Scientific African 12 (2021) e00808

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

Article

Farmers' perceptions on varietal diversity, trait preferences and diversity management of bush yam (*Dioscorea praehensilis* Benth.) in Ghana

Adeyinka S. Adewumi[a,b], Paul A. Asare[a], Michael O. Adu[a], Kingsley J. Taah[a], Selorm Akaba[c], Jean M. Mondo[b,d], Paterne A. Agre[b,*]

[a] *Department of Crop Science, University of Cape Coast, University Post Office, Cape Coast, Ghana*
[b] *International Institute of Tropical Agriculture, Ibadan 5320, Nigeria*
[c] *Department of Agricultural Economics and Extension, University of Cape Coast, University Post Office, Cape Coast, Ghana*
[d] *Department of Crop Production, Université Evangélique en Afrique, Bukavu 3323, Democratic Republic of Congo*

ARTICLE INFO

Article history:
Received 20 December 2020
Revised 14 May 2021
Accepted 27 May 2021

Editor: Dr B. Gyampoh

Keywords:
Dioscorea praehensilis
Participatory rural appraisal survey
Ghana
Farmers' preference criteria
Genetic resource conservation

ABSTRACT

Bush yam (*Dioscorea praehensilis* Benth.) is an important food and cash crop species in some West and Central African countries. Unfortunately, several socioeconomic, cultural, nutritional, and agronomic constraints hinder its cultivation, and thus lead to its underutilization and gradual disappearance. To effectively promote its cultivation and utilization, knowledge of its diversity, distribution, management, and farmers' varietal preferences is necessary. This study, therefore, used a participatory rural appraisal survey to assess such information in 23 villages from three regions of Ghana. A total of 42 *D. praehensilis* morphotypes were recorded and grouped in seven classes based on the tuber flesh colour. The Shannon diversity index (H' = 1.88), equitability (0.65), and Margalef species richness (2.53) revealed the presence of moderate diversity and distribution in the surveyed regions. Farmers' variety trait preferences included mainly the early maturity (21.1%), smooth tuber texture (16.5%), stability in tuber flesh colour (7.86%), good storage aptitude (7.6%), and high tuber productivity (12.8%). In contrast, *D. praehensilis* production and utilization rates have declined mainly due to poor culinary quality (39.9%) and poor agronomic traits (20.7%) of most morphotypes. Survey results showed that *D. praehensilis* is largely an *in-situ* conserved species in Ghana (60.0%). This study provided an insight on *D. praehensilis* diversity, distribution and farmers' varietal preferences in Ghana which will guide its genetic resource conservation and plant breeding interventions.

* Corresponding author.
E-mail addresses: adewumi.saburi@stu.ucc.edu.gh (A.S. Adewumi), pasare@ucc.edu.gh (P.A. Asare), michael.adu@ucc.edu.gh (M.O. Adu), ktaah@ucc.edu.gh (K.J. Taah), sakaba@ucc.edu.gh (S. Akaba), M.Mubalama@cgiar.org (J.M. Mondo), P.Agre@cgiar.org (P.A. Agre).

https://doi.org/10.1016/j.sciaf.2021.e00808

1. Introduction

Yam (*Dioscorea* spp.) is a common name for ~600 species in the *Dioscorea* genus, and it is extensively cultivated in tropical and subtropical areas for its starchy underground or aerial tubers. These species provide dietary energy from direct consumption and often contain secondary metabolites used for industrial and pharmaceutical purposes [1, 2]. In West Africa where more than 90% of global yam is produced, these crops sustain the livelihoods of ~300 million people [2] and play a significant cultural and religious role for local communities [3].

Apart from the commercial yam species, there are edible wild and semi-domesticated yams such as *D. burkilliana, D. minutiflora,* and *D. praehensilis*, which are grown on a subsistence basis. These wild yams are mostly found in forest areas and are used by the farmers and rural dwellers as a staple food in filling the hunger gap during drought periods as well as a source of traditional medicine [4-6]. The cultivation and domestication of these wild yams have been reported in Africa. For instance, *D. schimperiana* and *D. bulbifera* in Ethiopia [7]; *D. semperflorens, D. mangenotiana, D. burkilliana, D. minutiflora, D. smilacifolia,* etc. in south-eastern Cameroon [5] and *D. praehensilis* in West Africa, especially in Nigeria, Ghana, Benin, and Cameroon [8-10]. However, despite the critical role played by wild yams in the livelihood of many tropical rural dwellers, these crops remain underutilized [6]. The underutilization of these yam species suggests that there may be some complex, and perhaps inter-related constraints exerting variable limitations on the productivity, processing, commercialization, and hence, reduction in utilization of these wild yams. Therefore, these factors challenging wide use of wild and semi-domesticated yams should be investigated with respect to local socio-economic, cultural, technical, and agro-ecological realities to guide farmer-support structures and other stakeholders involved in maintaining biodiversity or promoting wide use of these yam species.

Among the wild yams, *D. praehensilis* emerged as the most popular species with a notable contribution potential to the food security and poverty alleviation in most rural areas of some West and Central African countries [11]. Like other yam species such as white Guinea (*D. rotundata*) and water (*D. alata*) yams, the tubers of bush yam are mainly consumed boiled. Bush yam (*D. praehensilis*) is a perennial vine, moderately to strongly vigorous plant with green to purplish thorny stems of up to 15 m long, often supported by trees. The leaves are usually alternate or opposite with cordate or sagittate shapes. Bush yam tubers are usually up to 60 cm long, with generally white flesh tinged with yellow, and a bitter violet layer beneath the skin [12].

Despite the importance of *D. praehensilis* and its potential role in tackling the problem of food insecurity in lean and unfavorable seasons among the rural farmers in West Africa, this species is gradually disappearing from the ecosystem [10]. Moreover, there are limited research efforts to improve the production status of this yam species and no information exist on the yield potentials of this crop compared to other yam species. There is a need to conduct a germplasm collection for *D. praehensilis* to serve as the basis for the development of varietal improvement programs and the implementation of conservation strategies.

Ghana is the second largest producer of yam in the world after Nigeria [13]. Its ecological conditions are suitable for the bush yam which is not only harvested from the forest but also grown and marketed by its inhabitants. However, there is limited information on farmers' perception of the diversity, distribution, varietal preference criteria, production constraints, seed systems, conservation methods, and farm management practices of *D. praehensilis* in Ghana. The only reported indigenous knowledge on *D. praehensilis* in Ghana was conducted along with other yam species (*D. rotundata, D. alata, D. cayenensis, D. esculenta,* and *D. dumetorum*) [14]. This implies that local knowledge on *D. praehensilis* has not been well explored, as it was just a secondary item among investigated species. The study by Aboagye et al. [14] focused on the diversity and production constraints of six yam species and no information was reported on varietal preference criteria, seed systems, conservation methods and farm management practices of yam in Ghana. As a result, only three morphotypes (*Otim*, *Odonor* and *Kat*) of *D. praehensilis* were reported in that study [14]. Pitalounani et al. [11] grouped *D. praehensilis* morphotypes of Togo, a neighbouring country to Ghana, into four classes based on tuber flesh colours (white, yellow, red, and black bayere) using farmers' perceptions and indigenous knowledge. Understanding the genetic diversity, uses, and distribution of orphan crops, such as *D. praehensilis,* is essential in determining what and where to conserve, for sustainable utilization. Therefore, conducting an extensive survey to assemble all the relevant information related to farmers' perceptions about this species of yam is crucial for guiding future genetic resource conservation, production, improvement and breeding interventions. This study will serve as baseline information in understanding the extent of diversity, farmers' varietal preference criteria and diversity management of *D. praehensilis* in Ghana.

In the sub-Saharan African countries where agriculture is the spearhead of the economy, improved crop varieties must be developed or simply discovered within the existing diversity to increase the resilience of African farming systems to rapid population growth, changes in eating habits, and climate change effects. In both cases, a good knowledge of the existing yam varietal diversity and the agronomic performance of these varieties are necessary for effective interventions [15]. Moreover, documentation and identification of high-performing cultivars based on farmers' varietal preference criteria will provide strategies to overcome constraints affecting *D. praehensilis* production in Ghana, and this will consequently enhance production and productivity of *D. praehensilis*, and thereby unraveling its potential contribution to food security and poverty reduction among rural farmers. Besides, farmers' participation in identifying needs and desirable traits for plant breeding and their involvement in the varietal selection process could increase the probability of farmers' new variety adoption rate.

