Chapter

State of the Art of Yam Production

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Abstract

Yam is a labor-intensive and weed-sensitive food crop. The labor-intensive nature of the yam means that the production process requires the attention of the farmer all year round. However, the dwindling labor situation and the proliferation of weeds have forced farmers to think of modern ways of controlling weeds on their farms, that is, the adoption of chemical (herbicides) weed control. Even though the adoption of these chemicals has no doubt brought relief to the farmers and has resulted in increased yam production over the years, it has also brought in its wake, negative externalities of environmental pollution, human health effects, and food quality issues. The study was thus designed to investigate how yam is produced, the human and environmental health effects of how yam is produced, and food quality effects of how yam is produced. This was done through literature review, and field and laboratory experiments. It was revealed that, in recent years, new innovations have been introduced in yam production, the manner in which farmers handle herbicides in their yam production process exposes them to high doses of pesticides, thereby endangering their lives. The study findings also suggest that the use of herbicides in yam production does not affect the quality of the yam.

Keywords: yam production, food security, Ghana, chemical herbicides and West Africa

1. Introduction

Yam plants belong to the genus *Dioscorea* and produce tubers, bubils, or rhizomes that are of economic importance. They are monocotyledons in the family *Dioscoreaceae* within the order *Dioscoreales* which also includes the families *Stenomeridaceae*, *Trichoodaceae*, and *Stemonaceae*. In addition to the genus *Dioscorea*, the family also includes the genera *Stenomeris, Avetra, Trichopus, Rajana*, and *Tamus*. However, *Dioscorea* is by far the largest genus of the family [1].

Although more than 600 cultivars of the tubers have been recorded [2], only a few are important as staple food in the tropics. These include white yam (*D. rotundata*), yellow yam (*D. Cayenensis),* water yam (*D. alata*), trifoliate yam (*D. dumetorum*), aerial yam (*D. bulbifera*), Chinese yam (*D. polystachya*), and Lesser yam (*D. esculenta*) [1, 3, 4]. *D. rotundata* is a native to West Africa, but it does not occur in the wild, and it was probably developed from *D. praehensilis* Benth. The extent of its cultivation parallels the preference of the people of West Africa for this type of yam over most other kinds. Its cultivation has also spread to other parts of the world as it is grown extensively in the Caribbean, Asia, and South America [5].

West Africa accounts for over 90% of world yam production with Nigeria, the largest single producer followed by Ghana and Cote d'Ivoire [5, 6]. In 2016, global yam production stood at 66 million metric tons (MT) with 86% of this coming from West Africa. In 2016, more than 90% (6.9 million ha) of the global area under yam cultivation was in West Africa, where the mean gross yield is 12 t/ha [5].

Worldwide annual consumption of yams is 18 million tons, with 15 million in West Africa. Annual consumption in West Africa is 61 kg/person/year [7]. Yams are consumed in the form of boiled, roasted, baked, or fried. Yam is an important staple food for many Ghanaians, accounting for 28% of total calorie sources in 2016 [8]. Per capita consumption of yam in Ghana increased from 83 kg/year 1995 to 160 kg/person/year in 2013, making yam the second most important calorie source after cassava in Ghana [8, 9]. Between 2005 and 2010, yam production in Ghana contributed about 16 percent to the country's agricultural gross domestic product [6].

In Ghana, as in many other West African countries, the yam species of economic importance include *D. rotundata*, *D. alata*, *D. cayenensis*, and *D. bulbifera* [3]. Among these economically important species, it is *D. rotundata*, popularly called white yam or white guinea yam, which is grown on a larger scale than any other yam species in the dominant yam production zone of West Africa and Central Africa [7]. Several varieties of yam are produced throughout Ghana. These include Pona (white yam), Dente, Asana, and Serwa. In recent years, Ghana's Crop Research Institute (CRI) introduced new high yield varieties, such as the Mankrong and Kukrupa. However, white yam/Pona (*D. rotundata*) remains the most preferred variety in both the domestic and export markets [6].

2. Results

2.1 Economic importance of Yam

In West Africa, yams are a major source of income and have high cultural value. They are used in fertility and marriage ceremonies, and a festival is held annually to celebrate its harvest in most cultures across West Africa. In West Africa, yam plays key roles in food security, income generation, and the sociocultural life of at least 60 million people [7]. It also serves as source of foreign exchange to government. Ghana has been exporting substantial quantities of yam to regions such as Europe, America, and African countries such as Mali, Burkina Faso, and Niger. Although the second largest yam producer after Nigeria, Ghana is the leading exporter of yam in the world [6, 7], exporting approximately 21,000 metric tons of yams annually, a number that has been increasing over the last decade. In addition to the food and market values, yams play vital roles in traditional sociocultural rituals and religions that the ethnocentric attachment to the crop remains strong for some ethnic groups in Africa [10].

In a typical Ghanaian urban center, household food budget formed about 51% of the total household budget [11]. Yam constituted about 12% of household at-home food budget and 13% of its away-from-home food budget. The shares of food budget that households allocate to yam generally increase during the peak harvest season (August to December) and drops during lean season (June to July) across all urban centers in Ghana [11].

Rank	Country	Production (ha)	Production (tons)	Yield (tons/ha)
1	Nigeria	6,307,232	50,052,977	8
2	Ghana	468,433	8,532,731	18
3	Cote D'Ivoire	1,200,405	7,654,617	6
4	Benin	228,998	3,150,248	14
5	Togo	98,547	868,677	9
6	Cameroon	62,008	707,576	11
7	Central African Republic	58,533	491,960	8
8	Chad	47,784	458,054	9.6
9	Papua New Guinea	21,185	363,387	17
10	Haiti	9983	63,358	6
	Total	**8,503,108**	**72,343,585**	

Table 1.
List of top 10 yam producers in the World [5, 8]. Retrieved 24/05/2022.

