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RESEARCH ARTICLE

# On-farm practices, mapping, and uses of genetic resources of Kersting's groundnut [*Macrotyloma geocarpum* (Harms) Maréchal et Baudet] across ecological zones in Benin and Togo

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**Abstract** Enhancing orphan crops productivity in developing countries is of paramount importance to providing quality diets to the growing population as well as resilience options to smallholder farmers in order to adapt to climate change. However, the status of genetic resources diversity and the utilisation patterns of many orphan crops have been poorly investigated to inform breeding programs and management strategies. In this study, we assembled Kersting's groundnut diversity, associated farmers' knowledge and production systems across three ecological zones in Benin and Togo. We collected data through focus group discussions in 43 villages. In addition, semi-structured interviews were conducted with 300 farmers. Four cell analyses was performed using cropping areas and number of Kersting's groundnut farmers as criteria. We conducted a comparative analysis of the Kersting's groundnut utilisations and production systems across ecological zones. In total, 308 accessions of Kersting's groundnut were collected using farmers' criteria such as grain colour, grain size, maturity time, yield potential, medicinal properties and marketability. Farmers grouped the accessions into five landraces based solely on grain colour. All landraces were cultivated in the Sudanian zone while only three of them were found in the Guinean and Sudano-Guinean zones. Most of these landraces were produced by a few farmers on small cropping areas. The choice of landraces for production depended on local intention for production and different use categories across ecological zones. Up to 46.80% of decrease in cropping areas was observed in most zones due to specific production bottlenecks such as drought and diseases. We discuss our findings and suggest tailored actions including effective in situ and ex situ conservation strategies, germplasm collection and characterization in other countries where the crop is produced, development of new cultivars with farmers' preferred traits and enhancement of the genetic base of the species.

**Keywords** Cultivar development · Folk nomenclature · Genetic resources conservation · Landrace · *Macrotyloma geocarpum* · On-farm diversity

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## Introduction

With the overwhelming population growth and global food demand, there is an unprecedented need to increase agricultural productivity. Many research and policy efforts were initiated to increase agricultural productivity and economic development with a focus on conventional staple crops (Jambo 2017; Tadele 2017). This has resulted in the development of improved agronomic practices as well as high yielding cultivars for several crops (Dalrymple 1986; Jambo 2017; Schroeder et al. 2013). However, food and nutritional insecurity still remains a big challenge especially in developing countries (FAO 2017). Therefore, actions to increase food productivity in these areas should also be reoriented towards other crops commonly referred to as orphan crops since they have been widely neglected by both researchers and industries (Aworh 2015; Baldermann et al. 2016; Padulosi et al. 2013). These resources play a pivotal role in marginal lands where the bulk of their genetic diversity and adaptive features help producers and consumers to utilise various environments and to develop natural resilience options (Cullis and Kunert 2017; Mayes et al. 2011).

In addition to increased productivity, crops of the next decades must exhibit clear nutritional values to attract more interest and contribute to resolving the overwhelming malnutrition bottlenecks, particularly in developing countries. In this regard, recent studies put forward several health benefits of orphan legumes for consumers (Cullis and Kunert 2017; Ebert 2014; Kouris-Blazos and Belski 2016). Consumption of orphan legumes provides essential proteins, vitamins and dietary fibre (Curran 2012). Some of the most reported orphan legumes include cowpea (*Vigna unguiculata* (L.) Walp.), bambara groundnut (*Vigna subterranea* (L.) Verdc.), and grass pea (*Lathyrus sativus* L.). However, local populations and resource-poor-farmers also rely on other orphan legumes including *Macrotyloma geocarpum* (Harms) Marechal et Baudet known as Kersting's groundnut (Achigan Dako and Vodouhè 2006; Dansi et al. 2012).

*Macrotyloma geocarpum* (Leguminosae) is an orphan legume with high economic value. It is widely consumed in West Africa and more increasingly during festive periods when the price can hike from XOF800 (US$ 1.45) per kg in abundance period to XOF4000 (US$ 7.27) per kg in scarcity period in Benin (Dansi et al. 2012). The grain is also used by several communities for food and medicinal purposes (Assogba et al. 2016; Ayenan and Ezin 2016). Although the nutritional value of Kersting's groundnut is not fully documented, reports indicate that Kersting's groundnut grains contain 21.3% of crude protein, 6.2% of crude fibre, 61.53–73.3% of carbohydrate and 3.2% of ash (Aremu et al. 2011). Also, Ajayi and Oyetayo (2009) investigating the potential of Kersting's groundnut as health food, reported that the grains contain a very low crude fat (1.0%) and a high concentration of arginine and amino acid for paediatric growth. Although the capacity of the crop to cope with severe climate adverse is yet to be investigated, *M. geocarpum* is a crop with best performance in drought-prone environments (Achigan Dako and Vodouhè 2006; Ayenan and Ezin 2016). Kersting's groundnut provides local communities with increased resilience options for sustainable livelihood.

Unfortunately, *M. geocarpum* has not benefitted from any major improvement or promotion programs despite its economic and nutritional importance. As consequence, the productivity of the crop remains low with a maximum of 500 kg/ha, and the production has been decreasing from year to year (Ayenan and Ezin 2016). Besides, there is a low availability of Kersting's groundnut genetic resources in international genebanks, even in national genebanks of countries of origin (e.g. Benin, Togo). This is a drawback in plant breeding and conservation perspectives. Also, previous investigations on the potential of Kersting's groundnut in Benin did not include all production zones (Assogba et al. 2016). As results, the authors reported only three landraces which were previously found to present a narrow genetic base (Ayenan and Ezin 2016; Pasquet et al. 2002). Therefore, there is a need to collect landraces of Kersting's groundnut and investigate associated indigenous knowledge in all production areas in those countries (Ayenan and Ezin 2016).

Genetic diversity is said to be higher in primary centre of origin (Hummer and Hancock 2015; Vavilov and Dorofeev 1992). For Kersting's groundnut, the centre of origin was reported to be central Benin or northern Togo (Achigan Dako and Vodouhè 2006). Moreover, within the primary centre of origin can emerge small areas with tremendous genetic diversity (Harlan 1971; Zhukovsky 1975). With regard to this, Benin and northern Togo could contain more than the three Kersting's groundnut landraces reported by previous studies. Furthermore, extensive survey for mapping and on-farm assessment of diversity provides key information to detect losses and define conservation strategies (Last et al. 2014). Understanding the genetic diversity, uses, and distribution of orphan crops is essential in determining what to conserve and where to conserve, for sustainable utilisation (Rao and Hodgkin 2002; Van Dusen 2005).

The objectives of this study were therefore: (1) to collect Kersting's groundnut genetic resources in the production systems of Benin and Togo, (2) to assess knowledge associated with Kersting's groundnut germplasm richness and utilisations, (3) to map the distribution of Kersting's groundnut genetic resources and use categories across ecological zones, and (4) to compare Kersting's groundnut on-farm practices and farmers' constraints between ecological zones. The following questions were addressed in this paper: (1) what are the implications of farmers' knowledge in naming and describing Kersting's groundnut and its landraces and what is the current status of Kersting's groundnut resources diversity in farmers' fields? (2) How are Kersting's groundnut landraces distributed across ecological zones? (3) What are the use categories of Kersting's groundnut in each ecological zone? (4) How is the production system organized and what is the dynamic of the production in each ecological zone? (5) What are the bottlenecks hindering Kersting's groundnut production and how do they relate to production zones?

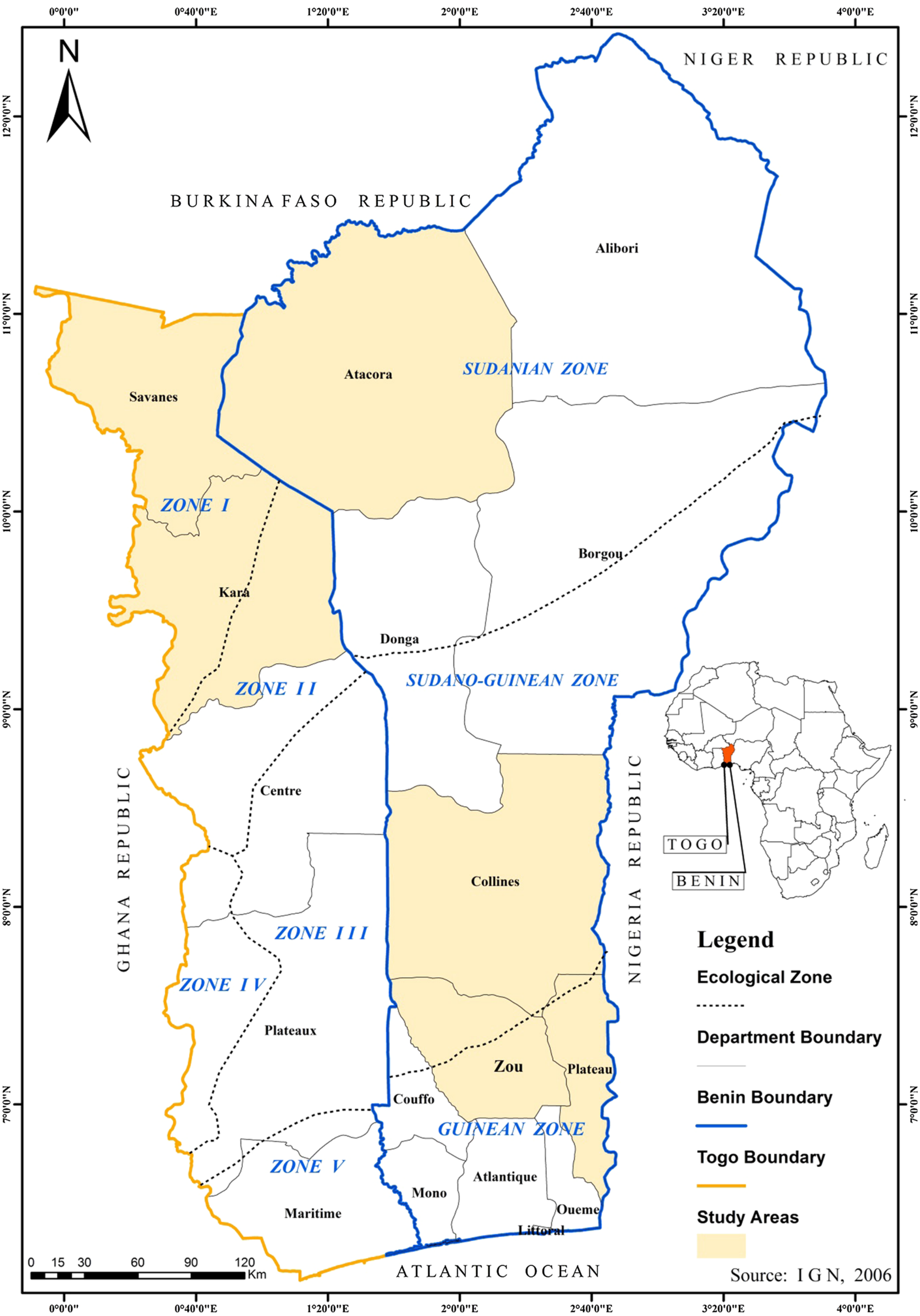
We hypothesized that (1) the genetic diversity of Kersting's groundnut in Benin and Togo is higher than reported by previous studies, (2) the knowledge associated with Kersting's groundnut germplasm is relevant for the scientific classification and description of the species and its landraces, (3) the distribution of Kersting's groundnut landraces and utilisation patterns varies with ecological zones, and (4) on-farm practices, production dynamic and farmers' constraints are specific to ecological zones.

