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AMPLIFICATION DE LA TRANSITION AGRO- ECOLOGIQUE POUR DES SYSTEMES DE PRODUCTIONS CEREALIERES ET MARAICHES PROFITABLES ET DURABLES DANS LES TERRITOIRES DE L'ATACORA AU BENIN ET DU HOUET AU BURKINA FASO (AGRO-ECO) [View project](#)

Article

Farmers' Preferences for Genetic Resources of Kersting's Groundnut [*Macrotyloma geocarpum* (Harms) Maréchal and Baudet] in the Production Systems of Burkina Faso and Ghana

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Abstract: Pulses play important roles in providing proteins and essential amino-acids, and contribute to soils' nutrients cycling in most smallholder farming systems in Sub-Saharan Africa (SSA). These crops can be promoted to meet food and nutrition security goals in low-income countries. Here, we investigated the status of Kersting's groundnut (*Macrotyloma geocarpum*, Fabaceae), a neglected pulse in West Africa. We explored its diversity, the production systems, the production constraints and farmers' preferences in Burkina Faso and Ghana. Focus groups and semi-structured interviews were conducted in 39 villages with 86 respondents grouped in five sociolinguistic groups. Our results indicated that *Macrotyloma geocarpum* was produced in three cultivation systems: in the first system, farmers grew Kersting's groundnut in fields, mostly on mounds or on ridges; in the second system, farmers grew it as field border; and in the third system, no clear tillage practice was identified. The main constraints of those farming systems included: difficulty to harvest, the lack of manpower and the damage due to high soil humidity at the reproductive stage. A total of 62 samples were collected and clustered in six landraces based on seed coat colors including cream, white mottled with black eye, white mottled with greyed orange eye, black, brown mottled, and brown. All six groups were found in the southern-Sudanian zone whereas only white mottled with black eye and black colors were found in the northern-Sudanian zone. The white mottled with black eye landrace was commonly known and widely grown by farmers. Farmers' preferences were, however, influenced by sociolinguistic membership and the most preferred traits included high yielding, drought tolerance, and resistance against beetles. These findings offer an avenue to develop a relevant breeding research agenda for promoting Kersting's groundnut in Burkina Faso and Ghana.

Keywords: breeding; *Macrotyloma geocarpum*; farmers' preferences; cropping systems; constraints; cultivar development; landraces; conservation; sociolinguistic groups

1. Introduction

To feed the growing population of sub-Saharan Africa (SSA), agricultural productivity needs to be increased significantly and the existing crops diversity strengthened. The crop yield per unit area in SSA is projected to decrease [1], against an estimated increase in demand for cereals of 335% between 2010 and 2050 [2]. Similarly, the demand for legumes is also expected to increase as consumers' income

increases with a likely shift in preferences from cereal grains to more nutrient-dense foods [3]. Moreover, the increasing world population will result in a substantial demand for additional proteins. This growing gap between demand and supply of food and nutrients in SSA will require a major re-focusing on grain legumes, with intensive research and development to identify climate-resilient species and cultivars with improved grain qualities [4]. While 19,500 species of legume were reported [5], only five are grown most widely in sub-Saharan Africa (SSA), namely common bean (*Phaseolus vulgaris* L.), chickpea (*Cicer arietinum* L.), cowpea [*Vigna unguiculata* (L.) Walp.], groundnut (*Arachis hypogaea* L.), and pigeonpea [*Cajanus cajan* (L.) Huth] [6]. Significant research and development work has been done in the past decade on those grain legumes through collaborative bilateral and multilateral projects as well as the CGIAR Research Program on Grain Legumes (CRP-GL) [7]. However, the bulk of edible legume species are mostly overlooked by research and development initiatives. Thus, they are often referred to as orphan legume crops. Key orphan legume crops in sub-Saharan Africa include Bambara groundnut [*Vigna subterranean* L. (Verdc.)], Yam bean [*Sphenostylis stenocarpa* (Hoechst ex. A. Rich.) Harms.], Faba bean (*Vicia faba* L.) and Kersting's groundnut (*Macrotyloma geocarpum*).

Kersting's groundnut is an example of an orphan legume crop of West-Africa [8] with a wide spectrum of importance, for both human and animal health. The crop is valuable to human nutrition, particularly in areas where access to animal protein is limited. Its seeds have a high protein content (21.3%) [9], carbohydrate (61.53%–73.3%) and crude fibre (6.2%) [10]. *M. geocarpum* is considered as healthy because its grains contain a very low crude fat (1.0%) and a high concentration in arginine, an amino acid for pediatric growth; the seeds are also a good source of mineral elements such as iron, zinc, calcium and magnesium [9]. This crop can be used for complementary food formulation for children to combat malnutrition [11]. Moreover, it provides substantial incomes for rural population in Benin, Togo, Ghana, and Burkina Faso; its price can hike from CFA 1000 (USD 2) per kg in abundance period to CFA 4000–5000 (USD 8–10) per kg in scarcity period [12,13]. The crop also exhibits several medicinal properties and is used in traditional healthcare by local communities [13–15]. The root system of Kersting's groundnut fixes atmospheric nitrogen and improves the quality and structure of soils [16]. With climate variability and the occurrence of prolonged drought, *M. geocarpum* is a candidate resilient crop for sustainable cropping systems.

Kersting's groundnut production systems, and landraces diversity were documented in some West-African countries including Benin, Togo, Ghana and Nigeria [12,13,17–19]. These studies showed that its cropping systems varied across its production areas, and revealed the existence of different groups of landraces basing on the seed coat colors. However, in Burkina Faso and Ghana, research on the species has been limited to utilization [14] and the farming systems [17,19]. In both countries, *M. geocarpum* production systems, germplasm collection and breeding objectives have received little attention. In addition, the diversity revealed in those countries—white mottled with black eye and black in Burkina Faso [14] and white mottled with black eye, black, and brown mottled in Ghana [16,17]—is less than the diversity reported in other countries such as Benin and Togo, where authors found five landraces: white, white mottled with black eye, white mottled with yellow eye, black, and red [12]. This knowledge discrepancy/complementarity needs to be highlighted when we seek to promote Kersting's groundnut production and its genetic improvement in those countries. In other words, the identification of farmers' preferred traits is useful for breeders in developing varieties and for extension agents in appropriate choice of varieties to be popularized [20]. Furthermore, knowledge on production systems and the rationale driving farmers' practices are key requirements for guiding successful variety introduction [21]. In the production systems of Burkina Faso and Ghana, we inquire about how Kersting's groundnut production system organized, and the factors constraining or influencing its production. How does the crop diversity vary across agroecological zones and how is it managed by sociolinguistic groups? Furthermore, what are the preferred traits of farmers and how are they correlated to social factors? In this study, we seek to understand the current traditional cropping systems and analyze factors limiting *M. geocarpum* production for its promotion in Burkina Faso and Ghana. We assumed that: i) on-farm practices, constraints and farmers' preferences are influenced

by sociolinguistic group membership; ii) the genetic diversity of Kersting's groundnut in Burkina Faso and Ghana is higher than findings reported by previous studies; iii) the distribution of the crop landraces varies with agro-ecological zones.

