On-farm management and participatory evaluation of pigeonpea (*Cajanus cajan* [L.] Millspaugh) diversity across the agro-ecological zones of Benin Republic

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Abstract

Background: Pigeonpea is a multipurpose food legume that contributes to food security in Benin. However, its production declined and some landraces are being threatened of disappearance. Previous investigations on pigeonpea in Benin have been restricted to South and Central Benin. Therefore, pigeonpea diversity in northern is still unknown. This study aimed to have a better knowledge of pigeonpea genetic diversity, for its promotion and valorization.

Methods: 500 producers of pigeonpea belonging to thirteen sociolinguistic groups were selected through 50 villages. Data were collected using methods and tools of participatory research appraisal. Folk nomenclatures, taxonomy of pigeonpea and seed system were investigated. The distribution and extent of pigeonpea landraces were evaluated using Four Square Analysis method. A comparative analysis of pigeonpea uses categories, production systems, pigeonpea production constraints, farmers' preference criteria and participative evaluation for existing landraces across agro-ecological zones was done.

Result: Folk nomenclature and taxonomy were mainly based on seed coat colour and size colour. Seven pigeonpea uses category were recorded including sacrifice, grain processing and fertilization. The results showed that pigeonpea seed system is informal. Based on seed characteristics, fifteen landraces were recorded with seven new landraces. A high rate of landraces threatened of disappearance was observed across the ecological zones. Ten constraints are known affecting pigeonpea production in Benin with pests and diseases as the most important in all agro-ecological zones. This study revealed that pigeonpea cultivation is increasing in the Sudanian zone. Landraces to be produced must be selected on the basis of 11 criteria among them precocity and resistance to pests and diseases, in the three ecological zones and adaptability to any type of soil in the Sudanian zone were the most important. The participatory evaluation revealed the existence of a few performing landraces.

Conclusions: The development of performing varieties is important to enhance pigeonpea production in Benin. Morphological and molecular characterizations of identified landrace are highly recommended to help select suitable varieties for breeding programs. *In situ* and *ex situ* conservation strategies are important to preserve landraces threatened of disappearance.

Background

Pigeonpea (*Cajanus cajan* [L.] Millspaugh) is a multipurpose food legume, serving as a lifeline to resource-poor farmers in tropical and subtropical regions of Asia, Africa, and Latin America [1]. Pigeonpea is an excellent source of protein (21.7 g/100 g), dietary fibres (15.5 g/100 g), soluble vitamins, minerals and essential amino acids [2, 3]. Moreover it is also used in traditional medicines and leaves, flowers, roots; seeds are used for the cure of bronchitis, sores, respiratory ailments and also acts as an alexeritic, anthelmintic, expectorant, sedative, and vulnerary [4, 3].

In Benin, pigeonpea is highly consumed in the South-East through the Adja cultural area and contribute to the improvement of household incomes [5]. The plant is used for soil conservation and weed

management in the fields [6, 7, 5]. Despite the importance pigeonpea [5], very few research effort has been undertaken to improve the production of the specie. As a result, the potential yield of pigeonpea is estimated at 2,500 kg/ha, while the yields obtained on farmer's fields is estimated at 620 kg/ha in Benin [8]. This low yield could be due to the lack of improved varieties in Beninese agriculture [9]. Therefore, an exhaustive collection of pigeonpea diversity cultivated at the country level is the base for the development of any varietal improvement program and the implementation of conservation strategy.

Several studies were done on pigeonpea diversity in Benin [9, 10, 11, 12]. However, all previous investigations on pigeonpea in Benin have been restricted to South and Central Benin [9, 10, 11, 12]. Therefore the pigeonpea diversity in northern Benin is still unknown. In addition, no comparative studies on pigeonpea production constraints across different ecological zones in Benin are not yet documented, varietal diversity as well as farmers' varietal preference criteria and their variation throughout ecological zones and sociolinguistic groups have been very little documented. While it is known that understanding the genetic diversity, uses, and distribution of orphan crops is essential in determining what to conserve and where to conserve, for sustainable utilisation [13, 14, 15]. Thus, there is important to dispose a comprehensive collection of pigeonpea genetic resources of Benin and to document all associated ethnobotanical knowledge by extensive survey [9, 11].

Seeds are the lifeblood and foundation of a successful farming and a crucial element in the lives of agricultural communities [16]. The procedures, through which a cultivar is bred, produced, certified, stored, marketed and used which includes all the channels through which farmers acquire genetic materials and in interaction with the commercial seed industry is known as seed system [17]. Thus, the success of crop varieties introduction is tightly linked to the uses, biophysical conditions, the cropping systems in which the crop is integrated which vary across growing areas [10].

In developing countries where agriculture is the spearheading of the economy, improved varieties must be developed or simply searched for within the existing diversity. In both cases, a good knowledge of the existing varietal diversity and the agronomic performances of varieties are necessary [18, 19]. Thus, farmers' participation in varietal selection process is determinant of variety adoption [20]. Moreover, documentation and identification of high-performance landraces based on farmer's varietal preference criteria will provide strategies to overcome constraints affecting pigeonpea production in Benin. Hence, it is important to evaluate the performance of pigeonpea existing landraces under participatory approach to enhance pigeonpea production and productivity contributing thereby to attain food security and reduce poverty.

This study on pigeonpea aimed to: (1) document the different pigeonpea landraces in Beninese agriculture (2) compare seeds management and conservation systems of pigeonpea genetic resources and use categories across different ecological zones, (3) compare constraints associated with pigeonpea production and varietal preference criteria across different ecological zones and sociolinguistic groups and (4) evaluate in participatory way the performances of different landraces in relation to agronomic and culinary traits.

Methods

Study area

The study was carried out in Benin. With a population size of 10 008 749 habitants [21] the Benin is located in the inter tropical zone between parallels 6° 30 ' North and 12° 30' North latitude, and meridians 1° East and 30° 40' East longitude [22]. With an area of 114,763 km², Benin is limited to the north by the Niger River in the northwest by Burkina Faso, to the west by Togo, the south by the Atlantic Ocean and to the east by the Nigeria (Figure 1). The Republic of Benin is divided into three ecological zones: the Guinean zone in the South (6° 25' North latitude and 7° 30' North longitude), the Sudano-Guinean zone (7° 30' North latitude and 9° 45' North longitude) in the Central and the Sudanian zone (9° 45' North latitude and 12° 25 North longitude) in the north [23]. The Guinean and Sudano-Guinean zones are both located in moist agro ecological zone characterized by a subequatorial bimodal climate with two dry seasons and two rainy seasons. The Guinean zone is characterized by an annual rainfall varying between 1200 and 1500 mm/year. The temperature ranges from 24 to 30 °C. The Sudano-Guinean zone annual rainfall varies from 1100 to 1300 mm/year (Table 1). The temperature in this zone varies between 25 and 34 °C. The Sudanian zone is located in the semi-moist agro ecological zone characterized by a unimodal climate pattern with one rainy season and one dry season. The annual rainfall varies between 900 and 1100 mm/year while the temperature ranges from 21 to 35 °C [23] (Table 1).

After exploratory study in agricultural research institutions, visits to local and urban markets, discussion with farmers and sellers, the villages surveyed were selected based on the pigeonpea production, their accessibility and the manner to cover all sociolinguistic groups. A total of 50 villages were prospected (Figure 1).

Data collection

The surveys were done using methods (group discussions, individual interviews and field visits) and tools (questionnaires) of participatory research appraisal following Dansi et al. [24].

