Erena & Alemu, 2019). Some of the major cultivars of this species have been used to develop various food products in Nigeria (Ojinnaka et al., 2017). Except for the higher crude fiber content, wild yams have nutritional compositions that are similar to most cultivated yams in many parts of the world (Bhandari et al., 2003).

2.2 Yam as a pharmaceutical plant

The tubers of both cultivated and wild yam species are high in nutrients, minerals, and bioactive metabolites, offering significant nutritional and therapeutic benefits (Obidiegwu et al. 2020). Patients with various health issues use yam-processed food as a medicine. The medicinal properties of yam stem from metabolites that have antimicrobial, anti-mutagenic, antioxidant, anti-diabetic, and anti-obesity properties. Ovarian cancer, menopause complications, female aging diseases, asthma, urinary tract infections, bladder-related complications, rheumatism, arthritis, and pelvic cramps are all treated with various yam species (Obidiegwu et al., 2020).

Yam is a source of dioscorin-soluble protein, which is used as a food additive for those with various disorders. It has enzymatic, antioxidant, antihypertensive, immune-modulatory, and lectin properties, as well as the ability to withstand chemical, thermal, and enzymatic digestion (Lu et al., 2012). It is used to treat hypertension by inhibiting the activity of angiotensin-converting enzymes (Hsu et al., 2002). Yams, therefore, are a nutrient-dense food. Functional meals made from yams that contain 140 mg of dioscorin are used to lower blood pressure (Liu et al., 2009).

Some yam species are sources of sapogenins, which are used in the manufacture of steroids and medications to improve male fertility (Martin 1969). *Dioscorea* is the main ingredient in Die-Huang-Wan, a Chinese herbal concoction that improves diabetic rats' responsiveness to exogenous insulin (Hsu et al., 2007).

3 Yam Production And Challenges

3.1 Global production

Yam has the ability to grow in the presence of biotic and abiotic stress factors, which makes it suitable to many agro-ecologies. It is small wonder, then, that it can be found in over 50 nations, with Africa accounting for 96.5 percent of its production, America for 2.4 percent, Asia for 0.4 percent, and Oceania for 0.7 percent (FAO, 2021). Yam production has increased at an annual rate of 3.6 over the last three decades. Over 74 million tons of yams were produced in 2020. Nigeria is the world's leading yam producer, accounting for 67 percent of total global production.

3.1.1 Yam production in Ethiopia

Since 1993, Ethiopian yam production has decreased each year, down to 45 thousand tons in 2020 despite genetic diversity, available cropland, and more released varieties. Farmers' criteria for selecting cultivars based on their resilience to diverse environmental stress circumstances limit the diversity and dispersion of different cultivars (Adigoun-Akotegnon et al., 2019). For example, the majority of landraces in Wolayita and Gamo-Gofa faced extinction, owing to their rarity and limited distribution (Tamiru et al., 2008).

3.2 Challenges to yam production

3.2.1 Lack of technology

Yam-based cropping systems in sub-Saharan Africa are threatened by the lack of technologies that can improve soil fertility, control weeds, and manage pests (Ekanayake & Asiedu, 2003). Miniscule investments in research have produced only four varieties that perform well under Ethiopian conditions, and farmers remain unaware of them. The country needs more varieties that can tolerate major biotic and abiotic stresses. Other major constraints are soil-borne pests and diseases, leaf diseases, storage pests and diseases, punishing labor costs, high cost of constructing barns and storage facilities, lack of materials for staking, antiquated ways of producing seeds, and a scarcity of planting materials (Bassey, 2017). The country badly needs techniques to produce seedlings from yam seed tubers on a large scale.

Several plant virus species, such as *dioscorea bacilliform virus*, *yam mild mosaic virus*, *yam chlorotic necrosis virus*, as well as *ampelo virus* and *secoviruses* bedevil yams (Filloux et al., 2018; Hayashi et al., 2017; Seal et al., 2014). Yam production is also stalled by inadequate soil quality, drought stress, and low rainfall (Srivastava et al. 2012)

Ethiopia needs the following to increase yam productivity: (1) improved seed tuber production; (2) optimal rates of chemical fertilizer application; (3) proper land and seedbed preparation; (4) appropriate planting and row planting methods; (5) integrated pest management (IPM) strategies; (6) proper crop harvesting after physiological maturity; (7) storage structures to minimize pest and disease losses; (8) postharvest processing and handling to add value and enhance demand; and (9) viable marketing and selling techniques.

3.2.2 Sociocultural and economic problems

Although Ethiopian culture sees yam production as the responsibility of men, women are the ones who protect the crop after harvest. Petros et al. 2018 confirmed that women's role in post-harvest increases to as much as 80% of the yield in cereals. They are in charge of storing and cultivating seeds, and as a result, they contribute to the season's yield. Women take the harvested yam home to see if it has been properly stored, and once they have, they plan how much will be kept for food and for seed for tuber production the following season. They handle all aspects of seed tuber management, which is necessary to minimize post-harvest losses. Extension field officers will do well to apply communication strategies that are sensitive to people’s age, educational level, primary occupation, and household size to improve women and youth participation in yam production (Adam et al., 2014).

The producers' acceptance of yam production practices and cultures is influenced by all of these factors. When communicating with communities, field officers must keep these factors in mind and use language that reflects their cultural values. It is also critical to provide farmers with training so that they understand the critical role that women play in increasing yam production. Field officers should also develop policies and procedures to ensure that farmers are aware of the role that new or other technologies can play in increasing productivity. Extension services must provide training to women and youth on how to use tools in yam cultivation as well as how to increase productivity on existing fields.