## Materials and methods

### Study area

This study was carried out from 2016 to 2017 in Benin and northern Togo, West Africa (Fig. 1). Benin is located on the Atlantic coast and borders Nigeria to the east, Togo to the west, and Burkina Faso to the northwest, and Niger to the northeast. It is composed of 10,008,749 habitants (INSAE 2015). Togo is situated in West Africa with a population size of 6,191,155 habitants (MPDAT 2011). It borders Benin to the east, Ghana to the west, Burkina Faso to the north (Fig. 1). These two countries are characterized by a vegetation pattern showing a humidity gradient northward due to the combined effects of climate variation and soils (Adomou 2005). As Kersting's groundnut has been reported to be susceptible to high humidity (Assogba et al. 2016; Ayenan and Ezin 2016), our study covered all ecological zones in the area. Therefore, in Benin, the study was conducted in three ecological zones namely the Guinean zone, the Sudano-Guinean zone and the Sudanian zone. In northern Togo, the study was carried out in two ecological zones referred to as Zone I and Zone II (Fig. 1).

The Guinean zone is characterized by an annual rainfall varying between 1200 and 1300 mm/year (Table 1). The temperature ranges from 24 to 30 °C. The vegetation pattern is the Guinean savanna with a mosaic of semi-deciduous rainforest or clear forests with *Elaeis guineensis* Jacq., *Tectona grandis* L.f., *Acaci*a spp. and *Vitex doniana* Sweet dominating. This zone has a bimodal rainfall pattern with two rainy seasons. Major crops include cereals [*Zea mays* L. and *Sorghum bicolor* (L.) Moench], and legumes (*Vigna unguiculata*, *Arachis hypogea* L. and *Macrotyloma geocarpum*). The Sudano-Guinean zone is the largest ecological zone with an annual rainfall from 1100 to 1300 mm/year (Table 1). The temperature in this zone varies between 25 and 34 °C. Besides, the Sudano-Guinean zone is a transitional ecological zone with a trend to unimodal rainfall pattern. It is characterized by some relics of semi-deciduous rainforests. In addition, farming systems in this zone are dominated by cereals (*Zea mays* and *Sorghum bicolor*), legumes (*Vigna unguiculata*, *Arachis hypogea* and *Macrotyloma geocarpum*) and roots and tubers (*Dioscorea* spp. and *Manihot esculenta* Crantz). The Sudanian zone of Benin and the two ecological zones of northern Togo are characterized by a unimodal rainfall pattern with one rainy season (Akoègninou et al. 2006; Fousseni et al. 2014). The annual rainfall varies between 900 and 1100 mm/year while the temperature ranges from 21 to 35 °C. The vegetation pattern is characterized by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BURKINA FASO REPUBLIC
GHANA REPUBLIC
NIGERIA REPUBLIC
ATLANTIC OCEAN
Alibori
Atacora
Savanes
SUDANIAN ZONE
ZONE I
Borgou
Kara
Donga
ZONE II
SUDANO-GUINEAN ZONE
Centre
Collines
ZONE III
ZONE IV
Plateaux
Zou
Plateau
Couffo
GUINEAN ZONE
ZONE V
Mono
Atlantique
Maritime
Oueme
Littoral
TOGO
BENIN
Legend
Ecological Zone
Department Boundary
Benin Boundary
Togo Boundary
Study Areas
Source: IGN, 2006
0 15 30 60 90 120 Km
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12°0'0"N 11°0'0"N 10°0'0"N 9°0'0"N 8°0'0"N 7°0'0"N

◀**Fig. 1** Study area. Ecological zones and surveyed departments

wooded savannah dominated by *Khaya senegalensis* (Desr.) A.Juss, *Berlinia grandiflora* (Vahl) Hutch. et Dalziel, *Uapaca togoensis* Pax, *Terminalia* spp., and *Acacia* spp. In addition, the farming systems in these zones are based on cereals (*Zea mays, Sorghum bicolor, Digitaria exilis* (Kippist) Stapf), and legumes (*Vigna unguiculata*, *Vigna subterranea*, *Glycine max* (L.) Merr.). In the analyses, we considered the Zones I and II of northern Togo as part of the Sudanian zone since both of them are characterized by the Sudanian climatic conditions (Fousseni et al. 2014). As a result, the whole research area was divided into three major ecological zones, i.e. the Guinean zone, the Sudano-Guinean zone and the Sudanian zone.

## Data collection

In each ecological zone, main markets were visited as entry points to identify Kersting's groundnut production municipalities. Thirteen municipalities were identified in all ecological zones. Moreover, interviews with local extension agencies helped us to identify one to nine Kersting's groundnut production villages in each municipality. The snowball technique was used to select Kersting's groundnut farmers in each village. A total of 300 farmers were selected and included in the survey. One focus group discussion was conducted in each village with farmers on the Kersting's groundnut naming, description of landraces and identification of rare and common landraces. Therefore, during the focus group discussions, farmers were asked to provide the rationale for Kersting's groundnut local names and describe the different traits they use to recognize each landrace. Additionally,

**Table 1** Characteristics of ecological zones in Benin and northern Togo

| Variables | Guinean zone | Sudano-Guinean zone | Sudanian zone | Zone I | Zone II |
|---|---|---|---|---|---|
| Country | Benin | Benin | Benin | Togo | Togo |
| Altitude (m) | 56–223 | 153–308 | 214–609 | 191–330 | 261–264 |
| Annual rainfall (mm) | 1200–1500 | 1100–1300 | 900–1100 | 900–1100 | 900–1100 |
| Vegetation | Guinean savannas, mosaic of semi-deciduous rainforest or clear forests | Mosaic of semi-deciduous rainforest and savannas | Wooded savanna with species including *Khaya senegalensis, Berlinia ladiflora, Uapaca togoensis, Terminalia* spp, *Acacia* spp. | | |
| Temperature (°C) | 24–30 | 25–34 | 21–35 | 22–35 | 21–34 |
| Dominant soils | Ferrallitic soils | Ferruginous and ferrallitic soils | Concreted or hardened ferruginous soils with small deep | | |
| Seasons | Guinean climate with two rainy seasons | Transitional zone with a trend to unimodal rain pattern | Unimodal rain pattern: one rainy season and more than seven dried months | | |
| Farming | Cereal (maize, sorghum), leguminous (cowpea, peanut, Kersting's groundnut)-based | Cereal (maize, sorghum), leguminous (cowpea, peanut, Kersting's groundnut), Yam-based | Cereal (maize, fonio, sorghum, millet), leguminous (cowpea, soybean, bambara groundnut, Kersting's groundnut)-based | | |
| Number of surveyed villages | 11 | 24 | 04 | 01 | 03 |
| Surveyed socio-linguistic groups | Fon | Fon, Mahi, Tchabè, Idaasha, | Otammari, Wama | Temb, Kabiyés | Tem, Kabiyès |

farmers were asked to indicate the minimum number of households and the minimum cropping area required before a given Kersting's groundnut landrace can be considered as common in the village. In addition to the focus group discussions, each farmer was interviewed using a questionnaire after their prior verbal agreement. The questionnaire was composed of five categories of questions, i.e. socio-economic background of farmers, biophysical resources, system management resources, Kersting's groundnut utilisation patterns, and production constraints. The socioeconomic background data included household head age, gender, household size and socio-linguistic group. Besides, the biophysical resources were composed of cropping areas, type of land, landrace diversity and seed access. Kersting's groundnut cropping areas were recorded for 2015, 2016 and 2017. The system management resources included cropping system, sources of labour, sowing time, harvest time and grain yield. Moreover, Kersting's groundnut utilisation patterns were composed of local intentions for the production and the different use categories. Finally, all production constraints were listed and scored by the interviewed farmer using a score between 1 and 10 for each identified constraint.