Focus groups

In each village, a group of 15 to 28 pigeonpea farmers has been identified and brought together with the help of administrative and/or local authorities (village chief, farmers' associations, etc.). Interviews were conducted with the help of local translators to facilitate discussions [25]. Prior to the meeting, farmers were requested in advance to bring samples of pigeonpea landraces they cultivate or knew about. After a brief presentation of the objectives to the farmers, they were asked to list all the pigeonpea landraces in cultivation, in the village. The distribution and extent of these landraces were evaluated using the participatory method of Four Square Analysis described by Brush [26]. This method permit to classify at village-level existing landraces into four groups (produced by many households on large areas, produced by many households on small areas, produced by small households on large areas and produced by few households on small areas). In agreement with the farmers, we agreed that a cultivar cultivated by few

households is that grown by no more than 20% of farmers in the context of the village; and that cultivated on a small area is that cultivated on not more than 0.25 ha. The participatory evaluation of identified landraces for agronomic and culinary parameters was carried out according to Gbaguidi et al. [27]. The considered parameters were the productivity, vegetative cycle, cooking, sensitivity to pests and disease and sensitivity to storage insects. The two-level evaluation method described by Loko et al. [28] was used. In this approach and for a given trait, a landrace is scored 1 when it is performing and 0 when it is not. After that, local nomenclature, folk taxonomy and the vegetative cycle of landraces have been documented. According to Dansi et al. [29], farmers were asked to list all the constraints related to pigeonpea production. The identified constraints were prioritized in groups by identifying and gradually eliminating the most severe constraint. In a first step, farmers were asked to identify, among the constraints they have listed, the most critical one. The constraint thus identified is ranked first and is eliminated from the list. The same procedure was repeated until the last constraint was ranked. Secondly, farmers were asked to list all the traits that could interest them and motivate them to continue growing pigeonpea. Using the same approach (gradual elimination of the most important criterion), the identified criteria were then prioritized. The discussions were free, open-ended and without a time limit being set.

Household surveys

After group discussion, ten households were identified for individual interviews by village. In each household, the person interviewed was chosen based on the common agreement from the host couple according to Christinck et al. [30]. Socio-economic data (gender, educational level, age, year of experience in pigeonpea cultivation and household size); the biophysical resources, cultural practices and seed system (number of cultivated landrace, sowing time, crop type, cropping system, perception about the evolution of pigeonpea cultivation, fertilization, sources of labour, level of intervention in the production chain, pests and diseases incidence and its management, pigeonpea cropping areas for 2015, 2016, 2017); the reasons for pigeonpea production; the different pigeonpea uses categories; pests incidence and its management have been documented. According to their incidence pattern, pests incidence was categorized by farmers as negligible (none), low, high and very high. Incidence was categorized as negligible when pest appeared in very low number while it categorized as low when infestation was responsible for growth retardation and high when infestation involves damage to flowers or pods and very high when infestation are responsible for death of plant.

Data analysis

Descriptive statistics were used to analyze data. To avoid overestimation of pigeonpea diversity in each ecological zone, correspondences between vernacular names were made following seed characteristics (seed color, color pattern, color pigmentation and the seed eyes color) according to Mohammed et al. [31], Ayenan et al. [9] and Zavinon et al. [11]. The frequency of disappearance of each landrace was calculated using the following formula: $FD = (z/Z) \times 100$; Where: z = Number of landraces threatened of disappearance (cultivated by few households on small areas) and Z = total landraces identified in the ecological zone. In order to facilitate comparisons and to reduce outliers, from one ecological zone to

another, the reasons for pigeonpea cultivation and the different uses (seed or other plant parts) were categorized [32, 33]. The Fidelity Level of each category of reason and use was calculated at the scale of the study area according to Akohoué et al. [15]. The Fidelity Level was calculated according the formula described by Friedman [34]: Fidelity Level (FL) = $(F/\Sigma F) \times 100$; Where: F = number of respondents for a given modality of use or reason that motivates pigeonpea cultivation and ΣF = sum of the number of respondents for all modalities of use or reason. The constraints were prioritized at the level of each ecological zone and the overall study area on the basis of the average of the following three parameters: the total number of villages in which the constraint is cited (TNV); the number of villages where the constraint is the major one or ranked first (MAC); the number of villages in which the constraint was classified among the principal constraints (PCO) i.e. among the first five. For each of these parameters, a high value indicates an importance for the constraint. Thus, the importance of the constraint is determined by the formula described by Dansi et al. [28]: $IMC = (NTV + MAC + PCO) / 3$. The same approach was used to rank farmers' varietal preference criteria. To compare socio-economic data, biophysical resources, cultural practices and seed system from one ecological zone to another, the Analysis of variance (ANOVA) and Turkey test was used for quantitative variables using Minitab 16 Software while the bilateral Z test was used for qualitative variables, using Statistica 7.1 Software. Before ANOVA, data were log-transformed ($\log(x + 1)$) for variances homogeneity. In order to determine a potential significant change in the cropping area from 2015 to 2017, analysis of variance was conducted.

Results

Socio demographic characteristics of respondents

In total 500 pigeonpea producing households including 190 in the Guinean zone, 200 in Sudano-Guinean zone and 110 in the Sudanian zone were surveyed. The age of the surveyed pigeonpea farmers ranged from 21 to 76 years with an average of 45.9 ± 9.2 years old. The majority (62.4%) of farmers were men. The majority of pigeonpea farmers were found to be illiterate (43.4%), while 31.6% and 25% were found to have primary and secondary levels of education, respectively. The average household size was 6.4 ± 2.1 members (ranging from 3 to 11 members). The experience year old was 15 ± 8 years, on average (Table 2).

Significant differences in age of the surveyed pigeonpea farmers were observed across ecological zones. On average, farmers in the Guinean zone are older (48.7 years against 44 years) and more experienced than those in the Sudano-Guinean zone (18.4 years of experience against 16.5). The number of farmers with none, primary and secondary level of education varied between ecological zones.

Local nomenclature

Across the thirteen sociolinguistic groups surveyed in the study area, 50 different pigeonpea local names were recorded in the local dialects. Referring to the various vernacular names identified, the generic name of pigeonpea varied according to sociolinguistic group and ecological zones (Table 3).

In the Guinean and Sudano-Guinean zones, pigeonpea is called Hounkoun, Kloué or Klouékoun referring to Cowpea by farmers belonging to Fon and Mahi sociolinguistic groups while in the Guinean and Sudanian zones, pigeonpea is called Otili in reference to a pod-producing tree by farmers belonging to Nago and Dendi sociolinguistic groups. However, Bariba and Peulh sociolinguistic groups designated pigeonpea by Wotiri in reference to a pod-producing erected tree. Moreover, in Guinean zone, farmers belonging to Holly and Yoruba sociolinguistic groups call pigeonpea Otini. Pigeonpea is called Ekloui or Kloui by Adja sociolinguistic group. In Sudano-Guinean zone, pigeonpea is called Colo (meaning is unknown to farmers) by Idaasha sociolinguistic group while pigeonpea is called Tissi Tounan and Itoun by Biali and Somba sociolinguistic groups respectively, referring to a cowpea.

Folk taxonomy

In the study area, 5 criteria were used by surveyed farmers to identify pigeonpea landraces. The great majority of names (90.7%) given to pigeonpea had a meaning. More than half pigeonpea vernacular names correspond to morphological aspect (71%) of seeds. Such as seed coat colour (85.5%), seed coat and eyes colour (9.2%), seed size (1.3%), seed coat colour and size (4%). Plant type (3.7%), seed origin (8.4%), vegetative cycle (10.3%) and referring to cowpea (3.7%) were also among the criteria used by farmers to name pigeonpea (Table 4).

The folk taxonomy of pigeonpea has a hierarchical structure with two hierarchy levels as found in several sociolinguistic groups (Adja, Bariba, Fon, Holly, Idaasha, Mahi, Nago, Peuhl and Yorouba). For example, in the Adja sociolinguistic group, the generic name of pigeonpea Ekloui or Kloui is subdivided into 5 infra-specific pigeonpea taxa (*Ekloui djou*, *Ekloui koudji*, *Ekloui ri*, *Ekloui wlanwlan*, *Ekloui wliwlito*). In the Fon sociolinguistic group, the generic name of pigeonpea Klouékoun is subdivided into 6 infra-specific pigeonpea taxa (*Klouékoun vòvò*, *Klouékoun wéwé*, *Klouékoun wéwé tété*, *Klouékoun wéwé noukoun vòvò*, *Klouékoun wéwé noukoun wiwi*, *Klouékoun wlanwlan*). While in the Bariba sociolinguistic group, the generic name of pigeonpea Wotiri is subdivided into 4 infra-specific pigeonpea taxa (*Wotiri gbika*, *Wotiri goukorou*, *Wotiri wonka*, *Wotiri souan*).