The top 10 yam-producing countries in the world are represented in **Table 1**. Together, they produced 72.3 million tons of yam in 2020, of which Africa accounted for about 99%. Most of the world's production comes from West Africa representing 97%, with Nigeria alone producing about 69%, equaling to more than 50 million tons [5].

Yam production is regarded as a source of food security and employment to a lot of people in many areas where it is cultivated [12]. Yam is among the major cash and most consumed food crops in West African countries like Nigeria, Cote D'Ivoire, Ghana, Benin, and Togo. Its cultivation is very profitable despite high costs of production and price fluctuations in the markets [13]. Over 60% of people grow yams as a primary source of livelihood [6].

In Ghana, yam is produced in commercial quantities in all the regions, except the Greater Accra region, Central region, and Upper east region. The highest concentration of yam production is found in the central and northern Savannah portions of the country [6]. The northern region is the second leading yam producer after the Brong Ahafo region (**Figure 1**). The region produces about 2.3 million metric tons of yam annually [14].

Even though, yam production is declining in some traditional yam-producing areas due to declining soil fertility, increasing pest pressures, and the high cost of labor [3, 15], production in Ghana has seen some steady increase over the past few years (**Figure 2**). Production grew by 19% between 2010 and 2020. This increase is mainly driven by growth in total hectares planted to yam, rather than growth in yam yields. The recent increases in production have often been attributed to the use of pesticides (herbicides) which allows small holder farmers to increase their area of cultivation [16]. The total yam production in Ghana in 2020 was 8,532,731 metric tons with mean gross yield of about 18 metric tons per ha [5].

2.2 Morphology and cultivation of yam

Yam is an annual or perennial vine and a climber with annual or perennial underground tubers. The life cycle of the yam plant consists of the following stages: propagules (true seed or tuber), emerging seedling or plantlet, mature plant, senescing

Figure 1.
Five top yam-producing regions of Ghana [14].

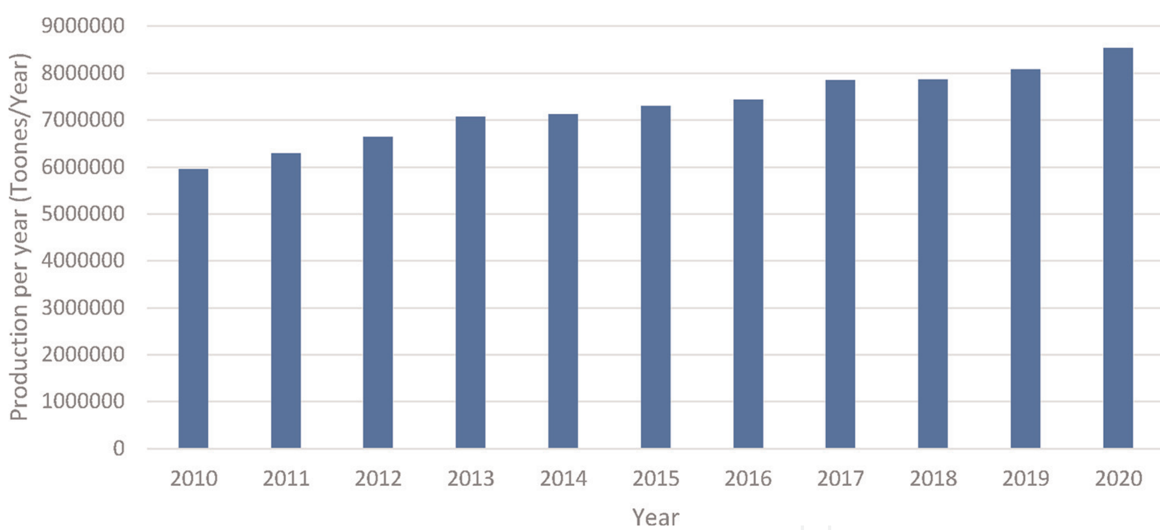

Figure 2.
Yam production in Ghana, 2010–2020 [5, 8]. Retrieved on 24/05/2022.

plant, and dormant tubers. Yam has an annual vegetative system (**Figure 3**) composed of a root system (some extend throughout the upper layers of the soil, others consist of root hairs), a stem system, a foliar system, and a reproductive system [17].

The root system generally consists of two categories of roots (**Figure 3**): the adventitious roots (appearing from the base of the stem) and roots arising from the skin of the tuber. The adventitious roots are usually about 3–6 mm thick and 1–3 m long and absorb nutrients and water. This type of roots extends throughout the upper layers of the soil and rarely branch out and emit few rootlets. The roots on the tuber are rarely more than few centimeters in length and are usually 1 or 2 mm thick [17].

Figure 3.
Yam plants growing in the field, roots on tuber skin, and adventitious roots.

These types of roots are not usually common on the tubers of the two yam varieties considered in this study (Laribako and Olodo).

The reproductive system consists of sexual components and a male or female inflorescence. The seed is flat, has a wing-like structure, and usually goes through a dormancy period of 3 to 4 months before germination can occur [3]. However, in Ghana and particularly in commercial production, yams are vegetatively propagated using the basal nodal region of the tuber, as flowering is rare.

The tuber, the economically important part of the yam plant, is rich in carbohydrates and contains modest amounts of mineral matter (calcium and iron), vitamin B, vitamin C, and crude fiber [3]. The plant usually produces a single annual tuber, which is 20–40 cm long and weighs from two to a dozen kilograms, depending on cultivar and growing conditions. The body can be elongated or spherical with a white, yellow, or purple flesh [18].

