UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

ASSESSMENT OF PHENOTYPIC DIVERSITY AND FARMERS' KNOWLEDGE OF CULTIVATION AND UTILIZATION OF PIGEON PEA [*Cajanus cajan* (L.) Millspaugh] IN BENIN

BY

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DECLARATION

I, hereby, declare that except for references to the work of other researchers which have been duly cited, this work is an original work and has not been submitted or presented in part or whole for any other degree.

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DEDICATION

This work is dedicated to my family for their never ending support and love.

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ABSTRACT

Pigeon pea plays a significant role in smallholder farmers' subsistence. In Benin, there is a dearth of information on the genetic diversity present in the crop. Indigenous knowledge used in folk medicines, taxonomy, crop management and seed system have not been assembled and documented. This study aimed at assessing farmers' knowledge related to pigeon pea cultivation and uses and genetic diversity of pigeon pea germplasm in Benin. Participatory Rural Appraisal including individual interview (n=302) and focus group was conducted. A triple lattice square design was used for agro-morphological characterization of 49 accessions. Results revealed that 98% of the pigeon pea growers practiced intercropping. Difficulty to harvest pulses, low productivity and lack of quality seed were the main factors constraining pigeon pea production. High yielding, early maturing and pod resistance to borers were the main farmers' preferred traits. Varietal naming of pigeon pea varieties was based on morphological traits, the origin of the variety and the perception of farmers on the variety. Based on the Shannon-Weaver Diversity Index (H'), the less and the most polymorphic qualitative traits in the germplasm were pod hairiness (H'=0) and flower streak colour (H'=1.88), respectively. Pod yield (CV=31.4%), seed yield (CV=35.1%), number of pod per plant (CV=31%) were the most variable quantitative traits in the pigeon pea collection. The PCA revealed that the first four principal components accounted for 78.96% of the total variation. The traits which contributed more to the variation in the germplasm were plant height, number of raceme per plant, pod bearing length, days to 50% flowering, days to 75% maturity, pod yield, seed yield, number of seeds per pod, number of pod per plant and 100 seeds weight. The clustering analysis using Tocher's method based on the Euclidean distance separated the accessions into 10 clusters with a clear cut between breeding materials obtained from IITA Ibadan and traditional cultivars collected in Benin. Significant association with biological interest ($r>0.71$, $P<0.05$) was found between number of raceme and days to 50%

flowering, days to 75% maturity and days to 50% flowering, pod bearing length and days to 50% flowering. Besides shelling percentage, all the traits showed medium or high heritability. The highest responses to selection were recorded for seed yield (GA%=48.83%), pod yield (GA% = 47.17%) and number of pod per plant (GA%=44.61%). This study provided a sound basis for designing appropriate strategies for sustainable production of pigeon pea in Benin and for successful variety development and introduction. In addition, Benin pigeon pea germplasm could potentially be exploited for yield improvement in international pigeon pea breeding programmes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1. INTRODUCTION

Pigeon pea (*Cajanus cajan* (L.) Millspaugh) is the sixth most important legume crop in the world (FAOSTAT, 2015). West Africa makes up a small proportion of the world pigeon pea production (FAOSTAT, 2015). However, the crop plays a key role in the subsistence of smallholders (Egbe and Vange, 2008; Dansi *et al.*, 2012). In Benin, in terms of production, the crop is the fifth legume after cowpea (*Vigna unguiculata*), Bambara groundnut (*Vigna subterranea*), soybean (*Glycine max*) and groundnut (*Arachis hypogaea*). The crop is grown on average on 4,059 ha with an average annual production of 2,799 tons [Ministère de l'Agriculture, de l'Elevage et de la Pêche (MAEP), 2013]. It is an important source of income for rural household (Dansi *et al.*, 2012). The crop is mainly grown in the southern and central part of the country and it is primarily used for human consumption (Dansi *et al.*, 2012; MAEP, 2013). Pigeon pea is integrated in the cropping systems mainly in alley cropping for soil fertility restoration (Versteeg and Koudokpon, 1993; Aihou *et al.*, 2006).

Pigeon pea seeds are highly nutritious with mature seeds containing 18.8% protein, 53% starch, 2.3% fat, 6.6% crude fiber and 250.3 mg $100g^{-1}$ minerals (Saxena *et al.*, 2010a). As a perennial shrub, pigeon pea has many advantages over annual legumes in that several harvests are possible and its capacity to enhance soil fertility is much higher (Høgh-jensen, 2011). The effects of the crop on soil protection against erosion are well known (Odeny, 2007; Upadhyaya *et al.*, 2013a). Pigeon pea has high tolerance to environmental stresses and has high biomass productivity (Lose *et al.*, 2003; Odeny, 2007).

With the current high variability in climate, pigeon pea offers resilience to cropping systems. Moreover, pigeon pea has a huge untapped potential for improvement both in quantity and quality of production in Africa (Odeny, 2007). For instance, in Benin, the average yield between 2010 and 2013 was about 686 kg/ha (MAEP, 2013) compared to reported yield of up to 4,600 kg/ha in on-farm variety trial in Kenya (Kimani, 2001).

Despite its importance, pigeon pea remains an orphan crop mainly because of lack of national promotion policy and lack of financial support for research targeting this crop (Dansi *et al.*, 2012). Earlier research on pigeon pea in Benin has dealt with its importance in pest management (Atachi, 2006), and soil fertility restoration (Versteeg and Koudokpon, 1993; Aihou *et al.*, 2006). There is a dearth of information on the genetic diversity present in the crop in Benin. Indigenous knowledge used in folk medicines, taxonomy, crop management and seed system have not been assembled and documented. It has been proven that knowledge on the different uses of a crop and analysis of its diversity are crucial for its conservation and management in order to avoid loss of diversity (Olango *et al.*, 2014). Through variability assessment using morphological traits, the pattern of genetic diversity in the crop would be identified and promising genotypes to be used to breed improved varieties would likely be identified (Upadhyaya *et al.*, 2007a; Upadhyaya *et al.*, 2013a).

The overall goal of this study was to assess farmers' knowledge related to pigeon pea cultivation and uses, and genetic diversity of pigeon pea germplasm in Benin.

The specific objectives were to:

- identify farmers' knowledge on cultivation and uses of the crop;
- assess farmers' perception on diversity of pigeon pea and preferred traits of desired varieties;
- assess variability and relatedness in the pigeon pea germplasm available in Benin;
- estimate the genetic parameters of quantitative traits in the crop.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Botany, Ecology and origin

2.1.1. Botany

Pigeon pea, (*Cajanus cajan* (L.) Millsp. 2n=2x=22), belongs to the genus *Cajanus* and to the tribe Phaseoleae, composing of other agronomically important genera such as *Vigna*, *Lablab*, *Phaseolus* and *Voandzeia*, and to the family Fabaceae (Singh and Oswalt, 1981; van der Maesen, 1990; Songok *et al.*, 2010). Pigeon pea has a genome size estimated at 833.07 Mbp (Varshney *et al.*, 2012). The genus *Cajanus* is composed of 32-34 taxa distributed into three clades, namely Australian, *scarabaeoides* and Indian (van der Maesen, 1990; Kassa *et al.*, 2012). When considering the gene pools as defined by Harlan and de Wet (1971); *C. cajan* has no wild species in its primary gene pool (Khoury *et al.*, 2015). Most of the relative of pigeon pea, including C. *cajanifolius* (Haines) van der Maesen, are in the secondary gene pool. C. *cajanifolius* is thought to be the most probable progenitor of pigeon pea (Kassa *et al.*, 2012). Species belonging to the secondary gene pool of pigeon pea can be used as materials to improve the crop for various traits such as abiotic and biotic stresses resistance, high protein content of seeds and male sterility (Khoury *et al.*, 2015).

Pigeon pea is a perennial shrub growing up to 4 m tall with a deep taproot (Singh and Oswalt, 1981). The leaves are trifoliate, disposed in alternate and in spirally around the stem. Leaves are composed of lanceolate and oblong leaflets having 2–10 cm of length and 2–4 cm of width (Singh and Oswalt, 1981). The leaflets are pubescent, green above and greyish-green beneath (Singh and Oswalt, 1981).

Flowers are hermaphrodite, papilionaceous and their colour varies from yellow to yellow with purple veins; and from yellow to diffused red. The flowers are usually 2 cm in length (Singh and Oswalt, 1981; van der Maesen, 2006). Natural out-crossing in pigeon pea ranges from 0 to 50% (Saxena *et al.*, 1990; Girithi *et al.*, 1991). The extent of out-crossing depends on the growing location and it is mostly mediated by insects and to a lesser extent by wind (Saxena *et al.*, 1990; Girithi *et al.*, 1991). The relatively higher degree of natural outcrossing has been exploited in the development of hybrids of pigeon pea (Saxena *et al.*, 2010a). However, due to high outcrossing rate, special interventions are needed to maintain genetic purity of pigeon pea varieties and germplasm (Saxena *et al.*, 1990; Girithi *et al.*, 1991; Saxena, 2006).

Pods are flat, acuminate, pubescent with 5–9 cm long, 12–13 mm wide. The seeds have shape varying from oval to round with colour ranging from light beige to dark brown. Seeds are contained in pods with 2 to 9 seeds per pod (Singh and Oswalt, 1981).

Three major growth patterns are distinguished in pigeon pea. The determinate growth pattern is characterized by cessation of growth when flowers are induced. The pods are clustered at the top of the canopy with an almost uniform maturity. For the indeterminate group, the terminal buds remain vegetative and pods maturity is not uniform. The semi-indeterminate group has intermediary characteristics of the determinate and the non-determinate (Saxena *et al.*, 2010b). Temperature and moisture influence pigeon pea growth habit (Manyasa *et al.*, 2009). Thus, some accessions develop an indeterminate pattern while growing in a high cool temperature and high moisture. Actually, combination of high cool temperature and high moisture leads to dense foliage, high branching, and a prolonged vegetative phase (Manyasa *et al.*, 2009).

2.1.2. Ecology of pigeon pea

Pigeon pea is grown in the tropics and subtropics between 30°N and 30°S latitudes under optimum temperatures ranging from 18–29°C (van der Maesen, 2006). Pigeon pea plant height is sensitive to temperature. Thus, there is a reduction in plant height when there is decrease in temperature during the growing period (Manyasa *et al.*, 2008).

Pigeon pea is sensitive to photoperiod and temperature. Flowering occurs during long days (Silim *et al.*, 2006). The photoperiod is more influential on late maturing group than early maturing group (Silim *et al.*, 2006; Saxena *et al.*, 2010b) but the reason for such observation remains to be elucidated. In controlled conditions, Silim *et al.* (2006) showed that the optimum temperature for rapid flowering generally decreases when the day to flower increases under photoperiods below 13 hours. In Africa, pigeon pea is grown at altitudes up to 2000 or even 2400 m (van der Maesen, 2006). A relationship has been established between the altitude of growth and the earliness in flowering. Manyasa *et al*. (2008) observed that when accessions from high altitude (northern highland of Tanzania) were grown in intermediate or low altitude, a delay in flowering and failure to flower was observed. In addition to the altitude, temperature in the growing area influences the flowering and the earliness of maturity (Silim *et al.*, 2006; Upadhyaya *et al.*, 2007b). Combined effects of temperature, photoperiod and altitude have a great influence on pigeon pea maturity. Based on days to 50% flowering, 10 maturity groups ranging from extra early group flowering (less than 60 days for 50% flowering) and late group flowering (more than 160 days to 50% flowering) have been identified at Patancheru in India (Saxena *et al.*, 2010b).