2. Materials and Methods

2.1. Study Area

The study was carried out in Burkina Faso and Ghana in West-Africa (Figure 1). Burkina Faso is a landlocked country located between latitudes 9° and 15° N, and longitudes 6° W and 3° E bordered to the north and west by Mali, to the east by Niger and to the south by Benin, Togo, Ghana and Côte d'Ivoire. It has an area of 274,200 km². Ghana is located on the southern coast of West Africa, between latitudes 4°44' N and 11°11' N and longitudes 3°11' W and 1°11' E with an area of 238,540 km² and limited by Burkina to the north. The study was conducted in two agroecological zones of Burkina Faso and Ghana: the northern-Sudanian (or Sudano-Sahelian) and southern-Sudanian (Sudanian). The two agroecological zones included are both characterized by the unimodal rainfall season (Table 1).

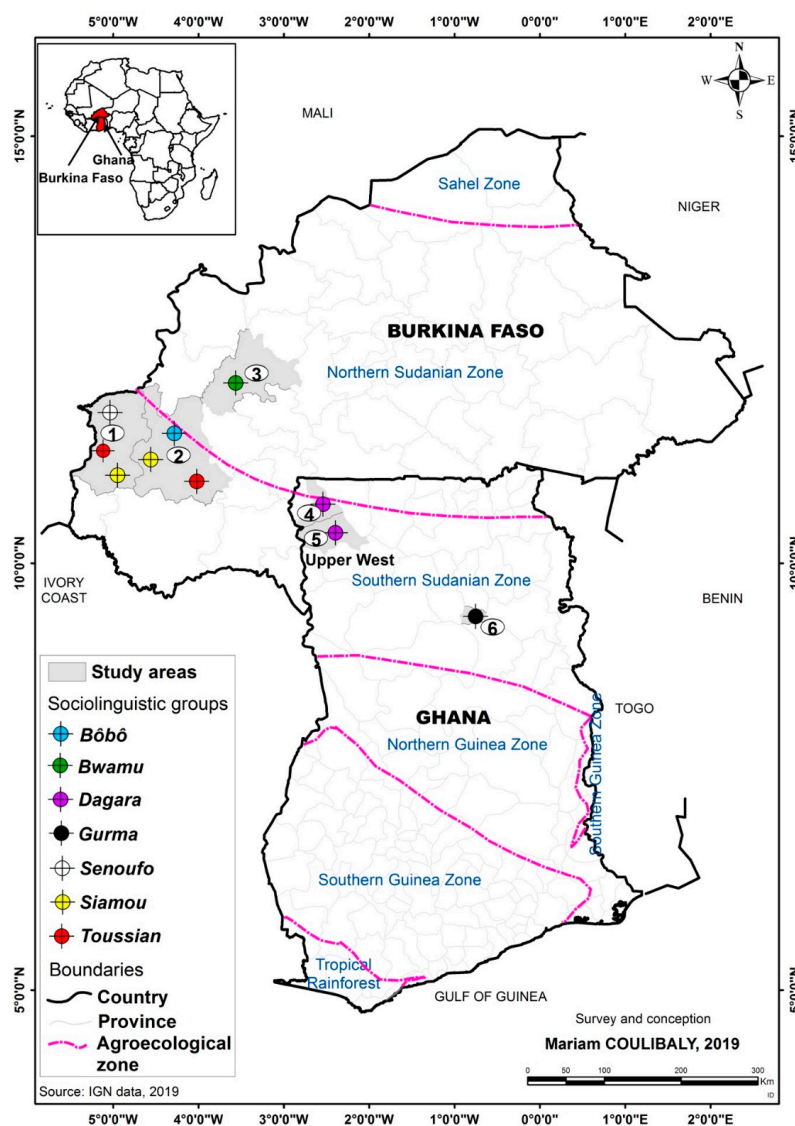


Figure 1. Study areas with agroecological zones in Burkina Faso and Ghana. 1: Kéné Dougou, 2: Houet, 3: Mouhoun, 4: Jirapa Lamboussie, 5: Nadowli, and 6: Tamale Metropolis.

Table 1. Characteristics of southern-Sudanian and northern-Sudanian agroecological zones of Burkina Faso and Ghana.

Country	Agroecological Zone	Latitude	Climatic Condition			Soil Condition		Vegetation	Cropping System	
			Growing Seasons	Rainfall mm/year	Temperature (°C)	Humidity (%)	Texture			Type
Burkina Faso	Northern-Sudanian	11°30'–14°00' N	150 days	700–900	28	75	Gravel	Ferruginous	Savanna with trees or shrubs	Cotton, sorghum, millet, cowpea, groundnut
	Southern-Sudanian	9°00'–11°30' N	150–180 days	900–1200	27	85	Sand-clayey	Feriferous	Semi-deciduous forest	Cotton, yams, cassava, sorghum, millet, maize, rice, cowpea and mangos, citrus, cashew
Ghana	Southern-Sudanian	8°00'–11°30' N	180–200 days	800–1200	28.1	61	Loamy sand granular	Ferruginous	Grassland with few trees	

The northern-Sudanian zone is approximately located between latitudes 14°00' and 11°30' N, and is characterized by an annual precipitation of 600–900 mm. The vegetation in the zone is a savanna with trees or shrubs. This zone is mainly a cotton (*Gossypium hirsutum* L.) production area. Other crops include sorghum [*Sorghum bicolor* L. (Moensch)], millet [*Pennisetum glaucum* (L.) R.Br.], groundnut (*Arachis hypogea*), and cowpea (*Vigna unguiculata*). In the northern-Sudanian zone, Kersting's groundnut production was limited to a few villages represented mainly by the Bwaba linguistic group of the Gur family, and representing 2.1% of the population in Burkina Faso [22].

Moving southwards, the rainfall increases to 900–1200 mm in southern-Sudanian zone located between latitudes 11°30' and 9°00' N in Burkina Faso and between 8°00' and 11°30' N in Ghana. The vegetation is characterized by a savanna with trees or shrubs, sparse forests in Burkina Faso and is made up of grassland with few trees in Ghana. Agriculture in the southern-Sudanian zone is characterized by perennial crops such as mango (*Mangifera indica* L.), citrus (*Citrus* spp.), cashew (*Anacardium occidentale* L.), etc. Farmers in this zone also grow cotton, cowpea, yams (*Dioscorea* spp.), cassava (*Manihot* spp.), sorghum, millet, maize (*Zea mays* L.), and rice (*Oryza sativa* L.). The Bôbô, Senufo, Siamou and Toussian of Burkina Faso and the Gurma and Dagara of Ghana are the main sociolinguistic groups producing and managing Kersting's groundnut in the southern-Sudanian zone. Senufo and Toussian groups are related to the Gur family [23] and represent respectively, 1.4% and less than 0.1% of the Burkina Faso population [22]. The Bôbô group belongs to the Mande language family and represents 1.4% of the population. The Siamou linguistic group was previously declared to belong to the Kru language family (from Ivory Coast and Liberia) [24]. The Siamou group represents 0.1% of the population of Burkina Faso [22]. These people live in the department of Orodara located in Kéné Dougou province. The Dagaaba and Gurma linguistic groups in Ghana belong to the Gur language family [25]. Linguistically, the Dagara are part of the Mole-Dagbani group which represents 16.6% of Ghanaians while the Gurma people represent 5.7% of the Ghanaian population.