2.3 Temperature requirements

Yams are essentially tropical crops. Their growth is severely restricted at temperatures below 20°C. In general, they require temperatures of 25–30°C for normal growth to occur. Closely linked to temperature for optimal growth of the yam plant is light. It has been observed that the length of the day plays an important role in tuber formation. Short days tend to favor tuber formation and tuber growth, while long days favor vine growth. Though the influence of light intensity on yam growth and productivity has not been fully investigated, several points suggest that it is not a shade-loving plant. It requires and tolerates high intensities of sunlight to be maximally productive [1]. Because of this, in the Nanumba traditional area of Ghana, yam farmers after land preparation will usually devote substantial amount of their time to burn down or prune big trees on their farms before planting.

2.4 Water requirement

Yams thrive best when they receive sufficient moisture (about 1000 mm rainfall) well distributed throughout the growing cycle [3]. Since most yams require 7–9 months from planting to harvesting, they do best in areas where the rainy season is relatively long and where there are fewer than three or four rainless months in a year. Even though, the yam plant can survive droughts, they usually will give disappointing harvest. Hence, if yam is to be grown in an area where the dry season is longer, then supplementary irrigation must be provided [1]. In Ghana, the rain starts in April and ends in October, thereby providing the growing yam plants with 5 months continuous rain. A minimum of 1000 mm of water is required for the optimum growth [19].

2.5 Soil requirement

Yam like other crops requires soils of high fertility in order do well. For this reason, in traditional yam cultivation, it is grown on fertile forest soils as the first crop after clearing large trees or after a long term of fallowing [3, 17]. They are also cultivated in sandier savannah types of soils in the northern parts of West African [3]. Soils in the Nanumba traditional area are generally loamy in structure with good organic matter content and good water-holding capacity. This explains why the area is good for yam production. Soil structure has an impact on harvesting and ultimately on the quality of the tuber as loamy soils make harvesting easy with less bruises and clayey soils make harvesting difficult with lots of bruises on the yam (Rahaman, personal communication).

2.6 Agronomic practices

Yam is propagated from seed tubers or sections of the tuber. The use of true seeds as propagules is restricted to research stations, mainly in crop improvement programs. Traditionally, farmers obtain seed tubers in different ways. They may select small tubers (e.g. 300–500 g) from each harvest, use tubers from the second harvest of early maturing varieties, use small tubers from varieties that produce multiple tubers per stand, or cut ware tubers into pieces [3, 20]. Yam is sometimes planted alone, but it is more often intercropped with maize, cassava, rice, or other crops such as the legumes [3, 15]. Depending on the type of planting material, species, and location, effective duration of crop growth ranges from 6 to 12 months, calculated from the time of seed emergence until senescence of the leaves [19].

Yam is cultivated either on mounds or on ridges, and the growing plants can be staked or allowed to spread on the ground without stakes, especially in the savanna agro-ecological zone. Though staking may increase tuber yield, depending on the cultivar, the cost of stakes, the labor demand for their placement, and the environmental damage associated with their use may render this practice uneconomical [21, 22].

In Ghana, as in many other yam-producing countries in West Africa, yam production involves seven main processes. These include land preparation, planting, mulching, staking, weeding, harvesting, and storage. Fertilizer application on yam is rarely practiced at the farm level in Ghana.

2.7 Land preparation

Traditionally, land preparation in yam production is done by first clearing the land either manually with the use of a hoe and a cutlass, or the use of a tractor or bullocks [3]. However, with the modernization of yam farming, the use of herbicides has been adopted for land clearing in some yam-growing communities. In the case of manual land clearing and the use of herbicides, 2–4 weeks are allowed for the stubble to dry so as to enable the farmer to burn them and raise mounds. In the case of tractor ploughing, the farmer will usually go through the ploughed land and further clear grasses that are left under trees after which a second ploughing will be done before mounds are raised. Even though, it is said that yam can be grown on either mounds or ridges [3, 22], ridging is not yet practiced in the Nanumba traditional area of Ghana and mounding is done manually by the use of a hoe. In forested areas or in the savannah woodlands where there are substantial tree populations, the land clearing process also involves the burning or pruning of trees.

The use of herbicides for land clearing in yam farming is catching up very fast with farmers in the northern savannah areas of Ghana, especially farmers in the Nanumba traditional area, since it makes subsequent land preparation operations such as mounding easy and also gives them a better tuber yield (Rahaman, personal communication).

2.8 Planting

In the Nanumba traditional area of Ghana, yam is usually planted from December to February, the peak of the dry season. As a result of this, the planting operation is usually accompanied by capping (mulching) the yam mounds with some grass or leaves (**Figure 4**) to protect the planted sett from excessive heat and desiccation [1, 3, 17]. However, farmers who are not able to plant around this time would usually wait until the rain starts in April/May.

The time of planting yam depends on a number of factors, including the onset of the rains, the type of cultivars, the local ecological conditions, and the demand. For example, many *D. rotundata* and *D. cayenensis* cultivars are planted in the middle of the dry season, i.e. January–March [17]. These are generally cultivars with a short dormancy period whose long initial stems do not collapse on overheated soils and have a waxy coating that limits water loss.

Figure 4.
Yam planted and mulched on manually prepared mounds [2].

2.9 Staking

Staking is one of the yam farmer's main concerns [17, 21], since it is becoming increasingly difficult to obtain stakes throughout the yam-growing zones, especially in the dry savannah regions of West Africa. In its rudimentary form as it is practiced by yam farmers in the Nanumba traditional area of Ghana, stakes are obtained by cutting down young growing trees or cutting of the branches of bigger trees. Sometimes, trees that are burnt in the process of land preparation also serve as stakes. The stakes can be of different sizes (**Figure 5**) ranging from 1 to 4 m. The smaller ones are usually planted on the yam mound, while the bigger stakes are placed between yam mounds so that several plants can climb on it.