Even though pigeon pea tolerates drought, the crop thrives well when the optimum annual rainfall is 600–1000 mm and well distributed over the growth cycle. Pigeon pea also tolerates high rainfall even over 2500 mm (Singh and Oswalt, 1981, van der Maesen, 2006). Adaptation of pigeon pea to semi-arid and arid regions and to poor soils makes it a suitable crop to provide income and ensure food security in these regions which are less suited to many other crops (Odeny, 2007; Kassa *et al.*, 2012; Khoury *et al.*, 2015). Drained soils of intermediate water-holding capacity and with pH 5–7 are favourable and a soil salinity of 6–12 dS/m is tolerated by many cultivars (van der Maesen, 2006).

Daylength and temperature influence plant height, canopy and days to maturity (Silim *et al.*, 2006). This implies that large difference could be observed when accessions are characterized in environments different from their collection or adaptation regions (Silim *et al.*, 2006). In fact, the ecology in which pigeon pea is grown confers to it some specific adaptation patterns (Carberry *et al.*, 2001; Silim *et al.*, 2006). Thus, genetic resource from each pigeon pea growing region needs to be collected and characterized in order to identify traits to be included in breeding programmes.

2.1.3. Origin of pigeon pea

Pigeon pea is a tropical and sub-tropical species (Thothathri and Jain, 1980; van der Maesen, 1990). The name pigeon pea was first coined in Barbados where the seeds were used to feed pigeon (Plukenet, 1692 cited by Saxena *et al.*, 2010a). The origin of pigeon pea was not unanimously accepted by scientists. Some researchers working on pigeon pea first indicated Africa as the centre of origin of the crop (Krauss, 1932; Vavilov, 1951; Purseglove, 1968; Thothathri and Jain, 1980). According to these researchers, pigeon pea originated from Africa and through trade exchanges, it was sent to West Indies, Caribbean and then to Latin America (Tothill, 1948). This position seems to be supported by the presence of wild relatives of *Cajanus* in Africa and the finding of pigeon pea seed in ancient Egyptian tombs (2200-2400 B.C) as reported by Schweinfurth (Sturtevant, 1972). However, only *Cajanus kerstingii (Harms)*, endemic to West Africa and *Cajanus scarabaeoides* (L.), are wild relative of *C. cajanus* found in Africa (van der Maesen, 2006). The second group of scientists favoured India as the primary centre of origin of pigeon pea (van der Maesen, 1979). Evidences related to archeological findings, the different usages in the diets and the linguistic evidences have supported India as the centre of origin of pigeon pea (van der Maesen, 1980; Thothathri and Jain, 1981). In addition, a large diversity of pigeon pea and wild relatives such as *C. atylosia*, C. *scarabaeoides*, C. *cajanifolia* (probable progenitor of pigeon pea) and others have been collected from this region (van der Maesen, 1990; Kassa *et al.*, 2012). Molecular characterization of *C. cajanus* accessions collected from Africa and India have reinforced the position of India as primary centre of diversity and Africa as a secondary centre of diversity with greatest diversity found in Indian accessions as compared to African accessions (Songok *et al.*, 2010).

In short, the greatest diversity of pigeon pea, the linguistic and archeological facts, and the presence of putative progenitor positioned India as the centre of origin and primary centre of diversity and East Africa as the secondary centre of diversity of pigeon pea with a subsequent spread in West Africa, Southeast Asia, Caribbean and the Latin America (Khoury *et al.*, 2015).

2.2. Distribution and production

Pigeon pea is grown in Asia, Africa, Americas and Caribbean and Oceania on 6.23 million hectare and the yield averaged 751 kg/ha (FAOSTAT, 2015). Statistics about pigeon pea productions are probably underestimated since they do not cover all the growing countries notably the minor ones where the crop is cultivated on small areas by smallholder farmers (Mula and Saxena, 2010). Asia with India as leading country accounts for the major part (82.1%; 3.84 million tons) of the world production in 2013 (FAOSTAT, 2015). Africa occupies the second place (15.3%; 0.72 million tons in 2013) with Uganda, Tanzania, Kenya, Zambia as the major producers. West Africa, Latin America and Caribbean are considered as a minor growing region of pigeon pea (Versteeg and Koudokpon, 1993; Joshi *et al.*, 2001; Mula and Saxena, 2010). The current annual growth for the harvested area, the production and the yield was respectively 2.65%; 3.71% and 1.03% (FAOSTAT, 2015).

Pigeon pea is drought tolerant and thrives where most of the common crops fail (Odeny, 2007; Khoury *et al.*, 2015). Due to the rapid changes in climate, the cultivation of pigeon pea is expected to expand to new regions (Khoury *et al.*, 2015). This observation is supported by evidences provided through different climate projection models indicating an increase in the occurrence of extremes weather hazard particularly drought in Africa (Berry *et al.*, 2010).

In Africa, the production of pigeon pea benefits from the existence of local, regional and international markets emphasizing the potential of pigeon pea to contribute to food security and alleviate poverty in growing areas (Odeny, 2007). The potential of pigeon pea to mitigate the effect of climate change in Nigeria has been shown by Emefiene *et al.* (2013) and it is likely to be applied to Benin, which is subjected to desertification and the effect of climate change as well.

2.3. Pigeon pea production systems

To establish their pigeon pea fields, farmers have developed various strategies to have access to seeds. They heavily rely on informal seed systems through seed saved, seed exchanges, purchase on local market (Manyasa *et al.*, 2009; Audi *et al.*, 2008; Silim *et al.*, 2005). In some regions, for instance in Tandur (India) and Eastern Kenya, farmers have been organized and trained for seed production through interventions such as community-based seed production, producer-marketing groups, seed vouchers and fairs facilitating access to improved cultivars (Audi *et al.*, 2008; Holmesheoran *et al.*, 2012).

Pigeon pea is integrated in various cropping systems. Rotation farming and intercropping are common practices where small-scale farmers make use of pigeon pea (Odeny, 2007). These practices enable pigeon pea to increase soil fertility through symbiotic nitrogen fixation which results in yield increase of intercropped crops (Mallikarjuna *et al.*, 2011; Høgh-jensen, 2011; Adjei-Nsiah, 2012; Emefiene *et al.*, 2013). In intercropping, pigeon pea functions as an excellent trap crop for the heteropteran species in pest management of cowpea (Atachi *et al.*, 2006).

Pigeon pea based cropping systems vary across growing areas. In Tanzania, cropping systems involving pigeon pea are different across the growing regions but the intercropping with cassava, maize and sorghum were found to be the prevailing system (Silim *et al.*, 2005). In Uganda, depending on the growing districts, pigeon pea is mainly intercropped with finger millet, maize, or sorghum (Manyasa *et al.*, 2009). The potential to intercrop pigeon pea with pyrethrum was reported in Kenya; this could enable farmers to diversify the sources of income (Mwangi *et al.*, 2010). In India, pigeon pea is mostly grown in intercropping with annual crops such as sorghum, pearl millet and groundnut (Saxena *et al.*, 2010a). In Nigeria, farmers grow pigeon pea in pure stand or intercropping systems with maize, sorghum, yam, cassava, sweet potatoes and millet (Egbe and Vange, 2008).

Intercropping systems involving pigeon pea and annual crops such as maize significantly improves the yield of the latter and contributes to poverty alleviation among smallholder farmers (Høgh-jensen, 2011; Adjei-Nsiah, 2012). The practice of intercropping requires the use of cultivars with adapted maturity duration; architecture and adequate biomass production in order not to reduce the yield of the associated crop (Saxena 2006; Manyasa *et al.*, 2009; Mula and Saxena 2010). Such cultivars may be either bred or isolated from germplasm. The latter makes collection, characterization and evaluation of existing germplasm a useful option in developing new cultivars matching cultural practices (Manyasa *et al.*, 2009). Pigeon pea is also grown to reduce soil erosion (Upadhyaya *et al.*, 2013). Soil conservation and use for lac production were found to be the primary reason for growing pigeon pea in Southern Hills in China (Chaohong *et al.*, 2001; Mula and Saxena, 2010; Gowda *et al.*, 2012). Besides its importance in cropping systems, pigeon pea has several ethnobotanical uses.

2.4. Utilization of pigeon pea

Based on knowledge that has been transmitted over time and generation, communities make use of a given crop species in various ways (Jarvis *et al.*, 2000; Osawaru and Dania-Ogbe, 2010). The existence of vernacular appellation and the different uses of pigeon pea in a given area stress the social and economic role of the crop and its historic link with the communities (Arias-Reyes *et al.*, 2000). The use of the different parts of the plant varies from one community to another and depends on social factors (Jarvis *et al.*, 2000).

In almost all the pigeon pea growing areas, seeds are primarily used for human consumption and incorporated in diverse dishes. In India and in many countries in Eastern Africa, Dhal dish, made up of pigeon pea seed, is a popular meal (Odeny 2007; Mula and Saxena, 2010; Saxena *et al.*, 2010a). Pigeon pea seed flour is an interesting ingredient and used in many dishes and snacks (Odeny, 2007; Mula and Saxena, 2010).

Pigeon pea leaves are used in the treatment of various diseases. Aiyeloja and Bello (2006) reported the use of pigeon pea leaves in treatment of malaria in Southern Nigeria. This finding was supported by Ajaiyeoba *et al.* (2013) who identified a potential antimalarial compound, Cajachalcone, 2, 6'-dihydroxy-4-methoxy chalcone extract from pigeon pea leaves and they opined that Cajachalcone may be used in making anti-malaria drug. Leaves usage in the treatment of measles and chickenpox was reported in Southern Nigeria (Oladunmoye and Kehinde, 2011). Pigeon pea is indicated in the treatment of many other diseases such as jaunice, hepatitis, diabetes, dysentery, skin irritation, fever and measles, vertigo (Grover *et al.*, 2002; Zu *et al.*, 2010; Pal *et al.*, 2011). Pigeon pea is known in chinese traditional medicine as a sedative, stanch blood and pain relief (Chaohong *et al.*, 2001; Pal *et al.*, 2011). Promising effect of pigeon pea leaf extract in treatment of liver dysfunction induced by alcohol has been proven (Kundu *et al.*, 2008). The antimicrobial activities of pigeon pea leaves against *Staphylococcus aureus* (major cause of skin, respiratory, soft tissue, endovascular, bone disorders) has been demonstrated (Zu *et al.*, 2010).

Green leaves and the husk of the pods serve as fodder and feed (Chaohong *et al.*, 2001; Saxena and Rao, 2002). The plant is used in the production of honey. The dry branches and stem serve as firewood and roofing (Mula and Saxena, 2010).

Despite the different medicinal uses of pigeon pea found in the literature, this area remains under investigated in Africa (Odeny, 2007). Documentation of the different uses (form of consumption, medicinal, religious uses) of pigeon pea is important not only to avoid loss of knowledge but also to serve as basis for further investigations that may lead to development of pharmaceutical products.