4 Opportunities To Enhance Yam Production

4.1.1 Wide suitable land resources

Many factors bode well for increased yam production in Ethiopia. For one, the country has a large land area (1,221,480 sq km), although arable land area is limited; more than 15% is under cultivation. Cropland is estimated to be more than 60% of the cultivated area.

4.1.2 Broad yam genetic diversities

Ethiopia has germplasm collections with significant genetic diversity (Bekele & Bekele, 2020) that breeders can tap to develop varieties with tolerance to common biotic and abiotic stresses. These collections, established in various areas of South, Southwestern, and Western Ethiopia, can be exploited using traditional and modern plant breeding methods.

The southern and southwestern parts of Ethiopia alone hold a large number of accessions of three yam species (*D. alata, D. bulbifera*, and *D. abyssinica*) (Tamiru et al., 2007). In the Sheko district, yam accessions are distributed and cultivated informed by farmers' indigenous knowledge (Garedew et al., 2017). Some of the accessions of yams from southwestern Ethiopia are identified for their potential to be used in breeding for yield improvement (Tewodros Mulualem and Mohamed Hussien, 2012). In a study by Mulualem et al. 2018, accessions with the highest genetic dissimilarity index were identified as potential sources of novel genes that could be used to improve the genetics of yams in Ethiopia.

A significant phenotypic variation was found in 75 accessions of 30 different named farmers' landraces grown in Ethiopia (Asfaw et al., 2021). Asfaw and colleagues (2021) discovered differences in the agronomic performance of landraces, collections, and varieties that are widely grown. Thus, Ethiopia's yam genetic resources that can be used to supplement the breeding programs of West Africa is broad enough. This broad genetic resource provides breeders with the opportunity to improve the genetics of yams for enhanced production in Ethiopia.

4.1.3 Availability of released varieties

According to Ethiopia's Ministry of Agriculture (2020), four yam varieties have been released and registered in the country thus far. Across years and locations, two varieties, "Bulcha" and "Lalo" outperform others in terms of productivity and disease tolerance (Akassa et al., 2015). Pre-extension activity began promoting “Bulcha” (Bekele et al., 2021), a significant step toward scaling-up rapid methods of propagation.

Furthermore, over the last 40 years, 78 yam varieties with improved yield, resistance to major diseases, and tuber qualities have been released in sub-Saharan Africa (SSA) (Alene et al., 2015). This is an excellent opportunity for Ethiopia to adopt and/or adapt some varieties released by the International Institute of Tropical Agriculture (IITA) for immediate use. IITA has contributed 80 percent of the yam varieties developed for sub-Saharan Africa.

5 Ways To Improve Yam Production In Ethiopia

5.1 Increasing yam land coverage in growing areas

According to the United States Department of Statistics (2021), Ethiopia’s potential arable land area has increased from 10 million hectares in 1993 to 16 million hectares in 2019. There has also been a significant increase in crop coverage over the last two decades, from 0.08 million hectares to 0.17 million hectares, despite the fact that there is still much land that can be used to grow crops. However, yam harvested area decreased significantly from 28,000 hectares to 4,874 hectares, resulting in a drop in production from 200,000 tons in 1993 to 45,000 tons in 2020. Few households cultivate yam accessions share a small land area and invest less capital in the Basketo and Dera Malo Districts of southern Ethiopia (Gebre 2019). This phenomenon, yet to be explained, indicates that production declined as the area planted to yams decreased in each season of production, which calls for the urgent need to increase yam land coverage to at least 1993 levels.

Despite the fact that yam productivity is affected by a lack of fertile land, technology, and labor, production can increase by 0.93 percent while the cultivated area is increased by 1 percent (Degla and Sourokou 2020).

5.2 Yam technology development and application

With the application of information and communication technologies and devices, technology producers can be in closer touch with those for whom technologies are developed in the first place. Identifying other barriers to technology adoption promises to be a fruitful area of endeavor. The provision of subsidized farm inputs and improved varieties to farmers to encourage adoption has raised the number of farmers above the poverty line (AO 2018).

Modern biotechnology, such as molecular markers linked to genes controlling traits, offers a golden opportunity to improve yam production. Biotechnology innovations that hold promise include the identification of genes or QTLs underlying various agronomically important traits (Mignouna et al., 2003) and optimization of chemical and physical conditions for *in vitro* micropropagation (Borges et al., 2004; Mantell et al., 1978; Ondo Ovono et al., 2007) and cleaning of viral disease (Wang et al., 2008; Ita et al., 2020), genetic transformation (Nyaboga et al., 2014), developing low cost, high throughput, scalable disease diagnostic tools (Filloux et al., 2018), and gene editing of genotypes for increased production.

5.2.1 Yam genomics and molecular breeding

Advances in molecular breeding can also help propel yam production in Ethiopia. Genotype yield potential can now be predicted based on measurements of yield-related characteristics, which allows breeders to easily identify the best yielding varieties (Harry, 2017). Some agronomic traits of *D. alata* have been observed to be strongly associated with, and can thus be used for, genetic analysis and the development of markers for both tuber yield and quality, as well as anthracnose tolerance (Alieu & Robert, 2014). All of these contribute to the genetic improvement of yam in Ethiopia.

It is also necessary to screen Ethiopian genotypes for tolerance to low soil nutrients and fertilizer minerals. Varieties with these characteristics will be most useful to farmers who practice low-input yam production. Some Guinea genotypes have been identified as having the potential to perform well in environments with limited soil nutrients and fertilizer minerals (Matsumoto et al., 2021). Ethiopia needs more improved varieties with farmer-preferred properties, but the rate of variety release is slow (Alene et al., 2015). Biotechnology and emerging breeding tools can supplement traditional breeding approaches (Darkwa et al., 2020).