This study aimed, therefore, at contributing to the understanding of the perceptions of local farmers on *D. praehensilis* varietal preferences to guide efforts in its diversity conservation and management in Ghana. It specifically sought to: (i)

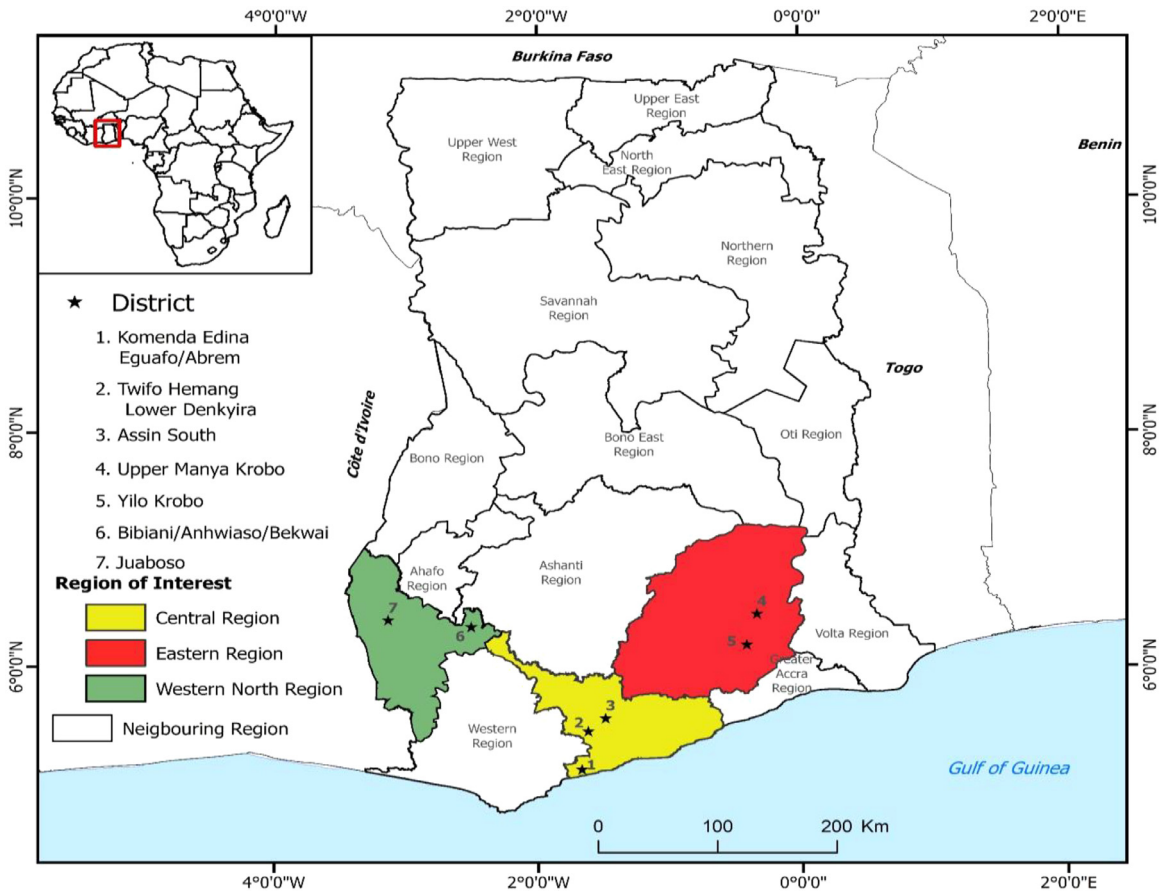

Fig. 1. Map of Ghana showing the geographical locations of regions and districts surveyed for *Dioscorea praehensilis* diversity.

investigate farmers' knowledge and perception of the diversity, distribution, conservation methods, and farm management practices of *D. praehensilis* in Ghana, (ii) determine the major factors limiting the production and utilization of *D. praehensilis* in Ghana, and (iii) inventory the farmers' preference criteria for *D. praehensilis* genotypes in Ghana.

2. Materials and methods

2.1. Description of the study area

Three administrative regions (Central, Eastern, and Western North) where *D. praehensilis* is predominantly cultivated in Ghana were selected for this survey (Figure 1). The three regions are located in the southern part of Ghana. The Central region is bordered to the north by Ashanti and Eastern regions, Western region to the west, Greater Accra region to the east, and the south by the Gulf of Guinea. The Western North region is bounded to the west by the Côte d'Ivoire border, the Central region in the southeast, and the Ashanti, Ahafo, and Bono regions in the north. The Eastern region is bordered to the east by the Lake Volta, to the north by the Bono and Ahafo regions, to the west by the Ashanti region, to the south by the Central and Greater Accra regions. All the three surveyed regions are located in the deciduous forest agro-ecological zone of Ghana (Table S1). The deciduous forest ecological zone is the largest agro-ecological zone in Ghana. It is characterized by a bimodal climate with two rainy and two dry seasons [16]. The dominant crops grown in this zone are mainly plantation crops such as cocoa, kola, coffee, oil palm and coconut and other food crops such as yam, maize and cassava. It is noteworthy that *D. praehensilis* is confined to the forest and cocoa cultivation zones of Ghana where it is called "kokoo ase bayèrè", meaning yam under cocoa plantation.

2.2. Sampling techniques and data collection

Prior to data collection, a pre-survey was conducted by consulting regional departments of agriculture and other resource persons (extension agents, farmers' associations representatives, local authorities, experienced persons in yam cultivation, etc.) at Central, Eastern and Western North regions where *D. praehensilis* is mainly produced in Ghana. Discussions

with these resource persons aimed at determining the major *D. praehensilis* production areas within the selected regions of Ghana. A total of seven districts were then selected across the three target regions (Figure 1). Across the seven districts, and in view of high coverage, 23 villages were randomly selected among those listed by resource persons as major bush yam producers from each selected district. In each selected village, a chain-referral sampling technique (also referred to as snowball sampling), which is a non-probability technique, was used to select bush yam farmers [17]. A chain-referral technique involved the selection of the first respondent, a well-known expert on bush yam in a village, who subsequently provided another well-known respondent until all the respondents (target sample size) in the village were covered. In each village, 20 farmers were interviewed and their fields were visited for plant sample collection (bush yam tubers) and field management data record. In selected villages where snowball sampling technique could not identify the target population size (less than 20), all the available bush yam farmers were surveyed. A total of 437 *D. praehensilis* farmers were individually interviewed across the three regions. Individual interviews with farmers were conducted by administering a pre-elaborated semi-structured questionnaire with the help of local translators.

The collected data included farmers' socio-demographic information (age, gender, education status, family size, farming experience, family income, primary occupation, non-farm income-generating activities, and farm size), the *D. praehensilis* genetic resources (number of cultivars, farmers' preference criteria, and the diversity management), and reasons behind *D. praehensilis* production decline and varietal losses and abandonment by farmers. Abandonment and varietal loss in this study were assessed by comparing the number of *D. praehensilis* morphotypes a farmer used to exploit and the one he/she continued using at the time of the survey. The interpretation of the socio-demographic information is provided in Table S2. Farmers' perceptions on the performance of the morphotypes based on agronomic and culinary characteristics were documented using 11 traits (yield potential, tolerance to insect pests, tolerance to diseases, flowering rate, no/less thorns on tubers, earliness to maturity, tuber flesh texture (boiled tuber texture), tuber taste after cooking, tuber flesh colour/non-oxidative browning, aroma, and storage capability) (Table S3). A binary database was then constructed using the 11 traits and morphotypes were scored "1" if performance was good for a characteristic and scored "0" otherwise.

2.3. Statistical analysis

Descriptive statistics (frequencies, means, standard deviations, minimum, maximum, etc.) were used in generating summary tables. To estimate the influence of socio-demographic parameters (age, years of experience, farm size, family size, marital status, education level, secondary occupation) on the number of morphotypes maintained at each household and across the surveyed villages, the Pearson's correlation analysis was performed using corrplot R package version 0.84 [36]. Shannon Weiner (H'), evenness or equitability (E), and Margalef species richness (d) diversity indices were computed using Paleontological statistics software (PAST) 326b version [37] to quantify the diversity of *D. praehensilis* at the village and region levels.

Analysis of variance at 5% *p*-value level of significance was used to determine the influence of gender and age categories on the diversity of *D. praehensilis* (translated by the number of morphotypes).

The Pearson's chi-square test was used to compare the influence of regions surveyed and farmer's gender on the practices used in *D. praehensilis* production and utilization.

To assess the distribution and concentration of each *D. praehensilis* morphotype across the surveyed regions, quotation frequency described by Adigoun-Akotegnon et al. *****[20] was used to compute the proportion of the respondents that quoted a given morphotype on the basis of total number of farmers surveyed. The quotation levels for ranking were: 1=quoted by 1–10% respondents; 2=quoted by 11–20% respondents; 3=quoted by 21–60% respondents, and 4=quoted by >60% respondents.

Subject to synonymy / homonymy, a database was constructed by considering the unique morphotypes based on different villages and the farmers' identified agronomic and culinary traits (11 traits in total). A database was then developed considering the key traits and was used to generate genetic distance among the identied morphotype using R cluster package [38] implemented in R core team [39]. Generated dissimilarity matrix was then used to construct hierarchical clusters (dendogram) using ward.2 method implemented in cluster package [39]. The silhouette method implemented in Cluster package and FactorMinerR [39] were used to determine the maximum cluster number and assess the effectiveness of grouping.