2.5. Constraints limiting the production of pigeon pea

The factors constraining the production of pigeon pea in Africa have been reviewed by Odeny (2007). It came out that there is a lack of improved varieties to meet farmers' needs. For instance, in transitional zone of Ghana, lack of early maturing cultivars was identified as one of the main challenges hindering the widespread cultivation of pigeon pea (Adjei-Nsiah, 2012). Furthermore, in regions where improved varieties exist, there is no functioning supply seed system since seed enterprises and governments are unwilling to invest in crops other than cash crops (Mutegi and Zingore, 2008; Bioversity International, 2014).

Poor agronomic practices and lack of organisation of the pigeon pea market negatively affect the productivity and the capacity of farmers to sell their products at fair prices (Odeny *et al.*, 2007; Mutegi and Zingore, 2008; Adjei-Nsiah, 2012; Bioversity International, 2014). Even though, pigeon pea shows less susceptibility to most pest and diseases, as compared to the cowpea, the crop is still constrained by biotic stresses such as wilt (*Fusarium udum* Butler), pod borers [(*Helicoverpa armigera* (Hűbner) and *Maruca testulalis* (Geyer)], podfly (*Melanagromyza chalcosoma* Spencer), phytophthora blight (*Phytophthora drechsleri* Tucker) and abiotic stresses such as salinity and flooding (Srivastava *et al.*, 2006; Sultana *et al.*, 2010; Upadhyaya *et al.*, 2013b). Potential genetic materials to overcome these biotic and abiotic stresses may be identified through collection and evaluation of pigeon pea germplasm collections along with farmers' knowledge on the crop.

2.6. Traditional knowledge and crop diversity

2.6.1. Traditional knowledge in relation with biodiversity conservation

According to Grey (2014), indigenous knowledge referred to *"the expressions, practices, beliefs, understandings, insights, and experiences of Indigenous groups, generated over centuries of profound interaction with a particular territory"*. Indigenous knowledge also termed traditional knowledge is dynamic and co-evolves with the changes in the environment (Cocks, 2006).

In recent years, the link between human beings and diversity of cultivated plants has drawn more attention and a parallelism has been established between cultural diversity and biodiversity (Arias-Reyes *et al.*, 2000; Cocks, 2006). Thus, several international mechanisms and organisations have emphasized on the contribution of indigenous knowledge in the maintenance of genetic diversity (Convention on Biological Diversity, 1992; Bioversity International, 2014). Literature abounds on how farmers use their traditional knowledge to adapt to their environment and meet their needs (King and Ravi, 2011; vom Brocke *et al.*, 2011). In this review, emphasis is put on how farmers use their acquired knowledge over time in the classification and conservation of crops species.

Traditional knowledge related to crop diversity includes different usages of crop species, their symbols for community, cultural value of the crop, preferences for cultivars, special recipes associated to the crop and genetic material exchange networks and management, songs and folks through which, knowledge is transmitted (Guarino, 1995; Jarvis *et al.*, 2000; Pfeiffer *et al.*, 2006; Dixit and Goyal, 2011). Within a community, social factors, including but not limited to gender, age, land tenure and farm size shape the utilization and maintenance of crop diversity at household level (Jarvis *et al.*, 2000). Farmers have deep knowledge of their environment. The choice of crops species, varieties, cropping system, area to be allocated to each crop are then meaningfully thought to adapt to environmental conditions and meet socio-economic needs (vom Brocke *et al.*, 2011). Farmers constantly seek to increase diversity within crops and among crops to increase their resilience to environmental hazards. However, traditional knowledge related to diversity use and conservation is threatened (Keller *et al.*, 2005). Actually, changes occurring in agricultural systems resulting from globalisation, urbanisation and related factors have focused on production of few major crops (Bioversity International, 2014; Massawe *et al.*, 2016). Consequently, there is a decline in production and diversity of minor crops, important for food security in marginal areas, and the traditional knowledge associated to their conservation (Massawe *et al.*, 2016). Future crop improvement and adaptation to environment will suffer from this genetic and knowledge erosion (Jarvis *et al.*, 2000; Bioversity International, 2014; Massawe *et al.*, 2016).

Identification of the custodians of agro-biodiversity, their motivation, seed exchange networks they are involved in and the processes through which they operate are important for conservation and participatory breeding programmes and for strengthening seed supply systems (Subedi *et al.*, 2003).

2.6.2. Informal seed systems and genetic diversity

Informal seed systems involve a flow, from production to distribution, of genetic materials among actors, outside the commercial seed industry, but most of the time based on social links (Tesfaye *et al.*, 2005). Farmers have always relied on this system to exchange genetic materials. The viability of seed exchange networks determines the long term availability, diversity and maintenance of cultivars (de Haan, 2009). Seed management systems influence on the diversity of a given crop. Seed management and exchanges are based on knowledge and rule at the community level or interpersonal relationship outside the community (Subedi *et al.*, 2003; vom Brocke *et al.*, 2011).

The flow of genetic material within or among the seed exchange systems is dynamic and depends on the social, economic and environmental (Subedi *et al.*, 2003; Delaunay *et al.*, 2008; de Haan, 2009; vom Brocke *et al.*, 2011). This dynamism favors adoption of suited varieties and the abandonment of non-suited ones leading to the extinction of the latter (vom Brocke *et al.*, 2011). Audi *et al.* (2008) found that the producer-marketing groups, whereby seed producers and market outputs are tied up, increases the diversity of cultivars available for farmers and ensured seed stability. In Tanzania, Manyasa *et al.* (2008) reported that pigeon pea farmers' preference to meet market demand has led to less diversified seed traits in Northern Highlands as compared to the other growing areas. This finding emphasizes the fact that farmers' preferences influence the diversity of cultivated crops since they grow varieties to meet specific and dynamic needs. Furthermore, a variety that is outdated today may be the most sought in the future to meet both environmental conditions and users preferences. It is then necessary to conserve germplasm on-farm or through systematic collection and *ex-situ* conservation.

2.6.3. Indigenous knowledge, diversity classification and nomenclature

Farmers maintain diversity as a livelihood strategy. The varieties cultivated by farmers represent the unit of selection overtime and conservation. Assessing diversity at community level requires an understanding of the classification, identification and naming of cultivars based on farmer knowledge and folk taxonomical systems (de Haan, 2009). In addition, understanding the way farmers identify and classify varieties is indispensable for appropriate external intervention and varieties introduction since the folk taxonomical system is used for communication between regions and generations (Jarvis *et al.*, 2000). The study of indigenous classification seeks to reveal the descriptors, folk, meaning, consistency of vernacular names given by farmers and it serves as a primary assessment of diversity (Jarvis *et al.*, 2000; de Haan, 2009).

Farmers have criteria that in many instances may be completely different from the ones used by breeders to classify crop varieties. Farmers use folk descriptors that involve morphological characters, origin of crop, the person who introduced the variety in the locality or indirect traits to name and differentiate their cultivars (Dansi *et al.*, 2010; Adoukonou-Sagbadja *et al.*, 2006; de Haan, 2009).

Criteria used by farmers in discriminating and selecting crop varieties offer breeders valuable tools to develop suitable cultivars and guide research programmes (Warren, 1992; Adoukonou-Sagbadja *et al.*, 2006; Dansi *et al.*, 2010). For instance, Adoukonou-Sagbadja *et al.* (2006) identified growth cycle, cooking qualities, grains size and colour as the main criteria used by farmers to differentiate fonio varieties in Northern Togo. In the same way, famers listed 35 folk descriptors and 2 pest resistance traits to identify potato cultivars in Peru (de Haan, 2009). Productivity, organoleptic, and resistance to biotic and abiotic stresses have also been reported as criteria used by communities to identify and classify varieties (Dossou-Aminon *et al.*, 2014).

However, the naming and classification criteria may vary among communities. Therefore, there may be inconsistency in the classification or grouping of varieties within a given crop. In fact, the same variety can be named differently from one ethnic group to another (multitude to one correspondence) or variety with the same vernacular name may be genetically different (one to multitude correspondence) (Jarvis *et al.*, 2000; de Haan 2009). A bias is then introduced in the estimate of the diversity based on farmers' criteria. A crossed-check in terms of morphological and/or molecular characterization is needed to back diversity revealed based on indigenous knowledge up (de Haan, 2009).

2.7. Phenotypic diversity and relatedness in pigeon pea

2.7.1. Phenotypic diversity in qualitative traits

Various studies ranging from preliminary field characterization to on station characterization use the morphological traits to assess diversity in pigeon pea germplasm (Upadhyaya *et al.* (2005; 2007b; 2013; Manyasa *et al.*, 2008 ; 2009). Shannon-Weaver Index is one of the most used indices to assess diversity in germplam collection based on qualitative characters. The Shannon-weaver Index measures the richness and evenness of alleles in the population. A high index for a trait indicates a high genetic diversity in this trait (Shannon and Weaver, 1948). Using the Shannon-Weaver diversity index, Upadhyaya *et al.* (2005) found in the world collection of pigeon pea made up of 11,402 accessions collected from 54 countries that flowering pattern and primary seed colour were the less and the most diverse qualitative traits, respectively.

Upadhyaya *et al.* (2007b) characterized pigeon pea core collection in India and reported lowest and highest Shannon-Weaver diversity indices in stem colour (H' = 0.04 ± 0.03) and primary seed colour (H' = 0.73 ± 0.07), respectively.

In the studies of Upadhyaya *et al.* (2005; 2007b), the authors used also the Shannon-Weaver Index to estimate the diversity of the quantitative traits. This might bring ambiguity in the interpretation of the results because of the subjectivity in the definition of classes and categories based on these traits.

Manyasa *et al.* (2008) characterized in Kenya 123 pigeon pea landraces collected from Tanzania and found low variation in qualitative traits. The lowest diversity (H'=0.0436) was recorded in stem colour while the highest diversity was recorded in flower streak (H'=0.4471).

In Ugandan pigeon pea landraces, seed eye colour showed the highest diversity Index (H` = 0.532) while the stem colour showed the lowest diversity Index (H` = 0.021) (Manyasa *et al.*, 2009). The recorded Shannon-Weaver Index across all traits was relatively lower (H` = 0.325) in the Ugandan pigeon pea landraces as compared to the diversity index (0.464 ± 0.039) obtained across Africa where the highest germplasm diversity was recorded (Upadhyaya *et al.*, 2005).

Differences in the diversity of the traits across the various studies may be due to the differences in the number of accessions evaluated and the origin of the accessions (breeding materials or landraces). In fact, landraces are reported to be more diverse than breeding materials (Rauf *et al.*, 2010).

2.7.2. Phenotypic diversity in quantitative traits

Multivariate analyses are used to assess phenotypic variability and relatedness in germplasm. Upadhyaya *et al.* (2007b) used Principal Component Analysis (PCA) to discriminate pigeon pea genotypes and identified days to 50% flowering, plant height, number of secondary and tertiary branches, number of racemes, pods per plant, pod length, 100-seed weight and yield as traits accounting for most of the observed variation in pigeon pea core collection.