### Data analysis

Descriptive statistics were used to account for socio-economic background of households, biophysical resources and system management. To identify common and rare landraces of Kersting's groundnut in each ecological zone, we conducted a four-cell analysis based on the cropping areas and the number of households cultivating a given landrace (Rana et al. 2005; Sthapit et al. 2006). On the horizontal axis, we used 10 households as cutting point in the Guinean and the Sudano-Guinean zones as indicated by farmers. Likewise, on the vertical axis, we used 0.25 ha as cutting points in these zones. In fact, in these zones, a particular landrace is considered as common when it is produced by at least 10 households on a minimum cropping area of 0.25 ha. However, in the Sudanian zone, farmers indicated five households and 0.25 ha as cutting points, respectively, on the horizontal and the vertical axes. As perceived by farmers in this zone, a cropping area greater than 0.25 ha on average can be considered as large scale for Kersting's groundnut production. To quantify the relative importance of a particular intention for production of Kersting's groundnut and use category among farmers, we calculated the fidelity level (FL) within each zone and for each landrace (Ugulu 2012). The fidelity level was calculated using the following formula: $FL = \left(\frac{F}{\sum F}\right) * 100$, where FL = fidelity level, F = frequency of farmers who cited the species for a particular use category and $\Sigma F$ = sum of frequencies of farmers per for all use categories (Hoffman and Gallaher 2007; Ugulu 2012). To compare Kersting's groundnut production between ecological zones, we performed analysis of variance or Kruskal–Wallis test and multiple proportion test on all categories of variables. Analysis of variance and Kruskal–Wallis test were performed on quantitative variables while the multiple proportion tests were conducted on qualitative variables. Further, to check if there was a significant change in the evolution of cropping areas from 2015 to 2017, analysis of variance was conducted over all zones and within each zone. To illustrate the trends of cropping areas evolution over zones and within each zone, a ggplot was constructed using *geom* functions of the ggplot2 package (Wickham 2016). In addition, the production bottlenecks were compared between ecological zones using Friedman test (Abeyasekera 2005) in order to identify specific bottlenecks hindering Kersting's groundnut production within each zone. All statistical analyses were performed using R version 3.4.3 (R Core Team 2017).

## Results

### Local nomenclature, description, and distribution of Kersting's groundnut landraces

In total, eight socio-linguistic groups were visited where Kersting's groundnut was referred to with different local names depending on farmers' socio-linguistic groups and ecological zones (Table 2). There are four names across the three ecological regions visited: Doyikoun, Atchaka, Issanganané and Issagnanré. Most socio-linguistic groups, even from different ecological zones, used the same local names for the species. In the Guinean and the Sudano-Guinean zones, Fon and Mahi socio-linguistic groups referred to the species as a cowpea (reference to *Vigna*

**Table 2** Kersting's groundnut local names in socio-linguistic groups

| Socio-linguistic group | Local names | Meanings |
|---|---|---|
| Fon | Doyikoun | Underground cowpea |
| Tchabè | Atchaka | High economic and nutritional legume |
| Otammari | Issanganané | Bambara groundnut with long cooking time and high medicinal properties |
| Wama | Issanganané | |
| Idaasha | Atchaka | High economic and nutritional legume |
| Mahi | Doyikoun | Underground cowpea |
| Tem | Issagnanré | Bambara groundnut with long cooking time and high medicinal properties |
| Kabyès | Issagnanré | Bambara groundnut with long cooking time and high medicinal properties |

*unguiculata*) with underground pods (Doyikoun). Likewise, in the Sudano-Guinean zone, Tchabè and Idaasha socio-linguisitc groups, considered Kersting's groundnut as a legume with high economic and nutritional value (Atchaka). However, Otammari, Wama, Tem and Kabyès socio-linguistic groups in the Sudanian zone (of Benin and Togo) referred to Kersting's groundnut as bambara groundnut (reference to *Vigna subterranea*) with long cooking time and many medicinal properties (Issanganané or Issagnanré).

Furthermore, Kersting's groundnut farmers used a set of traits for describing the different landraces (Table 3). Seed coat colour, grain size, maturity time, yield, medicinal properties, cookability, and marketability were the traits used by farmers to describe Kersting's groundnut landraces. Although all those traits were important to farmers, they first used seed coat colour as a major trait (96.3% of farmers) to distinguish among landraces. Grain size, maturity time, yield, medicinal properties and marketability were second rank criteria for naming landraces. Based on farmers' description, five landraces were identified namely "White-seeded landrace", "Black-seeded landrace", "Red-seeded landrace", "White with black eye seeded landrace" and "White with yellow eye seeded landrace" (Fig. 2).

**Table 3** Farmers' criteria for describing Kersting's groundnut landraces in Benin and Togo

| Trait | Attribute | Percentage of farmers (%) |
|---|---|---|
| Grain color | White | 96.32 |
| | Black | |
| | Red | |
| | White with black eye | |
| | White with yellow eye | |
| Grain size | Small | 75.62 |
| | Medium | |
| | Large | |
| Maturity time | Early | 20.15 |
| | Late | |
| Yield potential | Low | 38.55 |
| | Medium | |
| | High | |
| Medicinal properties | Used | 30.45 |
| | Not used | |
| Marketability | Low | 90.25 |
| | Medium | |
| | High | |


**Fig. 2** Kersting's groundnut landraces (*WSL* white seeded landrace, *BSL* black seeded landrace, *WYL* white with yellow eye seeded landrace, *RSL* red seeded landrace, *WBL* white with black eye seeded landrace, scale is in cm with 1 mm as step). (Color figure online)

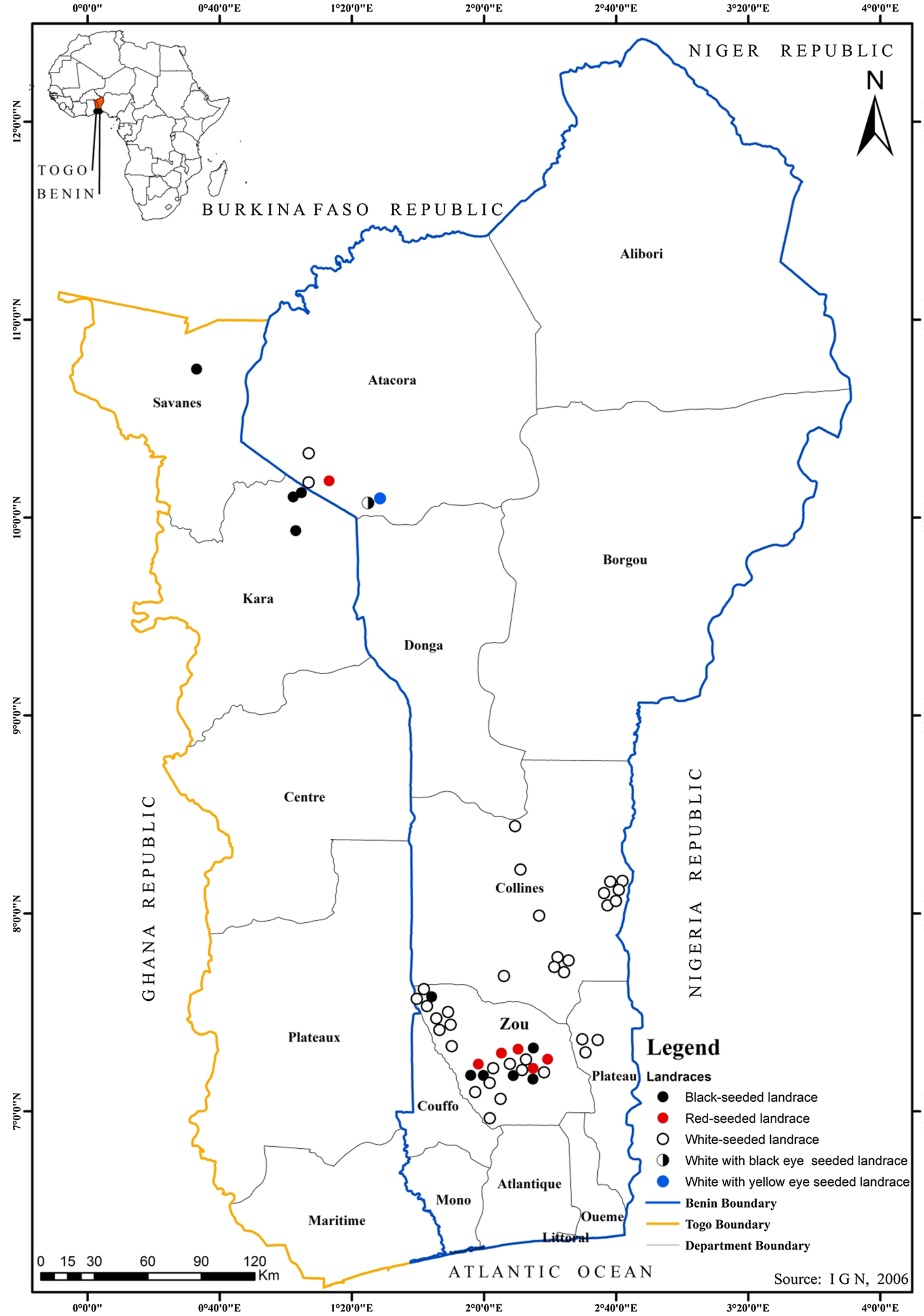
The analysis of the distribution (Fig. 3) showed that in the Sudanian zone, all landraces were present while in the Guinean the Sudano-Guinean zones only three of them were found. The white-seeded, red-seeded and black-seeded landraces were found in all ecological zones. However, the white with black eye seeded and the white with yellow eye seeded landraces were specific to the Sudanian zone. At farm level, the four-cell analysis revealed that in the Guinean and the Sudano-Guinean zones, out of three landraces cultivated, only the white seeded landrace fell into the first cell where large cultivation areas were devoted for cropping by many households (Fig. 4a, b). However, the two other landraces namely the black-seeded and the red-seeded landraces are rare and produced by a few households on a small cropping area. They fell into the second cell (small cropping areas by a few households). In the Sudanian zone, out of five landraces recorded, the black-seeded landrace was commonly produced by many households on a large cropping area (Fig. 4c). The red-seeded landrace fell in the second cell; it was grown by few farmers on a relatively large cropping area. Further, the three remaining landraces namely white with black eye seeded landrace, white with yellow seeded landrace and the white-seeded landrace fell into the third cell. These landraces were considered as rare in the Sudanian zone as they were produced by only few farmers on a small cropping area.