Diversity of cultivated pigeonpea landraces

Based on seed characteristics, fifteen pigeonpea landraces were identified in the study area (Figure 2). At village level, the number of pigeonpea landrace ranges from 1 to 5 with an average of 2.7 ± 1 . The highest number of landrace (5) per village was reported at Ouèssènè in the department of Alibori. At the household level, the number of pigeonpea landrace held by producers ranges from 1 to 3 with an average of 1.3 ± 0.5 . Seventy two point two (72.2%), 27.6% and 0.2% of the producers cultivated 1, 2 and 3 landraces respectively. The highest number of landrace (3) per household was reported at Ouèssènè in the department of Alibori and maintained by only one producer. The Sudano-Guinean zone contained the highest number of landraces followed by the Guinean and Sudanian zones (11, 9 and 7 landraces respectively) while the highest number of landraces (5) per village and per household (3) was recorded in the Sudanian zone.

Distribution and extent of pigeonpea landraces

Within each ecological zone, the production was limited to specific districts and departments. In the Guinean zone, the production was restricted to the districts of Adja-Ouèrè, Kétou and Pobè in the department of Plateau and to the districts of Aplahoué, Klouékanmè and Lalo to the districts of Couffo. In the Sudano-Guinean zone, pigeonpea was cultivated in the districts of Dassa-Zoumè, Ouèssè, Savalou and Savè in the department of Collines and the districts of Covè, Djidja, Zakpota and Zangnannado in the department of Zou. Lastly, in the Sudanian zone, pigeonpea was cultivated in the districts of Bembèrèkè and Kalalé in the department of Borgou and the district of Gogounou in the department of Alibori. The Four Squares Analysis revealed that in the Sudanian zone, among the 9 landraces presents, 1 (*Klouékoun wéwé noukoun vòvò* (Mahi and Fon sociolinguistic groups)) was cultivated by many households on a large area, 1 (*Otili founfoun kékéélé* (Idaasha sociolinguistic group)) was cultivated by few households on large area while the 7 remaining ((*Ekloui djou* (Adja sociolinguistic group), *Wlétchivé kloui* (Adja sociolinguistic group), *Carder ekloui* (Adja sociolinguistic group), *Otili founfoun lakoun* (Idaasha sociolinguistic group), *Klouékoun wéwé tété* (Mahi sociolinguistic group), *Otili kpoukpa* (Nago sociolinguistic group) and *Klouékoun vòvò* (Fon and Mahi sociolinguistic groups)) were grown by few households on small area. In the Sudano-Guinean zone, the *Klouékoun wéwé nounkoun wiwi* (Mahi and Fon sociolinguistic groups) was cultivated by many households on large area, *Klouékoun wéwé tété* (Mahi sociolinguistic group) and *Otili founfoun kékéélé* (Idaasha sociolinguistic group) were cultivated by few households on large area, and the *Wlétchivé kloui* (Adja sociolinguistic group) and *Klouékoun wlanwlan* (Fon sociolinguistic group) by many households on small area while the *Klouékoun wéwé nounkoun wiwi* (Mahi and Fon sociolinguistic groups), *Otini kpoukpa* (Holly sociolinguistic group), *Colo kpikpa* (Idaasha sociolinguistic group), *Otili founfoun lakoun* (Idaasha sociolinguistic group), *Otili kpoukpa* (Nago sociolinguistic group) and *Klouékoun vòvò* (Fon and Mahi sociolinguistic groups) were cultivated by few households on small area. Finally, in the Sudanian zone, 2 landraces ((*Klouékoun wéwé nounkoun wiwi* (Mahi and Fon sociolinguistic groups) and *Otili founfoun kékéélé* (Idaasha sociolinguistic group)) were cultivated by many households on large area while 1 landrace ((*Klouékoun wlanwlan* (Fon sociolinguistic group)) is cultivated by few households on large area, 4 landraces ((*Ekloui djou* (Adja sociolinguistic group), *Wotiri wonka* (Bariba sociolinguistic group), *Wotiri souan* (Bariba sociolinguistic group) and *Klouékoun vòvò* (Fon and Mahi sociolinguistic groups)) were cultivated by few households on small area. Thus, in the Guinean zone, 7 landraces were threatened of disappearance, 6 in the Sudano-Guinean zone against 4 in the Sudanian zone. In areas where landraces were threatened of disappearance, the frequency of disappearance varied between 50 and 100% (Table 5).

The distribution analysis revealed that the *Otini kpoukpa* (Holly sociolinguistic group), *Colo kpikpa* (Idaasha sociolinguistic group) and *Klouékoun wéwé nounkoun wiwi* (Mahi and Fon sociolinguistic groups) were specific to the Sudano-Guinean zone; *Wotiri souan* (Bariba sociolinguistic group) and *Wotiri wonka* (Bariba sociolinguistic group) were specific to the Sudanian zone and *Carder ekloui* (Adja sociolinguistic group) was specific to the Guinean zone while the *Klouékoun wéwé nounkoun wiwi* (Mahi and Fon sociolinguistic groups), *Otili founfoun kékéélé* (Idaasha sociolinguistic group) and the *Klouékoun vòvò* (Fon and Mahi sociolinguistic groups) were cosmopolitan for the three ecological zones (Table 12).

The *Wlétchivé kloui* (Adja sociolinguistic group), *Otili founfoun lakoun* (Idaasha sociolinguistic group), *Klouékoun wéwé tété* (Mahi sociolinguistic group) and *Otili kpoukpa* (Nago sociolinguistic group) were present in the Guinean and Sudano-Guinean zones, *Ekloui djou* (Adja sociolinguistic group) in the Guinean and Sudanian zones while the *Klouékoun wlanwlan* (Fon sociolinguistic group) was present in the Sudano-Guinean and Sudanian zones (Table 12).

Reasons for pigeonpea production and uses category

Our study revealed that pigeonpea is produced for three main reasons depending on the ecological zones (Table 6).

In the Guinean and Sudano-Guinean zones, nutritional value is the main source of motivation while in the Sudanian zone land fertilizing power is the main source of motivation. The third reason is the market value. The different pigeonpea uses categories were mainly concentrated on grains. Based on their fidelity level, pigeonpea is more used in medicine in the Guinean (FL = 19.5%) and Sudanian (FL = 23.9%) zones. According to farmers, boiled leaves are used by oral route to treat malaria. Also, the decoctate of the leaves is used in bath to treat measles and is also used as an antibiotic to treat mouth's sores or tooth decay. The roots, when chewed, prevent the rise of snake venom, in the case of snake bite. The use of pigeonpea grains as an offering for food or symbolic purposes and in sacrifice to divinity was specific to the Sudano-Guinean and restricted to Holly and Nago sociolinguistic groups. While grain processing into donuts is specific to Guinean (FL = 4.3%) and Sudano-Guinean (FL = 2%) zones and restricted to Holly and Adja sociolinguistic groups. In these zones, pigeonpea are roasted and reduced to flour to sprinkle sauces as nutritional supplement by the first one or to make donuts by the second one. Consumption, weed control and land fertilization are common to all three ecological zones (Table 6).

Cultural practices

Pigeonpea was considered as an annual plant by most of surveyed farmers (93.2%). Only 6.2% of farmers considered this legume as a perennial plant. For the last one, plant is left in the field and is harvested the following year. The main pigeonpea farming activities included: ploughing, sowing, weed control, pod harvest, pod plugging and winnowing. Seeding and weed control were practiced by all the farmers. Pigeonpea is sown between April, May, June (73.6%) in intercropping with other seasonal crops (82.8%) or in pure stand (17.2%). Three sources of labour were observed. For farming activities, 13.2% of farmers used family labour, 73% combined family and friends labour while 13.8% used a combination of family, friends and jobber labour (Table 7).

Land fertilization was not reported while only 14% of farmers included in this study used pesticide. The average grain yield in farmers' fields was estimated at 553.4 ± 36.3 kg/ha. According to farmers, during the three last years, Sudano-Guinean zone were the largest cropping area followed by the Guinean zone while farmers in the Sudanian zone produced pigeonpea on a small cropping area (Table 7). Sowing was more realized between April, May and June in the Guinean and Sudano-Guinean zones (97.9% and 91% respectively) whereas it was more realized between June, July and August in the Sudanian zone (68.2%).