3. Results

3.1. Socio-demographic characteristics of D. praehensilis farmers

A total of 437 *D. praehensilis* farmers including 159 in the Central region, 120 in the Eastern region, and 158 in the Western North region were surveyed. The majority (72.5%) of the respondents were male, 19.5% had no formal education, and only 4.1% had tertiary education while 32.3 and 44.2% had primary and secondary education, respectively. The main activity of these farmers across the study areas was farming (~90%). Some farmers had non-farm income-generating activities such as the artisanry, petty trading, clergy, and civil services. The surveyed farmers were between 20-82 years old with an average age of 47 years. The mean family size was 6 members, although some households were accommodating up to 30 members from the extended family. The *D. praehensilis* farm sizes in sole and intercropping systems ranged between 0.2

Table 1
Diversity of *D. praehensilis* across surveyed regions in Ghana.

Regions	Villages	Number of morphotypes (S)	Shannon (H')	Evenness/Equitability (E)	Margalef Species Richness (d)
Central	Aburansa	5	1.05	0.57	1.17
Region	Komfokrom	11	1.77	0.53	2.64
	Kwametah	7	1.45	0.61	1.63
	Frami	5	1.19	0.66	1.21
	Nyameani	7	1.37	0.56	1.70
	Watreso	8	1.56	0.60	1.83
	Achiase	10	1.84	0.63	2.60
	Asamankese	9	1.59	0.54	2.20
	Manso	6	1.33	0.63	1.43
	Mean		**2.66**	**0.75**	**4.25**
Eastern	Dzaman	10	1.62	0.50	2.25
Region	Esuom Manya	12	2.41	0.93	2.52
	Nsutapong	9	1.78	0.66	2.11
	Brukum	13	2.01	0.57	3.21
	Klo Agogo	11	1.78	0.54	2.71
	Sutapong	14	2.35	0.75	3.55
	Mean		**3.22**	**0.84**	**6.87**
Western	Anhwiaso	7	1.66	0.75	1.43
North	Dominibo No. 2	12	2.37	0.89	2.55
Region	Adupri	11	2.09	0.74	2.35
	Adobawura No. 1	12	2.07	0.66	2.76
	Naama	10	1.96	0.71	2.26
	Nyetina	10	1.99	0.73	2.27
	Adwumam	8	1.61	0.63	1.78
	Juaboso	7	1.36	0.56	1.48
	Mean		**2.90**	**0.79**	**5.07**
	Overall mean		**1.88**	**0.65**	**2.53**

and 20 ha with a mean of 2.1 ha. The farmers' experience in *D. praehensilis* cultivation ranged between 1 and 60 years with a mean of 14 years (Table S4).

3.2. Genetic resources of D. praehensilis *across the surveyed areas*

Subject to synonymy/homonymy, the number of *D. praehensilis* morphotypes cultivated in the surveyed villages varied from 5 to 14. The highest number of morphotypes (14) was recorded at Sutapong village located in the Eastern region, while the lowest (5) was recorded at Aburansa and Frami villages located in the Central region (Table 1).

The diversity index means of 1.88, 0.65 and 2.53 were recorded for Shannon Weiner index (H'), evenness/equitability (E) and Margalef species richness (d), respectively, across the study areas (Table 1). Esuom Manya village in the Eastern region recorded the highest H' (2.41) and equitability E (0.93) among the villages surveyed, while Aburansa village in the Central region recorded the lowest H' (1.05), and Komfokrom recorded the lowest index for equitability (0.53). Highest Margalef morphotype richness (3.55) was observed in the village Sutapong in Eastern region, while the lowest (1.17) was observed in Aburansa village in Central region. Across the regions, the highest diversity indices (H'=3.22, equitability = 0.84, and Margalef species richness = 6.87) were recorded in Eastern region while the lowest (H'=2.66, equitability (E) = 0.75, and Margalef species richness (d) = 4.25) were recorded in the Central region.

There was no significant difference in the number of morphotypes cultivated by either male or female respondents, as well as the age categories across the surveyed regions (Table S5). An average of two *D. praehensilis* morphotypes were cultivated by male and female farmers irrespective of the age categories.

The relationship between the socio-demographic characteristics and the number of morphotypes cultivated by *D. praehensilis* farmers in the study area is presented in Figure S1. Family income, family size, farm size, years of experience in *D. praehensilis* farming, and education level had a positive influence on the number of morphotypes cultivated by the farmers. In contrast, gender, age, primary occupation, and marital status had a negative impact on the number of morphotypes cultivated by the farmers.

3.3. Spatial distribution of D. praehensilis *across the surveyed regions in Ghana*

A total of 42 *D. praehensilis* morphotypes were collected across the surveyed regions and varied morphologically in tuber flesh colour (Table S6). The morphotypes were grouped into seven different classes based on the tuber flesh colour: white, yellow, cream, purple, red, brown, and black flesh colour (Figure 2, Table S6). The distribution of these morphotypes based on flesh colour classes varied across the surveyed regions. White, yellow, red, and black flesh coloured yams were found in all the regions. Cream and purple flesh coloured yams were found only in Central and Eastern regions. The most predominantly cultivated classes across the surveyed regions were yams with white and yellow tuber flesh colours.

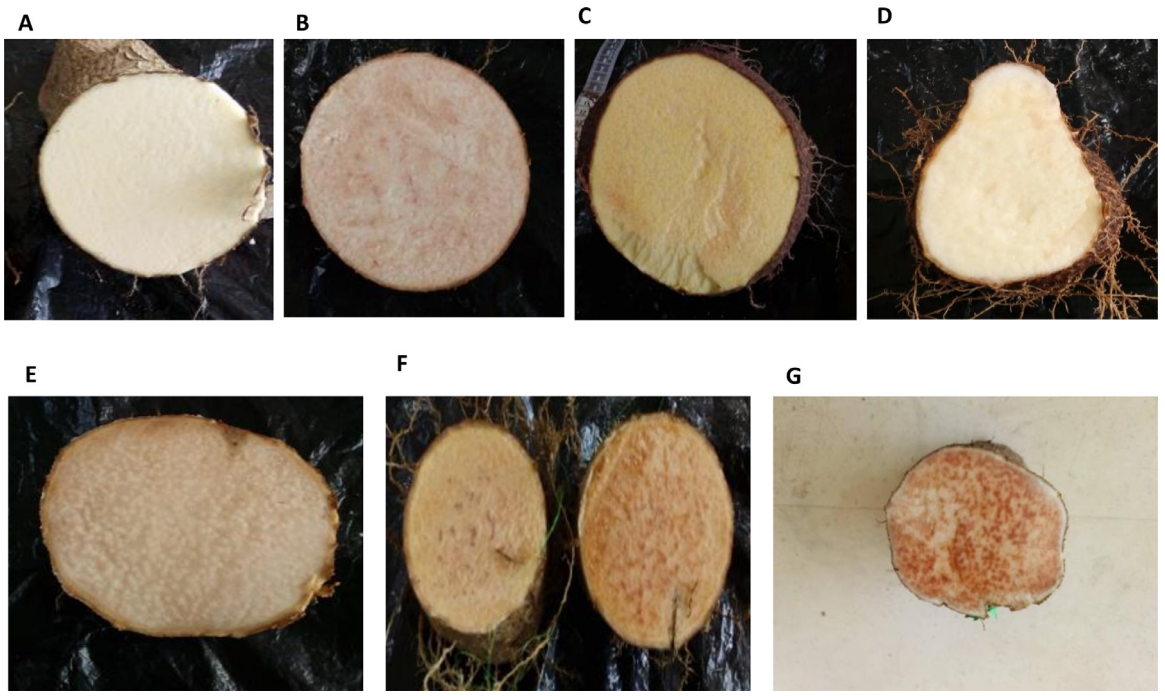

Fig. 2. Some morphotypes of *D. praehensilis* based on tuber flesh colour. **A**: White (*Odonor*); **B**: Purple (*Ewuruku*); **C**: Yellow (*Mamsoso*); **D**: Cream (*Sika a ɔhowa*); **E**: Black (*Tumtum*); **F**: Brown (*Bredum*); **G:** Red (*Tsutsu*)

The Eastern region recorded the highest number of morphotypes (29), while the lowest was recorded in the Central region (17). The spatial distribution of the morphotypes revealed that the morphotypes *Fufuw, Akoko-angoa, Memen*, and *Kat* were the most cultivated in the Central region. In the Eastern region, *Futaa, Yumu, Kungwɔ zɔ, Kokoasobayere, Mamsoso, Kat*, and *Asobayere* were mostly cultivated, while in the Western North region, *Afu, Akyekyere, Asobayere, Tumtum, Kokoasobayere, Mamsoso, Ngani, Fufuw, Akoko-angoa, Bobeyere*, and *Fowking* were the most cultivated *D. praehensilis* morphotypes. Some morphotypes were mostly concentrated in each of the regions. For example, *Adongo, Esiam,* and *Ɔtse dɛ wim* were concentrated in the Central region; *Chamachron, Cherimanche, Keke, Wo su, Tsu tsu, Odonor,* and *Obobi* in the Eastern region, and *Apubayere, Bootan, Kwah, Nkamfo,* and *Tolege* in the Western North region. Some morphotypes were found across the three surveyed regions. These include *Akyekyere, Asɔbayere, Kat, Kokoasobayere, Mamsoso*, and *Ngani*.