## Farmers' choice of Kersting's groundnut landraces in ecological zones

Our study revealed that Kersting's groundnut is produced for two main intentions depending on the ecological zones (Table 4). In the Guinean and Sudano-Guinean zones, the main motive for Kersting's groundnut production is the high price and marketability of its grains. Over the year a kilogram of Kersting's groundnut grains vary from US$ 2 to US$ 10. On contrary, in the Sudanian zone, Kersting's groundnut is mainly produced for its contribution to dietary diversity. Moreover, grains were the part of the plant mostly used by farmers in all ecological zones. The use categories of Kersting's groundnut depend upon the ecological zones. The fidelity levels showed that medicinal uses were more mentioned by farmers in the Guinean and the Sudanian zones ($22.0\% \leq$ FL $\leq 25.00\%$). Also, grain processing was a common use among farmers in the Sudano-Guinean and Sudanian zones ($20.3\% \leq$ FL $\leq 20.3\%$). Moreover, social use was raised by some farmers in the Guinean and the Sudano-Guinean zones. Uses for consumption and soil fertility were common in all zones (Table 4).

Also, within each ecological zone, intentions and use categories were specific to landraces. For instance, the white-seeded landrace was mainly produced for its

**Fig. 3** Distribution of Kersting's groundnut landraces across ▶ ecological zones. Color gradient to indicate type of landrace. (Color figure online)



NIGER REPUBLIC
BURKINA FASO REPUBLIC
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Savanes
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Donga
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Zou
Plateau
Couffo
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Oueme
Littoral
Maritime
GHANA REPUBLIC
NIGERIA REPUBLIC
ATLANTIC OCEAN
Legend
Landraces
Black-seeded landrace
Red-seeded landrace
White-seeded landrace
White with black eye seeded landrace
White with yellow eye seeded landrace
Benin Boundary
Togo Boundary
Department Boundary
0 15 30 60 90 120 Km
Source: I G N, 2006
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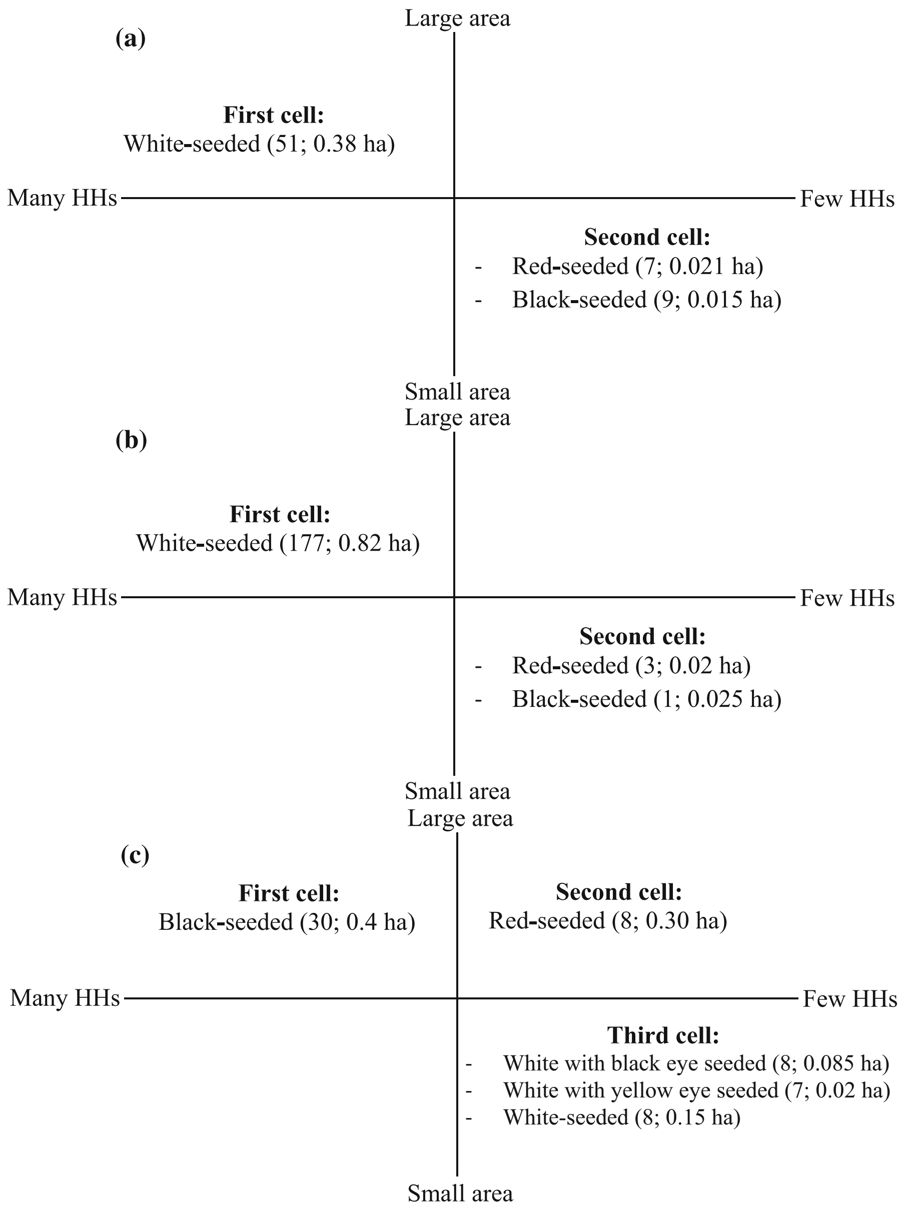
12°0'0"N 11°0'0"N 10°0'0"N 9°0'0"N 8°0'0"N 7°0'0"N

**Fig. 4** Results of four cell analysis. **a** Guinean zone, **b** Sudano-Guinean zone, **c** Sudanian zone (*HHs* households)




high marketability and income provision to households (FL = 82.0%) while the black-seeded and the red-seeded landraces were produced for their contribution to dietary diversity (FL = 100%). The other landraces namely the white with black eye seeded landrace and the white with yellow eye seeded landrace were produced in low quantity (Table 5). Regarding the use categories, the black-seeded landrace was specifically used for medicinal purposes (FL = 27.9%) and ritual use (FL = 21.3%). The red-seeded and the white-seeded landraces were used for grain processing. Also, the white-seeded landrace was used by some farmers for social actions such as gift of Kersting's groundnut grains to friends and folks during festive periods (FL = 12.00%). The two other landraces namely the white with black eye landrace and the white with yellow eye landrace were used for medicinal purposes and grain processing. Moreover, uses for consumption and soil fertility management were common to all identified landraces (Table 5).

**Table 4** Differential utilizations of Kersting's groundnut in ecological zones in Benin and Togo

| Criteria | Variant | Guinean zone (n = 67) | | Sudano-Guinean zone (n = 180) | | Sudanian zone (n = 53) | |
|---|---|---|---|---|---|---|---|
| | | F | FL | F | FL | F | FL |
| Intentions | High marketability | 59 | 83.09 | 175 | 97.22 | 0 | 0.00 |
| | Dietary diversity | 12 | 16.90 | 5 | 2.77 | 53 | 100 |
| | ΣF | 71 | – | 180 | – | 53 | – |
| Use categories | Consumption | 30 | 32.96 | 130 | 35.61 | 38 | 29.68 |
| | Medicine | 20 | 21.97 | 40 | 10.95 | 32 | 25.00 |
| | Social | 14 | 15.38 | 30 | 8.21 | 0 | 0 |
| | Ritual | 0 | 0 | 0 | 0 | 2 | 1.56 |
| | Grain processing | 10 | 10.98 | 85 | 20.33 | 26 | 20.31 |
| | Soil fertility | 17 | 18.68 | 80 | 21.91 | 30 | 23.43 |
| | ΣF | 91 | – | 365 | – | 128 | – |

*n* number of interviewees per ecological zone, *F* frequency, *ΣF* sum of frequency per variant, *FL* fidelity level