Intercropping with other seasonal crops such as maize and millet was specific to Guinean (100%) and Sudano-Guinean (98.5%) zones while pigeonpea was more cultivated in pure stand in Sudanian zone (75.4%). Family and the friends was the main source of labour for various farming activities in the Guinean and Sudano-Guinean zones (87.9% and 61.5% respectively) while it was family (49.3%) in the Sudanian zone. Our results revealed that the average pigeonpea yield in the Sudanian zone is lower ($522.3 \pm 44 \text{ kg/ha}$) compared to the Guinean and Sudano-Guinean zones ($557.5 \pm 15.9 \text{ kg/ha}$ and $566.6 \pm 35.8 \text{ kg/ha}$ respectively).

Seed system

Three sources of seeds were observed. Farmers used seeds from previous harvest (60.2%) or friends (22%) or local market (17.8%). After each harvest, 67.8% of farmers stored seeds until scarcity at market while 32.2% of them sell seeds in local markets. Comparing seed system between ecological zones, previous harvest was the main source of seed in the Guinean and Sudano-Guinean zones (70% and 62.9% respectively) while friends was the main source (50.4%) in Sudanian zone and after each harvest, farmers stored more grains in the Guinean and Sudano-Guinean zones (70% and 84% respectively) while they were more immediately sold in Sudanian zone (65.5%) (Table 7).

Pigeonpea production constraints

In total, 10 constraints were identified as affecting pigeonpea production. The long vegetative cycle was ranked as the major constraint in Benin following by pests and diseases and rainfall irregularity (Table 8). According to farmers descriptions, pigeonpea production is faced by Low productivity is seventh among the constraints followed by the sensitivity to storage insects. All constraints have been reported in the three ecological zones. However, their relative importance varied from one zone to another. The most important constraint in the Guinean and Sudano-Guinean zones is the long vegetative cycle followed by the sensitivity to pests and diseases, while in the Sudanian zone pest and diseases followed by soil poverty were the most important constraints (Table 8).

Incidence of pests on pigeonpea yield and control methods

According to farmers, the impact of pests and diseases in pigeonpea production in farmers' fields varied from one zone to another (Table 9). The impact is low in the Guinean and Sudano-Guinean zones (52.6% and 42.5% respectively) while it is high in the Sudanian zone (81.8%). Pests control was only reported in the Sudanian zone (63.7%). Three reasons justified the non-control of pest reported by farmers: the high price of pesticides (49.6%), the risk of intoxication (29.6%) and the lack of sprayers (20.8%).

Evolution of pigeonpea production in Benin

Overall, the majority of farmers (69.4%) reported a decrease in pigeonpea production in Benin. According to farmers, this downward trend was the fact to the Guinean and Sudano-Guinean zones (75.79 % and 85.5% respectively). In these zones, the decrease in cropping area is highly significant ($p \leq 0.001$). Indeed, the average of cropping area was $0.9 \pm 0.2 \text{ ha}$ in 2015, $0.8 \pm 0.1 \text{ ha}$ in 2016 and $0.5 \pm 0.1 \text{ ha}$ in 2017, in the

Guinean zone (Table 7). Similarly, in the Sudano-Guinean zone, average cropping area was 1.3 ± 0.8 ha in 2015, 0.9 ± 0.4 ha in 2016, 0.7 ± 0.3 ha in 2017, in the Sudano Guinean zone (Table 7). In contrary, in the Sudanian zone, pigeonpea cultivation is increasing (70.91%). In this zone, the cropping area increasing is highly significant ($p \leq 0.001$). The average cropping area was 0.3 ± 0.1 ha in 2015, 0.4 ± 0.1 ha in 2016 and 0.4 ± 0.1 ha in 2017 (Table 7). According to farmers, the reasons for this increasing are the fertilizing power of the plant (89.1 %) and weeds control (10.9%).

Farmers' preference criteria of pigeonpea

Through the study area, 11 criteria depending on the ecological zones and different sociolinguistic groups underlined the choice of pigeonpea landraces to be cultivated by the farmers. The most important criteria were precocity, resistance to pests and diseases, rapid for cooking, adaptability to any types of soil, good taste and high productivity (Table 10).

In Guinean and Sudano-Guinean zones, precocity was the most important criterion followed by the resistance to pests and diseases while in the Sudanian zone, the resistance to pests and diseases was ranked first followed by the adaptability to any type of soil (Table 10). Precocity appeared at the front of the criteria of all sociolinguistic groups except for Nago sociolinguistic group for whom adaptability any types of soil was the first criterion. Moreover, in addition to precocity, resistance to pests and diseases, rapid for cooking, adaptability to any types of soil and good taste were the choice criteria for farmers belonging to Bariba sociolinguistic group (Table 11).

In addition to the choice criteria for Bariba sociolinguistic group, farmers belonging to Boo sociolinguistic group had strong tendency to varieties cultivable at any time of the year and resistant to storage insects while those belonging to Dendi sociolinguistic group preferred varieties with high productivity and cultivable at any time of the year and those belonging to Peuhl sociolinguistic group preferred high productive and resistant to storage insects varieties. Lastly, precocity, resistance to pests and diseases, rapidity for cooking and adaptability to any type of soil were farmers belonging to Yoruba sociolinguistic group criteria.

Participatory evaluation of pigeonpea landrace grown in Benin

The results revealed that for landraces identified simultaneously in the three ecological zones, none of them were performing for a given character simultaneously in the three ecological zones (Table 12). Moreover, none landrace were performing simultaneously for all 5 evaluated characters. Nevertheless, the *Carder ekloui* (Adja sociolinguistic group) only identified in Guinean zone combined 4 good performances (high productivity, rapid for cooking, resistant to pests and diseases, resistant to storage insects). Moreover, *Carder ekloui* (Adja sociolinguistic group) and *Otili founfoun kékéké* (Idaasha sociolinguistic group) showed high productivity in Guinean and Sudano-Guinean zone but showed low productivity in the Sudanian zone. These two landraces, however, showed resistance to pests and diseases. In addition, *Klouékoun vòvò* (Fon and Mahi sociolinguistic groups) showed high productivity, rapid for cooking, resistant to pests and diseases, resistant to storage insects and short vegetative cycle in Guinean and

Sudano-Guinean zone, however, showed low productivity and susceptible to pests and diseases in the Sudanian zone (Table 12).

Discussion

Our study showed that pigeonpea generic names varied according to sociolinguistic group and ecological zones. Our findings are similar to those of Ayenan et al. [9] and Zavinon et al. [11]. However, different sociolinguistic group from the same ecological zone or different ecological zones designate the pigeonpea by the same generic name, this convergence in the generic name within different sociolinguistic groups could be explained by the fact that these groups could have common origins or that cohabitation would have facilitated the transfer of knowledge over time. In addition, based on the generic names meanings, farmers across sociolinguistic groups within the three ecological zones recognized pigeonpea referring to cowpea. This suggests that farmers don't have a good knowledge of the botanical systematic of pigeonpea. There is therefore no link between folk nomenclature and the scientific classification regarding to pigeonpea. Knowing that there is correspondence between the folk nomenclature and the scientific classification of the species [35], our findings are contrary to those of Akohoué et al. [15] on Kersting's groundnut in Benin. However, the hierarchical characterization of pigeonpea folk taxonomy in the study area was similar to that observed by Loko et al. [36] on common bean and reflects the high diversity level of pigeonpea in the surveyed sociolinguistic groups. Our findings in Adja sociolinguistic group infra-specific pigeonpea taxa is contrary to those of Ayenan et al. [9] and Zavinon et al. [11] who distinguished respectively 2 and 3 infra-specific pigeonpea taxa. However, local names do not necessarily reflect the genetic history of landraces of crops because different names may be given to identical seeds of landraces or a single name may apply to heterogeneous crops [37]. Such a situation may contribute to under or over-estimate the diversity within a species [38, 23, 39, 9]. So to avoid redundancies and optimizing the efficient conservation and sustainable use of pigeonpea, it is important to conduct morphological and molecular characterizations to avoid redundancies and establish equivalence between the local names [26, 40, 41].