Already, the use of genomics tools has accelerated genetic improvement programs and shortened the lengthy breeding cycle of yams (Bhattacharjee et al., 2012). Moreover, molecular technologies for genome analysis make yam breeding easier (Mignouna et al. 2008). Mignouna and colleagues (2002) created the first linkage map, covering 65 percent of the genome of *Dioscorea alata* with 469 AFLP markers. A marker has been identified that is linked to the gene that confers tolerance to anthracnose. A total of 349 AFLP markers were used to map the genome of *Dioscorea rotundata* (Mignouna et al., 2002). Mignouna and colleagues (2002) discovered quantitative trait loci (QTLs) that underpin resistance to yam mosaic virus that devastate yams in West Africa. The architecture of yam plants affects production because stacking is required, which exposes farmers to additional expense and labor. The creation of simple sequence (SSR) markers improves yam breeding for dwarf varieties with desired plant architecture (Viruel et al., 2010).

The location of sex-determining genes mapped in the genome of *Dioscorea alata* via genotyping by sequencing is critical to distinguish male from female plants (Cormier et al., 2019). Varieties resistant to anthracnose are released more quickly using molecular technologies (genomics-assisted breeding) and high throughput phenotyping (Ntui et al., 2021). Postharvest hardening is another important constraint on tuber storage ability in various yam species. The genes involved in postharvest hardening are known, and breeding for varieties producing tubers with improved storage duration is carried out in a shorter period than traditional breeding.

A highly contiguous chromosome-scale genome assembly of greater yam combined with dense genetic mapping can identify the location of genes for susceptibility to various diseases and several tuber quality traits. Publicly available genomic resources include a comprehensive set of EST-SSRs, genomic SSRs, whole-genome SNPs, and reduced representation SNPs useful in yam genetic improvement (Saski et al., 2015). High-density SNPs that are essential are now available to the public (Darkwa et al., 2020a; Agre et al., 2019). Flowering candidate genes have been identified, and their use has improved yam breeding efficiency (Girma et al., 2019).

5.3 Yam tissue culture for the production of planting material

The lack of high-quality planting materials has always constrained yam production. Traditional vegetative propagation using tuber sets of 25 g-100 g pieces is inefficient for large-scale seed yam production; a low-cost multiplication scheme is required. Plant tissue culture is used to produce high-quality (uniform and disease-free) planting material on a large scale (Chen et al., 2003; Mantell et al., 1978) and to develop cultures for *in vitro* screenings for various stress factors and genetic transformation.

For *in vitro* regeneration and multiplication, the most responsive sources of explant and suitable media formulation are needed. The best explant source for commercial micropropagation was nodal segments excised from young, fast-growing vines of *Dioscorea cayenensis, D. trifida*, and *D. rotundata* (Mitchell et al., 1995). Using precisely isolated meristems, disease-cleaned plantlets are produced from diseased mother plants. Mantell and colleagues (1980) confirmed the eradication of flexous rod virus from plantlets regenerated using meristems excised from infected mother plants using electron microscopy of sap and leaf tissue. The present study focuses on micropropagation as a means of addressing planting material shortages.

Micropropagation involves producing microtubers or plantlets on a large scale. Seed yams are grown using tissue culture, either directly regenerating 500 gm microtubers (Li et al., 2014; Ondo Ovono et al., 2007) or indirectly using tissue cultured plantlets to grow mini-tubers in the greenhouse or field. However, for large-scale production of seed yams via tissue culture, efficient and reproducible protocols should first be optimized using various explant types and plant growth regulators. Chen et al. (2003) achieved *in vitro* regeneration and multiplication of *Dioscorea zingiberensis* plantlets using a stem as an explant. Leaf petioles of *Dioscorea rotundata* species were also used for *in vitro* culture regeneration after somatic embryogenesis (Angela & Arizal, 2011). When regeneration and multiplication of yam explants from *in vitro*-conserved germplasm are required, they are used to initiate regeneration and multiplication. Borges et al. (2004) reported that using *in vitro*-conserved material as a source of explants resulted in a high rate of regeneration (100 and 98 percent) and multiplication of *in vitro* cultures.

Organogenesis and embryogenesis techniques can be used directly or indirectly to regenerate and multiply different species of yam. Induction of callus, most commonly by using leaf discs as explants, is sometimes required for indirect regeneration of a large number of plantlets. *Dioscorea composita* and *Dioscorea cayenensis* calli were induced using embryos as explants for plantlet regeneration (Viana & Mantell, 1989). Plantlets are produced as a result of indirect organogenesis or embryogenesis, allowing multiplication to occur during the growth stage of calli, which are made up of actively dividing cells. As a result, a large number of plantlets can be produced directly from the intermediate callus or after proliferation on a 2,4-D supplemented medium.

5.4 Establishing women and youth cooperatives for seed tuber production

Planting materials for seed tuber production find great use in the hands of women and youth as evidenced by the performance of 50 seed producing cooperatives in West and Central Africa (Diallo et al. 2018). Cooperatives made up of women and youth can sell yam seeds they themselves can produce. Small-size tubers that save approximately 2 t/ha of harvested crop for food rather than seed are recommended (Aighewi et al., 2020). Women's co-operatives are significantly empowering and encouraging women's participation in agricultural production in addition to serving as a source of income (Lecoutere 2017). Increasing women's participation in agricultural production increases their decision-making power in pest and disease management, which leads to enhanced crop production and productivity (Okonya et al. 2021). Women and youth who own seed tuber production cooperatives play multiple roles: they produce and make seed tubers available to farmers, allowing them to earn money while contributing to increased yam production; they demonstrate and encourage women's participation in agricultural production enhancement.