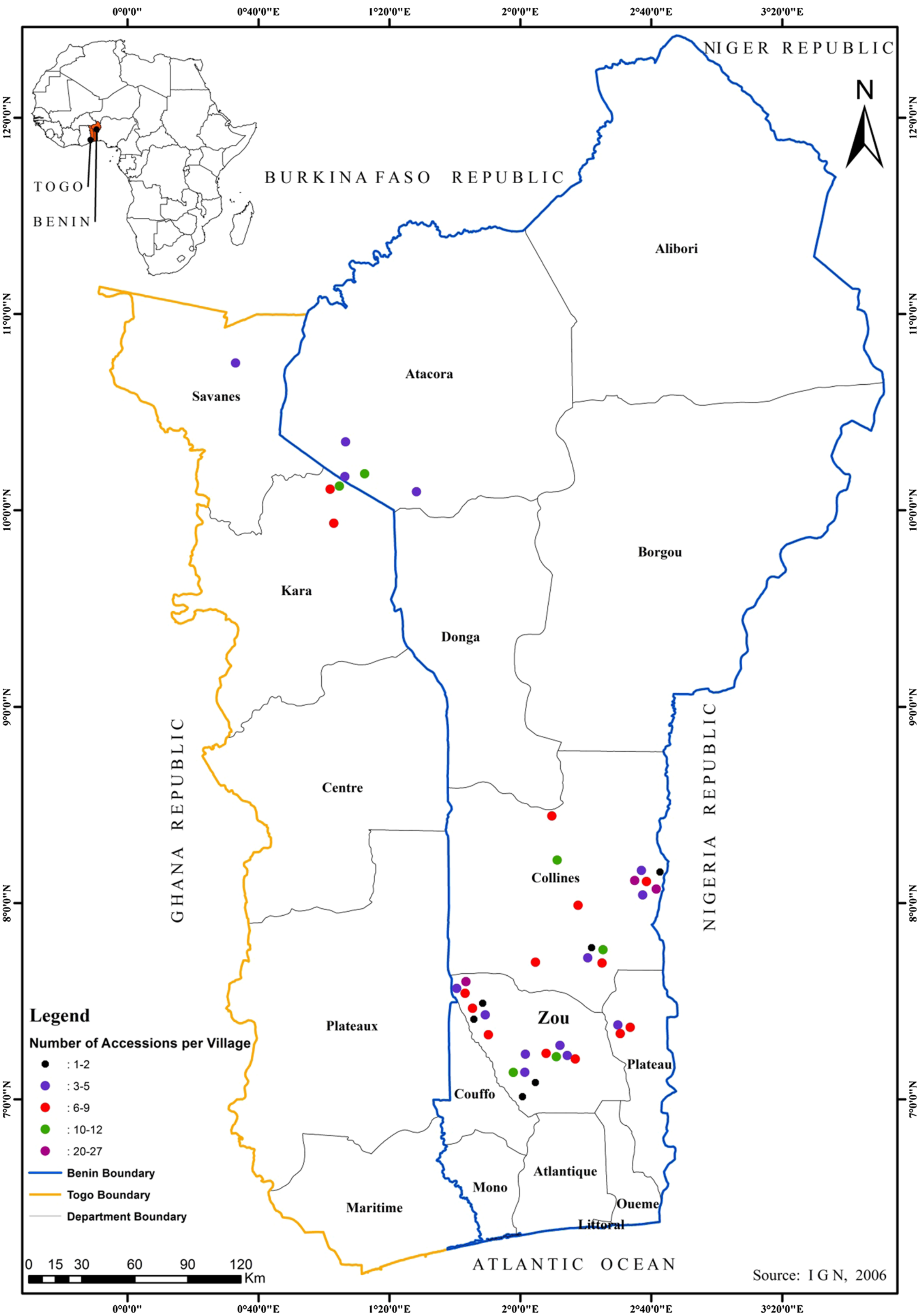
**Table 5** Specific intentions and use categories of Kersting's groundnut landraces in Benin and Togo

| Criteria | Variant | WSL (n = 236) | | BSL (n = 40) | | RSL (n = 18) | | WBL n = 8 | | WYL n = 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F | FL | F | FL | F | FL | F | FL | F | FL |
| Intentions | High marketability | 210 | 82.03 | 0 | 0.00 | 0 | 0.00 | 3 | 30.00 | 5 | 41.66 |
| | Dietary diversity | 46 | 17.97 | 40 | 100 | 18 | 100 | 7 | 70.00 | 7 | 58.33 |
| | ΣF | 256 | – | 40 | – | 18 | – | 10 | – | 12 | – |
| Use categories | Consumption | 228 | 49.78 | 34 | 27.86 | 14 | 37.83 | 8 | 38.09 | 7 | 36.84 |
| | Medicine | 0 | 0.00 | 34 | 27.86 | 0 | 0.00 | 2 | 9.52 | 0 | 15.78 |
| | Social | 45 | 12.00 | 04 | 03.27 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Ritual | 0 | 0 | 26 | 21.31 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | Grain processing | 96 | 20.96 | 0 | 0.00 | 13 | 35.13 | 5 | 23.80 | 6 | 31.57 |
| | Soil fertility | 89 | 19.43 | 24 | 19.61 | 10 | 27.02 | 6 | 28.57 | 3 | 15.78 |
| | ΣF | 458 | – | 122 | – | 37 | – | 21 | – | 19 | – |

*WSL* white seeded landrace, *BSL* black seeded landrace, *RSL* red seeded landrace, *WBL* white with black eye seeded landrace, *WYL* white with yellow eye seeded landrace, *F* frequency, *FL* fidelity level

## Geo-referenced distribution of Kersting's groundnut accessions

In total, 308 accessions (Table S1, supplementary file) were collected with 300 farmers in 43 different villages (Fig. 5). On average we collected 7.16 ± 3.58 accessions per village. In the Sudano-Guinean zone, we obtained a maximum of 27 accessions per village on contrary to the Guinean and the Sudanian zones where the maximum number of accessions per village was 9. Also, about 55.8% of surveyed villages were located in the Sudano-Guinean zone while 18.7% of them were located in the Sudanian zone. Likewise, 60.0% of surveyed Kersting's groundnut farmers were found in the Sudano-Guinean while 17.7% of them belonged to the Sudanian zone. Within each ecological zone, the production was limited to specific municipalities and departments (Fig. 5). In the Guinean zone, the production was restricted to the municipalities of Abomey, Agbangnizoun, Zogbodomey, Za-Kpota in the department of Zou and the municipality of Kétou in the department of Plateau. In the Sudano-Guinean zone, Kersting's groundnut was cultivated in the municipality of Djidja in the department of Zou and the municipalities of Dassa-Zoumè, Glazoué and Savè


0°0'0"
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NIGER REPUBLIC
BURKINA FASO REPUBLIC
TOGO
BENIN
N
Alibori
Atacora
Savanes
Borgou
Kara
Donga
Centre
GHANA REPUBLIC
NIGERIA REPUBLIC
Collines
Plateaux
Zou
Plateau
Couffo
Atlantique
Mono
Maritime
Oueme
Littoral
ATLANTIC OCEAN
Source: I G N, 2006
Legend
Number of Accessions per Village
: 1-2
: 3-5
: 6-9
: 10-12
: 20-27
Benin Boundary
Togo Boundary
Department Boundary
0 15 30 60 90 120
Km

◀**Fig. 5** Distribution of Kersting's groundnut accessions in Benin and Togo with frequency of accessions collected per village. Color gradient to indicate number of accessions. (Color figure online)

in the department of Collines. Further, in the Sudanian zone, the species was cultivated in the department of Atacora in Benin, and the departments of Kara and Savanes in Togo.

Kersting's groundnut farming systems

Kersting's groundnut farmers included in this survey were, on average, 48.24 years old with a range of 35–98 years. About 30.4% of farmers were women. The average household size was nine members (ranging from 3 to 10 members). Three sources of labour were observed namely family labour, hired labour and mutual aid. For various activities, 80.7% of farmers combined family and hired labour while 19.3% of farmers used a combination of family labour and mutual aid for farming activities (Table 6). Labour was hired for farming practices such as land clearing, tillage and weeding. All interviewed farmers adopted ridge as the appropriate mode of tillage for the species. The average cropping area devoted to Kersting's groundnut production was 0.64 ha (0.01–2.5 ha). After each harvest, 61.6% of farmers stored seeds for the following season while 39.5% of them purchased seeds in local markets (Table 6). On average, each farmer produced 1.03 Kersting's groundnut landrace (one to two) on his farm. Likewise, Kersting's groundnut farming can be divided into two sets of practices: pre-harvest and post-harvest practices. Pre-harvest activities include land clearing, tillage, sowing and weeding (Table 6). Activities such as fertilization and application of pesticide were never practiced by farmers included in this study. Moreover,

**Table 6** Description of socio-economic, cropping systems and biophysical resources (n = 300)

| Categories | Variables | Unit | Mean | Freq. | SE |
|---|---|---|---|---|---|
| Socio economic resources | Age | year | 48.24 | | 0.97 |
| | Gender | % female | | 30.41 | |
| | HH size | Number of persons | 7.21 | | 0.04 |
| | Family and hired labours | % of yes | | 75.66 | |
| | Family labour and mutual aid | % of yes | | 24.33 | |
| Biophysical resources | Cropping area | ha | 0.64 | | 0.03 |
| | Seed storage | % of yes | | 61.55 | |
| | Seed purchase | % of yes | | 39.45 | |
| | Landraces per HH | Number of landraces | 1.03 | | 0.07 |
| | Land clearing | % of yes | | 100 | |
| | Tillage | % of yes | | 100 | |
| System management | Early sowing | % of yes | | 55.78 | |
| | Late sowing | % of yes | | 44.46 | |
| | Weeding | % of yes | | 100 | |
| | Cropping systems | % of pure stand | | 84.64 | |
| | | % of intercropping | | 15.35 | |
| | Land type | % of non-fallow | | 80.92 | |
| | | % of fallow | | 19.07 | |
| | Fertilization | % yes | | 0.00 | |
| | Pesticide use | % of yes | | 0.00 | |
| | Pods drying | % of yes | | 100 | |
| | Pods shelling | % of yes | | 100 | |
| | Grain yield | kg/ha | 420.93 | | 4.93 |

*HH* household

55.8% of farmers adopted early sowing while 44.5% of them practiced late sowing. Post-harvest activities include pod drying and shelling and were practiced by all interviewed farmers. The average grain yield was 420.93 kg/ha. In the study area, two types of land were used by farmers for Kersting's groundnut production namely fallow and non-fallow land. Fallow land in this context refers to land that was not cultivated for a maximum of 1 year. On the other hand, non-fallow land is defined as land that was cultivated during the season preceding Kersting's groundnut production. Furthermore, 84.6% of farmers produced Kersting's groundnut on a pure stand while 15.4% of them intercropped the species with other annual crops (Table 6).