Farmers use morphological aspect of seeds (coat colour, seed eyes colour, and seed size), plant type, seed origin and vegetative cycle for identification of folk varieties. These criteria of pigeonpea classification and identification are among the descriptors of *C. cajan* recommended by IBPGR and ICRISAT [42] and used by many authors in morphological characterization of this legume. Our study revealed that morphological aspect of seeds (in particular the seed coat colour) was the predominant criterion used by farmers to classify and identify pigeonpea landraces. The main reason is that seed coat colour is unique to each landrace while other traits may be commonly shared [15]. Our finding is contrary to those of Manyasa et al. [43] who reported pigeonpea seed size and maturity as the most important criteria used by farmers in Ugandan. However, similar observations were reported by Esan and Ojemola [44] in Nigeria, Ayenan et al. [9] and Zavinon et al. [11] in Southern and Central Benin and suggested that selection based on morphological aspect of seeds will have a definite role in the framework of on-farm conservation of this legume in Benin.

According to Ayenan et al. [9] and Zavinon et al. [11] respectively eight and seven pigeonpea landraces were recorded in Benin. However, in our study, we recorded fifteen pigeonpea landraces based on seed characteristics difference. The seven new landraces are the blackish seeded landrace called Otini kpoukpa (Holly sociolinguistic group), the brown seeded landrace called Colo kpikpa (Idaasha sociolinguistic group), the cream with black eye seeded landrace called Klouékoun wéwé nounkoun wiwi (Mahi and Fon sociolinguistic groups), the cream seeded landrace called Klouékoun wéwé tété (Mahi sociolinguistic group), the light red seeded landrace called Otili kpoukpa (Nago sociolinguistic group), the purple and mottled seeded landrace called Wotiri wonka (Bariba sociolinguistic group) and the red and mottled seeded landrace called Wotiri souan (Bariba sociolinguistic group). Thus, given that the previous studies did not take into account the entire production area as insignificant as it may seem, a part of the existing pigeonpea landraces in Benin was left out. This finding suggests that extent of the study area affect varieties richness [45, 15]. Thus a study that better reflects the existing diversity of cultivated species should not be restricted to the major production areas of the species.

Our results also revealed that the on-farm level diversity of pigeonpea was specific to ecological zones. In fact, the same landraces haven't the same distribution and extent across ecological zones. This practice involves the indirect selection of some of landraces in certain ecological zones while it promotes the gradual disappearance for another one. Hence, conservation strategy should be defined for landraces threatened of disappearance according to their ecological zones. Moreover, each ecological zone could be favorable candidate for in-situ conservation of pigeonpea genetic resources in Benin. The highest number of landraces per village and per household was recorded at Ouèssènè in the department of Alibori in the Sudanian zone. Therefore, Sudanian zone becomes important for the conservation of pigeonpea genetic resources in Benin.

The fertilizing power of pigeonpea as main reasons for producing this legume reported in present study is not surprising because pigeonpea has significant position in dry land farming systems especially adopted by small and marginal farmers in many parts of world by fixing nitrogen, flexibility for mixed cropping or inter crop [46, 47]. The use of pigeonpea leaves to treat various diseases such as malaria corroborates the observations made by Ayenan et al. [9] and Zavinon et al. [11] in Benin and those of Aiyeloja and Bello [48] and Oladunmoye et al. [49] in Nigeria. Also, the use of pigeonpea as weeds control has been reported by several authors in Benin [50, 51, 5]. However, the use of pigeonpea roots to prevent the rise of snake venom, in the case of snake bite reported in the current study has not been reported elsewhere. Also, grain processing into donuts identified in the current study has not yet reported by previous studies. Unfortunately, this technological ability of pigeonpea is weakened by its retention of oil. Thus, this possibility of transformation of pigeonpea must be explored and improved, like the soybean's transformation in cheese, in Benin. This action will help to reduce malnutrition in rural populations and improve in situ conservation of the existing pigeonpea diversity. Moreover, the use of pigeonpea grains as an offering for food or symbolic purposes and in sacrifice to divinity has not yet reported by previous work. All these findings are found to be sociolinguistic groups and ecological zones-dependent and suggest that pigeonpea farmers in Benin do not have the same knowledge on the use of pigeonpea. However, specific knowledge related to the plant part uses might be kept and transmitted within

communities in some areas as a result of vertical knowledge transmission [52, 15]. Knowing that integrating cultural practices of local communities permit an efficient on farm conservation [53, 36], this specific use category of pigeonpea genetic resource show the potentiality of cultural approach for the conservation of this legume in Benin.

Our study reveals that in the Sudanian zone, pigeonpea cultivation is increasing while it is in decreasing in the Guinean and Sudano-Guinean zone. In fact, the productivity of the smallholder farming system in this zone is under threat due to soil fertility decline [54]. Research in many parts of Africa including Benin has shown that legumes have the potential to sustain soil fertility in smallholder farming systems [55, 56, 47]. Thus, thanks to the project "Protection and Rehabilitation of Soils to Improve Food Security (ProSOL)" of the German Federal Ministry for Economic Cooperation and Development (BMZ), an integrated soil fertility management (GIFS) through a maximization of the use of different organic sources of fertilizers such as pigeonpea was initiated in 2015. This project allowed, in this area, the popularization of pigeonpea using its fertilizing power. This finding support the fact that Sudanian zone is important for the conservation of pigeonpea genetic resources in Benin.

The results showed that pigeonpea seed system in Benin is informal. Similar observations were made on pigeonpea in Tanzania [57] and India [16]. This informal seed system has the advantage to facility seed exchanges among farmers and among villages [17]. However, marketed seeds must deserve attention. In fact, seed acquisition from market does not guarantee genetic purity [58]. It is so important to make available to farmers good quality seeds in order to increase productivity of pigeonpea [58, 10]. The association of pigeonpea with other crops has been reported in others countries such as Uganda [43] and Kenya [59]. After each harvest, the great majority of farmers stored seeds until scarcity at market before selling them. However, farmers in Sudanian zone sold immediately their seeds that help resolving urgent problems such as children education. These findings justify the fact that pigeonpea is an essential source of household income which can contribute to poverty reduction in Benin as reported by Dansi et al. [5].

In Benin, many factors negatively affect pigeonpea production. Long vegetative cycle followed by pests and diseases were the main constraints affecting pigeonpea production. Indeed, african pigeonpea were characterized by the late maturity [60, 12]. According to farmers theses genotypes cultivation in sole crop occupies land that should be used for other crops. The pests and diseases ranked first in the Sudanian zone are not surprising. In fact, in this zone pigeonpea is more cultivated on pure land, which facilitates pests' attraction. Our findings confirm the observations made by Sarkar et al. [47] which revealed that intercropping system minimizes the attack of pest and diseases as compared to intercropping system. Farmers in this zone have limited access to pesticides and are suffering most from this production loss. Although the impact of pests and diseases was found to be low in the study area, their presence is the key indicator of the urgent need to develop strategies against these pests. Instead of the use of pesticides, an integrated pest management is recommended, through the combination of biological control based on the use of natural enemies of these pests and genetic control based on the use of tolerant or resistant cultivars [61, 62, 27].

As in the majority of leguminous where the attack of storage insects is a major constraint [63], surveyed farmers reported that seeds are sometimes subject to attack by storage insects. Farmers use some toxic products to protect their seeds. A sensitization of farmers or consumers for a purely biological conservation, as the use of small peppers, is highly recommended, as it is the case of Kersting's groundnut [64]. Curiously, low productivity ranked seventh among constraints. This suggests that low productivity represents only a small portion of the constraints mentioned by farmers. Thus, low productivity is the direct consequence of the negative effects of the other constraints [59]. In view of the observed, the lack of improved varieties as a challenge to pigeonpea production. The availability of improved varieties and their distribution across the different ecological zones according to their specific needs can alleviate the constraints affecting pigeonpea production in Benin. Therefore, government should encourage small-scale enterprises to provide farmers with improved seeds.