6 Conclusions: Yams For Food Security In Ethiopia

In developing countries, orphan crops like yams have the potential to provide food, income, and employment. Several opportunities in Ethiopia can be harnessed to improved yam production. These include new high-performing varieties released by the IITA (Alene et al., 2015) and the Ethiopian Institute of Agricultural Research (EIAR), and the Regional Agricultural Research Institutes RARC (Akassa et al., 2015). The development of molecular technologies for use in breeding for varieties with important agronomic and quality traits also will help boost yam production in Ethiopia. Information and communication technologies, used to exchange information among yam-growing countries, will also contribute significantly. Seed yam can be grown in two ways through controlled crossing (Mignouna et al., 2009) or by using minitubers regenerated from vine cuttings (Aighewi et al., 2021).

Tissue culture techniques can also help in the production of seed yam of many varieties (Aighewi et al., 2015; Forsyth & Van Staden, 1981). The promotion of locally-developed yam varieties is a significant step toward scaling up improved rapid methods of propagation to end-users. Yam production has significantly improved farmers' living standards in Nigeria (Igbinidu, 2015), and promises to do the same for the farmers of Ethiopia. Other places where the country can go to for assistance, technical or otherwise, include Benin, Colombia, Côte d'Ivoire, Ghana, Jamaica, Nigeria, Papua New Guinea, and Togo.

To improve yam production both for domestic consumption and export, Ethiopia needs to invest in upgrading the crop's genetic potential with the use of advanced DNA molecular markers combined with high throughput phenotyping. Other biotech approaches, such as the agrobacterium-mediated transformation of *D. rotundata* using axillary buds as explants, will provide a useful platform for future genetic engineering studies and the deployment of functional genomics for yam improvement (Nyaboga et al., 2014; Zhu et al., 2009).

Researchers will do well to exploit the tremendous genetic diversity found in Ethiopian yam (Asfaw et al,. 2021); artificially induced variations using traditional and modern technologies broaden the base of yam genetic diversity. More importantly, the CRISPR/Cas9-based gene editing platform developed in yam by Syombua and colleagues (2021) allows for more precise genome editing, allowing for faster improvements to elite yam varieties. Some tissue culture protocol optimization activities that are nearing completion will aid in the scaling up of elite yam varieties using genetic engineering and CRISPR/Cas-9 gene-editing techniques.

Declarations

Conflict of interest statement:

The author affirms no conflict of interest in the conduct and reporting of this study.

References

1. Adam, H., Zakaria, H., & Abujaja, A. M. (2014). Sociocultural implications on innovation adoption: the case of adoption of yam minisett technology among farmers in Northern Region, Ghana. *Journal of Agricultural Economics, Extension and Rural Development*, 1(7), 105–113
2. Adigoun-Akotegnon, F. A., Adoukonou-Sagbadja, H., Fadinan, C., Tchougourou, A., Agassounon-Tchibozo, M., & Ahanhanzo, C. (2019). Diversity, distribution and ethnobotanical importance of cultivated and wild African trifoliate yam [Dioscorea dumetorum (Kunth) Pax] in Benin. *Genetic Resources and Crop Evolution*, 66(3), 659–683. https://doi.org/10.1007/s10722-019-00739-z
3. Agidew, A. meta A., & Singh, K. N. (2018). Determinants of food insecurity in the rural farm households in South Wollo Zone of Ethiopia: the case of the Teleyayen sub-watershed. *Agricultural and Food Economics*, *6*(1), 1–23. https://doi.org/10.1186/s40100-018-0106-4
4. Agre, P., Asibe, F., Darkwa, K., Edemodu, A., Bauchet, G., Asiedu, R., et al. (2019). Phenotypic and molecular assessment of genetic structure and diversity in a panel of winged yam (Dioscorea alata) clones and cultivars. *Scientific Reports*, 9(1), 1–11. https://doi.org/10.1038/s41598-019-54761-3
5. Aighewi, B. A., Asiedu, R., Maroya, N., & Balogun, M. (2015). Improved propagation methods to raise the productivity of yam (Dioscorea rotundata Poir.). *Food Security*, 7(4), 823–834. https://doi.org/10.1007/s12571-015-0481-6
6. Aighewi, B., Maroya, N., Asiedu, R., Aihebhoria, D., Balogun, M., & Mignouna, D. (2020). Seed yam production from whole tubers versus minisetts. *Journal of Crop Improvement*, 34(6), 858–874. https://doi.org/10.1080/15427528.2020.1779157