3.4. Constraints in production and utilization of D. praehensilis *morphotypes across the studied regions of Ghana*

The challenges associated with the declining production and utilization of *D. praehensilis* morphotypes in Ghana are presented in Table 2. These include poor tuber culinary and quality characteristics (39.9%), and among which, the fast tuber flesh oxidation (22.7%), poor post-harvest shelf-life (10.8%), fibrous tuber texture (5.0%), and poor taste (1.4%) were the most mentioned. Agronomic constraints contributed up to 20.7% of the factors limiting the production and utilization of *D. praehensilis* by surveyed farmers. Among these agronomic constraints, prolonged dormancy (7.6%), low productivity (4.8%), difficulty in harvesting (3.9%), inadaptation to poor soil fertility (1.4%), and lack of sufficient quality seeds (3.0%) were the most important bottlenecks faced by the bush yam farmers. Marketing challenges were mainly the low market values and the lack of organized markets (14.9%) for bush yam. Abiotic (bush burning and drought susceptibility), biotic (insect pests and diseases), and socio-cultural (loss of cultural values and introduction of new yam species) challenges represented 10.5, 11.0, and 3.2%, respectively.

3.5. Farmers' preference criteria of D. praehensilis *morphotypes and utilization in the studied regions of Ghana*

Twelve (12) criteria grouped into three categories (agronomic, culinary, and economic characteristics) were perceived by the farmers as the most important traits across the study areas (Table 3). These categories accounted for 51.6, 43.2, and 5.5% of the responses from *D. praehensilis* farmers, respectively. Among the 12 cited as preferred criteria, "early maturity" in the category of agronomic quality traits was the most determinant (21.1%) while "readily available during the dry season" in the category of economic characteristics was the least of the preferred criteria (0.9%). However, the farmers' preferences varied from one region to another. Early maturity (27.4%) was the most preferred criteria in the Central region, followed by smooth tuber texture (14.5%) and good tuber flesh colour (14.5%). The most preferred criteria in the Eastern region were early

Table 2
Challenges limiting production and utilization of *D. praehensilis* yam in Ghana.

Challenge categories	Factors	% of responses
Culinary and quality traits	High tuber flesh oxidation	22.7
	Short post-harvest shelf-life	10.8
	High fibrous (boiled) tuber texture	5.0
	Poor taste	1.4
	Sub-total	**39.9**
Agronomic traits	Prolonged dormancy	7.6
	Low productivity	4.8
	Difficulty in harvesting	3.9
	Lack of quality seed	3.0
	Inadaptation to low soil fertility	1.4
	Sub-total	**20.7**
Marketing	Low market value	12.1
	Lack of organized markets	2.8
	Sub-total	**14.9**
Biotic	Insect pests	8.9
	Diseases	2.1
	Sub-total	**11.0**
Abiotic	Bush burning	5.5
	Susceptibility to drought stress	5.0
	Sub-total	**10.5**
Socio-cultural	Introduction of new yam species	2.3
	Loss of cultural values (ceremonies and yam festivals)	0.9
	Sub-total	**3.2**

Table 3
Farmers' varietal preference criteria and their importance across Ghanaian regions.

Category	Preference criteria	% respondents across surveyed area	Central	% respondents Eastern	Western North
Culinary and quality traits	Smooth tuber texture	16.5	14.5	14.9	19.6
	Good taste	12.4	11.3	17.2	9.5
	Non-oxidizing tuber flesh	7.8	14.5	5.2	5.0
	High poundability	3.7	8.1	0.0	3.4
	Good aroma	2.8	0.8	3.7	3.4
	Sub-total	**43.2**	**49.2**	**41.0**	**40.8**
Agronomic traits	Early maturity	21.1	27.4	17.9	19.0
	High productivity	12.8	13.7	16.4	9.5
	Tolerance to insect pests and diseases	10.1	5.7	12.7	11.2
	High in-soil storage aptitude	7.6	2.4	4.5	13.4
	Sub-total	**51.6**	**49.2**	**51.5**	**53.1**
Economic characteristics	High market value	4.6	1.6	6.0	5.6
	Readily available during off season	0.9	0.8	1.5	0.6
	Sub-total	**5.5**	**2.4**	**7.5**	**6.2**

maturity (17.9%), followed by good taste (17.2%). In the Western North region, the most preferred criteria were smooth tuber texture (19.6%) and early maturity (19.0%). Across the studied regions, 92.9% of the surveyed farmers utilized *D. praehensilis* for direct consumption (subsistence), 6.1% commercialized it, and less than 1% used it for medicinal purpose (Table S9).

3.6. Perceptions of farmers on agronomic and culinary traits of D. praehensilis

The perception of local farmers on agronomic and culinary characteristics of bush yam is presented in Figure S2. More than 90% of the respondents acknowledged high yield potential, high flowering rate, and good aroma of *D. praehensilis*. About 70% of the respondents reported high tolerance of *D. praehensilis* to insect pests and diseases. On the other hand, 37% of the respondents reported good storage capability of *D. praehensilis*. Thirty-two percents (32%) of the respondents reported no or less thorns of *D. praehensilis*. Less than 30% of the respondents reported smooth tuber texture, earliness to maturity, non-oxidising tuber flesh and good taste as preferred traits from *D. praehensilis*.

3.7. Perceptions of age categories on the preferential criteria for D. praehensilis *morphotypes*

The perception of different age categories of respondents on their preferences for culinary, quality and market traits of *D. praehensilis* is presented in Table S7. The respondents in the age category of 40-49 years old reported highest preference for most of the listed attributes: good aroma (41.7%), non-oxidising tuber flesh (41.2%), high market value (40%), smooth tuber texture of boiled yam (31.9%), good taste (29.6%) and early maturity (26.1%). Respondents in the age category of 50-59 years

old reported highest preference for the attributes such as readiness during off-season (50%), high yield potential (30.4%), and high poundability (25%). The age category of 30-39 years old reported 30% for high market value, 26.4% for smooth tuber texture of boiled yam and 25% for high poudability.

3.8. Conservation techniques by D. praehensilis *farmers in the studied regions of Ghana*

Two conservation techniques, *in-situ* and *ex-situ* techniques, were reported in the study area. The *in-situ* conservation technique involved the retaining of mature tubers in the mounds until the time was suitable for harvest and sale. The farmer's location significantly influenced conservation techniques adopted by bush yam farmers (Table S8). *In situ* conservation technique was used by 60.0% *D. praehensilis* farmers. These farmers conserved mature tubers in the mounds for a period of 1-3 months (34.1%), 4-6 months (20.8%), 7-9 months (2.3%), and 10-12 months (2.8%) (Table S8). *Ex-situ* conservation techniques accounted for 41.1% of the farmers' responses. In *ex-situ* conservation techniques, nine (9) methods were reported. Conservation in traditional huts (10.1%) was the most preferred *ex-situ* conservation. Another popular method was storage in rooms on bare ground (8.7%) while the least popular *ex-situ* conservation practice was storage in the basket (0.5%) (Table S8). The widely used *in-situ* conservation technique was pre-storage in the mounds for 1-3 months irrespective of the location: Central (34%), Eastern (42.5%), and Western North (23.4%). The gender of the bush farmers had no significant relationship with conservation techniques adopted. The *in-situ* conservation was used by 60.8% female farmers and 58.0% male farmers. On the other hand, *ex-situ* conservation techniques were practiced by 42% male farmers vs. 39.2% female farmers. The most commonly used *in-situ* technique irrespective of the farmer's gender was 1-3 month storage in the mound, 36.7% women vs. 30.9% men . The most commonly used *ex-situ* conservation technique among women was storage in room under bareground (12.5%), while storage in traditional hut (8.8%) was mostly used by men.

3.9. Harvesting frequency and criteria adopted by farmers for estimating time to harvest D. praehensilis *based on farmers' region and gender*

The harvesting frequency significantly varied with farmers' location ($\chi^2 = 64.0$, p (0.05) = 0.000) (Table S9). Double harvesting was the most practiced in the Central (69.2%) and Western North regions (74.1%) while single harvesting was most popular (57.5%) in the Eastern region. The gender of the *D. praehensilis* farmers had also significantly influenced the harvesting frequency ($\chi^2 = 8.8$, p(0.05) = 0.012) (Table S9). Double harvesting was the most practiced irrespective of the farmer's gender: 72.5% females and 58.4% males .