## Comparative analysis of Kersting's groundnut production in ecological zones

Our study revealed high significant difference for most variables between the three ecological zones (Table 7). Apart from household age, household size and number of landraces per household, all variables vary significantly across ecological zones. Hence, in the Guinean and Sudano-Guinean zones, the proportion of women in Kersting's groundnut production was relatively low (20% for Guinean zone and 17.8% for Sudano-Guinean zone). In addition, all farmers in these zones combined family and hired labour for farming activities, and produced Kersting's groundnut in pure stand (Table 7). Local markets were the main source of seeds used by most farmers in these zones (between 74.5 and 80.3%).

However, the results showed some differences between the Guinean and the Sudano-Guinean zones. Firstly, farmers in the Guinean zone produced Kersting's groundnut on a small cropping area (0.35 ha on average). Also, most farmers (89.7%) in Guinean zone adopted late sowing while in Sudano-Guinean zone farmers (69.7%) preferred early sowing of Kersting's groundnut. Early sowing of Kersting's groundnut was done from 1st to 15th July while late sowing was done between 1st and 15th August. Lastly, the average Kersting's groundnut yield in the Guinean zone is lower (352.30 kg/ha) compared to the Sudano-Guinean zone (525.36 kg/ha).

**Table 7** Analysis of Kersting's groundnut farming practices across ecological zones

| Variables | Unit | Mean | | | Frequency | | | Diff |
|---|---|---|---|---|---|---|---|---|
| | | GZ | SGZ | SZ | GZ | SGZ | SZ | |
| Age | Year | 55.16 | 45.17 | 52.14 | | | | ns |
| Sex | % female | | | | 20 | 17.81 | 95.62 | *** |
| HH size | Number of persons | 6.33 | 5.66 | 4.86 | | | | ns |
| Family and hired labours | % of yes | | | | 100 | 100 | 1.25 | ** |
| Family labour and mutual aid | % of yes | | | | 0.00 | 0.00 | 98.75 | *** |
| Cropping area | ha | 0.35[a] | 0.83[b] | 0.27[a] | | | | *** |
| Seed storage | % of yes | | | | 20.66 | 25.55 | 98.25 | *** |
| Seed purchase | % of yes | | | | 80.33 | 74.45 | 1.75 | ** |
| Landraces per HH | Number of landraces | 1.16 | 1.01 | 1.00 | | | | ns |
| Early sowing | % of yes | | | | 10.33 | 76.66 | 100 | *** |
| Late sowing | % of yes | | | | 89.66 | 23.33 | 0 | *** |
| Cropping system | % of pure stand | | | | 100 | 100 | 0 | *** |
| | % of intercropping | | | | 0 | 0 | 100 | *** |
| Land type | % of non-fallow | | | | 100 | 79.10 | 100 | *** |
| | % of fallow | | | | 0 | 20.90 | 0.00 | *** |
| Grain yield | kg/ha | 352.30[a] | 525.36[b] | 531.88[b] | | | | *** |

*GZ* Guinean zone, *SGZ* Sudano-Guinean zone, *SZ* Sudanian zone, *HH* household, *Diff* statistical difference between ecological zones, ns = no significant difference

[a, b]Are used to separate means of quantitative variables; values followed by the same superscript letter are statistically identical

***$p < 0.001$; **$p < 0.01$

On contrary to the Guinean and the Sudano-Guinean zones, most of Kersting's groundnut farmers (95.26%) in the Sudanian zone were women (Table 7). Besides, farmers in the Sudanian zone produced Kersting's groundnut on smaller cropping areas (on average 0.27 ha) and used a combination of family labour and mutual aid (98.8% of farmers) for farming activities. Most of the farmers (98.3%) stored their own seeds for Kersting's groundnut production. Also, all farmers in this zone adopted early sowing (1st–15th July). They intercropped Kersting's groundnut with *Zea mays* and *Sorghum bicolor*. The average Kersting's groundnut yield in this zone was higher (531.88 kg/ha) compared with the Guinean and the Sudano-Guinean zones.

Evolution of Kersting's groundnut cropping areas and production bottlenecks in ecological zones

Analysis of Kersting's groundnut cropping areas from 2015 to 2017 revealed a highly significant decrease for the whole study area and within ecological zones (Fig. 6). In the Sudano-Guinean zone, there was a significant decrease ($p = 0.03$) in Kersting's groundnut cropping areas. Average cropping areas in this zone were 0.93 ha in 2015, 0.82 ha in 2016 and 0.68 ha in 2017. Likewise, in the Guinean zone the decrease in cropping areas was highly significant ($p < 0.001$) during this period. The average cropping areas were 0.47 ha in 2015, 0.34 ha in 2016 and 0.23 ha in 2017. On contrary to the Guinean and the Sudano-Guinean zones, the decrease in Kersting's groundnut cropping areas in the Sudanian zone from 2015 to 2017 was not statistically significant ($p = 0.12$).

Moreover, many bottlenecks accounted for the decrease in Kersting's groundnut cropping areas in ecological zones (Fig. 7). The main bottlenecks hindering Kersting's groundnut production were disease pressure (85% of farmers), weather variability (70% of farmers), high seed price (62.5% of farmers) and mistakes in sowing period (60% of farmers). Other bottlenecks include stored seed susceptibility to beetles and labour requirements. Most of these constraints were significantly dependent on ecological zones (Table 8). Disease pressure, seed price and mistakes in sowing period were highly scored by farmers in Guinean and Sudano-Guinean zones. Weather variability was raised by farmers in Sudano-Guinean and Sudanian zones.

## Discussion

The meaning of local names attributed to Kersting's groundnut by socio-linguistic groups within the three ecological zones, were relevant for the classification of the species. In all ecological zones, socio-linguistic

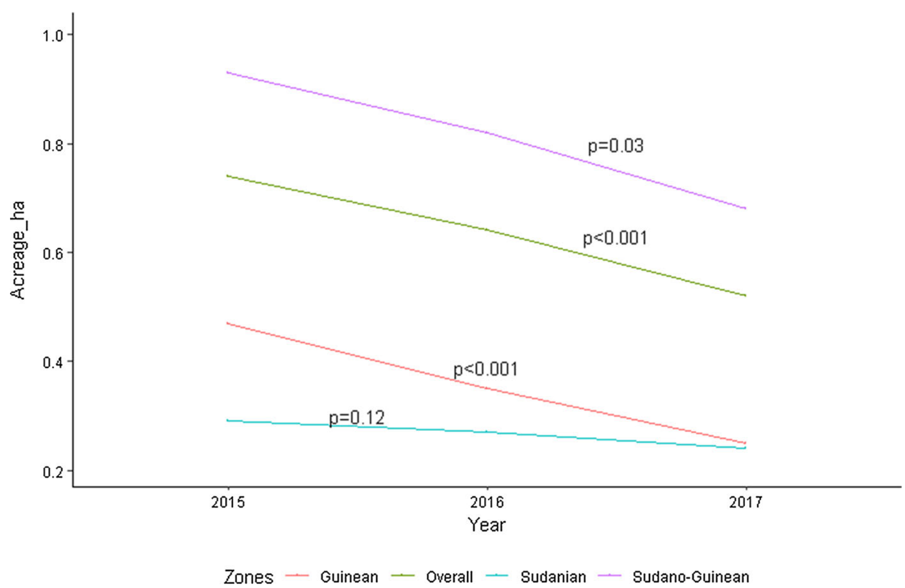


**Fig. 6** Evolution of Kersting's groundnut cropping areas in ecological zones from 2015 to 2017. (Color figure online)

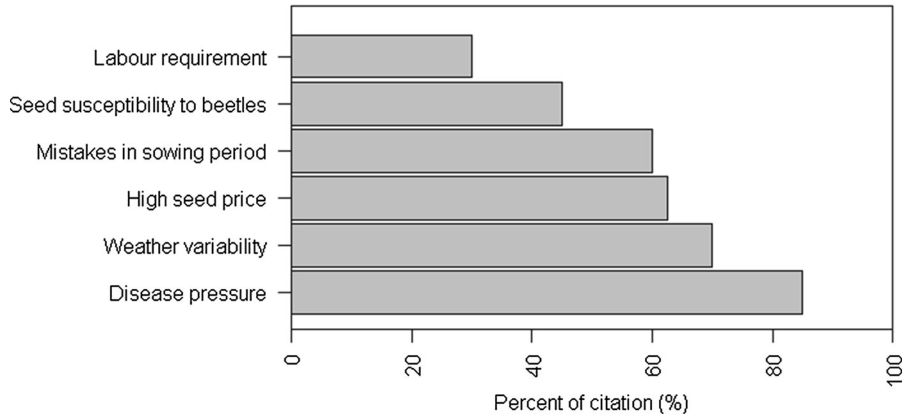


**Fig. 7** Kersting's groundnut production bottlenecks in Benin and Togo

**Table 8** Scoring of Kersting's groundnut production bottlenecks in ecological zones in Benin and Togo

| Bottlenecks | Guinean zone | Sudano-Guinean zone | Sudanian zone | Friedman's test |
|---|---|---|---|---|
| Disease pressure | 8.42 | 7.97 | 2.48 | *** |
| Weather variability | 2.47 | 5.96 | 6.55 | *** |
| High seed price | 6.36 | 7.50 | 1.60 | *** |
| Mistakes in sowing period | 6.68 | 5.02 | 0.00 | *** |
| Seed susceptibility to beetles | 2.10 | 2.02 | 2.39 | ns |
| Labour requirement | 4.36 | 4.53 | 4.15 | ns |