7. Aighewi, B., Maroya, N., Kumar, P. L., Balogun, M., Aihebhoria, D., Mignouna, D., & Asiedu, R. (2021). Seed yam production using high-quality minitubers derived from plants established with vine cuttings. *Agronomy*, 11(5), 1–13. https://doi.org/10.3390/agronomy11050978
8. Akassa, B., Negera, A., Chemeda, G., Wandimu, T., Teshome, N., Ararsa, L., et al. (2015). Registration of “Bulcha” and “Lalo” Yam Varieties. *East African Journal of Sciences*, 9(1), 65–68. http://www.ctahr.hawaii.edu/
9. Alene, A. D., Abdoulaye, T., & Rusike, J. (2015). V. M. and T. S. W. The Effectiveness of Crop Improvement Programmes from the Perspectives of Varietal Output and Adoption: Cassava, Cowpea, Soybean and Yam in Sub-Saharan Africa and Maize in West and Central Africa. In T. S. W. and J. Alwang (Ed.), *Crop Improvement, Adoption and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa* (pp. 74–121)
10. Alieu, S., & Robert, A. (2014). Segregation of vegetative and reproductive traits associated with tuber yield and quality in water yam (Dioscorea alata L.). *African Journal of Biotechnology*, 13(28), 2807–2818. https://doi.org/10.5897/ajb2014.13839
11. Angela, L., & Arizal, T. (2011). Somatic Embryogenesis in Yam (Dioscorea rotundata). *Revista Facultad Nacional de Agronomía*, 64(2), 6037–6042
12. AO, A. O. and A (2018). The Impact of Agricultural Technology Adoption on Poverty: The Case of Yam Minisetts Technology in Ekiti State, Nigeria. *Journal of Agricultural Research*, 3(9), 1–11. https://doi.org/10.23880/oajar-16000195
13. Asfaw, B. T., Worojie, T. B., & Mengesha, W. A. (2021). Assessing morphological diversity in Ethiopian yams (Dioscorea spp.) and its correspondence with folk taxonomy. *Systematics and Biodiversity*, 19(5), 471–487. https://doi.org/10.1080/14772000.2021.1890269
14. Bassey, E. E. (2017). Constraints and Prospects of Yam Production in Nigeria. *European Journal of Physical and Agricultural Sciences*, 5(1), 55–64
15. Beckford, C., Campbell, D., & Barker, D. (2011). Sustainable food production systems and food security: Economic and environmental imperatives in yam cultivation in Trelawny. *Jamaica. Sustainability*, 3(3), 541–561. https://doi.org/10.3390/su3030541
16. Bekele, M., Debara, M., & Dotora, Z. (2021). Pre-Extension Demonstration of Newly Released Yam Variety (Bulcha). *EAS Journal of Nutrition and Food Sciences*, 3(6), 125–129. https://doi.org/10.36349/easjnfs.2021.v03i06.001
17. Belachew Garedew, B., & Haile, A. A. (2017). Distribution, Diversity and Potential Production of Yams (Dioscorea spp.) in Sheko District, Southwest Ethiopia. *American Journal of Life Sciences*, 5(3), 86. https://doi.org/10.11648/j.ajls.20170503.12
18. Bhandari, M. R., Kasai, T., & Kawabata, J. (2003). Nutritional evaluation of wild yam (Dioscorea spp.) tubers of Nepal. *Food Chemistry*, 82(4), 619–623. https://doi.org/10.1016/S0308-8146(03)00019-0
19. Bhattacharjee, R., Gedil, M., & Lopez-Montes, A. (2012). Genomics for transforming yam breeding. *IITA Feature Issue*, 8, 31–34. http://r4dreview.org/2012/05/genomics-for-transforming-yam-breeding/

20. Borges, M., Ceiro, W., Meneses, S., Aguilera, N., Vázquez, J., Infante, Z., & Fonseca, M. (2004). Regeneration and multiplication of Dioscorea alata germplasm maintained in vitro. *Plant Cell, Tissue and Organ Culture*, 76(1), 87–90. https://doi.org/10.1023/A:1025804516226
21. Caddick, L. R., Wilkin, P., Rudall, P. J., Hedderson, T. A. J., & Chase, M. W. (2002). Yams reclassified: A recircumscription of Dioscoreaceae and Dioscoreales. *Taxon*, 51(1), 103–114. https://doi.org/10.2307/1554967
22. Chen, Y., Fan, J., Yi, F., Luo, Z., & Fu, Y. (2003). Rapid clonal propagation of. *Plant Cell*, *73*(2002), 75–80
23. Cormier, F., Lawac, F., Maledon, E., Gravillon, M. C., Nudol, E., Mournet, P., et al. (2019). A reference high-density genetic map of greater yam (Dioscorea alata L.). *Theoretical and Applied Genetics*, 132(6), 1733–1744. https://doi.org/10.1007/s00122-019-03311-6
24. Coursey, D. G. (1967). *Yams: an account of the nature, origins, cultivation and utilisation of the useful members of the Dioscoreaceae*.Science(Vol. 163)
25. Darkwa, K., Agre, P., Olasanmi, B., Iseki, K., Matsumoto, R., Powell, A., et al. (2020). Comparative assessment of genetic diversity matrices and clustering methods in white Guinea yam (Dioscorea rotundata) based on morphological and molecular markers. *Scientific Reports*, 10(1), 1–14. https://doi.org/10.1038/s41598-020-69925-9
26. Degla, P., & Sourokou, N. (2020). Food, Socio-Cultural and Economic Importance of Yam in the North-East of Benin. *Journal of Agriculture and Environmental Sciences*, 9(2), 97–107. https://doi.org/10.15640/jaes.v9n2a12
27. Deressa, T. T., & Hassan, R. M. (2009). Economic impact of climate change on crop production in ethiopia: Evidence from cross-section measures. *Journal of African Economies*, 18(4), 529–554. https://doi.org/10.1093/jae/ejp002
28. Diallo, Y., Pasqualini, T., & Verhagen, I. (2018). *The Rise of the Seed- producing Cooperative in Western and Central Africa*. https://www.accesstoseeds.org/app/uploads/2018/07/The-Rise-of-the-Seed-producing-Cooperative-in-Western-and-Central-Africa.pdf
29. Dutta, B. (2015). Food and medicinal values of certain species of Dioscorea with special reference to Assam. *Journal of Pharmacognosy and Phytochemistry*, 3(4), 15–18. https://www.academia.edu/download/47835485/7.1.pdf
30. Ekanayake, I. J., & Asiedu, R. (2003). Problems and Perspectives of Yam-Based Cropping Systems in Africa. *Journal of Crop Production*, 9(1–2), 531–558. https://doi.org/10.1300/J144v09n01_08
31. Epping, J., & Laibach, N. (2020). An underutilized orphan tuber crop—Chinese yam. *Planta*, 252(4), 1–19. https://doi.org/10.1007/s00425-020-03458-3
32. Erena, B. A., & Alemu, I. D. (2019). Ethnobotany and nutritional value of two domestic yams (Dioscorea spp.) in Abaya Woreda, southern Ethiopia. *Ethnobotany Research and Applications*, 18(March), 1–10. https://doi.org/10.32859/era.18.9.1-10
33. Filloux, D., Fernandez, E., Loire, E., Claude, L., Galzi, S., Candresse, T., et al. (2018). Nanopore-based detection and characterization of yam viruses. *Scientific Reports*, 8(1), 1–11.