Data collected from three sites in Kenya and Tanzania was pooled to assess diversity pattern of Tanzanian pigeon pea landraces' collection. The accessions were separated following plant height, days to flower, days to maturity, number of pods per plant, pod bearing length and number of primary and secondary branches based on the first component accounting for 42.16% of the variability (Manyasa *et al.*, 2008).

In Ugandan pigeon pea germplasm, days to flower, days to maturity, number of racemes per plant, number of secondary branches per plant, pods per plant, plant height, pod length, 100-seed weight and seeds per pod contributed the most to the variability in the collection (Manyasa *et al.*, 2009).

Pooled agro-morphological data from three locations in India revealed that days to 50% flowering, 100 seed weight, protein content were the traits that contributed the most to genetic divergence in 73 pigeon pea genotypes composed of cultivars and stable inter-specific derivative between *Cajanus cajan* x *C. scarabaeoides* (Durgesh *et al.*, 2015).

Plant height and number of pods per plant are consistent across the different studies as part of the quantitative traits contributing the most to the variability in pigeon pea germplasm. However, some discrepancies are noted in the number of traits accounting for the variability in the characterized pigeon pea germpalsm collections. Such a difference may be due to the fact that the number of morphological traits considered varies across the different studies. In fact, a trait with a major contribution in a study (eg.: tertiary branches in Upadhyaya *et al.*, 2007b) may not be considered in another study (eg.: Durgesh *et al.*, 2015). In addition, the difference in origin and the nature of the accessions considered in the studies and the environments where they were characterized would influence the expression of the quantitative traits that are used to assess the variability of a given collection.

A comprehensive assessment of relatedness of accessions requires the use of clustering analysis. Clustering enables the formation of groups of materials based on their similarities or dissimilarities (Jolliffe, 2002). Thus, based on accessions grouping, duplicates of accessions can be revealed, desirable parents can be selected to start a breeding programme (Singh *et al.*, 2010). In addition, the grouping of accessions allows for the formation of heterotic groups among which crosses may lead to hybrid and high genetic gain (Bharathi and Saxena, 2015). Different methods are used to cluster genotypes. Durgesh *et al.* (2015) characterized pigeon pea collection using Tocher's method (Rao, 1952) based on Mahalanobis distance (D^2) and the collection was grouped in 9 clusters with an inter cluster distance ranging from 2.774 to 16.417.

The same clustering method groups the collection evaluated by Patel and Acharya (2011) and Singh *et al.*, (2014) in eight clusters with an inter cluster distance D^2 ranging from 2.124 to 5.463 and 3.92 to 10.28, respectively. The obtained genetic distance in these studies seems to reveal an appreciable genetic diversity in the pigeon pea collections. However, genetic diversity based phenotypic traits in pigeon pea collection can be overestimated. The use of molecular markers reveals rather a low genetic basis in the cultivated pigeon pea (Burns *et al.*, 2001; Odeny, 2006; Yang *et al.*, 2011; Bharathi and Saxena, 2015).

Upadhyaya *et al.* (2005 ; 2010) used Ward (1963) minimum-variance based on Euclidean distance and the accessions in their studies were grouped into three clusters. Manyasa *et al.* (2008) applied the same clustering method and six clusters were formed in the characterized collection. The trend in genetic diversity analysis in pigeon pea collections, using agro-morphological characters, is mostly based on Ward algorithm and Tocher's method. The rationale behind the choice of the clustering method in the different pigeon pea accessions clustering studies is not elucidated. However, the result of clustering can be influenced by the clustering method (Fred, 2001; Mohammadi and Prasanna, 2003; Silva *et al.*, 2013). Accuracy and consistency in materials grouping are important for an appropriate usage of germplasm (Mohammadi and Prasanna, 2003) and for defining conservation units for the development of core collection in pigeon pea (eg.: Upadhyaya *et al.* (2005). In order to cluster accurately materials in a collection, it is useful to choose the most appropriate method. Toward this end, a comparison of a set of methods based on their efficiency in clustering genotypes is recommended (Fred, 2001; Mohammadi and Prasanna, 2003; Silva *et al.*, 2013). This is important in characterizing pigeon pea collections where information on the comparative efficiency of the methods widely used is scarce.

2.8. Association among quantitative traits in pigeon pea

Assessment of the correlation among traits provides breeders with information on the degree of association among traits. Advanced correlation using path analysis allows for the determination of the contribution of each trait to the targeted economic trait (yield, biomass, fruits) (Bharathi and Saxena, 2013). When the traits are highly correlated, selection can indirectly be performed on the traits with high heritability or a trait that is easy and cost effective to select for (Saxena and Sharma, 1981). For instance, Upadhyaya *et al.* (2010) reported that because of the correlation between days to 50% flowering and days to 75% maturity, indirect selection for days to 75% maturity may be performed on days to 50% flowering. This results in time gaining in the breeding process since earlier selection can be performed. Correlation among traits also enables the development of indices for multiple traits selection and the understanding of evolutionary process of traits (Bharathi and Saxena, 2013).

Traits association is considered to be of biological interest when the absolute value of the correlation coefficient is higher than 0.71 (Skinner *et al.*, 1999). In fact, the square of the correlation coefficient accounts for the proportion of variance in one trait that is explained by its linear relationship with a second trait (Snedecor and Cochran, 1980). Thus, an absolute correlation coefficient of at least 0.71 reveals that least 50% of the variation in one trait is predicted by the other (Skinner *et al.*, 1999). This threshold serves only as guideline and as recognised by these authors, depending on the traits of interest for the breeders, strength of association less than 0.71 may still be interesting.

Several studies have assessed the strength of association between quantitative traits. Leaf components such as leaf area, leaf weight and petiole length were positively correlated to seed size, day to flower and seed yield even though the relationship with the latter was not meaningful to be exploited in indirect selection for yield (Saxena and Sharma, 1981).

Correlations among some of the quantitative traits depend on the maturity group (Upadhyaya *et al.*, 2005). Significant, high and positive correlation was found in pods per plant and secondary branches among accessions in extra early (r = 0.756) and late maturity groups (r = 0.776) and the entire collection as well (r = 0.728). Regardless of the maturity group, significant, high, and positive correlation (r = 0.901) was found between number of raceme and pods per plant (Upadhyaya *et al.*, 2005).

Days to flower, plant height, number of primary and secondary branches, number of seeds per pod and seed size were positively associated to seed yield in inbred lines of pigeon pea (Saxena and Sharma, 1990; Sodavadiya *et al.*, 2009).

Number of pods per plant, secondary branches, days to maturity and 100 seed weight were correlated positively and significantly in advanced genotypes of pigeon pea (Kumara *et al.*, 2013).

However, Bharathi and Saxena (2013) found in Cytoplasmic nuclear sterility-based pigeon pea hybrids that only the number of pods per plant was positively and significantly associated to seed yield whereas the number of primary branches was negatively associated to seed yield. Such differences may be due to the differences in the evaluated genotypes and to the propensity of hybrids pigeon pea to produce more biomass followed by important flower drop (Bharathi and Saxena, 2013).

A proper exploitation of traits association in breeding programmes depends on genetic parameters notably the heritability of associated traits.

2.9. Heritability estimates in pigeon pea

Heritability and related genetic parameters (genetic advance, genotypic and phenotypic coefficient of variation) estimates for traits in germplasm collections provide breeders with information on breeding strategies and expected genetic gain from different selection strategies (Holland *et al.*, 2003; Piepho and Mohring, 2007; Ajay *et al.*, 2012). Heritability estimate is important in comparing the same trait within a population or across populations to uncover the relative importance of environmental and genetic factors (Visscher *et al.*, 2008).

Depending on the data available and the research objectives, two types of heritability can be calculated. The broad sense heritability is the proportion of phenotypic variation that is explained by genetic effects including additive, dominance and epistasis effects (Falconer and Mackay, 1996; Holland *et al.*, 2003). In the same manner, narrow sense heritability is defined as the proportion of the phenotypic variance due to variation in additive effect, heritable genetic effect (Falconer and Mackay, 1996; Holland *et al.*, 2003). Different methods are used to estimate heritability with the most used being parent-offspring regression, variance components. Analysis of variance is also used to estimate heritability when evaluating potential progress in a germplasm collection while used as starting materials for a breeding programme (Acquaah, 2012). In this case, the analysis of variance from a replicated trial can be used to estimate the heritability, which can be either in narrow sense while dealing with inbred and pure lines or in broad sense when it is a segregating population (Acquaah, 2012). In pigeon pea, because of the relatively high rate of outcrossing (Saxena *et al.*, 1990), lines are rarely pure and the heritability estimated based on the analysis of variance is mostly in broad sense (eg: Manyasa *et al.*, 2008; Singh *et al.*, 2014). Although heritability in broad sense does not reveal the fixable variation in traits and may be biased upward by the non-genetic variances, this estimate is still useful and informative. For instance, if the estimate of heritability in broad sense were high enough, it would be time and resource saving to conduct the selection on single replication or environment basis (Holland *et al.*, 2003).

In pigeon pea, there is a large variation in the estimate of heritability of important traits reported in the literature (Saxena *et al.*, 2010b). However, it is useful for breeders to have an insight into the magnitude of heritability of targeted traits selection in their breeding programmes. Thus, Saxena and Sharma (1981) defined three classes of heritability by grouping traits with the same magnitude of heritability. Traits with heritability estimates less than 50%, ranging from 50%-75%, and more than 75% are qualified as low, medium and high heritability, respectively. Even though such a classification seems to be subjective, it provides a basis for the magnitude of heritability. Traits such as number of pods per plant, number of seeds per pod, grain yield, protein content, leaf area, leaf weight, petiole length fall into the category of low heritable traits (Saxena and Sharma 1981; Manyasa *et al.*, 2008; Saxena *et al.*, 2010b). Days to 50% flowering, days to maturity, plant height and number of raceme showed high broad sense heritability. On the other side, days to maturity, number of primary branches and 100 seed mass had medium heritability (Manyasa *et al.*, 2008).

Based on the heritability classes defined by Saxena and Sharma (1981), Upadhyaya *et al.* (2010) found in vegetable type pigeon pea, that seeds per pod, shelling percentage, 100 seed weight (g), seed soluble sugar and seed protein showed medium heritability whereas days to 50% flowering, days to 75% maturity, pod length, pod width, dry pods per plant and dry seed yield per plant had high heritability.

Singh *et al.* (2014) reported that primary branches, secondary branches, pod per plant, seed per pod and seed yield per plant had medium heritability while day to 50% flowering, days to maturity, plant height, pod length, 100-seed weight showed high heritability in a collection of 102 pigeon pea genotypes evaluated under rainfed conditions. Plant height, days to 50% flowering and maturity showed high heritability regardless of the environment. However, the magnitude of heritability for some traits varies across studies.

Heritability of a trait is estimated as a function of the evaluated genotypes, the environment and conditions under which the evaluation is performed. Comparing heritability across different evaluation environment and among different populations may not be too informative (Holland *et al.*, 2003). For a meaningful interpretation of the heritability, a clear definition of the environment and sampled population is required (Holland *et al.*, 2003; Piepho and

Mohring, 2007). It would not be cautious to draw an overall conclusion or make generalisation on this estimate, unless it has been proven to be similar in all the studies. Thus, the estimation of the heritability of traits in the environment or similar environment where breeding programmes and cultivation of pigeon pea will be carried out might be an appropriate way for the reliability of the results. Consequently, useful and more reliable parameters regarding selection and genetic gain in a breeding programme can be estimated.