Farmers cultivating *D. praehensilis* adopted different criteria to determine when the tubers are mature and ready for harvesting (Table S9). Significant relationship ($\chi^2 = 124.5$, p (0.05) = 0.000) was observed between the farmers' region and the criteria used for estimating time to harvest. Time from planting to harvest was the most used criterion in Central (39% of respondents) and Eastern regions (35% of respondents). Approximately 35% of the farmers across the surveyed regions reported that browning of the leaves and time of planting to harvesting are the major criteria they use in determining the maturity of the tubers. Approximately 24% believe that cracks in mounds or ridges are a sign of maturity, ~7% used senescence of inflorescence to determine the maturity of tubers, while 3.2% adopted wilting of vine tips to determine the tuber maturity. There was no significant relationship between the farmers' gender and the criteria for estimating the time to harvest ($\chi^2 = 3.0$, p (0.05) = 0.56). Time from planting to harvest was the major criteria adopted by both females (36.7%) and males (34.7%), while the least used was wilting of vine tips, females (1.7%) and males (3.8%).

3.10. Pratices used in D. prahensilis *production based on regions and farmers' gender*

No significant relationship was established between the farmers' region and the adopted cropping system in *D. praehensilis* cultivation ($\chi^2 = 4.6$, p (0.05) = 0.10) (Table S9). The intercropping was predominant (89.2%). Sole cropping accounted for only 10.8% of *D. praehensilis* farms (Table S9). The same trend was reported across the regions with 93.1, 82.5, and 91.1% of intercropped farms in Central, Eastern, and Western North regions, respectively (Table S9). The relationship between the farmers' gender and the cropping system was not significant ($\chi^2 = 1.14$, p (0.05) = 0.58) (Table S9). About 90.2% males and 86.7% females practiced intercropping system for *D. praehensilis* cultivation, while 9.8% males and 13.3% females practiced the sole cropping system.

More than 80% of *D. praehensilis* farms were under cocoa plantations. Remaining farms (~14%) were grown with cassava, plantain, cocoyam, banana, maize, and vegetables.

The majority (of ~14%) of the *D. praehensilis* farmers who intercropped bush yam with crops other than cocoa plantations (cassava, cocoyam, banana, maize, and vegetables) used live stakes in supporting the crops for proper foliar and tuber development (Table S9). The most popular tree species that are used as live stakes were *Newbouldia laevis* (Neem, Sesemansa or Nyabatso), mahogany, *Albizia zygia, Milicia excels, Gliricidia sepium* (Gliricidia), and *Leucaena leucocephala* (Leucanea).

There was a significant relationship between the farmers' region and sources of planting materials/yam seeds ($\chi^2 = 31.9$, p (0.05) =0.000) (Table S9). Exchange with neighbouring farmers was the most practiced means of getting *D. praehensilis* planting materials across the three regions: Central (83%), Eastern (74.2%), and Western North (55.1%). The farmer's gender had no influence on how they were acquiring yam seeds ($\chi^2 = 3.94$, p (0.05) = 0.21) (Table S9). For instance, 72.5% male and 65.8% female farmers practiced mostly exchange from the neighbouring farmers to acquire germplasm. In general, the

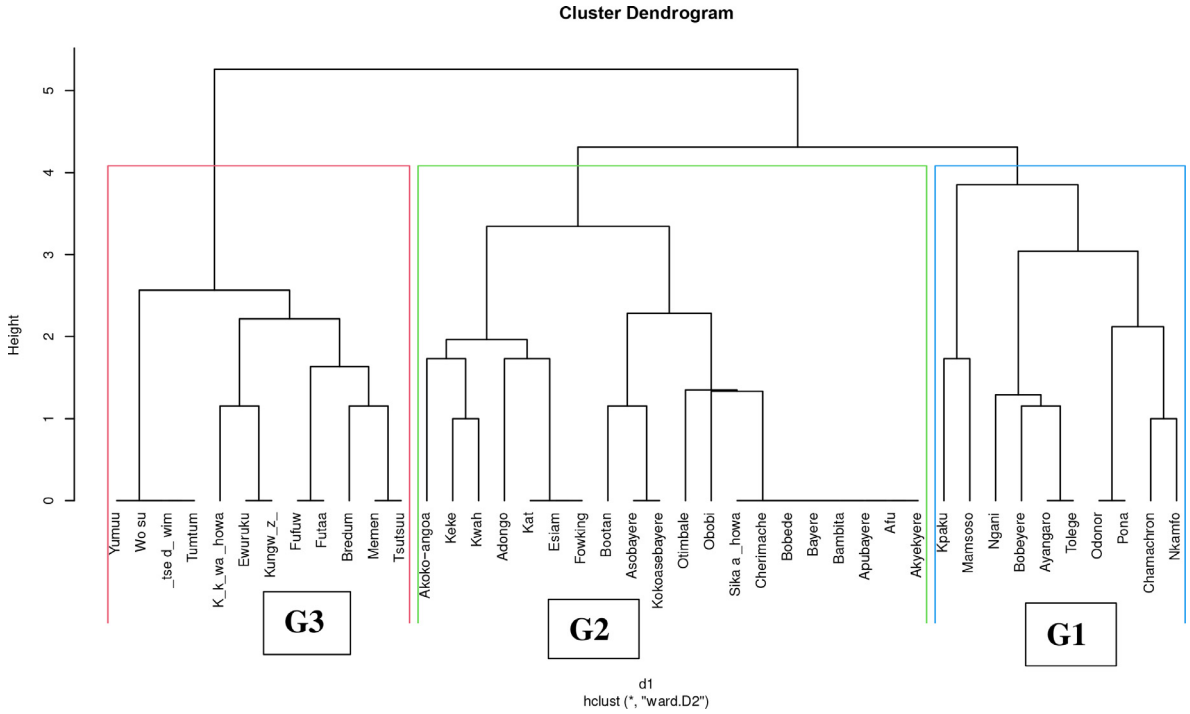

Fig. 3. Dendrogram classifying *D. praehensilis* morphotypes from Ghana into 3 groups (red (G3), green (G2) and blue (G1)) based on agronomic and culinary traits using ward method.

main source of *D. praehensilis* planting materials in Ghana was the exchange with neighboring farmers (70.5%), while the markets and collection in wild environments accounted for 27.7 and 1.8%, respectively (Table S9).

A significant correlation was observed between the farmers' region and the final utilization/destination of harvested *D. praehensilis* ($\chi^2 = 25.8$, p (0.05) = 0.000) (Table S9) . Across the studied regions, the majority of farmers used *D. praehensilis* as source of food (for direct family consumption): Central (98.7%), Eastern (83.3%), and Western North (94.3%). On the other hand, 15.8% farmers from Eastern, 5.1% from Western North, and 1.3% among Central region farmers utilized harvested *D. praehensilis* yams for commercial purpose, while only ~1% among farmers used *D. praehensilis* as source of medicine. The farmer's gender had no relationship with the final destination of harvested *D. praehensilis* ($\chi^2 = 0.95$, p (0.05) = 0.62) (Table S9). Approximately 93.0% of both female and male farmers used harvested *D. praehensilis* for direct food consumption, while ~7.0 female and 6.0% male farmers utilized the crop for commercial purpose, and only ~1% among males utilized it for medicinal purpose.

3.11. Relationship among collected Ghanaian's D. praehensilis *morphotypes*

The relationship for the culinary and agronomic characteristics among the 42 collected *D. praehensilis* morphotypes is presented in Figure 3. Cluster analysis partitioned the morphotypes into three groups (Figure S3). Group 1 (G1) comprised of morphotypes with high yield, high flowering rate, good taste, no/less tuber flesh oxidation (no or less change in tuber flesh colour), tolerant to pests and diseases but late maturing with short tuber shelf-life, and hard tuber flesh texture. G2 comprised of morphotypes with high yielding ability, high flowering rate, good taste, and smooth tuber flesh texture, but late maturing with high tuber flesh oxidation, presence of thorns on tubers and short tuber shelf-life. G3 comprised of morphotypes with high yielding potential and high flowering rate, tolerant to pests and diseases but late maturing with poor taste, hard tuber flesh texture, and high tuber flesh oxidation, presence of thorns on tubers, and short shelf-life.

4. Discussion

4.1. Diversity and distribution of D. praehensilis *in studied regions of Ghana*

Tuber flesh colour was the only criterion used by Ghanaian farmers in grouping *D. praehensilis* genotypes. In total across the surveyed regions, 42 *D. praehensilis* morphotypes were identified and grouped into seven (7) classes based on the tuber flesh colours (white, yellow, red, black, purple cream, and brown). This study reported 42 morphotypes than three (3) morphotypes (*Otim*, *Odonor* and *Kat*) previously reported by Aboagye et al. [14]. We also identified three (3) additional flesh

colour classes (purple, cream, and brown), making seven, compared to only 4 flesh colour classes reported in Togo [11]. This study has, therefore, found more *D. praehensilis* morphotypes in Ghana than reported in Togo.