2.2. Sampling Strategy and Respondents' Consent

Field trips and collection of ethnobotanical data were carried out from February to May 2018. Semi-structured interviews [26] were conducted with 86 respondents in Burkina Faso and Ghana. In each country, the investigations started by market visits to identify the sources/suppliers of Kersting's groundnut seed sellers and to get growers' contacts. The surveyed localities were identified with the help of extension agents in the regions and communities. We shared the pictures of *M. geocarpum* seeds, pods and plant with the focal points who identified and confirmed the growing areas of the crop in their localities. The chain-referral sampling technique [27], a non-probability sampling technique, was used in both countries to select the respondents. In this sampling, the first contact with the community was selected as a well-known expert; in a subsequent phase, the expert indicated another expert until all the informants in the community were covered. The informant was a grower who knew more about the crop, who used it and grew or used to grow it. In each surveyed locality, we explained the objectives of the study to local authorities and farmers and requested prior informed consent from all participants, and ensured participants' confidentiality by anonymizing their identities in databases and publications.

2.3. Data Collection

One focus group was conducted in each village. Participants included male and female farmers selected based on their willingness to participate in the study. However, in some areas, to eliminate gender dominance in discussions, separate discussions were held with men and women farmers. The focus group discussions provided an insight into the different types of landraces grown, the constraints to Kersting's groundnut production and farmers' major landrace preference criteria. The intent of this study was not to rank farmers' preference criteria but to identify the most important traits farmers seek in a variety at village level. Different seed coat colors were shown to farmers and the questionnaire was used to interview farmers who recognized and grew or used to grow the crop.

In Ghana, the Agriculture technical services and the Savanna Agricultural Research Institute (SARI) agents also assisted the surveyors to identify the respondents in the villages by using the crop pictures and its local names.

The questionnaire was drawn up using Sphinx Plus version 4.5 [28]. For each informant, we recorded personal information about age, gender, sociolinguistic group, education level, occupation, cropland areas and the area allocated for Kersting's groundnut production. During the interviews, the respondents were requested to indicate vernacular names of the plant and the landraces they knew and the landraces they grew. Information regarding the farmers' practices and the constraints to the crop production were also recorded. Other questions were related to the criteria to choose to grow a specific landrace, and the traits of interest for the crop improvement. All interviews were conducted in the respondent's native language to ensure that questions were well understood. Local measurement units named 'tomato box', 'tine' and 'Yoruba plat' were estimated/converted in kg to determine farmers' yield of Kersting's groundnut.

In addition to interviews, seeds collection was organized with farmers who still possessed seeds of *M. geocarpum*. A color-chart was used to better identify the seed coat color and classify samples collected into different phenotypic groups.

2.4. Data Analysis

Statistical analyses of both quantitative and qualitative data were performed using R software version 3.6.1 [29]. Descriptive statistics were used to estimate frequencies, proportions and means for citations, socio-economic variables and Kersting's groundnut diversity data. The study areas and the diversity of Kersting's groundnut across the agroecological zones were analyzed by incorporating the germplasm collection data into a geographic information system framework to map the distribution of Kersting's groundnut diversity using ArcMap software version 10.5.

The varietal diversity analysis was performed using the farmers' knowledge, the landraces they grow and the landraces collected in the study areas. The proportion of citations of each Kersting's groundnut landrace known and landrace grown were estimated and used to calculate ratios for each sociolinguistic group.

The total number of samples per landrace collected in the two agroecological zones was calculated. In addition, ecological models were employed to analyse the level of Kersting's groundnut diversity. Following Magurran [30], we defined landrace diversity as the number of landraces collected in the study area. Based on a simple count of landraces cultivated per farmer, Margalef's and Simpson's diversity indices were computed [30]. Landraces' richness (locally adapted inter-varietal diversity) among the two agroecological zones was compared using Margalef's index (D_{Mg}) as follows:

$$D_{Mg} = (L - 1)/\ln(S)$$

where D_{Mg} stands for the Kersting's groundnut diversity maintained in an agroecological zone by farmers; L is the total number of Kersting's groundnut phenotypic groups or landraces collected from farmers and S the total number of samples collected in an agroecological zone and \ln is the natural logarithm.

The Simpson's index (D) was measured to take into account the number of landraces as well as the relative abundance of each landrace. The following formula was used following Tadesse [31]:

$$D = \sum_{i=1}^n (p_i)^2$$

where p_i , the proportional abundance of the i th landrace = (n_i/N) , n_i is the number of samples for the landrace i and N the total number of samples. As D increases, the diversity decreases; consequently, the sum of the squared proportions was subtracted from 1, $(1-D)$, to express the abundance of each

landrace. The value of this index ranges between 0 and 1; the greater the value, the greater the phenotypic group diversity.

Furthermore, Factorial Analysis of Correspondence (FAC) was performed to assess the relationships between farmers' preferences and sociolinguistic groups. To better understand Kersting's groundnut cultivation systems, the Factorial Analysis of Mixed Data (FAMD) was used to cluster farmers' cropping practices into farming systems. Both analyses were performed using the packages FactoMineR version 2.0 [32] and factoextra version 1.0.6 [33]. Graphs were generated using ggplot2 version 3.2.1 package [34].

3. Results

3.1. Socio-Demographical Characteristics of Respondents

60.47% of the respondents in this study were women. The respondents' age was between 27 and 103 years old with a mean value of 54.31 ± 1.42 . Most of the respondents were illiterate (74.42%) with farming as the main activity (75.58%). Seven sociolinguistic groups were surveyed across the agroecological zones: Bôbô, Senufo, Siamou, Toussian, Gurma, Dagara in the southern-Sudanian zone and the Bwamu in the northern-Sudanian zone. The Dagara and Toussian were the most represented in the study with a proportion of 26.74% each. They were followed by the Bwamu (16.28%) and the Bôbô (12.79%) groups. Other sociolinguistic groups, with less than 10 respondents, included the Senufo (8), Siamou (5) and Gurma (2). They represented 17.44% of the total samples. The socio-demographical characteristics of the respondents are presented in the Table 2.

Table 2. Socio-demographical characteristics of respondents in southern-Sudanian and northern-Sudanian zones of Burkina Faso and Ghana.

Variables	Modalities	Southern-Sudanian	Northern-Sudanian	Total
Number of villages		28	11	39
Number of respondents		72	14	86
Gender (%)	Male	36.11	57.14	39.53
	Female	63.89	42.86	60.47
Age (Years \pm SE)		54.43 ± 1.53	53.71 ± 3.84	54.31 ± 1.42
	<50 years	38.89	28.57	37.21
	≥ 50 years	61.11	71.43	62.79
Marital status (%)	Married	81.94	85.71	82.56
	Widow	18.06	14.29	17.44
Study degree (%)	Illiterate	80.56	42.86	74.42
	Primary school	13.89	21.43	15.12
	High school	5.56	35.71	10.47
Socio-linguistic groups (%)	Bôbô	15.28	0.00	12.79
	Bwamu	0.00	100	16.28
	Dagara	31.94	0.00	26.74
	Toussian	31.94	0.00	26.74
	Others	20.83	0.00	17.44
Socio-professional groups (%)	Farmer	75.58	85.71	76.74
	Other	24.42	14.29	23.26

3.2. Kersting's Groundnut Diversity and Folk Description

The vernacular names used by farmers to identify *M. geocarpum* were relatively different across sociolinguistic groups (Table 3). The folk nomenclature of the crop landraces depended mainly on the farmers' own criteria of describing it. Therefore, the names given by farmers had different meanings to the generic names of the crops. The criterion 'seed coat color' was widely used by farmers (84.88%) to identify Kersting's groundnut different landraces. The identification of the crop was based also on the agronomic properties (33.72%), the seed size (8.14%), the religious utilizations of the crop (5.81%), and the growth habits (3.47%). Farmers' descriptions of *M. geocarpum* referred sometimes to other legume crops, such as Bambara groundnut, because of the underground nature of both crops, and cowpea, because of their similarity in seed coat color (white mottled with black eye) and taste.