https://doi.org/10.1038/s41598-018-36042-7

34. Fones, H. N., Bebber, D. P., Chaloner, T. M., Kay, W. T., Steinberg, G., & Gurr, S. J. (2020). Threats to global food security from emerging fungal and oomycete crop pathogens. *Nature Food*, 1(6), 332–342. https://doi.org/10.1038/s43016-020-0075-0
35. Forsyth, C., & Van Staden, J. (1981). An improved method of in vitro propagation of Dioscorea bulbifera. *Plant Cell, Tissue and Organ Culture*, 1(1), 275–281. https://doi.org/10.1007/BF02318924
36. Gebre, T. (2019). Yam landrace diversity and distribution in Basketo and Dera Malo Districts, Southwest Ethiopia. *Int.J.Sci*, 2(2), 45–58
37. Girma, G., Natsume, S., Carluccio, A. V., Takagi, H., Matsumura, H., Uemura, A., et al. (2019). Identification of candidate flowering and sex genes in white Guinea yam (D. Rotundata Poir.) by SuperSAGE transcriptome profiling. *PLoS ONE*, 14(9), 1–18. https://doi.org/10.1371/journal.pone.0216912
38. Harry, E. E., B. and G. I (2017). Identification of Characters Correlated with Tuber Yield in Guinea White Yam (Dioscorea rotundata Poir). *Journal of Plant Biology & Soil Health*, 4(1), 1–5. https://doi.org/10.13188/2331-8996.1000016
39. Hayashi, E. A. I., Blawid, R., de Melo, F. L., Andrade, M. S., Pio-Ribeiro, G., de Andrade, G. P., & Nagata, T. (2017). Complete genome sequence of a putative new secovirus infecting yam (Dioscorea) plants. *Archives of Virology*, 162(1), 317–319. https://doi.org/10.1007/s00705-016-3104-4
40. Hsu, F. L., Lin, Y. H., Lee, M. H., Lin, C. L., & Hou, W. C. (2002). Both dioscorin, the tuber storage protein of yam (Dioscorea alata cv. Tainong No. 1), and its peptic hydrolysates exhibited angiotensin converting enzyme inhibitory activities. *Journal of Agricultural and Food Chemistry*, 50(21), 6109–6113. https://doi.org/10.1021/jf0203287
41. Hsu, J. H., Wu, Y. C., Liu, I. M., & Cheng, J. T. (2007). Dioscorea as the principal herb of Die-Huang-Wan, a widely used herbal mixture in China, for improvement of insulin resistance in fructose-rich chow-fed rats. *Journal of Ethnopharmacology*, 112(3), 577–584. https://doi.org/10.1016/j.jep.2007.05.013
42. Igbinidu, O. (2015). Effect of Yam-Based Production on Food Security Status of Farm Households in Edo South, Nigeria. *International Journal of Environmental & Agriculture Research (IJOEAR)*, 1(6), 28–35
43. Islam, A. H. M. S., von Braun, J., Thorne-Lyman, A. L., & Ahmed, A. U. (2018). Farm diversification and food and nutrition security in Bangladesh: empirical evidence from nationally representative household panel data. *Food Security*, 10(3), 701–720. https://doi.org/10.1007/s12571-018-0806-3
44. Ita, E. E., Uyoh, E. A., Nakamura, I., & Ntui, V. O. (2020). Efficient elimination of Yam mosaic virus (YMV) from white yam (Dioscorea rotundata Poir.) by cryotherapy of axillary buds. *South African Journal of Botany*, 130, 123–129. https://doi.org/10.1016/j.sajb.2019.12.022
45. Kwabena Darkwa, B., Olasanmi, R., & Asiedu, A. A. (2020). Review of empirical and emerging breeding methods and tools for yam (Dioscorea spp.) improvement: Status and prospects. *Plant Breeding*, 139(3), 474–497. https://doi.org/10.1111/pbr.12783