In the light of this review, most of the works on genetic diversity of pigeon pea have focused on the major growing areas. However, in minor growing areas like Benin, diversity can be harnessed, characterized and exploited in improvement programmes of the crop. To this end, methods that are more rigorous should be used in the diversity assessment of pigeon pea. Furthermore, farmers' knowledge for the management of the crop needs to be collected not only to identify success factors for varieties introduction in the area but also for designing conservation programmes. What is more, clarification should be brought on the most clustering methods used in pigeon pea grouping studies for a better grouping of accessions based on agro-morphological traits.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Utilization, cropping systems and perceptions on diversity of pigeon pea

3.1.1. Survey locations

The major pigeon pea growing areas in Benin were identified based on information collected from extension agents. Pigeon pea growing areas are located in three agro-ecological zones (V, VI and VII) in the southern (Plateau, Couffo and Zou Departments) and central (Collines Department) Benin (Figure 1) (Table1). In these areas, about 70% of the population lives in rural areas and agriculture is their major activity. Within each agro-ecological zone, surveyed villages were identified jointly with extension agents under the Ministry of agriculture [Ministère de l'Agriculture, de l'Elevage et de la Pêche (MAEP)] on pigeon pea production. Twenty villages were selected (Table 1).

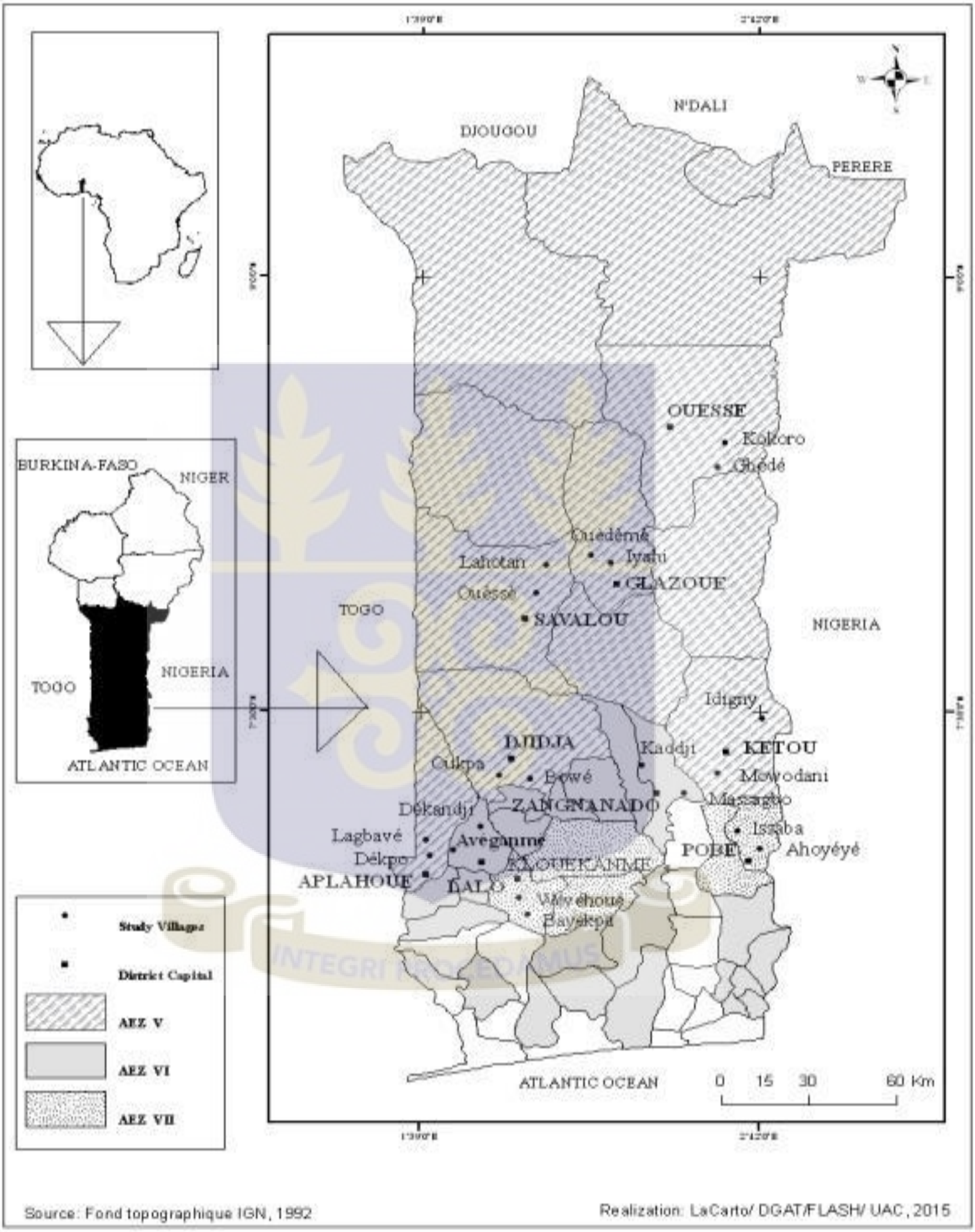


Figure 1: Map of the surveyed areas.

Table 1: Biophysical characteristics of the surveyed areas

Agroecological Zones and prospected municiaplities	Climate	Main soil type	Range of average annual rainfall	Main field crops
Zones V North: Ouèssè, Glazoué, Savalou, Djidja	Sudano-guinean with unimodal rainfall regime	Ferruginous	1100 to 1300 mm	Maize, rice, yam, cassava, cowpea, groundnut soybean and cotton
Zones V South: Ketou, and Aplahoué	Guinean with bimodal rainfall regime	Ferruginous	1100 to 1300 mm	
Zone VI : Klouékanmey and Zagnanado	Guinean with bimodal rainfall regime	Ferruginous	800 to 1400 mm	Maize, cassava, cowpea and groundnut
Zone VII: Lalo and Pobè	Guinean with bimodal rainfall regime	Vertisol	1100 to 11400 mm	Maize, cassava, cowpea, vegetables (pepper, tomato)

Adapted from (Sinsin *et al.*, 2004; MEPN, 2008).

3.1.2. Focus group discussion, sampling and questionnaire administration

Prior to data, local authorities (head of villages) were approached by the investigator and the objective of the study was explained to them. They helped in the identification of pigeon pea growers who represented the entry point for focus group discussion and the sampling for in-depth study.

A focus group discussion, involving from 9 to 13 pigeon pea growers including female, male, youth and elder, was carried out in each village using an interview guide (Appendix1a). The participants in the focus group were pigeon pea growers available at the moment of the discussion. The focus group discussions provided an insight into the different varieties of pigeon pea grown in the village and their traits, farmers' varietal preferences, folk taxonomy, meaning of pigeon pea varieties in the various ethnic groups in the village and the crop's role in ceremonies, or in symbolism. For each cultivated variety in the village, the extent (perceptions of farmers on allocated area to its cultivation) and distribution (perception on the number of household growing the variety) were recorded. In addition, information collected during the focus group was used to design a semi-structured questionnaire (Appendix 1b). A pre-test with 20 pigeon pea growers was carried in the municipality of Glazoué (one of the surveyed area) in order to make adjustments on the questionnaire. These farmers were not included in the sample.

Pigeon pea growers were sampled using the snow ball method (Subedi *et al.*, 2003; Delaunay *et al.*, 2008; Baco *et al.*, 2013). This sampling technique consists in widening the sample starting from a respondent who helps to find other potential respondents (Biernacki and Waldorf, 1981). This technique was used to identify only farmers involved in pigeon pea cultivation. Using this technique, 302 pigeon pea growers were reached in 20 villages (Table 2). In each village, sample size was obtained based on saturation of information. Data saturation was considered reached when new respondents provided no additional information (Guest *et al.*, 2006; Mason, 2010).

Informed consent of interviewees was obtained before data collection related to farmers' knowledge, following the guidelines of the International Society of Ethnobiology (International Society of Ethnobiology, 2006).

Table 2: Samples distribution; ethnic groups in surveyed areas

Departments	Municipalities	Villages	Sample size	Prevailing ethnic group
Zou	Zagnanado	Kaodji, Massagba	33	Mahi
	Djidja	Bowé, Oukpa	30	Fon
Couffo	Lalo	Bayékpa, Wévéhoué	31	Tchi
	Aplahoué	Dékpo-centre, Lagbavé	32	Adja
	Klouékanmey	Dékandji, Avéganmè	34	Adja
Plateau	Pobè	Issaba, Ahoyéyé	30	Holli
	Kétou	Idigny, Mowodani	30	Nago
Collines	Savalou	Ouèssè, Lahotan	25	Mahi
	Ouèssè	Gbede, Kokoro	28	Nago
	Glazoué	Ouèdèdmè, Magoumi	29	Mahi, Idatchaa

3.1.3. Data analysis

Qualitative data were analysed through cross-checking of information. Three classes of age that were formed, namely respondents under 30 years old, between 30 and 60 years old and above 60 years old were considered as young, adult and old people, respectively (Gbedomon *et al.*, 2015). Data were recorded in Microsoft Excel™ spreadsheet. Descriptive statistics (frequencies, means and standard error of mean) were calculated. In each village, during focus group discussion, farmers were asked to make a hierarchical ranking of encountered production constraints. To determine whether pigeon pea uses listed by respondents (frequency citation) depended on socio-demographic variables, namely age categories, ethnic group, region of residence and gender, Fisher Exact test was used since frequency of some cells was less than 5 (Crawley, 2010). The same test was used to assess whether the different crops combination with pigeon pea were dependent on the growing areas (Departments).

Respondents ranked the preferred traits sought in new varieties during focus group discussions. The different preferred traits enumerated by farmers during the discussion group were recorded. Each trait enumerated in a village was assigned the value 1 and 0 if not. A contingency table was then obtained by considering villages as individuals and preferences criteria as variables. A clustering analysis using Unweigthed Pair Group Method with Arithmetic mean (UPGMA) based on Jaccard distance was performed to reveal similarity and dissimilarity among surveyed villages based on the preference criteria.

Correlation between the number of varieties held at household level and socio-demographic variables, namely age of the producer, number of years of experience in pigeon pea cultivation, the household size, number of family members engaged in agricultural activities and pigeon pea harvested area was assessed. Relationship between gender and number of varieties was explored using an ordinal logistic regression. The analyses were done in R statistical software version 3.2.5 (R Core Team, 2016).

Distribution and extent of cultivation of different varieties was assessed using the Four Cells Analysis (Khatiwada *et al.*, 2000). Thus, in each village, farmers classified existing landraces into four groups using: i) landraces cultivated by many households on large areas; ii) landraces cultivated by many households on small areas; iii) landraces cultivated by few households on large areas, and iv) landraces cultivated by few households on small areas.. The Four Cells Analysis has the merit to identify landraces with high demand for livelihood, high demand on the market for quality traits and the rare landraces that should be considered for conservation (Audi *et al.*, 2008; Dansi *et al.*, 2010; Kombo *et al.*, 2012; Gbaguidi *et al.*, 2013).