Farmer preference criteria take an important place in breeding program and facilitate the adoption of improved varieties [38, 11]. Our study reveals that farmers perceived precocity, resistance to pests and diseases, good taste and rapidity for cooking as the most important preferred traits. Similar observation was observed, on pigeonpea, by Mergeai et al. [59] in Kenya, Shiferaw et al. [65] in Tanzania, Changaya [66] in Malawi, Ogbe and Bamidele [67] in Nigeria and Ayanan et al. [9] in Southern Benin. All these preference criteria are correlated with identified constraints. This suggests a veritable link between these two parameters as reported by Odjo et al. [68] on Rice. The precocity as criterion is important for farmers because short vegetative cycle varieties should certainly encourage them to produce pigeonpea. Indeed, in the global climate context where changes are noticeable, early varieties will provide producers the guarantee that pigeonpea plants attain a significant level of vegetative development before the cuts of rain. The high productivity as criterion of varietal choice is also not surprising as it is for any breeders and farmers the most desired criteria [69, 28]. Our findings are however contrary to those of Zavinon et al. [11] for whom, high market value is the main farmers' preference criterion. In fact, the high market value cannot appear at the first rank of preference criteria in the sense that this criterion is only the result of the adoption of an improved variety for one or the other of the criteria. Our study revealed that preference criteria varied across different sociolinguistic groups however, convergence in preference criteria between certain sociolinguistic groups was observed. This could be explained by the cultural links and the intensive knowledge's exchange between these sociolinguistic groups or due to the common origin of these sociolinguistic groups.

For a given character, the same landrace doesn't have the same performance, from one ecological zone to another. For instance, the landrace called Otili founfoun kékéle (Idaasha sociolinguistic group) which perceived by farmers as having high productive in Guinean and Sudano-Guinean zone has presented a low productivity in the Sudanian zone. This may be due to the variability in soil types, fertility and organic matter turn over, soil nutrient dynamics [70], water regime [71] across these ecological zones. In addition, the landrace called Klouékoun vòvò (Fon and Mahi sociolinguistic groups) which showed high productivity in Guinean and Sudano-Guinean zone but low productivity in the Sudanian zone reinforce the fact that variability in soil types, fertility and organic matter turn over, soil nutrient dynamics or water regime justify these agronomical difference. The Carder ekloui (Adja sociolinguistic group) only identified

in the Guinean zone must deserve attention. This landrace combine four good performances (high productivity, rapid for cooking, resistant to pests and diseases, resistant to storage insects), according to famers and is appear as a promising landrace. Unfortunately, this landrace is threatened of disappearance. There is urgent need to process to an ex-situ as well in situ conservation to preserve this landrace as well as all those threatened of disappearance in Benin. All identified landraces in the current study must however be tested for their identified performance according to farmers. Thus, morphological and molecular characterization is highly recommended to help select suitable varieties for breeding programmes. Thereafter, association mapping of candidates' genes/QTLs for desirables traits can be done and used in future marker-assisted breeding program. Otherwise breeding of adapted pigeonpea to any type of soil and resistant to pests and disease will be of dual interest to famers in the Sudanian zone. It will enhance the chain value this legume and will also help to restore the fertilizing power of impoverished lands. Waiting, taking into account farmer's preference criteria, the few performing landraces identified can be used in a varietal exchange programs to enhance pigeonpea production in Benin.

Conclusions

Our study area showed a great varietal diversity of pigeonpea with fifteen landraces identified based on seed characteristics. Seven new landraces were found and some were specific to an agro-ecological zone. A highly significant decrease in cropping areas occurred in the Guinean and Sudano-Guinean zones. Some of the landraces are threatened of disappearance due to several factors, which constraint pigeonpea production and need to be considered under specific conservation strategy to avoid diversity loss. The few performing landraces identified through participatory evaluation can be used in varietal exchange programs in order to mitigate the effects of these constraints. The development of new varieties based on farmers' criteria is important to enhance pigeonpea production in Benin. To develop new varieties, morphological and molecular characterizations of identified landrace are highly recommended to help select suitable varieties for breeding programs. In situ and ex situ conservation strategies on the one hand and on the other hand the preservation of traditional knowledge associated to pigeonpea is important to preserve landraces threatened of disappearance and to conserve pigeonpea diversity in Benin.

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Availability of data and materials

Raw and treated data generated during study are available from the corresponding author on reasonable request.

Authors' contributions

GK designed the study, collected and analyzed data and drafted the manuscript. AGF participated in the interview work. GD, LEYL, AD, CA and AD supervised data analysis and revised the manuscript. All authors read and approved the final manuscript.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable.

Abbreviations

p: p value

INSAE: Institut National de la Statistique et de l'Analyse Economique

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Tables

Table 1 Basic information regarding the biophysical characteristics of the surveyed zones

Variables	Guinean zone	Sudano- Guinean zone	Sudanese zone
Altitude (in m)	56- 223	153- 308	214- 609
Annual rainfall (mm)	1200- 1500	1100- 1300	900- 1100
Temperature (°C)	24- 30	25- 34	21- 35
Seasons	Bimodal rainfall regime : 2 dry seasons and 2 rainy seasons	Bimodal rainfall regime : 2 dry seasons and 2 rainy seasons	Unimodal rainfall regime: 1 dry season and 1 rainy season
Dominant soils	Ferrallitic soils	Ferruginous and ferrallitic soils	Concreted or hardened ferruginous soils with small deep
Number of surveyed villages	20	19	11
Surveyed sociolinguistic groups	Biali (Exotic), Somba (Exotic), Fon, Holly, Mahi, Nago, Idaasha	Adja, Fon, Holly, Mahi, Nago, Yoruba	Bariba, Dendi, Peuhl, Yoruba (Exotic), Boo

Table 2 Socio-demographic characteristics of the surveyed pigeonpea producers across agro-ecological zones of Benin

Variables	ZG (n=190)	ZSG (n=200)	ZS (n=110)	Overall (n=500)	diff
Gender (%)					
Male	56.9 ^a	66 ^a	65.5 ^a	62.4	ns
Female	41.2 ^a	44 ^a	34.6 ^a	37.6	
Education level (%)					
None	56.9 ^a	39 ^b	28.2 ^b	43.4	***
Primary	27.9 ^a	34 ^a	33.6 ^a	31.6	ns
Secondary	15.3 ^c	27 ^b	38.2 ^a	25	***
Age (years)					
Average	48.7 ^a	44 ^b	44.5 ^b	45.9	***
Range	30-69	21-76	26-65	21-76	
Experience (years)					
Average	18.4 ^a	16.5 ^b	6 ^c	15	***
Range	10-45	10-50	3-7	3-50	
Household size (units)					
Average	6.6 ^a	6.1 ^a	6.4 ^a	6.4	ns
Range	3-11	3-11	4-10	3-11	

Table 3 Pigeonpea generic names variation across sociolinguistic groups

Sociolinguistic groups	Designations	Meanings
Adja	Ekloui, Kloui	Common name
Bariba, Peulh	Wotiri	Pod-producing erected tree
Biali	Tissi Tounan	Referring to cowpea
Boo	Blacia	Referring to cowpea
Fon, Mahi	Houkoun, Kloué, Klouékoun	Referring to cowpea
Holly, Yoruba	Otini	Common name
Idaasha	Colo	Common name
Nago, Dendi	Otili	Pod-producing tree
Somba	Itoun	Referring to cowpea

Table 4 Meaning of pigeonpea vernacular names across study area

Criteria of denomination	% of vernacular names	Vernacular names	Meaning of the vernacular name
Morphological aspect (seed coat colour and size, eyes colour)	71	Colo founfoun, Ekloui koudji, Ekloui ri, Hounkoun wéwé, Klouékoun wéwé, Klouékoun wéwé tété	Cream pigeonpea
		Otili founfoun, Otini founfoun, Wotiri gbika, Wotiri goukorou	
		Ekloui djou, Otini dudu	
		Colo kpikpa, Hounkoun vòvò, Klouékoun vòvò, Otili kpoukpa, Otini kpoukpa, Wotiri souan	Red pigeonpea
		Egblèjin, Ekloui wlanwlan, Klouékoun wlanwlan, Otini tchofiti, Wotiri wonka	Mottled pigeonpea
		Klouékoun wéwé noukoun vòvò,	Cream pigeonpea having red eyes
		Klouékoun wéwé noukoun wiwi	Cream pigeonpea having black eyes
Seed origin	8.4	Otili founfoun lakoun,	Cream pigeonpea having high size
		Otili founfoun kékéélé	Cream pigeonpea having small size
		Ekloui wliwlito	Pigeonpea having small size
		Adja klouékoun, Adja kloui	Pigeonpea from Adja
		CA monlikoun	Pigeonpea introduced by CA
		Carder kloui, Carder kloui	Pigeonpea introduced by Carder
		Djidja kloui	Pigeonpea from Djidja
Vegetative cycle	10.3	Yovo loui	Pigeonpea introduced by European
		Bogan	Long vegetative