The diversity of 42 *D. praehensilis* morphotypes named by the farmers across the 23 surveyed villages may be facing the challenges of over- or under-estimation, since the same local name may be given to different morphotypes (synonyms), or different local names may be given to the same morphotype (homonyms) [19]. It is not certain that all the 42 morphotypes of the *D. praehensilis* collected from the study areas were genetically distinct. For instance, Adewumi et al. [20] reported the possibility of duplication in *D. praehensilis* planting materials as a result of the linguistic polymorphism in the Central region of Ghana. This possibility of duplication has also been reported for Guinea yam genotypes in Ghana [21], in Ethiopia [22], and Benin [23], and in *D. dumetorum* [18, 24]. Detection of duplicate morphotypes using phenotypic and molecular characterization is a prerequisite in the identification of true-to-type morphotypes for efficient management of crop genetic resources [20]. This study encourages further studies using molecular markers to complement the morphological *D. praehensilis* diversity analysis in Ghana.

We employed different diversity indices to assess the *D. praehensilis* diversity in the study areas. Shannon diversity index, equitability and Margalef species richness indices revealed moderate genetic diversity among *D. praehensilis* morphotypes across the surveyed regions. This could be attributed to favourable agro-ecological conditions such as high and well-distributed rainfall patterns and moderate relative humidity which are conducive for growth and development of most yam species, including *D. praehensilis*. There is also a high diversity in varietal preferences which partly explains the large number of morphotypes among bush yam farmers in Ghana. Moderate diversity of *D. praehensilis* was previously reported in Togo, a neighbouring country to Ghana, where different morphotypes were recorded [11, 25]. Selection or breeding of clones combining multiple traits is, therefore, a valuable option in promoting wide and commercial production of *D. praehensilis* yam in Ghana. These superior clones could be competitive and easier to multiply (as they are limited in number) compared to current clones and, thus, benefit a high uptake among Ghanaian farmers.

This study revealed that positive relationships exist between the number of used *D. praehensilis* morphotypes and some farmers' socio-demographic characteristics such as farm size, years of farming experience, family size, and education level. Having large farm and family sizes, farmers are offered the opportunity to test multiple options than those with limited plot size and family labour. Besides, *D. praehensilis* being mostly intercropped with cash crops such as cocoa, it is logical that they are found in larger plots. As it is difficult to find sufficient seed of a single yam clone as claimed by Ghanaian farmers, this could have explained the multitude of morphotypes when farmers grew *D. praehensilis* on large farms. Long experience in *D. praehensilis* cultivation could have enabled the farmers to familiarize with the promising morphotypes combining good adapation and tuber quality traits, while the education level could have increased awareness on efficient cultivation techniques and marketing opportunity of the practiced crop. Results of this study corroborate the finding of Andriamparany et al. [4] who reported a high influence of some socio-economic characteristics such as family size and education level on production and use of wild yams and medicinal plants in south-western Madagascar.

4.2. Challenges associated with production, marketing and seed systems of D. praehensilis *in Ghana*

From this study, poor culinary quality traits (poor post-harvest shelf-life, fast tuber flesh oxidation, poor tuber texture, and poor taste) were the major challenges affecting the production and marketing of *D. praehensilis* in Ghana. These challenges make farmers abandon the production of *D. praehensilis* for other yam species such *D. rotundata* (mainly Puna, Dente, Punjo, and Labroko varieties) and *D. alata* (Afase variety) which are good in making preferred recipes such as yam balls, fufu, yam chips, and mashed yam (mpotonpoto). Pitalounani et al. [11] also reported the influence of poor culinary quality on the abandonment (and production decline) of *D. praehensilis* in Togo. Poor culinary quality was also one of the factors responsible for the genetic erosion of *D. rotundata* and *D. cayenensis* as reported by Dansi et al. [26]. Our study results helped identify varieties (morphotypes) with good culinary quality and agronomic traits which could be the starting point for selecting most suitable *D. praehensilis* clones to promote wide cultivation and use in genetic resource conservation and improvement programs. By identifying traits constraining extensive production of this yam species, our study would also guide breeding programs to develop adapted novel yam varieties that could meet Ghanaian farmer's expectations.

Inadaptability to poor soil fertility and dry areas was also mentioned as a factor causing the decline in the *D. praehensilis* production and utilization in Ghana. According to the farmers, *D. praehensilis* requires more water and soil fertility for optimum growth, but with the irregular rainfall observed in some of the cultivation areas, especially in the Central region, the diversity of this crop has dropped. Bush burning and increased frequency of bush fires reported by farmers had also contributed to the loss of *D. praehensilis* diversity in the studied areas. During dry season, some farmers adopt the bush burning to trap bush meats in the forest areas where *D. praehensilis* is predominant. A diversity preservation program should, therefore, discourage bush fire to slow down the *D. praehensilis* genetic erosion. A clear policy on inventory, identification, research, and conservation of *D. praehensilis* germplasm should be formulated by relevant decision-makers in Ghana to serve as basis for the promotion of this underutilized, yet important species of yam.

From this study, most of the *D. praehensilis* farmers obtained their planting materials through the informal seed exchanges with neighbouring farmers. This encourages the distribution of *D. praehensilis* planting materials across the regions, and hence, result in wide distribution and concentration of some *D. praehensilis* morphotypes such as *Akyekyere, Asɔbayere, Tumtum, Kat, Kokoasobayere, Mamsoso*, and *Ngani* across the surveyed areas. Seed yams that serve as planting materials have been reported by the farmers to be inadequate and insufficient due to lack of appropriate storage facilities which results in

the loss of a large amount of planting materials before the next planting season and lack of the market for seed yam supply. There is no seed production system for bush yam in Ghana. Mini-set and aeroponic seed yam production techniques can be used to develop viable seed yam supply systems for multiplying and distributing the seed yams of superior clones to the farmers. These techniques have been successfully employed in developing seed yam supply systems for white yam (*D. rotundata*) [27]. Pests such as beetles, grasshoppers, yam beetles, rodents, and caterpillars are associated with *D. praehensilis* in this study area and contributed to the production decline of *D. praehensilis* and abandonment of most susceptible morphotypes in the study areas. Larvae of *Lilioceris latipennis* have been reported to cause serious destruction to the growing shoot apex of the *D. praehensilis* plant [12]. Screening for susceptibility to insect and disease attacks in *D. praehensilis* using morphological and molecular tools will provide more insight into insect pest and disease resistance in *D. praehensilis*.

4.3. Farmers' varietal preferences for D. praehensilis *clones in Ghana*

A farmer's preference criterion plays an important role in guiding breeding and crop improvement programs' priorities and facilitates improved varieties adoption rates by farmers [28]. According to the farmers, the demand for *D. praehensilis* as a staple food is very low among the rural dwellers due to its late maturity as a result of prolonged dormancy and poor culinary quality traits. This expresses the need of the farmers to have cultivars with good agronomic traits (early maturity, high in-soil storage aptitude, large tuber size, high productivity, insect pest and disease tolerance) and culinary quality traits (good taste, smooth tuber flesh texture, good tuber flesh colour, high tensile strength, and good aroma). *D. praehensilis* was reported to be a high yielding yam species in Ghana. This corroborates the report of high yielding ability of *D. praehensilis* in Togo [11]. Pitalounani et al. [11] reported the need to improve its culinary tuber quality traits to enhance its market demands as well as its cultivation. Application of high throughput phenotyping and cost-effective near-infrared reflectance spectroscopy (NIRS) that has been reported to be useful in screening and detecting physico-chemical properties linked to tuber flesh quality traits in *D. alata* and *D. rotundata* [29-31] can be employed in *D. praehensilis* to select desirable cultivars with good culinary attributes. Since the market opportunity of *D. praehensilis* is low compared to popular yam species such as *D. alata* and *D. rotundata*, its improvement program to enhance culinary quality and other traits should be gradual. The first stage would be collecting and screening existing materials for both agronomic and culinary traits with active participation of *D. praehensilis* farmers. Superior clones would then be extensively multiplied using rapid propagation/regeneration techniques (such as mini-set, aeroponic, semi-autotrophic hydroponic (SAH) technology, and others adequate yam seed multiplication) to control seed shortage as recognized by farmers. *D. praehensilis* farmers' support structures should be parallelly identifying market opportunities (i.e, export, processing, etc.) for probable high production volumes from promoting the species. It is only when the production has increased, the market is well-developed and the seed system established; then preliminary and cost-effective breeding activities could be initiated for *D. praehensilis* yam in Ghana and West Africa.