Tropical forests generally have high natural coppice rates, but these are reduced when trees are cut too close to the ground. It is suggested that ideally cuts should be made at least 45 cm from the ground to maximize regrowth. However, in an effort to get as much length from a sapling, yam stick cutters often cut sticks almost at ground level [23].

2.10 Weeding

Weeds are one of the serious challenges confronting yam production throughout the world [2]. The climbing growth habit of the plant coupled with its inability to shade the ground completely at any stage of its growth and development makes it very susceptible to weed interference [3]. In a study of Akobundu [24], it was observed that the critical period of weed interference in white yam is between the 8th and 16th week after planting. Proper weed management is necessary to obtain optimum yam yields. In general, a minimum of three to four weeding activities between planting and harvesting are necessary to minimize yield reduction. It is reported that weeds can cause yield loss in yam up to 90%. In most of the humid tropics, repeated hand weeding is a common feature of yam production. However, the commercialization of agriculture and high population growth with attendant increase in demand for yams,

Figure 5.
Staked yam farm.

in the absence of adequate labor [3], have created the need for the introduction of efficient and nonlabor-intensive methods of yam production [24].

In the yam-growing areas of Ghana, farmers usually go into the farm 1 month after planting with their hoe and cutlass to clear the farm of shrubs and other broad leaf weeds that have appeared. After this first weeding, the farmer can carry out three other weeding activities before harvesting in the case of manual weeding and one weeding in the case of chemical control.

In recent times, yam farmers in Ghana who are mostly located in rural areas adopt chemical weed control on yam. This is due to the dwindling labor force in the rural communities as a result of rural-urban migration of the youth in search of white collar jobs [25]. It can also be partly attributed to the expansion of farm sizes due to decreasing soil fertility and the commercialization of yam farming. However, whether a farmer uses chemical or manual weed control, the hoe is still employed, because the use of the hoe loosens the soil up to enhance aeration and water percolation.

2.11 Harvesting

Time for yam harvesting varies and may be spread out over several months in almost all regions due to the wide range of species and cultivars. For example, *D. rotundata* and *D. cayenensis* in West Africa are harvested twice [17], while *D. alata* is harvested only one time per season. This is similar to what pertains in the Nanumba traditional area in the northern region of Ghana (Rahaman, personal communication).

The first harvesting is done at a time when the plant has fully flowered (usually 6 months after planting) and the vines are about to cease growth with some of the bottom leaves turning yellow (**Figure 6**), that is usually around August and September. After this first harvest, the yam plant will regenerate and grow for some time and wither and finally dry up. This allows for the production of seed yam which is harvested in the second harvest period (December to January) together with late yam varieties like *D. alata* [26].

Early harvesting is done by the use of either a cutlass [2] or a sharp-ended stick where the mound is carefully cut open and the tuber is severed from the vine at the point below the base of the vine after which the mound is neatly covered to allow regenerative growth for seed tubers (**Figure 6**). On the other hand, late harvesting is done by the use of a hoe and cutlass, where the withered plant is cut off and half of the mound destroyed in order to remove the ware tuber or the seed tuber. In either

Figure 6.
Harvesting of yam.

situation, care is needed to minimize damage or bruises that lead to rot in tubers and a decrease in market value of the yam [6].

2.12 Storage

Yam as a tropical tuber crop has a relatively long shelf life (6–8 months) compared to other tropical fresh produce [3, 27]. This explains why, as a staple food, yam is available all year round for consumers. However, this long storability of yam notwithstanding, tubers are often damaged during harvesting and after harvesting, and this can lead to postharvest losses. After harvesting, yam can be stored either by adopting traditional or modern methods of storage [1, 12, 17]. The traditional system of yam storage varies among the different yam-producing countries of the world [27]. In Ghana, just as observed in other West African countries [27], yams can be stored by leaving them in the ground until they are needed for food or for sale. This system however exposes the yam tuber to attack by pests such as termites and rodents and harvesting also becomes difficult when the ground becomes hard during the dry season, resulting in tuber breakage and bruises which predispose the tubers to pathogens leading to loss of tubers in storage [28, 29]. Also, with this system, when there is heavy rain, the tubers may become rotten. The other traditional methods of yam storage include wooden platforms, cool and well-ventilated rooms, yam barns, heaping and covering with dry grass under trees, stored in a thatched shed, and Silo (burying in the soil) [27, 28, 30, 31]. The commonest traditional method of yam storage in Ghana is storage in the yam bam [32–34]. The modern methods on the other hand include chemical treatments (e.g. fungicides), storage in a cold room, and refrigeration; however, the method of cold storage is hardly practiced by farmers in West Africa [12, 28].

The efficacy of tuber storage structures for preserving yams until they are used is influenced by the cultivars, environmental conditions such as relative humidity and temperature, the physical condition of the tubers at the beginning of storage, and the effectiveness to exclude vermin such as rodents [27, 30, 32]. Traditional storage methods therefore vary according to ecology and the volume of yam produced [2].

Due to the economic circumstances in the yam-growing areas in Ghana and the Nanumba traditional area of Ghana in particular, farmers store yam through the traditional methods (**Figure 7**). In this traditional area, after harvest, farmers will usually burry the tubers in the soil or keep them under the shade of a tree and cover them with dry vines of yam or grass. They can also keep them in constructed barns on the farm or in the house or keep them in well-ventilated rooms. The latter practice is

Figure 7.
Yam storage in the field.

hardly done by farmers, but rather a common practice of yam traders (Imoro, personal communication).