Different local names can be assigned to the crop by the same sociolinguistic group. Furthermore, the same name can be used by different groups. For instance, the Toussian group referred to Kersting's groundnut mainly using three different names, such as Gwandjessi, Sidiin and Soonbia. The names Soonbia and Sidiin were also used by Bôbô and Siamou groups, respectively. In addition to these names, the Siamou called the crop Sissi, and the Bôbô used Zaka or Bôn to refer to the crop. The Dagara sociolinguistic group used names such as Sonsuonii and Sonsuolii, while the Gurma group referred to the crop as Susuonu. The Bwamu and Senufo groups, respectively, used Watié and Dougouvougûê as names for the crop.

Table 3. Local names of Kersting's groundnut landraces, farmers' description criteria and their characteristics across sociolinguistic groups in Burkina Faso and Ghana.

Description Criteria and Percentages of Respondents (%)	Vernacular Names	Local Languages	Description
Seed coat color (84.88)	Zaka dimi	Bôbô	Black seed coat color
	Doforo fiman, Dougouma sôssô fiman	Dioula *	
	Sissi, Sidiin	Siamou	
	Dougouvougûê, Davougûê	Senufo	
	Watié	Bwamu	
	Sonsuolii, Sonsuonii	Dagara	
	Zaka flô	Bôbô	White mottled seed color or cowpea seed color
	Doforo yingueni, Dougouma sôssô gueman	Dioula	
	Sissi	Siamou	
	Watié	Bwamu	
Soonbia, Sindiin, Dïï, Sôbia, S'dai	Toussian		
Dougouvougûê, Davougûê	Senufo		
Watié	Bwamu		
Sonsuolii,	Dagara		
Sonsuonii	Dagara	Mixed colors seeds	
Susuonu	Gurma		
Bôn	Bôbô	White seed color	
Doforo gueman	Dioula		
Agronomic properties (33.72)	Zaka, Soonbia	Bôbô	Tolerant to drought
	Bôn	Bôbô	Late matured cowpea
	Soonbia, Gwandjessi, Sindiin	Toussian	Tolerant to drought cowpea, late matured crop
	Djîn	Toussian	Early matured Bambara groundnut
Seed size (8.14)	Djîn	Toussian	Small seed size
	Sonsuonii, Sonsuolii	Dagara	Small Bambara groundnut seeds
Religious utilisations (5.81)	Zaka	Bôbô	Crop hunting the evil eye
	Djîn, Dïï	Toussian	Mystical crop
	Watié	Bwamu	Crop with multiple functions
	Dougouvougûê, Davougûê	Senufo	Crop for family protection and richness
Growth habit (3.47)	Bôn	Bôbô	Underground cowpea
	Dougouma sôssô, Solomia	Dioula	

Dioula *: a common language spoken mainly in the Western part of Burkina Faso.

3.3. Farmers' Knowledge and Extent of Kersting's Groundnut Diversity in Burkina Faso and Ghana

According to the frequency of citations for each landrace known and grown by farmers and the ratio values, the six landraces (Figure 2) recorded across sociolinguistic groups could be arranged into four groups (Table 4). Group 1 included well-known (>50% of respondents) and frequently grown (ratio > 50%) landraces; Group 2 was made up of well-known (>50%) but less-grown (<50%) landraces; Group 3 was represented by less-known (<50%) but frequently grown landraces; Group 4 included less-known and less-grown landraces. The two landraces—White mottled with black eye and

Black—were known by all the linguistic groups; they made the Group 1 and Group 2, respectively. The White mottled with black eye was mainly adopted by the Toussian (ratio = 95.65%) while it was less cultivated by the Bôbô (ratio = 14.29%). Apart from the Dagara, all the linguistic groups grew the Black landrace which was widely grown by the Bwamu people. Group 3 was composed of the Brown mottled with greyed orange eye, the Brown and the white mottled with greyed orange eye landraces mostly produced by the Dagara. In fact, the landraces White mottled with greyed orange eye and the Brown were cited only by the Dagara group. The Brown mottled with greyed orange eye was mentioned by Gurma and Dagara groups in Ghana. The White landrace was the least known and the least cultivated. It is produced by some Bôbô communities in Burkina Faso, while the Toussian and other groups knew it but did not produce it. The knowledge of Kersting’s groundnut landraces varied greatly across sociolinguistic groups. The Dagara were richer in terms of knowledge on *M. geocarpum* folk diversity while the Bwamu knew little about the wide diversity of this crop.

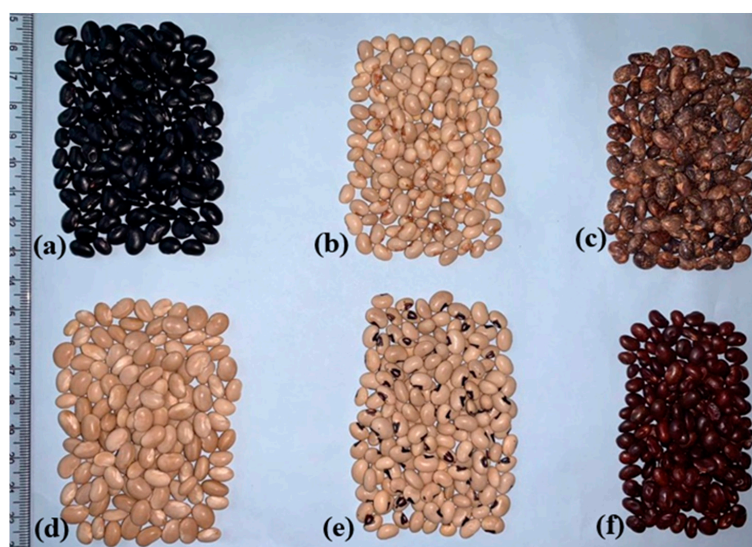


Figure 2. Kersting’s groundnut seed coat colors. (a) Black, (b) White mottled with greyed orange eye, (c) Brown mottled with greyed orange eye, (d) White, (e) White mottled with black eye, (f) Brown.

Table 4. Kersting’s groundnut diversity known (%) and grown (%) and grown/known ratios (%) across sociolinguistic groups in Burkina Faso and Ghana. Ratio (%) = 100 × frequency of grown/frequency of known.