46. Lecoutere, E. (2017). The impact of agricultural co-operatives on women's empowerment: Evidence from Uganda. *Journal of Co-operative Organization and Management*, 5(1), 14–27. https://doi.org/10.1016/j.jcom.2017.03.001
47. Li, M., Li, J., Liu, W., Liu, L., Lu, J., Niu, J., et al. (2014). A protocol for in vitro production of microtubers in Chinese yam (Dioscorea opposita). *Bioscience, Biotechnology and Biochemistry*, 78(6), 1005–1009. https://doi.org/10.1080/09168451.2014.912119
48. Liu, D. Z., Liang, H. J., Han, C. H., Lin, S. Y., Chen, C. T., Fan, M., & Hou, W. C. (2009). Feeding trial of instant food containing lyophilised yam powder in hypertensive subjects. *Journal of the Science of Food and Agriculture*, 89(1), 138–143. https://doi.org/10.1002/jsfa.3420
49. Lu, Y. L., Chia, C. Y., Liu, Y. W., & Hou, W. C. (2012). Biological activities and applications of dioscorins,the major tuber storage proteins of yam. *Journal of Traditional and Complementary Medicine*, 2(1), 41–46. https://doi.org/10.1016/S2225-4110(16)30069-4
50. Mantell, S. H., Haque, S. Q., & Whitehall, A. P. (1978). Clonal Multiplication of Dioscorea Alata L. and Dioscorea Rotundata Poir. Yams by Tissue Culture. *Journal of Horticultural Science*, 53(2), 95–98. https://doi.org/10.1080/00221589.1978.11514801
51. Mantell, S. H., Haque, S. Q., & Whitehall, A. P. (1980). Apical meristem tip culture for eradication of flexous rod viruses in yams (Dioscorea alata). *Tropical Pest Management*, 26(2), 170–179. https://doi.org/10.1080/09670878009414390
52. Martin, F. W. (1969). The species of Dioscorea containing sapogenin. *Economic Botany*, 23(4), 373–379. https://doi.org/10.1007/BF02860683
53. Martin, F. W., & Ortiz, S. (1963). Origin and Anatomy of Tubers of Dioscorea floribunda and D. spiculiflora. *Botanical Gazette*, 124(6), 416–421. https://doi.org/10.1086/336228
54. Massawe, F. J., Mayes, S., Cheng, A., Chai, H. H., Cleasby, P., Symonds, R., et al. (2015). The Potential for Underutilised Crops to Improve Food Security in the Face of Climate Change. *Procedia Environmental Sciences*, 29(Agri), 140–141. https://doi.org/10.1016/j.proenv.2015.07.228
55. Matsumoto, R., Ishikawa, H., Asfaw, A., & Asiedu, R. (2021). Low Soil Nutrient Tolerance and Mineral Fertilizer Response in White Guinea Yam (Dioscorea rotundata) Genotypes. *Frontiers in Plant Science*, 12(February), 1–9. https://doi.org/10.3389/fpls.2021.629762
56. Mignouna, H. D., Mank, R. A., Ellis, T. H. N., Van den Bosch, N., Asiedu, R., Abang, M. M., & Peleman, J. (2002). A genetic linkage map of water yam (Dioscorea alata L.) based on AFLP markers and QTL analysis for anthracnose resistance. *Theoretical and Applied Genetics*, 105(5), 726–735. https://doi.org/10.1007/s00122-002-0912-6
57. Mignouna, H. D., Mank, R. A., Ellis, T. H. N., Van den Bosch, N., Asiedu, R., Ng, S. Y. C., & Peleman, J. (2002). A genetic linkage map of Guinea yam (Dioscorea rotundata Poir.) based on AFLP markers. *Theoretical and Applied Genetics*, 105(5), 716–725. https://doi.org/10.1007/s00122-002-0911-7
58. Mignouna, H. D., Abang, M. M., & Asiedu, R. (2003). Harnessing modern biotechnology for tropical tuber crop improvement: Yam (Dioscorea spp.) molecular breeding. *African Journal of Biotechnology*, 2(12), 478–492. https://doi.org/10.5897/ajb2003.000-1097

59. Mignouna, H. D., Abang, M. M., & Asiedu, R. (2008). Genomics of Yams, a Common Source of Food and Medicine in the Tropics. In *Genomics of Tropical Crop Plants* (pp. 549–570). https://doi.org/10.1007/978-0-387-71219-2_23
60. Mignouna, H. D., Abang, M. M., Asiedu, R., & Geeta, R. (2009). Producing yam (dioscorea) seeds through controlled crosses. *Cold Spring Harbor Protocols*, 4(11), 3–5. https://doi.org/10.1101/pdb.prot5327
61. Mitchell, S. A., Asemota, H. N., & Ahmad, M. H. (1995). Effects of explant source, culture medium: Strength and growth regulators on the in-vitro propagation of three Jamaican yams: (Dioscorea cayenensis, D trifida and d rotundata). *Journal of the Science of Food and Agriculture*, 67(2), 173–180. https://doi.org/10.1002/jsfa.2740670206
62. Mulualem, T., Mekbib, F., Shimelis, H., Gebre, E., & Amelework, B. (2018). Genetic diversity of yam (Dioscorea spp.) landrace collections from Ethiopia using simple sequence repeat markers. *Australian Journal of Crop Science*, 12(8), 1222–1230. https://doi.org/10.21475/ajcs.18.12.08.PNE885
63. Ntui, V. O., Uyoh, E. A., Ita, E. E., Markson, A. A. A., Tripathi, J. N., Okon, N. I., et al. (2021). Strategies to combat the problem of yam anthracnose disease: Status and prospects. *Molecular Plant Pathology*, 22(10), 1302–1314. https://doi.org/10.1111/mpp.13107
64. Nyaboga, E., Tripathi, J. N., Manoharan, R., & Tripathi, L. (2014). Agrobacterium-mediated genetic transformation of yam (Dioscorea rotundata): An important tool for functional study of genes and crop improvement. *Frontiers in Plant Science*, 5(SEP), 1–15. https://doi.org/10.3389/fpls.2014.00463
65. Obidiegwu, J. E., Lyons, J. B., & Chilaka, C. A. (2020). The dioscorea genus (Yam)—An appraisal of nutritional and therapeutic potentials. *Foods*, 9(9), 1–45. https://doi.org/10.3390/foods9091304
66. Ojinnaka, M. C., Okudu, H., & Uzosike, F. (2017). Nutrient Composition and Functional Properties of Major Cultivars of Aerial Yam (Dioscorea bulbifera) in Nigeria. *Food Science and Quality Management*, *62*(2013), 2224–6088. www.iiste.org
67. Okonya, J. S., Mudege, N. N., Nyaga, J. N., & Jogo, W. (2021). Determinants of Women's Decision-Making Power in Pest and Disease Management: Evidence From Uganda. *Frontiers in Sustainable Food Systems*, 5(July), 1–8. https://doi.org/10.3389/fsufs.2021.693127
68. Ondo Ovono, P., Kevers, C., & Dommes, J. (2007). Axillary proliferation and tuberisation of Dioscorea cayenensis-D. rotundata complex. *Plant Cell, Tissue and Organ Culture*, 91(2), 107–114. https://doi.org/10.1007/s11240-007-9238-z
69. Padhan, B., & Panda, D. (2020). Potential of Neglected and Underutilized Yams (Dioscorea spp.) for Improving Nutritional Security and Health Benefits. *Frontiers in Pharmacology*, 11(April), 1–13. https://doi.org/10.3389/fphar.2020.00496
70. Petros, S., Abay, F., Desta, G., & O'Brien, C. (2018). Women Farmers' (Dis)Empowerment Compared to Men Farmers in Ethiopia. *World Medical and Health Policy*, 10(3), 220–245. https://doi.org/10.1002/wmh3.280