Storage is an important element within the yam production chain which, when not properly done, can lead to high postharvest losses leading to low incomes for farmers and food insecurity. Onwueme [1] and Ravi et al., [27] respectively observed that shading, ventilation, and constant inspection are three essential elements for good yam storage in a barn. They asserted that ventilation serves two purposes, i.e. preventing the buildup of high humidity which favors rotting and preventing tubers from heating up owing to their own respiratory activities.

Postharvest losses for yam in Ghana are as high as 24 percent of production, despite the Ministry of Agriculture's goal to reduce these losses to only 12 percent [35, 36]. The major causes of postharvest losses are weight loss due to evapotranspiration intensified by sprouting, rotting due to fungal and bacterial pathogens, and insect infestation [35, 37].

2.13 Pests, diseases and weeds

In spite of the importance of yam as a food security and cash crop, yam farmers in Ghana suffer serious challenges in the production process. Among these production challenges are field and storage pests and diseases and weed burden [37–40].

2.13.1 Pests

Yams are infested by a broad taxonomic diversity of insect pests [41]. In a study of Braimah et al. [42], field and storage pests of yam in Ghana are identified. These pests (**Table 2**) cause significant losses to tubers both in the field and in storage.

2.13.2 Diseases

Yam in Ghana is attacked by a couple of diseases both in the field and in storage. However, the common diseases are those caused by fungi (**Table 3**). Other diseases affecting yam in Ghana are bacterial and viral diseases [37].

Yam is prone to infection right from the seedling stage through to harvesting and even after harvesting (in storage); hence, diseases of yam can be grouped into field and storage diseases. The field and storage diseases are many and varied. While Aboagye-Nuamah et al. [37] found that *B. theobromae, F. oxysporium*, and *R. stolonifer* were the most frequently encountered spoilage microorganisms in storage, Ripoche [43] observed anthracnose caused by *Colletotrichum gloeosporioides* to be the most severe foliar disease of water yam in the tropics and Amusa et al. [44] observed yam mosaic virus (YMV) disease to be causing the most severe losses in yams in Nigeria.

Tuber rots through microbial attack are an important cause of postharvest loss in yam throughout the tropics [33]. Rot from microbial infection of healthy tubers reduces their table quality and renders them unappealing to consumers, as it leads to total loss of tuber carbohydrates by transforming it into inedible colored mass. It is reported that postharvest losses in yam due to tuber rots can be as high as between 20 and 60% [31, 45, 46]. The rots are of different types, including soft rots, dry rots, and wet rots [29, 45, 47, 48].

Due to the importance of microbial tuber rots in yam, studies have been conducted to identify the causal organisms. In Ghana, Cornelius [45] in a survey identified some fungal, bacterial, and nematode species (**Table 3**) to be responsible for yam tuber rots.

Pest	Scientific name	Order	Categorization
Termites	*Amitermes* spp	Isoptera	Field
Millipedes	*Deridontoyge* spp	Callipodida	Field
Tuber beetles	*Heterolygus meles*	Coleoptera	Field and storage
Leaf beetles	*Planococcus diocorea*	Coleoptera	Field
Mealybugs	*Pseudococcus brevipes*	Hemiptera	Storage
Scale insects	*Aspidiotus destructor*	Hemiptera	Field and storage
Crickets	*Gryllus campestris*	Orthoptera	Field
Nematodes	*Meloidogyna incognita*	Nematoda	Field
	Pratylenchus coffeae		
	Scutellonema bradys		

Table 2.
Field and storage pest of yam in Ghana.

Disease	Causal organism	Type	Categorization
Rots	Fungus	*Aspergillus flavus*	Storage
		Aspergillus niger	Storage
		Aspergillus oryzae	Storage
		Botryodiplodia theobromae	Storage
		Colletotrichum gloeosporioides	Field
		Fusarium culmorum	Storage
		Fusarium oxysporium	Storage
		Fusarium moniliforme	Storage
		Penicilium spp	Storage
		Rhizopus stolonifer	Storage
	Bacteria	*Erwinia carotovora*	Field and Storage
	Nematode	*Pratylenchus coffeae*	Field
		Scutellonema bradys	Field
Galling of tubers	Nematode	*Meloidogyne incognita*	Field
Yam mosaic	Virus	*Yam mosaic potyvirus* (YMV)	Field
		Dioscorea alata potyvirus (DaV)	Field

Table 3.
Diseases affecting yam in Ghana.

In a related study, Aboagye-Nuamah et al. [37] confirmed the fungal and bacterial species reported by Cornelius [45] to be the cause of yam tuber rots. Subsequently, Asare-Bediako et al. [49] in a study to identify microorganisms causing rot in white yam found *Aspergillus flavus*, *A. niger*, *A. ochraceus*, *Aspergillus* sp., *A. tamari*, *Sclerotium rolfsii, Cladosporium* sp. *Corynebacterium* sp. *Fusarium* sp. *Penicillium* sp., *Rhizopus stolonifer*, and *Trichoderma* sp. to be associated with the rots, with *Sclerotium rolfsii* causing the most severe rot, followed by *A. niger* and *Fusarium* sp. In Nigeria, Osai and Ikotun [50] in a study to identify the microbial causes of rot in yam minisetts observed that *Sclerotium rolfsii, Trichoderma longibrachiatum, Botryodiplodia theobromae*, and *Penicillium oxalicum* are the most pathogenic among nine fungal and two bacterial species, causing tuber losses between 40 and 60%. In a study of Ogaraku and Usman [48] in Nasarawa state of Nigeria, six fungal species *(Aspergillus niger, Aspergillus flavus, Rhizopus stolonifer, Sclerotium rolfsii, Fusarium oxysporum*, and *Rhizoctonia* spp*)* were isolated from rotted yam tubers. In Brazil, Muniz et al. [47] in a study identified three nematode species (*Scutellonema bradys*, *Pratylenchus coffeae*, and *Pratylenchus brachyurus*) to be associated with dry rots of yam. In China, Zhang et al. [51] reported for the first time that *Pythium ultimum* var. *ultimum* causes tuber rot in the Chinese yam (*Dioscorea polystachya*).