Sociolinguistic Group	Bôbô			Bwamu			Dagara		
	Known	Grown	Ratio	Known	Grown	Ratio	Known	Grown	Ratio
Landrace seed colors									
White	18.18	9.09	50	-	-	-	-	-	-
White mottled with black eye	63.64	9.09	14.29	35.71	21.43	60	17.39	4.35	25
White mottled with greyed orange eye	-	-	-	-	-	-	4.35	4.35	100
Black	90.91	81.82	90	100	100	100	73.91	-	0
Brown	-	-	-	-	-	-	69.57	60.87	87.50
Brown mottled with greyed orange eye	-	-	-	-	-	-	95.65	91.30	95.45
Sociolinguistic Group	Toussian			Others			Total		
Landrace seed colors	Known	Grown	Ratio	Known	Grown	Ratio	Known	Grown	Ratio
White	8.70	-	0	13.33	-	0	6.98	1.16	16.62
White mottled with black eye	100	95.65	95.65	46.67	40	85.71	53.49	38.37	71.73
White mottled with greyed orange eye	-	-	-	-	-	-	1.16	1.16	100
Black	52.17	4.35	8.33	86.67	53.33	61.54	76.74	37.21	48.49
Brown	-	-	-	-	-	-	18.60	16.28	87.5
Brown mottled with greyed orange eye	-	-	-	13.33	13.33	100	27.91	26.74	95.81

3.4. Distribution of Kersting’s Groundnut Landraces and Diversity Estimation

Landraces are the genetic bases for crop improvement. A total of 62 Kersting’s groundnut samples were collected in the study districts and varied morphologically in seed coat color. The samples were clustered in six different landraces according to the seed coat color: the cream (known as White), White mottled with black eye, White mottled with grey orange eye, Black, Brown and Brown mottled with grey orange eye (Figure 2). The distribution of these groups varied across the agroecological zones. All the six landraces were found in the southern-Sudanian zone while two (i.e., White mottled with black eye and Black) were found in the northern-Sudanian zone. There were four landraces specific to the southern-Sudanian zone, while no landrace was specific to the northern-Sudanian zone. The most common and widely grown landraces listed by farmers across the two agroecological zones were the White mottled with black eye and the Black. In the southern-Sudanian zone, the six landraces comprised in total 51 samples collected, and in the northern-Sudanian zone, the two landraces found comprised 11 samples. The distribution of landraces is represented in Figure 3 and summarized in Table 5. The landraces were collected in 25 villages out of the 39 villages surveyed. In the southern-Sudanian zone samples were found in 16 villages located in six departments namely: Bôbô Dioulasso, Pêni, Orodara, Kourinon, Morolaba and Jirapa. In the northern-Sudanian zone, samples were found in seven villages located in the departments of Ouarkoye and Bondokuy. Furthermore, some landraces were specific to each country. In fact, the White one was found only in Burkina Faso while the Brown, Brown mottled with greyed orange eye, and the White mottled with greyed orange eye ones were specific to Ghana.

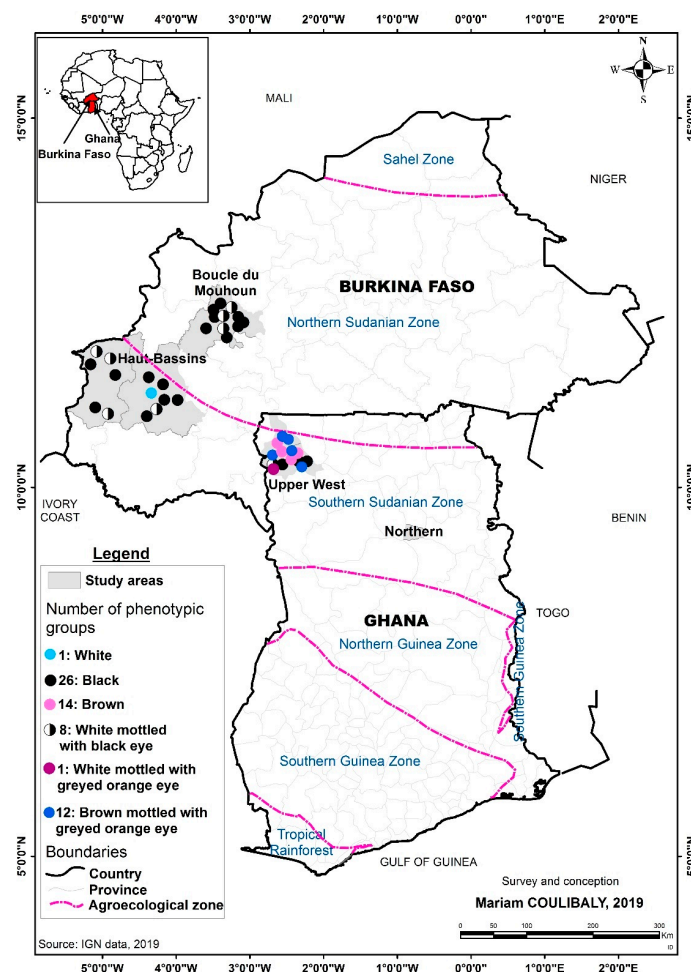


Figure 3. Distribution of Kersting’s groundnut landraces collected across agroecological zones of Burkina Faso and Ghana.

Table 5. Kersting’s groundnut landraces collected with diversity indices across agroecological zones of Burkina Faso and Ghana.

Landrace by Seed Coat Color	Southern-Sudanian	Northern-Sudanian
White mottled with black eye	5	3
Black	18	8
White	1	
White mottled with greyed orange eye	1	
Brown	14	
Brown mottled with greyed orange eye	12	
Diversity indices		
Number of landraces	6	2
Number of samples	51	11
Margalef’s index	1.27	0.42
Simpson’s index (1-D)	0.73	0.40

Diversity estimates (Table 5), based on the number of landraces (richness) and samples collected (abundance), revealed that the southern-Sudanian zone exhibited higher richness (Margalef = 1.27) and relative abundance (Simpson = 0.73) in terms of number of landraces and samples collected. The northern-Sudanian zone was found to be less diverse (Margalef = 0.42; Simpson = 0.40).

3.5. Criteria for Choosing Kersting’s Groundnut Landraces to Grow

Farmers had many criteria in selecting *M. geocarpum* landraces (Table 6). These criteria concerned the crop characteristics and the use categories. The three main criteria were the seed coat color, the medicinal purposes and the organoleptic qualities. Preference for a specific landrace was dependent on the area and/or the farmer. The Black landrace was mainly grown by farmers for medicinal and socio-cultural purposes, while the White mottled with black eye landrace was grown for consumption and was preferred by farmers because of its organoleptic qualities. In other villages, the Brown and Brown mottled landraces were grown mainly because of the eating habits of consumers.

Table 6. Criteria used by farmers for growing Kersting’s groundnut landraces in Burkina Faso and Ghana.

Criteria	Proportions of Citations (%)
Seed coat	37.21
Medicinal purposes	33.72
Organoleptic qualities	26.74
Eating habit	24.42
Socio-cultural purposes	23.26
Resistance to drought	10.59
Early maturity	4.71

3.6. Production Systems and Management across Sociolinguistic Groups in Burkina Faso and Ghana

In Burkina Faso and Ghana, Kersting’s groundnut was produced on an average cropping area of 0.079 ± 0.0162 ha with an average yield of 546.10 ± 64.30 Kg/ha. Farmers in these countries grew *M. geocarpum* in rotation with cereals or legumes or in pure stand. However, few farmers (4.65%) intercropped it with cereals, roselle or cassava. Another cultivation practice used by farmers was the utilization of the crop around the fields of cereals or legumes as field border. Most of the farmers adopted to grow the crop on ridges or on flat sowing, while some farmers adopted the mounds as tillage practice. Field management included weeding (21–30 days after planting) and often earthing up at the reproduction phase (45–75 days after planting) in order to facilitate the pods development. Moreover, farmers planted Kersting’s groundnut between May and August during the raining season and harvested after 4–5 months. Farmers stored the crop as dehulled seed and/or as pods in jars (61.63% of respondents), in garrets (26.74%), in plastic bottles (20.93%) and in bags (15.12%). Other material

such as gourds, bottles and barrels were also used by a few farmers to store Kersting's groundnut. Farmers mixed Kersting's groundnut seeds with sand, ash, extracts of plants or in some rare cases with chemical products (1.16% of respondents) to reduce beetles' attacks.