		Kpédovinon ovo, Kpèkloué	cycle pigeonpea Short vegetative cycle
		Nontchiovi ekloui, Nontchiovi kloui	pigeonpea Orphan
		Wlétchivé kloui	pigeonpea Pigeonpea producing twice a year
Plant type	3.7	Gbomandoui, Ladjia kloui Wotiri	Tall pigeonpea Pod-producing erected tree
Belonging to Cowpea	6.5	Itoun, Tissi tounan, Blacia	Referring to cowpea

Table 5 Distribution and extent of cultivated pigeonpea landraces across the ecological zones of Benin

Local names	Seeds characteristics	Distribution and extent			FD
		GZ	SGZ	SZ	
<i>Klouékoun wéwé nounkoun wiwi</i> (Mahi and Fon sociolinguistic groups)	Cream seed coat with black eye	NA	M-S- ^m	NA	100
<i>Klouékoun wéwé noukoun vòvò</i> (Mahi and Fon sociolinguistic groups)	Cream seed coat with red eye and intermediate size	M+S+	M+S+	M+S+	0
<i>Klouékoun wéwé tété</i> (Mahi sociolinguistic group)	Cream seed coat	M-S- ^m	M-S+	NA	50
<i>Wlétchivé kloui</i> (Adja sociolinguistic group)	Cream seed coat and highly mottled	M-S- ^m	M+S-	NA	50
<i>Klouékoun wlanwlan</i> (Fon sociolinguistic group)	Cream seed coat and mottled	NA	M+S-	M-S+	0
<i>Colo kpikpa</i> (Idaasha sociolinguistic group)	Brown seed coat	NA	M-S- ^m	NA	100
<i>Klouékoun vòvò</i> (Fon and Mahi sociolinguistic groups)	Red seed coat	M-S- ^m	M-S- ^m	M-S- ^m	100
<i>Otili kpoukpa</i> (Nago sociolinguistic group)	Light seed coat red	M-S- ^m	M-S- ^m	NA	100
<i>Otini kpoukpa</i> (Holly sociolinguistic group)	Blackish seed coat	NA	M-S- ^m	NA	100
<i>Otili founfoun kékéle</i> (Idaasha sociolinguistic group)	Cream seed coat with red eye and small size	M-S+	M-S+	M+S+	0
<i>Otili founfoun lakoun</i> (Idaasha sociolinguistic group)	Cream seed coat with red eye and high size	M-S- ^m	M-S- ^m	NA	100
<i>Carder ekloui</i> (Adja sociolinguistic group)	Cream seed coat and mottled with high size	M-S- ^m	NA	NA	100
<i>Ekloui djou</i> (Adja sociolinguistic group)	Black seed coat and mottled	M-S- ^m	NA	M-S- ^m	100
<i>Wotiri souan</i> (Bariba sociolinguistic group)	Red seed coat and mottled	NA	NA	M-S- ^m	100
<i>Wotiri wonka</i> (Bariba sociolinguistic group)	Purple seed coat and mottled	NA	NA	M-S- ^m	100
Total		9/15	11/15	7/15	-

M+S+: many households on large areas; M+S: many households on small areas; M-S +: few households on large areas; MS-: few households on small area; GZ: Guinean Zone; SGZ: Sudano-Guinean Zone; SZ: Sudanian Zone; FD: Frequency of Disappearance; m: landrace threatened of disappearance. $FD = (z/Z) \times 100$ Where: z = Number of landraces threatened of disappearance (cultivated by few households in small areas) and Z = total landrace identified in the ecological zone; NA: Not Available

Table 6 Importance of reasons for pigeonpea production and uses category in Benin

Criteria	Variables	GZ		SGZ		SZ	
		n = 190		n = 200		n = 110	
		F	FL	I p	FL	I p	FL
Reasons	Market value	107	37.8	80	29.6	66	24.1
	Nutritional value	176	62.2	190	70.4	98	35.8
	Land fertilizing power	-	-	-	-	110	40.2
	ΣF	283	-	270	-	274	-
Uses category	Consumption	164	34.8	188	38	96	31.9
	Medicine	92	19.5	75	15.2	72	23.9
	Offering	-	-	7	1.4	-	-
	Sacrifice	-	-	5	1	-	-
	Weed control	15	3.2	19	3.8	23	7.6
	Grain processing	20	4.2	10	2	-	-
	Fertilization	181	38.4	191	38.6	110	36.5
	ΣF	472	-	495	-	301	-

GZ: Guinean zone; SGZ: Sudano-Guinean Zone; SZ: Sudanean Zone; n: Number of respondents; FL = Fidelity Level, F = number of respondents for a modality of use or reason that motivates the culture and ΣF = sum of the number of respondents for all modalities of use or reason; FL = Fidelity Level

Table7 Biophysical resources, cultural practices and seed system across ecological zones

Variables	ZG (n=190)	ZSG (n=200)	ZS (n=110)	Overall (n=500)	diff
Cropping area in 2015 (ha)					
Average	0.9±0.2 ^b	1.3±0.8 ^a	0.3±0.1 ^c	0.9±0.6	***
Range	0.5-1.3	0.5-2.5	0.3-0.5	0.3-2.5	
Cropping area in 2016 (ha)					
Average	0.8±0.1 ^b	0.9±0.4 ^a	0.4±0.1 ^c	0.7±0.3	***
Range	0.5-1	0.5-1.5	0.3-1	0.3-1.5	
Cropping area in 2017 (ha)					
Average	0.5±0.1 ^b	0.7±0.3 ^a	0.4±0.1 ^c	0.6±0.3	***
Range	0.6-0.8	0.5-1.25	0.3-0.8	0.3-1.3	
Source of labour (% of yes)					
Family labour	12.1 ^b	13.5 ^b	49.3 ^a	13.2	***
Family and friends labour	87.9 ^a	61.5 ^b	42.2 ^c	73	***
Family friends and jobber labour	-	25 ^a	8.5 ^b	13.8	***
Seed system (% of yes)					
Seeds of previous harvests	70 ^a	62.9 ^a	46.2 ^b	60.2	***
Seeds of friends	9.2 ^b	10.5 ^b	50.4 ^a	22	***
Market Seeds	20.8 ^a	26.7 ^a	3.4 ^b	17.8	***
Conservation method	3.7 ^a	4.5 ^a	-	3.2	ns
Seed storage	70 ^b	84 ^a	34.6 ^c	67.8	***
Seed purchase	30 ^b	16 ^c	65.5 ^a	32.2	***
Plant type (% of yes)					
Annual plant	92.1 ^b	90.5 ^b	100 ^a	93.2	***
Perennial plant	7.9 ^a	9.5 ^a	-	6.8	ns
Land type (%)					
Intercropping system	100 ^a	98.5 ^b	24.6 ^c	82.8	***
Pure stand	-	1.5 ^b	75.4 ^a	17.2	***
Land, pests and diseases management (% of yes)					
Fertilization	-	-	-	-	ns
Use of pesticides	-	-	63.7	14	***
Sowing period (% of yes)					
April – June	97.9 ^a	91 ^b	-	73.6	***
April – May	2.1 ^a	9 ^b	-	4.4	***
June – August	-	-	68.2	15	***
July – August	-	-	31.8	7	***
Farming activities (% of yes)					
Ploughing	65.8 ^b	83 ^a	72.7 ^b	74.2	***
Sowing	100 ^a	100 ^a	100 ^a	100	ns
Weed control	100 ^a	100 ^a	100 ^a	100	ns
Pod harvest	92.6 ^b	97.5 ^a	87.3 ^b	93.4	***
Pod plugging	84.7 ^b	96 ^a	80.9 ^b	88.4	***
Winnowing	52.1 ^b	17 ^c	74.5 ^a	43	***
Yield (kg/ha)					
Average	557.5±15.9 ^a	566.6±35.8 ^b	522.3±44 ^c	553.4±36.3	***
Range	450-560	550-650	450-560	450-650	