3.2. Agro-morphological characterization of pigeon pea germplasm

3.2.1. Entries and field layout

The germplasm assembled was composed of 39 accessions collected from farmers' fields in Benin and 10 cultivars with known characteristics obtained from the genetic resource unit of IITA, Ibadan (Appendix 2). The cultivars obtained from IITA were only used for Principal Component Analysis (PCA) and cluster analyses.

To assess differences among the accessions and to estimate genetic parameters, a field experiment was set up at IITA sub-station in Abomey-Calavi (Republic of Benin). A 7x7 triple lattice square design was used. The soil at the experimental site is ferralitic. The average temperature and rainfall during the experiment (July 2015 to February 2016) on the experimental site was 27ºC and 317 mm, respectively.

Each accession was sown in one row plot of 4 m length. The spacing was 50 cm within row and 1.5 m between rows. Planting was done on June 26, 2015. Two seeds were sown per hill, which were thinned to one plant 19 days after planting. No fertilizer was applied. Three manual weeding were carried out. Insecticide CYPERCAL 50EC (active matter Cypermethrin) was sprayed at the dose of 1L ha^{-1} during flowering stage to control flower thrips. Irrigation was applied when required. Harvesting was done in October for the early maturing accessions and in February for the late maturing accessions.

3.2.2. Data collection on qualitative and quantitative traits of pigeon pea accessions

Data were collected following the Descriptors for pigeon pea (IBPGR and ICRISAT, 1993) (Appendix 3). Eighteen qualitative traits were collected on plot basis. Life cycle, growth habit, stem colour, leaflet shape, leaf colour, leaf hairiness were recorded at vegetative stage. Floral traits (base flower colour, flowering pattern, flower streak pattern, flower streak colour) were collected at flowering stage. Pod characteristics (pod colour, pod shape, pod hairiness) were recorded at pod setting stage. Seed colour pattern, primary seed colour, secondary seed colour, seed shape and seed strophiole were collected after maturation. Royal horticultural colour chart was used for colour identification.

Two quantitative traits, namely days to 50 % flowering (number of days from planting to flowering of 50% of plants) and 75% (number of days from planting to maturation of 5 pods on 75% of plants) were recorded on plot basis. Leaflet length and leaflet width were recorded on five fully expanded leaflets from three plants per plot at vegetative stage. Plant height, number of primary and secondary branches and number of racemes were recorded at maturation on three plants per plot. Pod length and seeds per pod were recorded after maturation on five randomly selected pods on three plants per plot. Number of seed per plant, seed yield per plant and pod yield per plant were recorded on three plants per plot after maturation. 100 seed weight were randomly selected after shelling and weighed. Shelling percentage was obtained as the ratio of seed yield and pod yield on three plants per plot.

Leaflet length and leaflet width were used to calculate the leaf area following the model: Leaf area (cm^2) = Leaf length x Leaf width x 0.7489 (Sharma *et al.*, 1987).

3.2.3. Data analysis

3.2.3.1. Variability and relatedness in the germplasm

Proportions of the categories within each qualitative trait were calculated (number of accessions for a category/48[1] (total number of accessions).

Diversity of each qualitative trait in the collection was assessed using Shannon-Weaver diversity Index following the formula.

$$H = -\sum_{k=i}^{k} \text{Pi} \ln(\text{Pi})$$

[1] One accession from IITA did not germinate

where *k* is the number of categories and *pi* is the proportion of the observations found in the category *i;* phrase differently, *pi* = frequency proportion of each qualitative trait category, and n= number of qualitative trait categories (Shannon and Weaver, 1948).

Means, variances, ranges and coefficient of variation were computed for all the quantitative traits of the germplasm collection. One of the accessions did not germinate and it was considered as missing value. Restricted Maximum Likelihood (REML) with accessions as fixed factor, blocks and replications as random factors was performed on the quantitative traits using the lmerTest package in R (Kuznetsova *et al.*, 2015).

A Principal Component Analysis (PCA) based on correlation matrix was performed to determine the main quantitative traits accounting for the most variation in the collection. Only the principal components having Eigen value higher than one were selected for analysis and interpretation (Kaiser, 1963). Traits revealed by the PCA as contributing the most to the variation in the germplasm were used for cluster analysis.

In order to assess the relatedness and variability in the collection, four clustering methods were used and their efficiency was assessed. A cluster analysis using Ward algorithm (Ward, 1963) based on Euclidean distance and Mahalanobis D^2 distance were carried out. Tocher's method of clustering based on Mahalanobis D^2 distance (Rao, 1952) and Euclidean distance were performed. The cophenetic correlation coefficients for Ward method were calculated. The cophenetic correlation coefficients for Tocher’s method were computed using biotools package (da Silva, 2016). Mantel permutation Test was used to assess the significance of the cophenetic correlation coefficients. The different cophenetic correlation coefficients were compared to assess the efficiency of each method. The higher the cophenetic correlation coefficient, the more appropriate was the clustering method for the analysis (Romesburg, 1984). Prior to cluster analysis, data were normalized using the package som (Yan, 2010). The cophenetic coefficients of correlation were significant ($P<0.001$) for all the clustering methods. Tocher clustering method (non-hierarchical clustering) based on the Euclidean distance showed the highest cophenetic coefficient of correlation (0.96) (Table 3). The clusters generated through this method were then much more consistent with the structure of the original data.

Table 3: Cophenetic coefficient of correlation of combination of two dissimilarity distances and two clustering method

	Ward	Tocher
Euclidean	0.87	0.96
D square generalized Mahalanobis	0.50	0.77

Associations among the traits were determined by calculating Pearson's coefficient of correlation of all combinations of the quantitative characters recorded (Snedecor and Cochran, 1980). Besides the statistical significance, characters association was considered to be biologically relevant when the absolute value of the correlation coefficient was higher than 0.71 (Skinner *et al.*, 1999). Analyses were performed using R statistical software version 3.2.5 (R Core Team, 2016).

3.2.3.2. Estimation of genetic parameters

Genotypic variance ($\sigma^2 g$), phenotypic variance ($\sigma^2 p$), genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV), genetic advance in percent of mean was estimated following method described by Singh and Choudhary (1985).

Broad sense heritability (H), genetic advance (GA) considering a selection intensity of 10% was calculated as described by Johnson e*t al.* (1955).

$$H\ (\%) = \frac{\sigma^2 g}{\sigma^2 g + \frac{\sigma^2 e}{r}}$$

Where $\sigma^2 g$ is genotypic variance; $\sigma^2 e$ is environmental variance. They were computed from the estimated means square obtained from the Restricted Maximum Likelihood model.

$$GA = \frac{\sigma^2 g}{\sigma ph} * K$$

Where, K = 2.06 (selection differential at 10%); $\sigma^2_{\ g}$ = genotypic variance; σ_{ph} = square root of phenotypic variance. Genetic gain (GA) was determined from genetic advance (GA) expressed as a percentage of the population mean.

CHAPTER FOUR

4. RESULTS

4.1. Uses of pigeon pea and cropping systems

4.1.1. Importance of pigeon pea in Benin

Pigeon pea growers had been cultivating the crop averagely for about 17 years with a large variability (1-50 years). The average farm size per household was about 2.92±0.15 ha of which about 1.24±0.06 ha on average was allocated to pigeon pea production associated with other crops.

More than 45% (46 - 50%) and more than 25% (28 - 50.5%) of pigeon pea growers cited home consumption and commercialization, respectively as the main reason driving pigeon pea production (Figure 2). In Couffo Department, economic reason was also one of the driving forces behind the cultivation of pigeon pea. Soil conservation was the third reason motivating the production of pigeon pea in Collines, Zou and Plateau Departments (Figure 2).

Dry pigeon pea seeds were consumed in various forms. They were boiled and mixed with ‘’*gari*’’ (cassava derived product) or with maize flour and groundnut oil or palm oil. This form of consumption was the most encountered across the surveyed areas. In Plateau Department, pigeon pea whole dry seeds were boiled with maize grains and the mixture was eaten with vegetable oil, notably oil palm. Other forms of consumptions such as boiled pigeon pea and rice accompanied with sauce were reported.

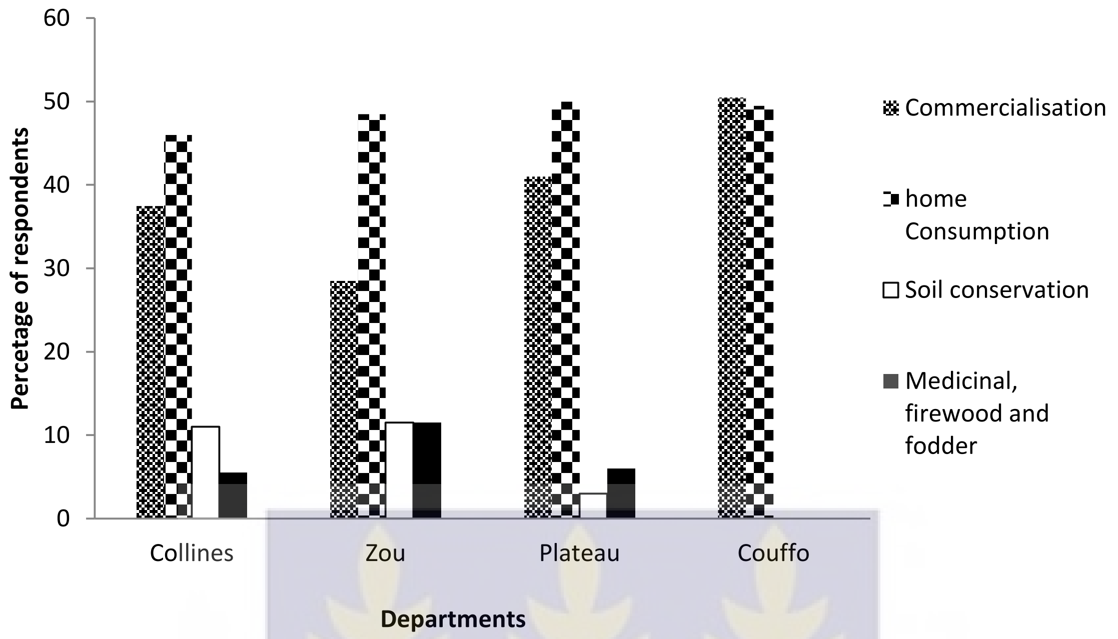


Figure 2: Reasons of cultivation of pigeon pea in Benin

The uses of pigeon pea plant parts (leaves and stems) depended on the ethnic group or locality of residence (P<0.001) of farmers (Table 4). The leaves are used for feeding animal especially in Couffo Department mainly by the ethnic group Tchi. The use of pigeon pea leaves in folk medicine to cure various diseases was reported all over the study areas but it was predominant in Zou and Plateau Departments. Farmers used pigeon pea for medicinal purposes, or as fodder or firewood regardless of their age and gender. It can be assumed that knowledge related to pigeon pea for medicinal purposes is widely shared within a given community.