The Factorial Analysis of Mixed Data (FAMD) of the cultivation practices revealed three farming systems in Burkina Faso and Ghana (Table 7). In the first system, all farmers grew Kersting's groundnut on mounds and 92.59% of them grew it on ridges; in this system, seeds were mainly stored in garrets as dehulled seed mixed with sand. In the second system, cropping Kersting's groundnut as field border and earthing up practices were used by most of the farmers (90.91% and 81.82%, respectively); in this system *M. geocarpum* was planted on flat sowing tillage and seeds were stored with plastic bottles mostly mixed with ash. In the third farming system there is no specific tillage practices; farmers in this system stored the crop as pod mixed with ash in jar.

Table 7. Results of Factorial Analysis of Mixed Data (FAMD) to cluster the cropping practices of Kersting's groundnut in Burkina Faso and Ghana.

Characteristics of Systems	Cla/Mod (%)	Mod/Cla (%)	Global	p-Value	v-Test
System 1					
Cultivation practices = field border	9.09	2.38	12.79	<0.001	-2.81
Tillage = ridges	92.59	59.52	31.40	<0.001	5.65
Tillage = mounds	100.00	19.05	9.30	<0.001	3.06
Tillage = flat sowing	23.26	23.81	50.00	<0.001	-4.75
Earthing up = yes	4.55	2.38	25.58	<0.001	-5.02
Storage form = as dehulled seed	52.50	100.00	93.02	<0.001	2.43
Storage material = garret	73.91	40.48	26.74	<0.001	2.76
Storage material = plastic bottle	22.22	9.52	20.93	<0.001	-2.50
Storage material = bag	15.38	4.76	15.12	<0.001	-2.58
Storage product = sand	88.46	54.76	30.23	<0.001	4.91
Storage product = ash	21.05	19.05	44.19	<0.001	-4.59
Seeds sources = family	15.79	7.14	22.09	<0.001	-3.26
System 2					
Cultivation practices = field border	90.91	25.64	12.79	<0.001	3.20
Cultivation practices = pure stand	31.71	33.33	47.67	<0.001	-2.38
Tillage = flat sowing	69.77	76.92	50.00	<0.001	4.54
Tillage = ridges	3.70	2.56	31.40	<0.001	-5.53
Earthing up = yes	81.82	46.15	25.58	<0.001	3.95
Storage material = plastic bottle	66.67	30.77	20.93	<0.001	1.98
Storage material = garret	17.39	10.26	26.74	<0.001	-3.15
Storage product = ash	78.95	76.92	44.19	<0.001	5.61
Storage product = sand	11.54	7.69	30.23	<0.001	-4.23
Seeds sources = family	73.68	35.90	22.09	<0.001	2.74
System 3					
Storage form = pod	100.00	100.00	5.81	<0.001	5.55
Storage material = jar	15.15	100.00	38.37	<0.001	2.71
Storage product = ash	10.42	100.00	55.81	<0.001	1.97

Cla/Mod: percentage of all surveyed farmers who use a specific farming practice and belong to a cluster (system). Mod/Cla: percentage of all farmers in a specific cluster (system) that also use a farming practice; p-value: level of analysis significance, v-test: measures the association between variables and clusters. It reveals which variables are positively or negatively associated with the clusters.

Kersting's groundnut growers got seeds from their family as gift or heritage. Seeds used by farmers came also from their own production but also used for consumption and other utilizations.

Macrotyloma geocarpum farming systems varied significantly ($p < 0.035$) across sociolinguistic groups in Burkina Faso and Ghana (Figure 4). The Dagara (Dagari) and Toussian adopted the first and the second farming systems. The Bôbô practiced the second and third farming systems. The Bwamu practiced all three farming systems. In general, the third system was less represented in the surveyed regions while the second farming system was the most practiced by all sociolinguistic groups.

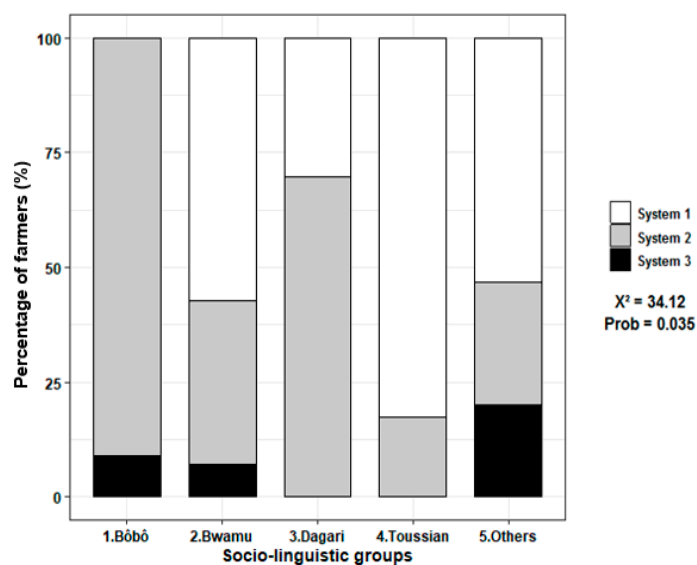


Figure 4. Frequency of Kersting’s groundnut farming systems across socio-linguistic groups in Burkina Faso and Ghana.

3.7. Bottlenecks to Kersting’s Groundnut Production

Farmers identified several factors constraining Kersting’s groundnut production. Out of the fourteen cited, the five main constraints facing farmers included the difficulty to harvest the pods (66.28% of respondents), the lack of manpower (27.91%), the high soil moisture at the reproduction phase (24.42%), post-harvest pests damage (23.53%), and drought (22.09%) (Figure 5). The non-availability of seeds and the need for intensive soil preparation were also cited by farmers as factors limiting crop production. According to them, although present, disease pressures were not a big challenge in their production system. Pests disturbing and causing damages to the crop in the field included domestic herds, rodents foraging fresh pods, and termites. Constraints varied significantly among sociolinguistic groups (Table 8). For instance, apart from the Bôbô, all the groups cited the difficulty to harvest as the main constraint they encountered. The high soil moisture during the reproductive phase was also cited by all groups apart from the Dagara. For the Bôbô, Dagara and the Toussian, drought was an important factor constraining Kersting’s groundnut production. Another factor cited by producers was the non-availability of seeds limiting the production in the farming systems of Bwamu and Toussian. The post-harvest pests were ranked by the Dagara group as important constraints in Kersting’s groundnut production.