*ns* no significant difference, 1 = lowest score, 10 = highest score

***$p$ value $< 0.001$

groups recognized the species as an underground grain legume. This revealed the correspondence between the folk nomenclature and the scientific classification of the species (Khasbagan and Soyolt 2008; Whaanga et al. 2013). Also, in Idaasha and Tchabè socio-linguistic groups of the Sudano-Guinean zone, the local name of Kersting's groundnut (Atchaka) highlights the high economic and nutritional value of the species. In Wama, Otammari, Tem and Kabyès socio-linguistic groups of the Sudanian zone, Kersting's groundnut local names revealed the high medicinal values of the species and the relatively long cooking time of its grains compared with bambara groundnut. This is the evidence that in addition to revealing the botanical traits of the species, folk nomenclature helped to understand the place of Kersting's groundnut in socio-linguistic groups across different zones and other quality attributes associated with the species. Moreover, farmers used a set of traits including seed coat colour, grain size, maturity time, yield potential, medicinal uses and marketability for intraspecific description of landraces. However, when it comes to naming the different landraces, farmers solely focused on seed coat colour. The main reason is that seed coat colour is unique to each landrace while other traits may be commonly shared. Furthermore, using seed coat colour as discriminant trait, we recorded five Kersting's groundnut landraces. Previous authors reported three traditional cultivars only (Adu-Gyamfi et al. 2011; Assogba et al. 2016). The two new landraces are the "White with black eye seeded" and the "White with yellow eye seeded". In fact, previous studies did not include all production areas. As a result, a part of the existing genetic diversity was left out.

Our results also revealed that Kersting's groundnut landraces presented different distribution patterns. The new landraces i.e. "White with black eye seeded" and "White with yellow eye seeded" were specific to the Sudanian zone while the three other landraces were recorded in all ecological zones. This finding provides more precision on the centre of origin of the species previously reported to be central Benin or northern Togo (Achigan Dako and Vodouhè 2006). In fact, the Sudanian zone can be considered as the primary centre of origin of Kersting's groundnut, therefore, important for the collection and the conservation of Kersting's groundnut genetic resources.

Further, the on-farm level diversity of Kersting's groundnut was specific to ecological zones. In the Guinean and Sudano-Guinean zones, the "White-seeded landrace" was commonly cultivated on large cropping areas. The two other landraces namely the "Black-seeded" and the "Red-seeded" landraces were disappearing from those areas and should be considered for conservation. However, in the Sudanian zone, the "Black-seeded" and the "Red-seeded" landraces were produced by farmers on large cropping areas. The "Black-seeded" landrace was cultivated by many households in contrast to the "Red-seeded" landrace. The three other landraces were considered as rare in the Sudanian zone. Therefore, conservation strategy should be clearly defined for those landraces. Farmers choose a Kersting's groundnut landrace based on several reasons related to local perceptions and use categories across ecological zones. Thus, in the Guinean and Sudano-Guinean zones, farmers cultivated Kersting's groundnut for the market. As consequence, only the "White-seeded" landrace was commonly cultivated because of the price and the high marketability of its grains, and consumers' preferences. This ascertained that market integration has significantly reduced Kersting's groundnut genetic diversity as also reported by Van Dusen and Taylor (2005) on in situ conservation of crop diversity in a context of ecological and market environments in Mexico.

In contrast, most farmers in the Sudanian zone cultivated Kersting's groundnut to mainly diversify their diets and gain from the health benefits of the species. Therefore, farmers of this zone preferred the "Black-seeded" landrace as it serves for rituals and has multiple medicinal properties. According to those farmers, "Black-seeded" landrace is used to treat malaria, diarrhoea and cysts. In addition, farmers cultivated the "Red-seeded" landrace for self-consumption and grain processing into infantile flour and traditional cakes. Moreover, the "White with black eye seeded" and the "White with yellow eye seeded" landraces combined according to farmers both market traits and medicinal properties. In consequence, they are conserved by some farmers of the Sudanian zone.

From our results, it was clear that tailored interventions should be undertaken for a sustainable production and promotion of Kersting's groundnut in Benin and Togo. Improving Kersting's groundnut production requires the definition of relevant conservation strategies of the genetic resources of the species. Both in situ and ex situ conservation strategies should be implemented. In situ conservation is a fundamental requirement for conservation of genetic resources diversity (Iwanaga 1996). In our context, the Sudanian zone is the appropriate zone for the implementation of in situ conservation of Kersting's groundnut since all the landraces are being cultivated by farmers in that zone. Also, actions aiming at maintaining intercropping systems in the Sudanian zone will facilitate in situ conservation of Kersting's groundnut genetic resources. Farmers in the Sudanian zone intercropped Kersting's groundnut with cereal crops while in other zones the Kersting's groundnut was cultivated in pure stand. According to farmers in the Sudanian zone, intercropping benefits the production and the management of cereals crops. As a legume crop, Kersting's groundnut has an intensive symbiotic activity with a high atmospheric $N_2$ fixation ratio for its growth and the benefit of other crops (Mohammed et al. 2015, 2016). Moreover, intercropping systems integrate high crop diversity that increases farmers' income and provides them with tools for a good environmental risk management in rainfed agriculture (Di Falco and Chavas 2006).

Moreover, effective preservation of genetic resources of Kersting's groundnut also requires ex situ conservation strategies to supplement on-farm conservation. This implies that all genetic resources of Kersting's groundnut must be thoroughly collected in other production countries including Ghana, Burkina Faso and Nigeria. Subsequently, the collected germplasm should be properly characterized in different environments for at least 2 years to get an accurate understanding of the genetic diversity of Kersting's groundnut with regards to farmers' traits. After the characterization, all accessions should be handed over to national and international genebanks for long-term conservation. Improving Kersting's groundnut production also requires the development of new cultivars with farmers' preferred traits. Given farmers current needs, plant breeders should target high yield, large grain size, disease resistance, drought tolerance, early flowering time, early maturity time and reduced grains cooking time. In these conditions, multiple traits selection could be an appropriate strategy to create new cultivars for the sustainable production of Kersting's groundnut. Since Kersting's groundnut is a self-pollinated crop, the existing diversity may not encompass all favourable alleles required to address farmers' needs. In this condition, broadening the genetic diversity in the species becomes a necessary action. Given the existing morphological variation in the species, crosses between landraces from different geographical and climate regions is a useful pathway to explore. Furthermore, interspecific hybridization with sister species such as *Macrotyloma tisserantii* Pellegr. could be of great interest. In addition, with the availability of genomic information, Targeted Induced Local Lesion IN Genomes (TILLING) could help identify new mutants with favourable alleles.

From our results, farmers are already processing grains of most landraces into infantile flour and traditional cakes. Therefore, improving industrial processing of Kersting's groundnut is a relevant action to enhance the promotion and the production of all landraces across ecological zones. This action will help to improve in situ conservation of the existing diversity of the species. As for implication, large germplasm of Kersting's groundnut should be screened for nutritional profile for the selection of high nutritious cultivars to reduce malnutrition and chronic diseases in rural populations.

In addition to labour requirements and high seed price identified by Assogba et al. (2016), we found that major bottlenecks hindering Kersting's groundnut production across zones include disease pressure and high susceptibility to beetles, and weather variability that cause mistakes in sowing date. Therefore, a sustainable production of Kersting's groundnut also requires effective pest and disease management strategies to assist farmers in controlling field diseases as well as post-harvest insects. Disease pressure was specific to the Guinean and the Sudano-Guinean zones. Diseases caused seedlings death, plant wilting, stem and pods rot. Pulse beetle, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) was the major post-harvest insect of Kersting's groundnut. Investigations are required on effective and low risk insecticides products for a better preservation of the grains (Badii et al. 2014). Also, a pathway to disease and pest resistant cultivars should be developed.

Moreover, farmers referred to weather variability as erratic rain and drought spells. Water shortage during the flowering time was found by farmers to reduce seed set and grain size. The finding implies that severe water shortage can reduce Kersting's groundnut yield. Similar results were obtained by Daryanto et al. (2016) on other grain legumes including cowpea and peanut. To cope with erratic rain and drought spells, farmers managed sowing date differently across production areas. For instance, most farmers in the Guinean zone have adopted late sowing contrary to farmers in the Sudano-Guinean and the Sudanian zones. Farmers delay the sowing to make sure that the maturity period of the crop will not coincide with heavy rain which huge causes grain losses. With erratic rain and drought spells, farmers need improved cultivars resilient to stress and that produce higher yield.

## Conclusion

In this paper, we assessed farmers' knowledge, Kersting's groundnut diversity and distribution across three ecological zones in Benin and northern Togo. We also conducted a comparative analysis of Kersting's groundnut production and farmers' bottlenecks across the three ecological zones. Based on farmers' knowledge and description we obtained five landraces with different distribution patterns across ecological zones. Two new landraces were found to be specific to the Sudanian zone. Landraces were cultivated to different extents across zones depending on local intentions and use categories. A highly significant decrease in cropping areas occurred in most of the zones due to specific production bottlenecks. Interventions to improving Kersting's groundnut production and promotion include the definition of effective in situ and ex situ conservation strategies, germplasm collection and characterization, development of new cultivars with farmers' preferred traits, enhancement of the genetic base of the species, improvement of Kersting's groundnut 'processability' and definition of effective pest and management strategies.