Even though there have been reports of the use of insecticides such as pirimiphos-methyl (Actellic 2% Dust) [52] leading to significant reduction in fungal infections and physical damage to yam tubers, yam farmers in the Nanumba traditional area currently do not treat yam on the field and after harvest with chemicals. They rather adopt crop rotation, bush fallow, and use of healthy planting materials. The use of chemical insecticides as practiced in the Delta State in Nigeria [53, 54] can indirectly reduce the incidence of rots in the yam tuber caused by fungi, because physical damage to the yam tuber, either mechanically or by insects attack, can serve as conduit for microbial infections [28, 30, 31].

2.13.3 Weeds

The common weeds found on yam farms in Ghana can be seen in **Table 4**. They belong to three groups, i.e. the dicotyledons, monocotyledons, and the parasites [38].

In a study by Akobundu [24], it was observed that annual weeds caused a tuber yield reduction of about 54% and 90%, respectively, when the period of weed interference lasted 3 and 4 months after planting.

Weed group	Name
Monocotyledons	*Axonopus compresus* (Sw.) P. Beauv.
	Cyperus esculentus L.
	Cyperus rotundus L.
	Digitaria horizontalis Willd.
	Eragrostis tremula Hochst. Ex Steud.
	Hackelochloa granularis (L.) O. Ktze.
	Kyllinga erecta Schumach. Var.
	Kyllinga squamulata Thonn. Ex Vahl.
	Paspalum scrobiculatum L.
	Rottboellia cochinchinensis (Lour.) Clayton
	Setaria pallide-fusca (Schum.) Stapf. & C.E. Hubbard
	Imperata cylindrica

Weed group	Name
Dicotyledons	*Corchorus olitorius* L.
	Commelina benghalensis L.
	Commelina diffusa Burm.
	Desmodium scorpluras (Sw.) Desv.
	Hyptis suoveolens Poit.
	*Mimosa invi*sa Mart.
	Mimosa pigra L.
	Mitracarpus villosus (Sw.) DC.
	Oldenlandia corymbosa L.
	Phyllanthus amarus Schum. & Thonn.
	Scoparia dulcis L.
	Tridax procumbens L.
	Triumfeta cordiflora A. Rich.
	Vernonia galamensis (Cass.) Less.
Parasites	*Striga hermonthica* (Del.) Benth.

Table 4.
Weeds associated with yam cultivation in Ghana.

3. Yam consumption

Yam, sweet in flavor, is consumed as boiled yam (as cooked vegetable) or fufu or fried in oil (**Figure 8**) and then consumed. It is often pounded into a dough-like paste after boiling and is consumed with soup [3]. It is also processed into flour for use in the preparation of the paste. The tuber is the edible part of the yam plant with high carbohydrate content and low in fat and proteins and provides a good source of energy. Yam is an important source of minerals such as calcium, phosphorus, iron, carbohydrates, and vitamins such as riboflavin, thiamin, vitamin B, and vitamin C [55, 56]. Yam has some inherent characteristics which make it attractive and keep it in a high demand. First and foremost, it is rich in carbohydrates, especially starch;

Figure 8.
Prepared yam dishes of fufu, boiled yam, and fried yam.

consequently, it has a multiplicity of end uses. Secondly, it is available all year round, making it preferable to other seasonal crops [13].

Yam contains products such as alkaloids (saponin and sapogenin) and proteins (dioscorin and diosgenin) which can cause side effects in humans and animals such as inflammations, allergic reactions, kidney problems, and interference with the metabolic system [57, 58]. However, these same properties of the yam plant are exploited in medicine for the treatment and management of conditions such as allergies, metabolic disorders, hypertension, inflammations, and hormonal irregularities [58–60]. Yam has been used in traditional medicine in Africa and among the Chinese and other Asiatic people to treat diseases like diabetes, to increase coronary circulation, and to prevent hypercholesterolemia [55, 61, 62]. Although the industrial use potential of yam has not been fully exploited, its use as an industrial starch has been established as the quality of some of the species is able to provide as much starch as in cereals [11, 63, 64].

In recent times, efforts have been made by the scientific community to investigate the suitability of yam to be fried into chips like French fries. In a study to investigate the effect of blanching and frying on the textural profile and appearance of yam for French fries [9], it was found that yam fries with desirable texture and color attributes can be produced with *Dioscorea rotundata* by blanching that yam species at 75–80°C for 5–8 min and frying at 180°C for 3–3.5 min.

4. Marketing

The importance of yam in the economy of some producing areas appears to be declining due partly to competition from other crops like cassava in Nigeria and taro in the South Pacific. However, in Ghana, the contribution of yam to the economy by way of meeting household food needs and foreign exchange earnings through exports has been growing [11].

Harvested yams in most communities are mostly for household consumption with only 16.4% of farmers selling more than half of their harvested yam [26]. Yam tubers meant for sale are mostly sold to merchants in local markets and also directly to ordinary people and food vendors in towns. These merchants come from other regions and move from village to village to purchase tubers directly from farmers. In the Nanumba traditional area of the northern region of Ghana, merchants come from Accra and Kumasi in Southern Ghana to buy yam [65]. This practice conforms with what happens in the Niger State of Nigeria where merchants come from Ibadan and Ilorin in southern Nigeria to buy yam [26].