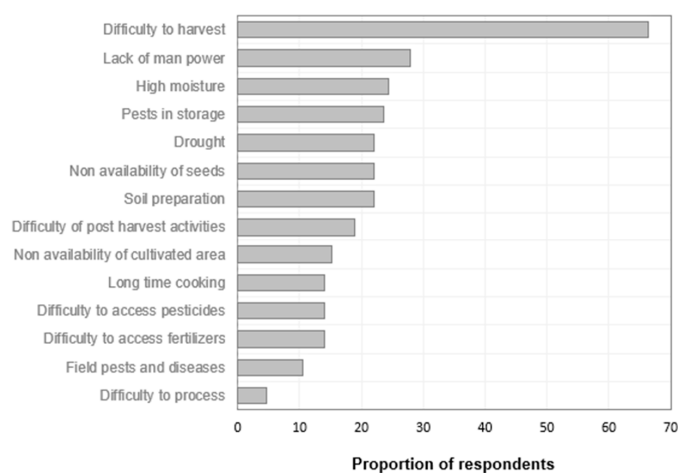


Figure 5. Constraints to Kersting’s groundnut production in Burkina Faso and Ghana.

Table 8. Proportion of citations of Kersting’s groundnut production bottlenecks across sociolinguistic groups in Burkina Faso and Ghana.

Constraints	Bôbô	Bwamu	Dagara	Toussian	Others	Kruskal Test
Difficulty to harvest	54.55	71.43	78.26	65.22	53.33	*
Non availability of seeds	0.00	28.57	0.00	39.13	40.00	***
Soil preparation	9.09	7.14	26.09	30.43	26.67	**
High soil moisture	27.27	28.57	13.04	34.78	20.00	*
Lack of labour	63.64	14.29	26.09	30.43	13.33	**
Pests in storage	9.09	21.43	43.48	17.39	13.33	***
Difficulty to access fertilizers	18.18	21.43	8.70	13.04	13.33	**
Difficulty to access pesticides	18.18	21.43	8.70	13.04	13.33	**
Field pests and diseases	27.27	14.29	0.00	8.70	13.33	***
Drought	45.45	7.14	26.09	26.09	6.67	***
Non availability of cultivated area	9.09	28.57	8.70	21.74	6.67	***
Difficulty of post harvesting activities	18.18	21.43	30.43	13.04	6.67	***
Long-time cooking	27.27	14.29	13.04	17.39	0.00	***
Difficulty to process	18.18	7.14	4.35	0.00	0.00	***

Kruskal Wallis test with frequencies of citations. *** p value < 0.001, ** p value < 0.01 and * p value < 0.05.

3.8. Preferred Traits for Kersting’s Groundnut Improvement

Thirteen traits were listed by producers as important for crop improvement (Table 9). The top five preferred traits included early maturing, high yielding, resistance to bruchids, tolerance to drought, and tolerance to high soil moisture. Farmers were also interested in some specific seeds’ attributes, as the nutritional content and time taken to cook on available cooking facilities. White mottled with black eye and White seeded landraces were preferred by farmers and can be used as background landraces.

Table 9. Traits identified by farmers for Kersting’s groundnut new varieties in Burkina Faso and Ghana.

Criteria	Traits	Percentage of Respondents
Agronomic	Early maturity	34.88
	High yield	33.72
Genetic resistance	Tolerance to drought	26.74
	Resistance to bruchids	26.74
	Tolerance to high soil moisture	22.09
Seeds coat colors	White seed coat	25.58
	White mottled seed coat	25.58
	Black seed coat	18.60
	Red seed coat	10.47
	Brown seed coat	8.14
Seeds attributes	Good seed quality	15.12
	Facility to cook	10.47
	Big seed size	9.30

The Factorial Analysis of Correspondence revealed variation of farmers’ preferred traits across sociolinguistic groups (Figure 6). The Bôbô group preferred the black seed coat color with resistance to high soil moisture. The Bwamu were interested in short seeds cooking time. The Dagara and Toussian groups preferred the White mottled with black eye landrace with high yielding, early maturing, and big seed size attributes.

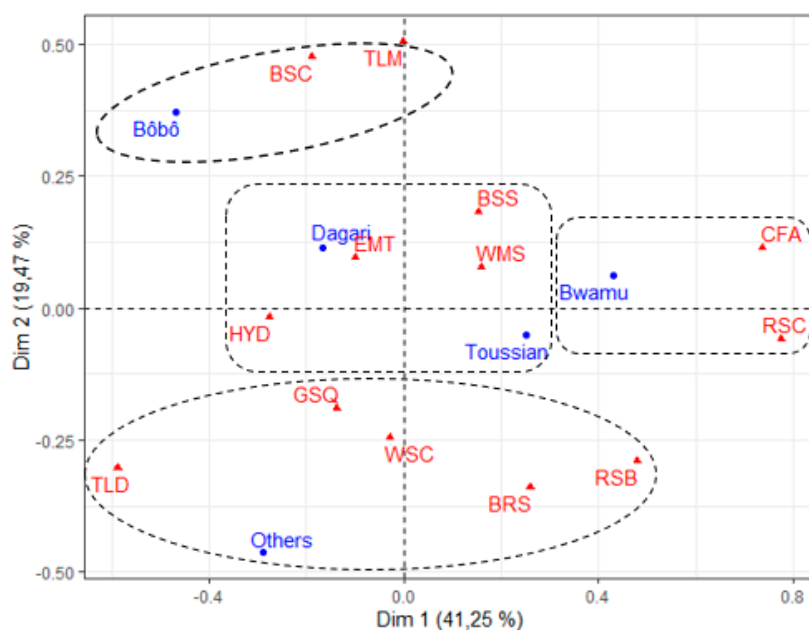


Figure 6. Traits identified by farmers for Kersting's groundnut improvement according to socio-linguistic groups. WSC: White Seed coat color; WMS: White mottled Seed coat color; RSC: Red Seed coat color; BSC: Black Seed coat color; BRS: Brown Seed coat color; TLD: Tolerance to drought; TLM: Tolerance to moisture; RSB: Resistance to bruchids; BSS: Big seed size; GSQ: Good seed quality; CFA: Facility to cook; HYD: High yield; EMT: Early maturity.

4. Discussion

4.1. Knowledge, Existence and Distribution of Kersting's Groundnut Diversity in Burkina Faso and Ghana

Sixty-two samples grouped in six different landraces were collected across both countries instead of the five landraces reported in previous studies [12,13,17]. Tamini [14] reported the White mottled with black eye and the Black landraces in Burkina Faso; whereas in this study, a White landrace was additionally recorded and collected. Similarly, the Brown and the White mottled with greyed orange eye were found only in Ghana and were not yet reported by previous investigations [17,35]. In this study, we therefore found additional diversity in the southern-Sudanian zone of Burkina Faso and Ghana. Those findings support the assumption that southern-Sudanian zone can be considered as the primary center of origin of Kersting's groundnut [12]. Previous reports indicated that the crop originated from central Benin and Northern Togo [36]. Amujoyegbe [18] mentioned Nigeria as the primary center of origin of the crop. Therefore, extended investigations followed by a wide diversity resource collection is expected across other West-African countries where the cultivation of the crop was mentioned. Future explorations could involve Nigeria, Mali and Ivory Coast in order to have a clear idea of the genetic diversity of this crop and the center of origin of that diversity. This large germplasm collection should be followed by the genetic characterization in different environments in order to better understand the genetic background and the stability of Kersting's groundnut specific traits. In addition, the association studies involving molecular tools could make more accurate the genetic characterization and can be useful in the identification of QTLs of functional and economic traits. Furthermore, ex-situ conservation strategies through National and International genebanks supported by the local conservation systems must be well organized to ensure the sustainable maintenance of the existing diversity. In Benin and Togo, the Black landrace was well known by farmers but less cultivated while the White one was widely grown and well appreciated by farmers and consumers [12,13]. As noticed by Akohoué [12] in Benin and Togo, farmers in Burkina Faso and Ghana also grew the Black landrace mainly because of medicinal and socio-cultural attributes. The White and the White mottled with black eye landraces were grown mainly for consumption and their organoleptic qualities. The preference of