Malaria was the most treated disease with pigeon pea and it was reported in all the surveyed villages, with some specifics with regard to the administered forms (Table 5). With regard to specificities in the uses of pigeon pea in folk medicine, the ethnic group Holli in Pobè and Ketou (South East) used filtrate obtained after triturating the leaves to treat fever, dizziness and eye infection while the use of leaves decoction was reported in the treatment of measles by ethnic groups Idaatcha, Mahi, Fon and Nago in Zou and Collines Departments in Central Benin (Table 5).

Table 4: Use frequency of pigeon pea across socio-demographic factors

Socio-demographic variables		Medicinal	Firewood	Fodder	Probability of Fisher Exact test
Age category	Youth	9	14	0	
	Adult	91	183	6	0.3223
	Old	8	29	3	
Gender	Male	60	133	5	0.8392
	Female	48	93	4	
Ethnic groups	Adja	24	81	5	
	Fon	36	41	0	
	Holli	10	17	0	
	Tchi	1	16	3	< 0.001
	Idaatcha	11	17	0	
	Nagot	12	30	0	
	Mahi	17	22	0	
Locality of origin	Couffo	24	96	8	
	Plateau	48	59	0	< 0.001
	Zou	22	19	0	
	Collines	17	50	0	

Table 5: Medicinal uses of pigeon pea

Diseases	Forms of use	Form administered	Villages
Malaria	- Triturate the leaves, filter and add lemon juice - Triturate leaves, and add either lemon or citronella leaves or both and then filter the mixture - decoction of pigeon pea leaves and acacia leaves	Drinking of filtrate	All the villages
Ulcer	- Leaves decoction	Drinking of decoction	Zagnanado (Kaodji, Massagbo)
Measles (children)	- Add water to triturated leaves - Leaves decoction	Use as bath water to treat children and/or drinking of decoction	Ouesse (Kokoro), Djidja (Oukpa), Zagnanado (Kaodji, Massagbo)
Fever	- Triturate fresh leaves, add to water and filtrate - Triturate fresh leaves, filtrate and add to vine or fermented water	Use as bath water and/or drinking of filtrate	Pobè (Issaba, Ahoyéyé)
Snake bite	Triturate fresh leaves	Apply the triturated leaves to the snake bite	Djidja (Oukpa, Bowe)
Eye infections	Triturate fresh leaves and filter	Drop the filtrate in eyes	Pobè (Issaba, Ahoyéyé)
Dizziness	Triturate fresh leaves and filter	Drinking of filtrate	Pobè (Issaba), Kétou (Mowodani)

It is worth noting that the different medicinal uses were not associated with a specific pigeon pea variety. Pigeon pea was used in ritual ceremony. In Wévéhoué village (Couffo Department), dry pigeon pea seeds are boiled and eaten during twin's naming ceremony.

Pigeon pea production in Benin has cultural significance. The most ancient went back to mid-nineteenth century, and it is related to the name Klouékanmey, a municipality, located in Couffo Department (South-West Benin). In fact, Klouékanmey in local language "*Adja*" means *"Pigeon pea field"*. The name was given based on the introduction and cultivation of the crop in this area, which has remained one of the major pigeon pea growing regions in Benin. Since 2013, a yearly festival is organized in Pobè to celebrate pigeon pea. Thus, during each Easter, Pobè people organize a festival to make a showcase of the different pigeon pea based meals and to promote the cultivation of the crop due to its economic importance for local population. This event named *"Odun Otini"* in *Nago* that literally means "Celebration of pigeon pea" offers a unique opportunity for the members of this community to meet. This underscores the role of pigeon pea in socio-cultural life of this community and its contribution to build social link (Balogou Ibouraïma, 2016 Personal communication).

4.1.2. Pigeon pea-based cropping systems and farmers' perception on productivity

Regardless of the pigeon pea based cropping system, pigeon pea cultivation involved plowing, sowing, field maintenance (weeding), first harvesting and second harvesting when the crop is maintained in the cropping system.

Farmers incorporated pigeon pea in various cropping systems. 98% of the pigeon pea producers practiced intercropping while only about 2% of them grew pigeon pea in sole crop notably in Collines and Plateau Departments. Cultivation of pigeon pea in pure stand was reported by farmers to control the weed species *Imperata cylindrica* and to improve soil fertility. Crops species associated with pigeon pea depended on the growing area ($P < 0.001$) (Table 6). In Plateau, Collines and Zou Departments, pigeon pea was predominantly associated with maize either on the same row or on different row. When the association was done on the same ridge, a spacing of about one meter between maize plant and pigeon pea plant was adopted. In Couffo Department, farmers tended to associate pigeon pea with maize-cowpea-cassava, cassava-groundnut-tubers and maize-cowpea-cassava-vegetables. The cultivation of pigeon pea in the backyard or as garden crop was mentioned by farmers who used the crop primarily for medicinal purposes. In crops rotation system, pigeon pea cultivation preceded maize.

In Plateau Department, 17% of the respondents mentioned harmattan, weather with dry, hot wind and high day temperature but low night temperature, as a major factor affecting pigeon pea productivity. Similar perception was recorded in Couffo Department. In Southern Benin including Plateau and Couffo Departments, harmattan generally occurs between December and February but this duration varies greatly from one year to another. Thus, the absence of harmattan was reported to negatively affect pigeon pea productivity while the productivity is improved in years when harmattan occurs.

Table 6: Proportion of farmers combining various crops combination with pigeon pea

Cropping systems	Zou (n=63)	Couffo (n=97)	Plateau (n=60)	Collines (n=82)
Pure stand	0	0	3.3 (2)	3.7 (3)
Maize	69.8 (44)	0	50 (30)	89 (73)
Legume	1.6 (1)	0	0	0
Maize, cassava/yam	4.8 (3)	0	21.7 (13)	4.9 (4)
Maize, legumes	(22.2) 14	10.3 (10)	8.3 (5)	2.4 (2)
Maize, vegetables	0	0	13.3 (8)	0
Maize, Marrow	0	0	3.3 (2)	0
Maize, legumes, cassava	1.6 (1)	43.3 (42)	0	0
Maize, legumes, vegetables	0	6.2 (6)	0	0
Maize, cassava, vegetables	0	2.1 (2)	0	0
Maize, banana, cassava	0	3.1 (3)	0	0
Maize, banana, vegetables	0	3.1 (3)	0	0
Maize, legumes, cassava, vegetables	0	23.7 (23)	0	0
Maize, legumes, banana	0	3.1 (3)	0	0
Maize, legumes, vegetables	0	3.1 (3)	0	0

n = number of respondents

Pigeon pea production and commercialization involved all household's members including men, women and children. However, the involvement of each member depended on the task to be performed (Table 7). The level of involvement is considered either as the physical participation in the implementation of the activities and/or in the mobilization of resources needed for the implementation of the activities. Thus, men were highly involved in decision affecting the production such as choice of variety to be cultivated, land allocation, land preparation and weeding. Female were mainly involved in decisions related to the harvest and commercialization.

Table 7: Gender and pigeon pea production

Level of decision	Male	Female
Choice of variety	+++	++
Land allocation	+++	+
Land preparation (clearing, plowing)	+++	+
Weeding	+++	+
Harvesting and threshing	++	+++
Commercialization	++	+++

More there is +, higher is the level of involvement

4.1.3. Constraints of production and strategies developed by farmers in pigeon pea growing areas

Pigeon pea production is constrained by several factors varying from one production area to another (Table 8). In Collines Department, difficulty to harvest pigeon pea pulses and high rainfall at flowering or pod setting stage were the major constraints limiting the production while in Zou Department, difficulties in pulses harvesting and threshing were the main challenge faced by farmers. High rainfall at flowering stage leading to flower drop, lack of financial resources were ranked as the most important factors constraining pigeon pea production in Plateau Department. Non-availability of quality seeds and low productivity were the two most important constraints reported in Couffo.

Various strategies are being developed by farmers to cope with these challenges. Farmers undertook actions such as hired labour, mutual aid to cope with lack of financial support and difficulty in pulse harvest. The use of seeds from previous harvest is the strategy developed by farmers to cope with difficulties related to access to quality seeds while insecticides were sprayed in order to control pest attacks. However, farmers were left with no option when confronting to low productivity, lack of financial resource in Collines and Plateau Departments for instance.

Table 8 : Constraints encountered by pigeon pea farmers and coping strategies

Departments/ Municipalities	Constraints (ranked from the most important to the less important)	Coping Strategies developed
Collines (Savalou, Glazoué and Ouèssè)	1. Difficulty to harvest	Hired labour and mutual aid
	2. Production negatively affected by high rainfall	Left with no option
		Left with no option
Zou (Zagnanado and Djidja)	1. Difficulty to harvest	Hired Labour
	2. Difficulty in shelling	Hired Labour
	3. Lack of financial resource to implement agricultural operations	''*Atcholou*''mutual aid to carry out cultivation operations
Plateau (Pobè an Ketou)	1. Insects attack	Left with no option
	2. Low productivity	Left with no option
	3. Lack of financial resource to carry out at appropriate time production activities	Left with no option
	4. Inexistence of seed of quality	Reuse of Saved seed
	5. Difficulty to market the grains	Left with no option
Couffo	1. Lack of quality seed (low rate of germination)	Reuse of saved seed
	2. Low productivity	Purchase cultivars of CARDER variety (a variety introduced by extension service)
	3. Insect attack on flowers and seeds	Use of insecticides

4.1.4. Post-harvest management and seed systems

4.1.4.1. Post-harvest handling and Seed conservation

Harvesting of pigeon pea is usually done from January to February. The harvest consists of picking the mature pods. The harvested pods were then threshed on tarpaulin using sticks. The grains were dried and stored. Farmers use various structures including calabash gourds, cans and sacks to store and conserve pigeon pea grains. The storage period ranges from 1 to 12 months with an average of about 6 months after harvesting. Overall, 90% of the farmers used no grain conservation product. However, in Plateau Department, 28% of the producers used kerosene and/or insecticides while 12% of the respondents in Couffo Department used chemical insecticides mainly temephos [0,0'-(thiodi-4,1-phenylene) bis (0,0-dimethyl phosphorothioate] (Figure 3). Two percent (2%) of the respondents used indigenous methods such as pepper or ash that they mixed with seeds and then packed the mixture in cans or calabash gourds (Figure 3). This method was mainly observed in Plateau Department. No pigeon pea grains conservation product was reported in Zou and Collines Departments. Farmers stored their saved seeds for next planting season mainly in cans and calabash gourds where seeds were less exposed to moisture and insects.