In Ghana, yam is generally traded in its original state and is not processed into a secondary product. Traders and chop bar owners (small restaurants) often buy yam to sell or prepare it for consumers directly. Yam for the export market is also not processed, but is treated, wrapped in paper, and packed in 20-kg boxes before it is shipped [37].

About a decade ago, the UK was the leading importer (49%) of Ghana yam export, followed by the Netherlands and the USA [6]. Since then, the trend has changed dramatically with the USA now leading the chat. In 2017, Ghana exported a total value of USD 38,393.00 worth of yam to 10 top importing countries of which the USA took 35%, followed by the UK and Belgium of 34% and 9%, respectively [66] (**Figure 9**). The large volumes of yam exported to these destinations are largely due to the high demand for yam by Ghanaians and other West Africans residing in these countries.

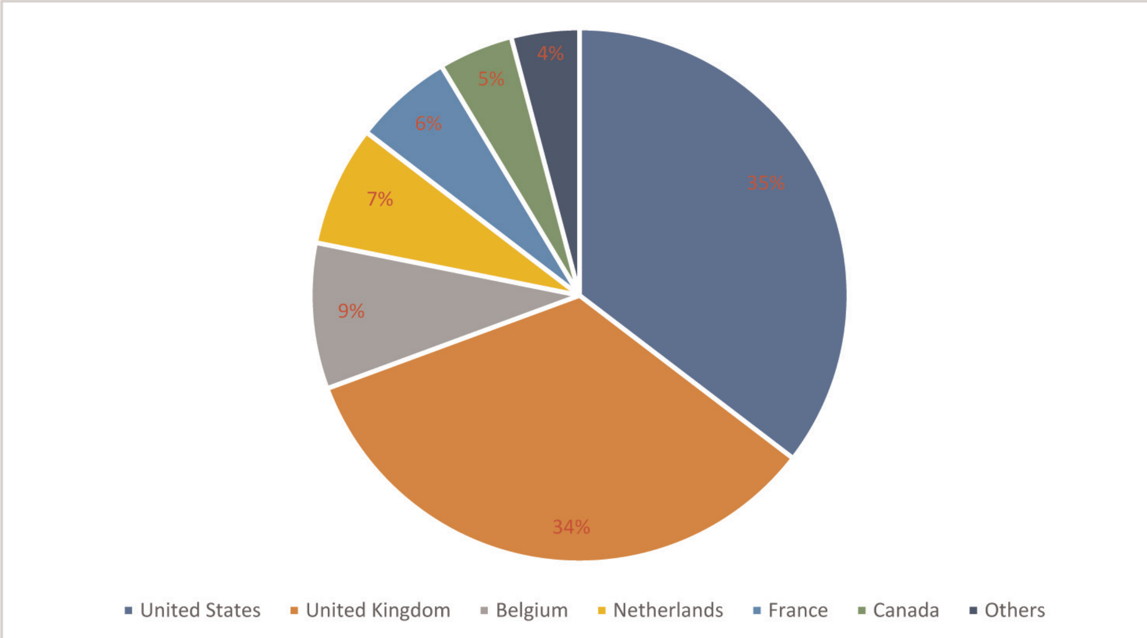

Figure 9.
Share of Ghana yam export by importing countries.

5. Monitoring of pesticides residues in yam

All over the world, there are concerns about pesticide residues resulting from the use of pesticides on crops [67]. For this reason, governments and especially in the EU allow pesticides to enter their respective countries as long as they are used in line with the law and the guidelines controlling their use.

In Ghana, public concerns are high about the use of pesticides by Ghanaian farmers and its attendant food safety and human health issues. This has led to the conduct of pesticides residue monitoring studies to assess the levels of pesticides in various food items. In a study by Asiedu [68] to determine pesticides residues in lettuce, garden egg, pineapple, and mango in three regions of Ghana, it was found that some market fruits and vegetables contained different types of pesticides of which chlorpyrifos (an organophosphate) and cypermethrin (a synthetic pyrethroid) were the most common ones. In a study by Bempah & Donkor [69] to assess the concentration of pesticides residues in fruits and vegetables from selected markets in Kumasi in the Ashanti region, it was found that 19% of the samples contained pesticides residues above the maximum residue level (MRL) with the health risk analysis further revealing that the pesticides endrin had exceeded the reference dose in vegetables, thereby suggesting a great potential for systematic poisoning in children that are considered as the most vulnerable population subgroup.

There is limited literature on pesticides residues in yam in contrast to other root and tuber crops in developing countries [70, 71]. This is partly because the crop is grown and consumed mostly in the developing world where there is limited scientific expertise and resources to set residue limits and to monitor them. In a study of Adeyeye and Osibanjo [70], 55% of yam samples from Nigerian markets were contaminated with one or more organochlorine pesticides (aldrin, dieldrin, HCH, and DDT). In a monitoring program by the "UK pesticides residue committee," to check whether pesticides residues in food and drink are above the maximum residue levels (MRLs), it was found that yam was among the food commodities with pesticides residues exceeding the MRLs [72]. Out of the 52 yam samples analyzed, 9 samples contained residues at or below the MRL, 11 samples contained residues above the MRL, and 13 samples contained more than one residue. The report observed further that as in previous years relatively high numbers of samples with residues over the MRL were found in the specialty vegetables, okra and yam. The yam samples used in this monitoring study originated from Ghana, Brazil, and Jordan. The samples from Ghana had residue levels of 0.2–0.3 mg/kg carbendazim (MRL = 0.1 mg/kg) and 0.4 mg/kg tebuconazole (MRL = 0.02 mg/kg). Since MRLs are not safety limits, risk assessment were carried out with the monitoring results which showed that the residues found in the yam will be unlikely to have adverse effects on health [72]. Similarly, in the studies of Wumbei et al., [73, 74] to investigate pesticides residues in yam, 12 pesticides, including five insecticides (cadusafos, fenitrothion, imidacloprid, profenofos, and propoxur), four fungicides (carbendazim, fenpropimorph,