farmers for these landraces represents a good opportunity for their sustainable conservation on-farm and across generations. On-farm management of agricultural biodiversity implies that smallholder farmers select and develop the species they need to match their diets, culture, markets and environment. Hence, in-situ conservation could be more organized through the valorization of Community Seed Banks (CSB). CSBs are local-level institutions that contribute to seed conservation, in particular of farmer varieties, countering erosion of crop diversity or its loss following natural disasters [37]. CSBs have been established recently in Burkina Faso and Ghana, but are limited to few regions [38]. This platform should be extended to other regions in order to limit the loss of genetic resources including Kersting's groundnut.

Landraces are considered to be an integral influence on farmers' decisions on maintenance, management, and exchange [39]. Farmers had a good knowledge of Kersting's groundnut varieties across sociolinguistic groups in terms of classification, identification, description and uses. Our results revealed that farmers go beyond just naming, by grouping landraces together based on common characters. Their indigenous knowledge would be extremely useful to agronomists, geneticists and breeders. The criteria used by farmers to describe different landraces included the seeds characteristics, agronomic and religious properties, and the growth habits of the crop. Similar results were found in other studies including on the common bean [40], fonio [41], millet [42] and Kersting's groundnut [12]. These characteristics used to identify different Kersting's groundnut landraces reflect the consistence of folk taxonomy. The seed color used by farmers as the main folk descriptor of this legume was considered as a true discriminant trait by growers as well as by scientists who performed the agro-morphological characterization of the species [13,15,43].

4.2. Kersting's Groundnut Production Systems in Burkina Faso and Ghana

Most legumes including Kersting's groundnut have been overlooked by research and development agencies and are generally considered as women's crops in some areas since they are often produced by women producers on small land areas meant primarily for home consumption [44], whereas men tend to dominate in the production and marketing of cereals in the food value chain [45]. This was true for Kersting's groundnut in the farming systems of Burkina Faso and Ghana. However, in other communities, men were mostly involved in the crop production as the crop certainly exhibits a high economical value in those communities [12,17]. The economical and the nutritional importance of this crop should be clearly highlighted and promoted across its production areas in order to better use the genetic resources available for food and nutrition security as well as for income generation.

Farmers generally grew *M. geocarpum* in rotation. Others intercropped or used it as field border (mainly the Bôbô group). Farmers in Nigeria [18], Benin and Togo [12] also intercropped the crop. According to farmers, Kersting's groundnut helps improve the fertility of the soil, thereby reducing the cost of fertilizer inputs in crop farming. This is certainly due to the nodulation property of the crop for symbiotic nitrogen fixation [16,46] leading to the positive contribution of legume crops in the yield improvement of associated crops [47–49].

Kersting's groundnut was grown generally on ridges or on mound in the farming systems Burkina Faso and Ghana. The same types of tillage were used in the production systems of the crop in Ghana [19], Benin and Togo [12,13,50]. The type of tillage was often different across sociolinguistic groups. In Benin, Kouelo [50] showed that the type of tillage practice can contribute significantly to improve *M. geocarpum* yield and was specific to the soil conditions. Therefore, investigations should be done in the different growing areas of Kersting's groundnut in order to propose to farmers the suitable tillage practice adapted to their soils' characteristics.

In Burkina Faso and Ghana, farmers stored Kersting's groundnut as pods. This practice, also reported in other countries [12,13,17], contributes to limiting pulse beetles' damages and permits a longer storage life. Badii [51] found that the Black and Brown landraces were less susceptible to the bruchids (*Callosobruchus maculatus* Fabricius) attacks than the White mottled with black eye. The genetic determinism of this resistance to *C. maculatus* in Brown and Black landraces needs be

deepened. Consequently, the possibility for introgression of bruchids-resistant gene from Brown and Black landraces into other landraces (White and White mottled with black eye) can be explored.

There was a number of barriers to *M. geocarpum* production, including the hard work required for harvesting while there is an increasing lack of manpower for cultivation. In addition, the crop was grown mainly by elderly people (above 50 years old) while young people were focused on cereals and cash crops—generally ignoring legumes. This situation was also reflected by many governments' policy and research institution priorities [52]. The difficulty to harvest appeared as a major challenge for growers in Benin and Nigeria as well [13,18].

Furthermore, the non-availability of seeds to meet farmers' needs is another constraint limiting Kersting's groundnut production. In fact, in most of the growing areas where the crop production was decreasing or disappeared, farmers lost their seeds and did not have the possibility of a new supply. Similarly, in Benin, the lack of market for seed supply was one of the reasons for the low production of Kersting's groundnut. The possibility for *M. geocarpum* commercial seeds production is still inexistent; farmers saved their own seeds for planting. At the same time, the easy access to quality seed can be achieved and guaranteed only if there is a viable seed supply system to multiply and distribute seeds that have been produced or preserved by farmers [53]. According to the same authors, the most effective alternative is to create smallholder seed enterprises, located in farming communities, with lower capital investment needs. These enterprises should be closed to smallholder farmers and be able to distribute quality seeds of improved and local varieties such as Kersting's groundnut.

4.3. Farmers' Preferences for Kersting's Groundnut and Implication for its Genetic Improvement

Kersting's groundnut production has been decreasing drastically because of its low yield, the small seed size and the late maturing time [12,13,18]. This explains the need expressed by farmers to have improved cultivars with high yield, drought tolerance, and early maturing attributes. Authors revealed that the crop exhibits variations in flowering time, seed size and grains yield [13,43]. This offers room for genetic improvement and selection of desired cultivars. However, the scarce knowledge of the reproductive biology and the narrow genetic basis [24,54], require a lot of investment to develop crosses and broaden the genetic background. Failing to establish the clear nature of Kersting's groundnut floral biology may hinder the success of its varietal improvement through the cross pollination of good landraces. Although there is room for mutagenesis, no studies have so far embraced this pathway. Mutation breeding—using both physical and chemical mutagens—has been extensively and successfully used in the development of improved cultivars of legumes such as Bambara groundnut [55,56] and groundnut [57].

5. Conclusions

This study revealed the diversity of Kersting's groundnut landraces grown in the southern-Sudanian and northern-Sudanian zones of Burkina Faso and Ghana. Results showed that farmers grew six different landraces. All those landraces were grown in the southern-Sudanian zone, while only two were grown in the northern-Sudanian zone. Farmers preferred their varieties to be high yielding and tolerant to drought, resistant to bruchids and early maturing. This finding is relevant and important for the definition of the Kersting's groundnut breeding objectives. The study also analyzed the cropping systems of the crop, the main constraints to its production and examined farmers' preferences for its improvement. The study revealed that farming practices across the surveyed areas were diverse and strongly influenced by sociolinguistic membership. In Ghana and Burkina Faso, farmers' knowledge about the crop and its production practices remains vital for the future promotion of the resource.

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