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**Compliance with ethical standards**

**Conflict of interest** The authors declared that they have no conflict of interest.

## References


Abeyasekera S (2005) Quantitative analysis approaches to qualitative data: why, when and how? In: Holland JD, Campbell J (eds) Methods in development research; combining qualitative and quantitative approaches. ITDG Publishing, Warwickshire, pp 97–106

Achigan Dako EG, Vodouhè SR (2006) *Macrotyloma geocarpum* (Harms) Maréchal & Baudet. In: Brink M, Belay G (eds) Plant resources of tropical Africa 1. Cereals and pulses. Backhuys Publishers CTA, PROTA, Wageningen, pp 111–114

Adomou A (2005) Vegetation patterns and environmental gradients in Benin. Implications for biogeography and conservation. Wageningen University, Wageningen

Adu-Gyamfi R, Fearon J, Bayorbor T, Dzomeku I, Avornyo V (2011) The status of Kersting's groundnut (*Macrotyloma geocarpum* [Harms] Marechal and Baudet): an underexploited legume in Northern Ghana. Outlook Agr 40:259–262

Ajayi OB, Oyetayo F (2009) Potentials of *Kerstingiella geocarpa* as a health food. J Med Food 12:184–187. https://doi.org/10.1089/jmf.2008.0100

Akoègninou A, Van der Burg W, Van der Maesen LJG (2006) Flore analytique du Bénin, vol 06.2. Backhuys Publishers, Wageningen

Aremu M, Osinfade B, Basu S, Ablaku B (2011) Development and nutritional quality evaluation of Kersting's groundnut-ogi for African weaning diet. Am J Food Technol 6:1021–1033

Assogba P, Ewedje E-EBK, Dansi A, Loko YL, Adjatin A, Dansi M, Sann A (2016) Indigenous knowledge and agromorphological evaluation of the minor crop Kersting's groundnut (*Macrotyloma geocarpum* (Harms) Maréchal et Baudet) cultivars of Benin. Genet Resour Crop Evol 635:513–529. https://doi.org/10.1007/s10722-015-0268-9

Aworh OC (2015) Promoting food security and enhancing Nigeria's small farmers' income through value-added processing of lesser-known and under-utilized indigenous fruits and vegetables. Food Res Int 76:986–991

Ayenan MAT, Ezin VA (2016) Potential of Kersting's groundnut [*Macrotyloma geocarpum* (Harms) Maréchal & Baudet] and prospects for its promotion. Agric Food Secur 5:1

Badii BK, Adarkwah C, Obeng-Ofori D, Ulrichs C (2014) Efficacy of diatomaceous earth formulations against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) in Kersting's groundnut (*Macrotyloma geocarpum* Harms): influence of dosage rate and relative humidity. J Pest Sci 87:285–294

Baldermann S et al (2016) Are neglected plants the food for the future? Crit Rev Plant Sci 35:106–119

Cullis C, Kunert KJ (2017) Unlocking the potential of orphan legumes. J Exp Bot 68:1895–1903

Curran J (2012) The nutritional value and health benefits of pulses in relation to obesity, diabetes, heart disease and cancer. Br J Nutr 108:S1

Dalrymple DG (1986) Development and spread of high-yielding rice varieties in developing countries. International Rice Research Institute, Washington

Dansi A et al (2012) Diversity of the neglected and underutilized crop species of importance in Benin. Sci World J 2012:932947

Daryanto S, Wang L, Jacinthe P-A (2016) Global synthesis of drought effects on cereal, legume, tuber and root crops production: a review. Agric Water Manag 179:16

Di Falco S, Chavas J-P (2006) Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture. Eur Rev Agric Econ 33:289–314

Ebert AW (2014) Potential of underutilized traditional vegetables and legume crops to contribute to food and nutritional security, income and more sustainable production systems. Sustainability 6:319–335

FAO (2017) Regional overview of food security and nutrition in Africa 2017. The food security and nutrition–conflict nexus: building resilience for food security, nutrition and peace. FAO, Accra

Fousseni F, Madjouma K, Dieudonné GY, Li PD, Hai ZX, Koffi A (2014) Global overview of flora and plant diversity in Togo (West Africa). J life Sci Res 1:24–30

Harlan JR (1971) Agricultural origins: centers and noncenters. Science 174:468–474

Hoffman B, Gallaher T (2007) Importance indices in ethnobotany. ERA 5:201–218

Hummer KE, Hancock JF (2015) Vavilovian centers of plant diversity: implications and impacts. HortScience 50:780–783

INSAE (2015) RGPH4: Que retenir des effectifs de population en 2013 ?. Institut National de la Statistique et de l'Analyse Economique, Cotonou

Iwanaga M (1996) IPGRI strategy for in situ conservation of agricultural biodiversity. In: DSE/ATSAF/IPGRI workshop in situ conservation and sustainable use of plant genetic resources for food and agriculture in developing countries, Bonn (Germany), 2–4 May 1995. IPGRI

Jambo N (2017) The impact of government spending on agricultural growth: a case of Zambia, Malawi, South Africa and Tanzania. Stellenbosch University, Stellenbosch

Khasbagan, Soyolt (2008) Indigenous knowledge for plant species diversity: a case study of wild plants' folk names used by the Mongolians in Ejina desert area, Inner Mongolia, P. R. China. J Ethnobiol Ethnomed 4:2. https://doi.org/10.1186/1746-4269-4-2

Kouris-Blazos A, Belski R (2016) Health benefits of legumes and pulses with a focus on Australian sweet lupins. Asia Pac J Clin Nutr 25:1–17

Last L et al (2014) Indicators for the on-farm assessment of crop cultivar and livestock breed diversity: a survey-based participatory approach. Biodivers Conserv 23:3051–3071

Mayes S, Massawe F, Alderson P, Roberts J, Azam-Ali S, Hermann M (2011) The potential for underutilized crops to improve security of food production. J Exp Bot 63:1075–1079

Mohammed M, Sowley E, Dakora F (2015) Symbiotic $N_2$ fixation, C assimilation and water-use efficiency (WUE) of five Rhizobium-inoculated Kersting's groundnut (*Macrotyloma geocarpum*) landraces measured using $^{15}N$ and $^{13}C$ isotopic techniques. S Afr J Bot 98:192

Mohammed M, Sowley E, Dakora F (2016) Variations in $N_2$ fixation of field-grown Kersting's groundnut (*Macrotyloma geocarpum*) landraces in response to inoculation with two Bradyrhizobium strains in the northern region of Ghana. S Afr J Bot 103:333

MPDAT (2011) Recensement général de la population et de l'habitat (06 au 21 Novembre 2010). Résultats définitifs. Lomé

Padulosi S, Thompson J, Rudebjer P (2013) Fighting poverty, hunger and malnutrition with neglected and underutilized species: needs, challenges and the way forward. Bioversity International, Rome

Pasquet R, Mergeai G, Baudoin J-P (2002) Genetic diversity of the African geocarpic legume Kersting's groundnut, *Macrotyloma geocarpum* (Tribe Phaseoleae: Fabaceae). Biochem Syst Ecol 30:943–952

R Core Team (2017) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org/. Accessed 27 Jan 2018

Rana RB, Sthapit BR, Garforth C, Subedi A, Jarvis DI (2005) Four-cell analysis as a decision-making tool for conservation of agrobiodiversity on-farm. In: Sthapit BR, Upadhyay MP, Shrestha PK, Jarvis DI (eds) On-farm conservation of agricultural biodiversity in Nepal, vol 2. IPGRI, Rome, pp 15–24

Rao VR, Hodgkin T (2002) Genetic diversity and conservation and utilization of plant genetic resources. Plant Cell Tissue Organ Cult 68:1–19

Schroeder C, Onyango TKO, Nar RB, Jick N, Parzies H, Gemenet D (2013) Potentials of hybrid maize varieties for small-holder farmers in Kenya: a review based on Swot analysis. Afr J Food Agric Nutr, Dev, p 13

Sthapit B et al (2006) Participatory four cell analysis (FCA) for local crop diversity. In: Sthapit B, Shrestha P, Upadhyay M (eds) On-farm management of agricultural biodiversity in Nepal: Good practices, vol 260. LI-BIRD, Nepal, pp 13–16

Tadele Z (2017) Raising crop productivity in Africa through intensification. Agronomy 7:22

Ugulu I (2012) Fidelity Level and knowledge of medicinal plants used to make therapeutic Turkish baths. Stud Ethno Med 6:1–9. https://doi.org/10.1080/09735070.2012.11886413

Van Dusen E (2005) Understanding the factors driving on farm crop genetic diversity: empirical evidence from Mexico. In: Cooper J, Lipper LM, Zilberman D (eds) Agricultural biodiversity and biotechnology in economic development. Springer, Boston, pp 127–145

Van Dusen ME, Taylor JE (2005) Missing markets and crop diversity: evidence from Mexico. Environ Dev Econ 10:513–531

Vavilov NI, Dorofeev VF (1992) Origin and geography of cultivated plants. Cambridge University Press, New York

Whaanga H, Papa W, Wehi P, Roa T (2013) The use of the Māori language in species nomenclature. J Mar Isl Cult 2:78–84. https://doi.org/10.1016/j.imic.2013.11.007

Wickham H (2016) ggplot2: elegant graphics for data analysis. Springer, Houston

Zhukovsky P (1975) World gene pool of plants for breeding: mega-gene-centres and endemic micro-gene-centres. USSR Academy of Sciences, Leningrad