Residues (mg/kg)		
	Fenitrothion	**Fenpropimorph**
Mean	0.0043	0.0003
Median	0.0023	0.0002
P75	0.0069	0.0002
P90	0.0069	0.0006
P95	0.0079	0.0007
P97.5	0.0097	0.0013
P99	0.0144	0.0031

Yam consumption (kg/kgBW/day)						
Mean	Median	P75	P90	P95	P97.5	P99
0.006	0.006	0.008	0.009	0.01	0.011	0.013

Estimated daily intake (EDI) (mg/kgBW/day)		
	Fenitrothion	Fenpropimorph
Mean	0.000026	0.000002
Median	0.000014	0.000001
P75	0.000055	0.000002
P90	0.000062	0.000006
P95	0.000082	0.000007
P97.5	0.000110	0.000014
P99	0.000187	0.000040
Acceptable daily intake (ADI) (mg/kgBW/day)	**0.005**	**0.003**

Table 5.
Estimated daily intake of fenpropimorph and fenitrothion through deterministic exposure assessment and corresponding ADIs. Adopted from Wumbei et al. [32, 74, 75].

metalaxyl, and propiconazole), and three herbicides (bentazone, glyphosate, and pendimethalin) were detected. However, when consumption risk assessment was carried out, it was revealed that there was no risk of dietary intake of these pesticides in yam under the deterministic approach (**Table 5**) and simple distribution approach (**Table 6**), but there was intake risk in about 10% of the study population to fenpropimorph and fenitrothion under the probabilistic (upper bound scenario) approach (**Table 7**) [75].

	Residues (mg/kg)				
	Cadusafos	**Carbendazim**	**Glyphosate**	**Imidacloprid**	**Metalaxyl**
	0.0005	0.0007	0.12	0.0007	0.0009
Statistical dist. of yam consumption (kg/kgBW/day) = Loglogistic (−0.017192; 0.02288; 14,635)					
	EDI (mg/kgBW/day)				
	Cadusafos	Carbendazim	Glyphosate	Imidacloprid	Metalaxyl
Mean	0.0000029	0.0000041	0.00070	0.0000041	0.0000053
Median	0.0000028	0.0000039	0.00068	0.0000039	0.0000051
P75	0.0000037	0.0000052	0.00089	0.0000052	0.0000067
P90	0.0000047	0.0000066	0.00113	0.0000066	0.0000084
P95	0.0000054	0.0000075	0.00129	0.0000075	0.0000097
P97.5	0.0000061	0.0000085	0.00146	0.0000085	0.000011
P99	0.0000071	0.00001	0.00169	0.00001	0.000013
ADI (mg/kgBW/day)	0.0004	0.02	0.5	0.06	0.08
	Residues (mg/kg)				
	Pendimethalin	Profenofos	Propiconazole	Propoxur	Bentazone
	0.0003	0.0004	0.0002	0.0004	0.0007
	EDI (mg/kgBW/day)				
	Pendimethalin	Profenofos	Propiconazole	Propoxur	Bentazone
Mean	0.0000018	0.0000023	0.0000012	0.0000023	0.0000041
Median	0.0000017	0.0000022	0.0000011	0.0000022	0.0000039
P75	0.0000022	0.0000029	0.0000015	0.0000029	0.0000052
P90	0.0000028	0.0000037	0.0000019	0.0000037	0.0000066
P95	0.0000032	0.0000043	0.0000021	0.0000043	0.0000075
P97.5	0.0000036	0.0000049	0.0000024	0.0000049	0.0000085
P99	0.0000042	0.0000056	0.0000028	0.0000056	0.00001
ADI (mg/kgBW/day)	**0.125**	**0.03**	**0.04**	**0.02**	

Table 6.
Estimated daily intake of cadusafos, carbendazim, glyphosate, imidacloprid, metalaxyl, pendimethalin, profenofos, propiconazole, and propoxur through simple distribution and corresponding ADIs. Adopted from Wumbei et al. [32, 74, 75].

Statistical distributions of residue and consumption data				
Fenpropimorph (mg/kg)	**Fenitrothion (mg/kg)**		**Yam consumption (kg/kgBW/day)**	
LB (0), UB (0.0035)	LB (0) UB (0.0115)		Loglogistic (−0.017192; 0.02288; 14,635)	
EDI (mg/kgBW/Day)				
Percentile	Fenpropimorph		Fenitrothion	
	Lower bound	Upper bound	Lower bound	Upper bound
Mean	0.000008	0.00058	0.000024	0.0012
Median	0.000000	0.00001	0.000000	0.0001
P75	0.000000	0.00002	0.000043	0.0022
P90	0.000006	0.0023	0.000076	0.0042
P95	0.000011	0.0051	0.0001	0.0052
P97.5	0.000019	0.0066	0.00013	0.0060
P99	0.000044	0.0082	0.0002	0.0071
ADI (mg/kgBW/day)	**0.003**	**0.003**	**0.005**	**0.005**

LB = Lower bound, UB = Upper bound.

Table 7.
Estimated daily intake of fenpropimorph and fenitrothion through probabilistic exposure assessment. Adopted from Wumbei et al. [32, 74, 75].

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