GZ: Guinean zone; SGZ: Sudano-Guinean Zone; SZ: Sudanean Zone; n: Number of respondents; diff: difference; for the same variable, means or percentages that have no common letters are statistically different ($p < 0.05$); *** $p \leq 0.001$; ns : non-significant difference at the 5% level

Table 8 Comparative table of pigeonpea production constraints across ecological zones

Constraints	Overall					Rank per zone		
	NTV	MAC	PCO	Imp	Rank	ZG	ZSG	ZS
Long vegetative cycle	50	28	48	42	1	1	1	3
Pests and diseases	48	14	48	36.7	2	2	2	1
Rainfall irregularity	30	3	25	19.3	3	3	4	4
Weeding	25	1	23	16.3	5	4	5	6
Lack of improved varieties	26	-	24	16.7	4	5	3	5
Storage insects	10	-	7	5.7	8	6	9	8
Sol poverty	15	3	13	10.3	6	7	8	2
Harvest and post-harvest work	10	1	4	5	9	8	9	7
Low productivity	11	-	10	7	7	9	6	6
Lack of cultivable land	5	-	3	2.7	10	10	7	9

ZG: Guinean zone; ZSG: Sudano-Guinean Zone; ZS: Sudanian zone; TNV: Total Number of Villages in which the constraint is cited; MAC: Number of villages where the constraint is the major one or ranked first; PCO: number of villages in which the constraint was classified among the principal constraints i.e. among the first five; Imp: Importance

Table 9 Evaluation of pests and diseases impact in pigeonpea production

Evaluation level (%)	Variables	Overall (n = 500)	ZG (n = 190)	ZSG (n = 200)	ZS (n = 110)	Diff
Impact	None	12.8	18.4 ^b	28.5 ^a	2.7 ^c	***
	Low	51.3	52.6 ^a	42.5 ^b	1.8 ^c	***
	Average	32.1	29 ^a	29 ^a	9.1 ^b	***
	High	2.6	-	-	81.8	***
	Very high	1.3	-	-	4.6	***
Control of pests and diseases	None		-	-	36.3	***
	Use of cotton pesticides		-	-	63.7	***

GZ: Guinean zone; SGZ: Sudano-Guinean Zone; SZ: Sudanian Zone; n: Number of respondents; diff: difference; for the same variable, means or percentages that have no common letters are statistically different ($p < 0.05$); *** $p \leq 0.001$; ns: non-significant difference at the 5% level

Table 10 Farmers' preference criteria of pigeonpea across ecological zones

Preference criteria	Overall					Rank per zone		
	NTV	MCR	PCr	Imp	Rank	ZG	ZSG	ZS
Precocity	50	23	49	40.7	1	1	1	3
Resistance to pests and diseases	45	16	45	35.3	2	2	2	1
Rapid for cooking	39	0	30	23	4	3	5	5
Adaptability to any type of soil	28	5	25	19.3	6	4	8	2
Good taste	38	0	35	24.3	3	5	4	4
High productivity	35	3	23	20.3	5	6	3	7
Cultivable at any time of the year	22	1	10	11	7	7	7	8
High market value	11	2	10	7.7	8	8	6	-
Resistance to storage insects	10	0	5	5	9	9	10	6
Easy for ginning	6	0	1	2.3	11	10	-	10
Drought resistance	11	0	3	4.7	10	10	9	9

GZ: Guinean zone; SGZ: Sudano-Guinean Zone; SZ: Sudanian Zone; TNV: Total Number of Villages in which the criterion is cited; MCR: Number of villages where the criterion is the major one or ranked first; PCr: number of villages in which the criterion was classified among the principal criterion i.e. among the first five; Imp: Importance

Table 11 Importance (in rank) of varietal preference criteria across different sociolinguistic groups

Preference criteria	Adj	Bar	Bia	Boo	Den	Fon	Hol	Idaa	Mah	Nag	Peu	Som	Yor
Precocity	1	1	1	1	1	1	1	1	1	3	1	1	1
Resistance to pests and diseases	2	1	-	1	1	2	1	1	2	3	1	1	1
Rapid for cooking	2	1	-	1	1	3	1	2	2	2	1	-	1
Adaptability to any type of soil	5	1	1	1	1	5	2	-	5	1	1	-	1
Good taste	4	1	1	1	1	2	1		3	2	1	1	2
High productivity	3	2	1	2	1	2	3	2	2	2	1	-	3
Cultivable at any time of the year	5	3	-	1	1	6	3	2	4	1	2	-	1
High market value	6	-	1	-	-	6	2	1	5	-	-	1	-
Resistance to storage insects	-	3	-	1	-	7	-	-	5	-	1	-	4
Easy for ginning	7	4	-	2	-	-	-	-	5	-	2	-	4
Drought resistance	-	2	-	2	-	4	-	-	-	-	-	-	3

Adj: Adja sociolinguistic group; Bar: Bariba sociolinguistic group; Bia: Biali sociolinguistic group; Boo: Boo sociolinguistic group; Den: Dendi sociolinguistic group; Fon: Fon sociolinguistic group ; Hol : Holly sociolinguistic group ; Idaa : Idaasha sociolinguistic group ; Mah : Mahi sociolinguistic group ; Nag : Nago sociolinguistic group ; Peu : Peulhl sociolinguistic group ; Som : Somba sociolinguistic group ; Yor : Yorouba sociolinguistic group

Table 12 Agronomic and culinary characteristics of pigeonpea landraces grown accros Benin's ecological zone

Landraces	ZG	ZSG	ZS
CBSL	NA	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects	NA
CRISL	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects	Low productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects
CSL	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	NA
CHMSL	Low productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	Low productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	NA
CMSL	NA	Low productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	Low productivity; Slow for cooking; Long vegetative cycle; Susceptible to diseases and pests; Resistant to storage insects
BWSL	NA	Low productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	NA
RSL	High productivity; Rapid for cooking; Short vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	High productivity; Rapid for cooking; Short vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	Low productivity; Rapid for cooking; Short vegetative cycle; Susceptible to diseases and pests; Resistant to storage insects
LRSL	High productivity; Rapid for cooking; Short vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	High productivity; Rapid for cooking; Short vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	NA
BKSL	NA	Low productivity; Slow	NA

for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects

CRSSL	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects	Low productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects
CRHSL	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Susceptible to storage insects	NA
CMHSL	High productivity; Rapid for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	NA	NA
BMSL	High productivity; Slow for cooking; Long vegetative cycle; Resistant to diseases and pests; Resistant to storage insects	NA	Low productivity; Slow for cooking; Long vegetative cycle; Susceptible to diseases and pests; Resistant to storage insects
RMSL	NA	NA	Low productivity; Slow for cooking; Long vegetative cycle; Susceptible to diseases and pests; Resistant to storage insects
PMSL	NA	NA	Low productivity; Slow for cooking; Long vegetative cycle; Susceptible to diseases and pests; Resistant to storage insects

BKSL: Blackish seeded landrace; BMSL: Black and mottled seeded landrace; BWSL: Brown seeded landrace; CBSL: Cream with black eye seeded landrace; CHMSL: Cream and highly mottled seeded landrace; CMHSL: Cream and mottled with high size seeded landrace; CMSL: Cream and mottled seeded landrace; CRHSL: Cream with red eye and high size seeded landrace; CRISL: Cream with red eye and intermediate size seeded landrace; CRSSL: Cream with red eye and small size seeded landrace; CSL: Cream seeded landrace; LRSL: Light red seeded landrace; PMSL: Purple and mottled seeded landrace; RMSL: Red

and mottled seeded landrace; RSL : Red seeded landrace; ZG: Guinean zone; ZSG: Sudano-Guinean Zone; ZS: Sudanian zone ; NA : Landrace Absent

Figures

Figure 1

Map of Benin showing the geographical locations of the surveyed villages.

Figure 2

Different pigeonpea landraces cultivated across ecological zones of Benin.