4.4. Utilization, cultural practices, and conservation techniques of D. praehensilis *in Ghana*

In this study, geographical regions had high influence on the practices used in *D. praehensilis* production and utilization. For all the villages surveyed, *D. praehensilis* was more exploited for subsistence than commercial purposes. Like other yam species such as white Guinea (*D. rotundata*) and water (*D. alata*) yams, the tubers of bush yam are mainly consumed boiled (Ampesi) with vegetable soups. According to most farmers surveyed, bush yam can also be pounded into fufu and consumed with soups such as light, palmnut, and groundnut soups as for other cultivated yam species. In the off-season (lean season) when the popularly cultivated yams (*D. rotundata* and *D. alata*) are out of stock, *D. praehensilis* has been used in filling hunger gaps by the local farmers [32]. *D. praehensilis* was also reported as source of valuable starch due to its high solubility, high density, and high water absorption capacity [33]. *In situ* conservation technique is mostly preferred by *D. praehensilis* farmers in the majority of the surveyed villages because of the belief and perception that such conservation method preserves the culinary qualities of the tubers. Several other conservation techniques (Table S8) have been mentioned by the farmers in the surveyed areas. Tostain et al. [32] reported the conservation of *D. praehensilis* in agroforestry under mango and neem trees (*Azardiracta indica*) as live stake. To enhance the production and cultivation of *D. praehensilis* in Ghana, there is a need to screen this crop for all the conservation techniques mentioned by the farmers and select those that can be effective in preserving *D. praehensilis* for longer periods.

From this study, Ghanaian farmers generally cultivate *D. praehensilis* in cocoa plantations. *Dioscorea praehensilis* is able to survive in the cocoa plantations due to its ability to form cataphyll stems and branches that climb cocoa trees until it reaches sunlight conditions and forms a leaf crown that covers the canopy vegetation [12]. Some farmers also intercrop it with other staples such as cassava, cocoyam, and sweet potatoes. *D. praehensilis* has been reported to be often associated with *D. dumetorum* in a study conducted in Benin [32]. In this study, some farmers also reported the sole cultivation of *D. praehensilis* like other cultivated yam species in the surveyed villages.

According to the farmers in the surveyed villages, the common cultural practices include mounding, staking, and weeding. Farmers also reported the use of live stakes such as cocoa trees, mahogany, and some local trees in supporting the stems of the crop because of its crawling and climbing nature. This allows *D. praehensilis* to climb to the top of the trees to receive sunlight to enhance its tuber initiation and development [34]. Staking elevates shoots above the soil surface, permits better leaf exposure, and reduces mutual shading of leaves, thus enhancing the photosynthetic capacity of the plant and ultimately leads to improved yield. Live staking, where vines of the yams are elevated up from the ground level on growing

trees, has many advantages over dead stakes. Farmers reported that live staking is especially useful for *D. praehensilis* which can remain in one place for decades, giving one early and late harvest per year.

4.5. Role of farmers' gender and age categories on the diversity and practices used in D. praehensilis *production in Ghana*

No significant effect of the farmers' gender and age was found on the diversity and practices engaged in *D. praehensilis* farming. This is an indication that gender and age play no role in the selection of this crop varieties, cultivation and conservation techniques and utilization in Ghana. Besides, there was equal participation of men and women, young and old in the production of bush yam across the surveyed regions. This supports the findings of Haleegoah [35] who reported that the roles which were regarded as men activities in yam production system such as seed yam cutting, planting and field maintenance are now currently performed by women and youths. Traditionally, female spouses did not own yam farms, but currently, male spouses now allocate portion of yam farm to females for seed yam production [35]. Although more men were involved in *D. praehensilis* as a result of its association with a male crop (cocoa); behaviours, perceptions and practices were not influenced by the farmer's gender.

5. Conclusions

This study revealed a moderate *D. praehensilis* diversity across the surveyed regions in Ghana. The diversity and distribution were high in the Eastern and Western North regions compared to the Central region. Farmers preferred early maturing and high productive varieties with good tuber size and tolerance to insect pests and diseases and good culinary quality traits. This study showed that poor culinary tuber quality traits were the major cause for declining production and abandonment of some *D. praehensilis* morphotypes in Ghana. This study also revealed that the utilization of *D. praehensilis* is primarly for filling the hunger gaps in lean seasons and that farmers rely on informal exchange for planting materials. The establishment of a genetic resource conservation program to maintain diversity among *D. praehensilis* morphotypes and gradual development of an effective clonal selection, seed delivery system and breeding programs to meet farmers' preference criteria could increase *D. praehensilis* production and profitability in Ghana.

Author contributions

Conceptualization, A.S.A., K.J.T., P.A.A.[1], and P.A.A.[2]; Methodology, A.S.A.; Data analysis, A.S.A., P.A.A.[2], S.A.; Supervision, K.J.T., P.A.A.[1], P.A.A.[2], M.O.A.; Writing-original draft, A.S.A.; Manuscript review and editing, A.S.A., P.A.A.[2], M.O.A., J.M.M., P.A.A.[1], K.J.T., S.A. All authors read and agreed on the published version of the manuscript.

Declaration of competing interest

The authors declare no conflict of interest.

Funding

The African trans-regional cooperation through academic mobility (ACADEMY) project, reference number 2017-3052/001-001, funded by the European Union Commission and African Union within the framework of "Intra Africa Mobility Scheme" granted a Ph.D. scholarship to the first author to study at the University of Cape Coast, Ghana.

We also acknowledge funding support from the Bill and Melinda Gates Foundation (BMGF) through the AfricaYam project of the International Institute of Tropical Agriculture (IITA) (OPP1052998).

Acknowledgement

Authors acknowledge the provision of research fund to the first author by the ACADEMY project. Directorate of Research, Innovation, and Consultancy of the University of Cape Coast is also acknowledged for managing the ACADEMY project. We appreciate all the local bush yam farmers and agricultural extension service personnel at the three regions surveyed in Ghana. We are grateful to local authorities in all surveyed villages for facilitating data collection. We also thank Daniel Nana-Yaw Gyebi and Azure Kwanema Sanleri for their assistance during the course of the surveys.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2021.e00808.

References

[1] R.S. Couto, A.C. Martins, M. Bolson, R.C. Lopes, E.C. Smidt, J.M.A. Braga, Time calibrated tree of *Dioscorea* (Dioscoreaceae) indicates four origins of yams in the Neotropics since the Eocene, Bot. J. Lin. Soc. 188 (2018) 144–160, doi:10.1093/botlinnean/boy052.

[2] E.J. Price, M. Drapal, L. Perez-Fons, D. Amah, R. Bhattacharjee, B. Heider, ..., P.D. Fraser, Metabolite database for root, tuber, and banana crops to facilitate modern breeding in understudied crops, The Plant J 101 (2020) 1258–1268.

[3] J.E. Obidiegwu, E.M. Akpabio, The geography of yam cultivation in southern Nigeria: Exploring its social meanings and cultural functions, J. Ethn. Foods 4 (2017) 28–35.

[4] J.N. Andriamparany, K. Brinkmann, V. Jeannoda, A. Buerkert, Effects of socio-economic household characteristics on traditional knowledge and usage of wild yams and medicinal plants in the Mahafaly region of south-western Madagascar, J. Ethnobiol. Ethnomed. 10 (2014) 1–21, doi:10.1186/1746-4269-10-82.

[5] H. Sato, The potential of edible wild yams and yam-like plants as a staple food resource in the African tropical rain forest, Afr. Study Monogr. 26 (2001) 123–134.

[6] H. Sato, A brief report on a large mountain-top community of *Dioscorea praehensilis* in the tropical rainforest of Southeastern Cameroon, Afr. Study Monogr. 33 (2006) 21–28.

[7] E. Hildebrand, S. Demissew, P. Wilkin, Local and regional landrace disappearance in species of *Dioscorea* L. (Yams) in Southwest Ethiopia: causes of agrobiodiversity loss and strategies for conservation, in: J.R. Stepp, F.S. Wyndham, R.K. Zarger (Eds.), Ethnobiology and biocultural diversity, Proceedings of the 7th International Congress of Ethnobiology and Biocultural Diversity, Athens, Georgia, USA, October 2000, pp. 678–695.

[8] A. Dansi, A. Orobiyi, M. Dansi, P. Assogba, A. Sanni, K. Akpagana, Sélection de sites pour la conservation *in situ* des ignames sauvages apparentées aux ignames cultivées : cas de *Dioscorea praehensilis* au Bénin, Int. J. Biol. Chem. Sci. 7 (2013) 60–74, doi:10.4314/ijbcs.v7i1.6.

[9] N. Scarcelli, S. Tostain, C. Mariac, C. Agbangla, O. Da, J. Berthaud, J.L. Pham, Genetic nature of yams (*Dioscorea* sp.) domesticated by farmers in Benin (West Africa), Gen. Res. Crop Evol. 53 (2006) 121–130, doi:10.1007/s10722-004-1950-5.

[10] N. Scarcelli, P. Cubry, R. Akakpo, A.C. Thuillet, J. Obidiegwu, M.N. Baco, E. Otoo, B. Sonké, A. Dansi, G. Djedatin, C. Mariac, M. Couderc, S. Causse, K. Alix, H. Chaïr, O. François, ..., Y. Vigouroux, Yam genomics supports West Africa as a major cradle of crop domestication, Sci. Adv. 5 (2019), doi:10.1126/sciadv.aaw1947.

