

Food and Nutritional Security Impact of Exploiting Opportunities and Developing Strategies in Increase Yam (*Dioscorea Spp.*) Production in Ethiopia

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Abstract

Purpose: The purpose of this article is to examine the prospects available and to provide solutions for increasing yam production in Ethiopia. To design strategies to boost production of underutilized food and nutritional security crops like yams in Ethiopia, it is necessary to first understand the gaps and opportunities.

Design/Methodology/Approach: I began by reviewing the literature on yam production challenges and solutions from throughout the world. I've also looked at the global yam production trend, with a particular focus on Ethiopian yam production. Then I went over and over the yam production constraints in Ethiopia, analyzing them and coming up with strategies to improve yam production.

Findings: The availability of a widely diverse landrace, large tracts of arable land, and newly released cultivars holds much promise for Ethiopia's yam production.

Practical Implication: This paper proposes that (1) increasing yam land cover; (2) increasing research investments in seed tuber production technologies and the development of biotic and abiotic stress-resistant varieties; and (3) increasing seed tuber production cooperatives of farmer-preferred varieties will significantly increase yam production in Ethiopia.

Theoretical Implication: Efforts to investigate, invest in the development/adoption, and promote the use of yam technology could assist Ethiopia in improving food security by increasing yam production.

Originality/Value: Understanding the opportunities and proposing strategies for agricultural research, extension, and development policies in Ethiopia helps them focus on the importance of research, yam technology adoption and extension, and seed producing cooperatives for increased yam productivity and production in Ethiopia.

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; yams nutritional value; yams for functional foods

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 [1]. 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 [2].

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 [3]. Already, despite Ethiopia's abundance of natural resources, more than five million live in poverty. As a result, the number of people living in poverty increases as crop net revenue per hectare decreases over time due to climate change [4].

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 [5]. 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 [6]. Among them are yams (*Dioscorea* spp.), whose nutritional and pharmacological properties can combat hidden hunger caused by micronutrient deficiency [7, 8]. 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.

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 [9].

There are over 600 yam species in the tropics and subtropics. Report the geographical origins and domestication, distribution, botanical classification, morphology, and cytology of yam species [10]. 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, 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. Confirmed that *D. abyssinica* originated in Ethiopia, although its cultivation is limited within the country [11, 12].

Importance of Yams

Yam for Global Food Security

Grown primarily for its tubers that are rich in carbohydrates, pro-

teins, lipids, fibers, and minerals, yams are a major food source; its foliage is used to make pharmaceutical products [13]. It provides a living for over 300 million people in the tropics and subtropics, but its potential for food, employment, income, and nutrition, remains untapped [14-16].

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 [8]. In India, many yam species are eaten and used to treat various ailments [17]. The greater yam, *Dioscorea alata*, is grown in India and is known for its high tuber yield. *Dioscorea bulbifera* is one of the species that grow in southern Ethiopia that has high levels of carbohydrates [18]. Some of the major cultivars of this species have been used to develop various food products in Nigeria [19]. 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 [13].

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 [20]. 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 [20].

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 [21]. It is used to treat hypertension by inhibiting the activity of angiotensin-converting enzymes [22]. Yams, therefore, are a nutrient-dense food. Functional meals made from yams that contain 140 mg of dioscorin are used to lower blood pressure [23].

Some yam species are sources of sapogenins, which are used in the manufacture of steroids and medications to improve male fertility [24]. *Dioscorea* is the main ingredient in Die-Huang-Wan, a Chinese herbal concoction that improves diabetic rats' responsiveness to exogenous insulin [25].

Yam Production and Challenges

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.

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 [16]. For example, the majority of landraces in Wolayita and Gamo-Gofa faced extinction, owing to their rarity and limited distribution [26].

Challenges to Yam Production

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 [27]. 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 [28]. 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. Yam production is also stalled by inadequate soil quality, drought stress, and low rainfall [29-32].

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.

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. Confirmed that women's role in post-harvest increases to as much as 80% of the yield in cereals [33]. 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 [34].

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.

Opportunities to Enhance Yam Production

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.

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*) [12]. In the Sheko district, yam accessions are distributed and cultivated informed by farmers' indigenous knowledge [35]. Some of the accessions of yams from southwestern Ethiopia are identified for their potential to be used in breeding for yield improvement. In a study by , 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 [36].

A significant phenotypic variation was found in 75 accessions of 30 different named farmers' landraces grown in Ethiopia [37]. 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.

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 [38]. Pre-extension activity began promoting "Bulcha" a significant step toward scaling-up rapid methods of propagation [39].

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) [40]. 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.

Ways to Improve Yam Production in Ethiopia 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 [41]. 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 [42].

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 [43].

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 agronomical important traits and optimization of chemical and physical conditions for *in vitro* micro propagation and cleaning of viral disease, genetic transformation [44-50]. Developing low cost, high

throughput, scalable disease diagnostic tools, and gene editing of genotypes for increased production [29].

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 [28]. 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. 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 [51]. Ethiopia needs more improved varieties with farmer-preferred properties, but the rate of variety release is slow [40]. Biotechnology and emerging breeding tools can supplement traditional breeding approaches [52].

Already, the use of genomics tools has accelerated genetic improvement programs and shortened the lengthy breeding cycle of yams [53]. Moreover, molecular technologies for genome analysis make yam breeding easier [14]. 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* [54]. 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 [55].

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 [56]. Varieties resistant to anthracnose are released more quickly using molecular technologies (genomics-assisted breeding) and high throughput phenotyping [57]. 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. High-density SNPs that are essential are now available to the public. Flowering candidate genes have been identified, and their use has improved yam breeding efficiency [58-60].

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 and to develop cultures for *in vitro* screenings for various stress factors and genetic transformation [61, 46].

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* [62]. Using precisely isolated meristems, disease-cleaned plantlets are produced from diseased mother plants. Mantell and colleagues (1980) confirmed the eradication of flexuous 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 or indirectly using tissue cultured plantlets to grow mini-tubers in the greenhouse or field [63, 47]. 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. Achieved *in vitro* regeneration and multiplication of *Dioscorea zingiberensis* plantlets using a stem as an explant [61]. Leaf petioles of *Dioscorea rotundata* species were also used for *in vitro* culture regeneration after somatic embryogenesis [64]. When regeneration and multiplication of yam explants from *in vitro*-conserved germplasm are required, they are used to initiate regeneration and multiplication. 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 [65].

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 [66]. 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.

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 [67]. 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 [68]. Women's co-operatives are significantly empowering and encouraging women's participation in agricultural production in addition to serving as a source of income [69]. 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 [70]. 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.

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 and the Ethiopian Institute of Agricultural Research (EIAR), and the Regional Agricultural Research Institutes RARC [8, 9]. 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 or by using mini tubers regenerated from vine cuttings [71, 72].

Tissue culture techniques can also help in the production of seed yam of many varieties [73, 74]. 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, 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 [75].

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 [50, 76].

Researchers will do well to exploit the tremendous genetic diversity found in Ethiopian yam artificially induced variations using traditional and modern technologies broaden the base of yam genetic diversity [37]. More importantly, the CRISPR/Cas9-based gene editing platform developed in yam by allows for more precise genome editing, allowing for faster improvements to elite yam varieties [77]. 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.

Conflict of Interest Statement

The author affirms no any financial and non-financial conflict of interest in the conduct and reporting of this study.

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