71. Saski, C. A., Bhattacharjee, R., Scheffler, B. E., & Asiedu, R. (2015). Genomic resources for water yam (Dioscorea alata L.): Analyses of estsequences, de novo sequencing and GBS libraries. *PLoS ONE*, 10(7), 1–14. https://doi.org/10.1371/journal.pone.0134031
72. Seal, S., Turaki, A., Muller, E., Kumar, P. L., Kenyon, L., Filloux, D., et al. (2014). The prevalence of badnaviruses in West African yams (Dioscorea cayenensis-rotundata) and evidence of endogenous pararetrovirus sequences in their genomes. *Virus Research*, 186, 144–154. https://doi.org/10.1016/j.virusres.2014.01.007
73. Semahegn, Z. (2021). The Potential of Food Security Crops in Ethiopia:Review. *Journal of Natural Sciences Research*, 12(2), 8–14. https://doi.org/10.7176/jnsr12-2-02
74. Srivastava, A. K., Gaiser, T., Paeth, H., & Ewert, F. (2012). The impact of climate change on Yam (Dioscorea alata) yield in the savanna zone of West Africa. *Agriculture, Ecosystems and Environment*, 153, 57–64. https://doi.org/10.1016/j.agee.2012.03.004
75. Syombua, E. D., Zhang, Z., Tripathi, J. N., Ntui, V. O., Kang, M., George, O. O., et al. (2021). A CRISPR/Cas9-based genome-editing system for yam (Dioscorea spp.). *Plant Biotechnology Journal*, 19(4), 645–647. https://doi.org/10.1111/pbi.13515
76. Tamiru, M., Becker, H. C., & Maass, B. L. (2007). Genetic diversity in yam germplasm from Ethiopia and their relatedness to the main cultivated dioscorea species assessed by AFLP markers. *Crop Science*, 47(4), 1744–1753. https://doi.org/10.2135/cropsci2006.11.0719
77. Tamiru, M., Becker, H. C., & Maass, B. L. (2008). Diversity, distribution and management of yam landraces (Dioscorea spp.) in Southern Ethiopia. *Genetic Resources and Crop Evolution*, 55(1), 115–131. https://doi.org/10.1007/s10722-007-9219-4
78. Tewodros, M.,M., H (2012). Genetic variability and association among yield and yield related traits in Aerial Yam / Dioscorea bulbifera (L.)/ Accessions at South- western Ethiopia. *Journal of natural sciences research*, 2(9), 63–70
79. Viana, A. M., & Mantell, S. H. (1989). Callus induction and plant regeneration from excised zygotic embryos of the seed-propagated yams Dioscorea composita Hemsl. and D. cayenensis Lam. *Plant Cell, Tissue and Organ Culture*, 16(2), 113–122. https://doi.org/10.1007/BF00036519
80. Viruel, J., Catalán, P., & Segarra-Moragues, J. G. (2010). New microsatellite loci in the dwarf yams Dioscorea group Epipetrum (Dioscoreaceae). *American Journal of Botany*, 97(11), 121–123. https://doi.org/10.3732/ajb.1000304
81. Wang, Q., Cuellar, W. J., Rajamäki, M. L., Hirata, Y., & Valkonen, J. P. T. (2008). Combined thermotherapy and cryotherapy for efficient virus eradication: Relation of virus distribution, subcellular changes, cell survival and viral RNA degradation in shoot tips. *Molecular Plant Pathology*, 9(2), 237–250. https://doi.org/10.1111/j.1364-3703.2007.00456.x
82. Zhu, Q., Wu, F., Ding, F., Ye, D., Chen, Y., Li, Y., & Zhifan, Y. (2009). Agrobacterium-mediated transformation of Dioscorea zingiberensis Wright, an important pharmaceutical crop. *Plant Cell, Tissue and Organ Culture*, 96(3), 317–324. https://doi.org/10.1007/s11240-008-9489-3