[11] W.E.N. Pitalounani, M. Dourma, K. Wala, Y. Woegan, A. Gbogbo, K. Batawila, A. Dansi, K. Tozo, ..., K. Akpagana, Agrodiversity, peasant management and importance of *Dioscorea praehensilis* Benth. In the Subhumid Zone of Togo, Afr. J. Food, Agric., Nutr. Dev. 17 (2017) 12455–12475, doi:10.18697/ajfand.79.15930.

[12] B. Di Giusto, E. Dounias, D.B. McKey, Facing herbivory on the climb up: Lost opportunities as the main cost of herbivory in the wild yam *Dioscorea praehensilis*, Ecol. Evol. 7 (16) (2017) 6493–6506, doi:10.1002/ece3.3066.

[13] FAO FAOSTAT. Available online: http://www.fao.org/faostat/en/#data/QL (accessed on 8th December 2020).

[14] L.M. Aboagye, D. Nyadanu, M.O. Opoku-Agyeman, S.K. Owusu, E. Asiedu-Darko, Survey of diversity and production of yams in four communities in Southern Ghana, Afr. J. Agr. Res. 10 (2015) 2453–2459, doi:10.5897/ajar2014.9468.

[15] A Orobiyi, A. Dansi, P. Assogba, L.Y. Loko, M. Dansi, R. Vodouhè, A. Akouegninou, ..., Sanni, A. Chili, (*Capsicum annuum* L.) in southern Benin: production constraints, varietal diversity, preference criteria and participatory evaluation, Int. Res. J. Agric. Sci. Soil. 3 (2013) 107–120.

[16] F. Kemausuor, J.O. Akowuah, E. Ofori, Assessment of Feedstock Options for Biofuels Production in Ghana, J. Sustain. Bioenergy Syst. 3 (2) (2013) 119–128, doi:10.4236/jsbs.2013.32017.

[17] I. Etikan, R. Alkassim, S. Abubakar, Comparision of snowball sampling and sequential sampling technique, Biometric. Biostatist. Int. J. 3 (1) (2016) 55.

[18] F.A. Adigoun-Akotegnon, H. Adoukonou-Sagbadja, C. Fadinan, A. Tchougourou, M. Agassounon-Tchibozo, C. Ahanhanzo, Diversity, distribution, and ethnobotanical importance of cultivated and wild African trifoliate yam [*Dioscorea dumetorum* (Kunth) Pax] in Benin, Genet. Resour. Crop Evol. 66 (3) (2019) 659–683, doi:10.1007/s10722-019-00739-z.

[19] H. Adoukonou-Sagbadja, C. Wagner, A. Dansi, J. Ahlemeyer, O. Daïnou, K. Akpagana, F. Ordon, ..., W. Friedt, Genetic diversity and population differentiation of traditional fonio millet (*Digitaria spp.*) landraces from different agro-ecological zones of West Africa, Theor. Appl. Genet. 115 (7) (2007) 917–931, doi:10.1007/s00122-007-0618-x.

[20] A.S. Adewumi, K.J. Taah, P.A. Asare, M.O. Adu, P.A. Agre, Assessment of Genetic Diversity of *Dioscorea praehensilis* (Berth.) collected from central region Ghana using simple sequence repeat (SSR) markers, ES J. Agri. Curr. Res. 1 (1) (2020) 1005.

[21] E. Otoo, R. Akromah, M. Kololesnikova-Allen, R. Asiedu, Ethno-botany and morphological characterisation of the yam pona complex in Ghana, in: Afr. Crop Sci. Conf. Proc, 9, 2009, pp. 407–414.

[22] M. Tamiru, H.C. Becker, B.L. Maass, Diversity, distribution and management of yam landraces (*Dioscorea spp.*) in Southern Ethiopia, Genet. Resour. Crop Evol. 55 (1) (2008) 115–131, doi:10.1007/s10722-007-9219-4.

[23] Y.L. Loko, A. Dansi, M. Dansi, R. Vodouhe, A. Sanni, Indigenous knowledge and management of Yam (*Dioscorea cayenensis – Dioscorea rotundata* Complex) pests and diseases in Northern Benin, Int. J. Appl. Biol. Pharm. 4 (3) (2013) 276–279.

[24] J. Laly, D.S.J.C. Gbemavo, A.A. Gbaguidi, I. Dossou-Aminon, A. Dansi, *Dioscorea dumetorum* (Kunth) Pax, a neglected and underutilized yam species in Benin: folk classification and post-harvest conservation, Genet. Resour. Crop Evol. 66 (4) (2019) 965–979, doi:10.1007/s10722-019-00762-0.

[25] A. Gnamkoulamba, W. Tchala, S. Tostain, I. Soumana, Le bayere, une forme domestiquée de *Dioscorea praehensilis* dans la prefecture de Wawa (Togo), Ann. Sci. Agron. 3 (2) (2002) 45–53, doi:10.4314/asab.v3i2.43382.

[26] A. Dansi, H. Dantsey-Barry, I. Dossou-Aminon, E.K. Kpenu, A.P Agré, Y.D. Sunu, K. Kombaté, Y.L. Loko, M. Dansi, P. Assogba, R. Vodouhè, Varietal diversity and genetic erosion of cultivated yams (*Dioscorea cayenensis* Poir - *D. rotundata* Lam complex and *D. alata* L.) in Togo, Int. J. Biodivers. Conserv. 5 (2) (2013) 223–239, doi:10.5897/IJBC12.131.

[27] B.A. Aighewi, R. Asiedu, N. Maroya, M. Balogun, Improved propagation methods to raise the productivity of yam (*Dioscorea rotundata* Poir.), Food Secur. 7 (4) (2015) 823–834, doi:10.1007/s12571-015-0481-6.

[28] Z. Fiacre, A.S. Hubert, A. Léonard, V. Raymond, A. Corneille, Quantitative analysis, distribution and traditional management of pigeon Pea [*Cajanus cajan* (L.) Millsp.] Landraces' diversity in Southern Benin, Eur. Sci. J. 14 (9) (2018) 184–211 2018, doi:10.19044/esj.2018.v14n9p184.

[29] V. Lebot, R. Malapa, Application of near infrared reflectance spectroscopy for the evaluation of yam (*Dioscorea alata*) germplasm and breeding lines, J. Sci. Food Agric. 93 (7) (2013) 1788–1797, doi:10.1002/jsfa.6002.

[30] O.E. Alamu, M. Adesokan, B. Maziya-Dixon, Calibration development for nutritional evaluation of Yam (*Dioscorea sp.*) using Near-Infrared Reflectance Spectrophotometry (NIRS), Cogent Chem 5 (1) (2019) 1–13, doi:10.1080/23312009.2019.1565623.

[31] E.O. Alamu, M. Adesokan, A. Asfaw, B. Maziya-dixon, Effect of sample preparation methods on the prediction performances of near infrared reflectance spectroscopy for quality traits of fresh Yam (*Dioscorea spp*), Appl. Sci. 10 (2020) 6035, doi:10.3390/app10176035.

[32] S. Tostain, T. Allomasso, N. Sokpon, Conservation de l'igname sauvage *Dioscorea praehensilis* dans les forêts sacrées du département de l'atlantique (sud du Bénin) et dans les jardins de cases., Ann. Agron. Sci. 4 (1) (2002) 55–72.

[33] S. Songuimondenin, K.T. Martin, B. Siaka, K.K. Appolinaire, K.K. Hubert, K.E.J. Parfait, Functional properties of flours from fresh and boiled wild Yam *Dioscorea praehensilis* tubers, Advances in Research 17 (3) (2018) 1–13, doi:10.9734/air/2018/45146.

[34] R. Dumont, A. Dansi, P. Vernier, J. Zoundihèkpon, *Biodiversity and Domestication of Yams in West Africa Traditional Practices Leading to Dioscorea Rotundata Poir*. Editor, David Manley, CEMAGREF, CIRAD, IFREMER, INRA, IPGRI, 2006 ISBN (CIRAD): 978-2-7592-0149-5. 2006. https://doi.org/10.1017/S0014479707005649

[35] J.A.S Haleegoah, Changing gender roles in seed yam production among smallholder farmers in Ghana: implications for food security, 3rd Global Food Security, Food Safety & Sustainability Conference:, May 2018.

[36] S. Wei, R package "corrplot": Visualization of a Correlation Matrix (Version 0.84)., Available from https://github.com/taiyun/corrplot. (2017).

[37] Ø. Hammer, D.A. Harper, P.D. Ryan, PAST: Paleontological statistics software package for education and data analysis, Palaeontologia electronica 4 (1) (2001) 9.
[38] M. Maechler, et al., Cluster Analysis Basics and Extensions. R package version 2.1.0., Available online (2019).
[39] R Development Core Team, R: A Language and Environment for Statistical Computing., R Foundation for Statistical Computing:Vienna, Austria, 2019.