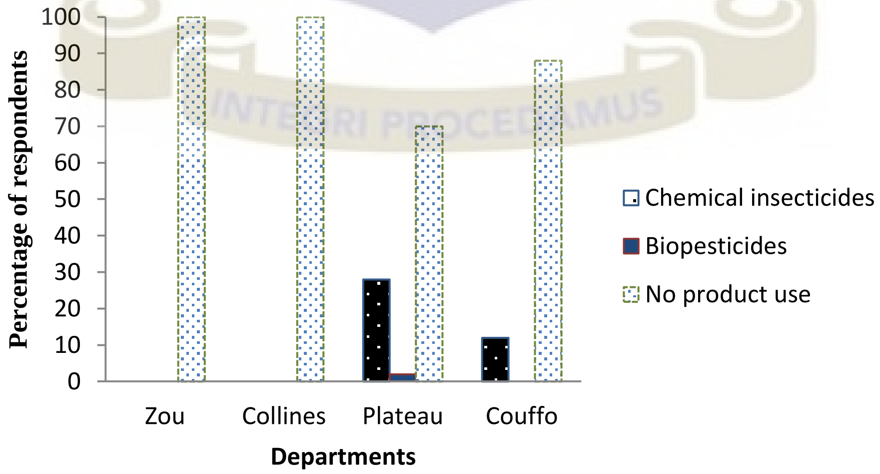


Figure 3: Proportion of pigeon pea growers using various conservation products

4.1.5.2. Seed systems

Fifty five (55%) and 45% of pigeon pea producers purchased and got seeds as gift/ heritage, respectively to establish their first pigeon pea field. Once farmers started growing pigeon pea, 79% of them saved seed to plant the next season while 12% and 9% purchased seed from fellow farmers and received seeds as gift from friends, family members and extension services, respectively. Farmers' saved seeds were taken from the previous harvest (bulk seed after threshing). In the farmers saved seed system, after sowing, the remaining saved seed was sold to fellow farmers or used as grains for consumption (Figure 4). Pigeon pea growers purchased seeds when they lost their production or their saved seed was not enough to plant the field or when they found a new variety with desired traits.

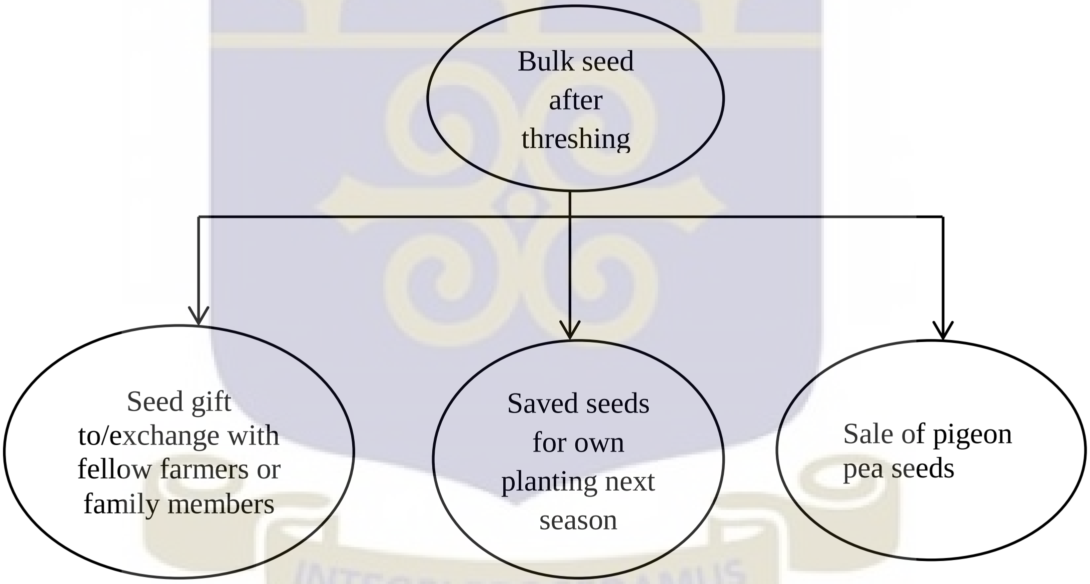


Figure 4: Pigeon pea seed system

4.1.5. Farmers' preferences and traits sought in new varieties

Four groups of villages can be distinguished based on farmers' preference (Figure 5). Villages in the same growing area (Department) tended to be grouped together. Group 1 included all the surveyed villages in the departments of Zou and Collines. In these villages, pigeon pea growers mentioned early maturity and high yielding as the major characteristics sought in new varieties. Group 2 was composed of surveyed villages Ahoyéyé and Issaba, in the municipality of Pobè (Plateau Department). In these villages, apart from high yielding and early maturity, farmer cited resistance to pod borers, tolerance to flood and grains attributes such as sweet taste of grains and short cooking time as desired traits in varieties that should be introduced. Villages in the Group 3 are located in Couffo Department and farmers in this area mentioned the same preference traits as in the municipality of Pobè except tolerance to flood. In addition, large seed size was part of the desired traits in Couffo. Mowodani and Idigny villages formed the fourth group, and they are located in the municipality of Ketou. Farmers' preferences were related to high yielding, early maturity, resistance to pod borers, sweet taste of grains and short cooking grains. High yielding and early maturity were commonly mentioned by farmers across the growing areas while traits like tolerance to flood or large seed size were specific to farmers in the municipality of Pobè and Couffo Department, respectively.

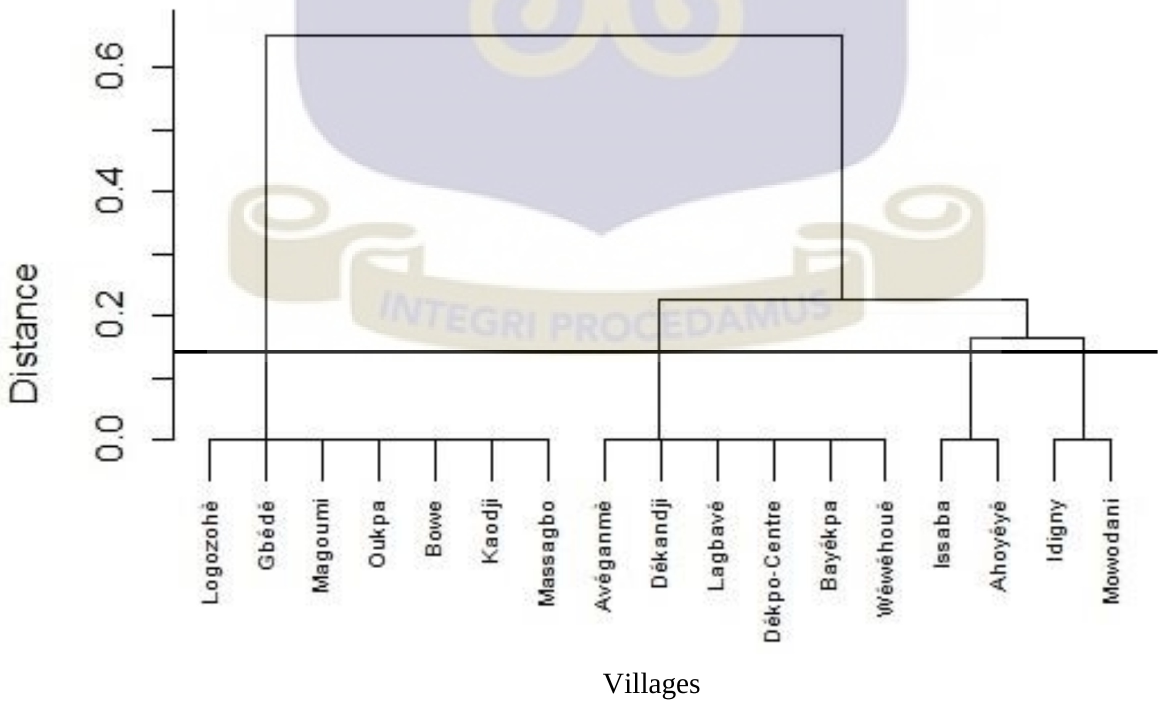


Figure 5: Clustering analysis of surveyed villages based on farmers' preferences

4.2. Folk taxonomy, varietal diversity and farmers' perception on distribution and extent of pigeon pea diversity

4.2.1. Folk taxonomy and varietal diversity

All the ethnic groups had a vernacular name for pigeon pea with similarity between the ethnic groups Mahi and Fon; Tchigbé and Adja, and Holli and Nago. The meaning of vernacular name of pigeon pea depended on the ethnic group.

Varietal naming of pigeon pea based on farmers' knowledge varied across surveyed area but the name of the varieties were either based on the seed colour, or the origin of the variety ('*Adja klui*': pigeon pea originated from Adja region), the perception of farmers on the variety ('*Klui Gbali*': common pigeon pea). Taking into account the grain colour, '*Otini founfoun*', '*Kolo foufoun*', '*Klouékoun wéwé*' respectively in Nago/Holli, Idatchaa and Mahi/Fon mean literally ''White pigeon pea''. Under reserve of one to multiple or multiple to one correspondence, in total, 17 varieties were identified of which 5; 4; 4 and 4 varieties were recorded in Couffo, Plateau, Zou and Collines, respectively (Table 9).

At household level, the number of pigeon pea varieties held by farmers ranges from one to three. Twenty eight percent (28%), 25% and 13% of the respondents in Plateau, Zou and Collines, respectively cultivated two varieties conversely to Couffo where each household grew one variety. The highest number of varieties (3) per household was reported in Zou and maintained by one farmer. There was no significant association ($P > 0.05$, n=302) between the number of varieties held by household and the age of the producer, number of years of experience in pigeon pea cultivation, the size of household, number of family members engaged in agricultural activities, pigeon pea harvested area and gender. In fact, relatively very few varieties were grown per household (1.16 ± 0.37), and no special requirement as for farming operations or land access discriminate pigeon pea growers in terms of number of varieties.

Varietal classification of pigeon pea by farmers were based on eight criteria including morphological (seed colours, seed size, plant height), physiological (maturity groups), agronomic (productivity, sensitivity to insects), organoleptic and culinary (taste, required time for grains to cook).

4.2.2. Distribution and extent of varietal diversity

Varieties with white primary seed colour were the most grown not only in terms of allocated area but also in terms of number of households that cultivated them. The varieties with red, spotted, black primary seed colour (Figure 6a, e, f, g and h) are not preferred by consumers and their production tended to decline. As a result, the following varieties '*Klouekoun vovo'*, '*Klouekoun wlanwlan'*, '*Klouékoun'*, '*Klui gbali'*, '*Adja Kloui'*, '*Otini kpoukpa'*, '*Otini fifin'*, '*Otini doudou'*, '*Kolo kpikpa'*, '*Kolo olèyiawo'* (Table 9) are likely to be totally abandoned by farmers because they have low market value. Varieties like '*Kloui gbali'* grown in Dékandji, Wéwéhoué and klouékoun cultivated in Bayékpa were still being cultivated by many households in these villages because they were the only variety available for producers. Furthermore, farmers reported the disappearance of some varieties like '*Adja kloui'* in Lagbavé, Dékandji and Avéganmè villages and '*Gbahoun kléli'* in Dekanji. The abandonment of their production was due to their undesirable traits such as long cooking time, small grains, late maturing, very tall, low yield, bitterness (especially for '*Gbahoun kléli'*). This observation applied to '*Kolo eko'* in Glazoué where it was no longer cultivated.

a: *'Klouékoun Wlanwlan' ; 'Adja kloui', 'Kolo olèyiawo'*

b: *'Tadogou'*

c: *'Klouékoun Wéwé', 'kolo founfoun'*

d: *'Kloui gbali'*

e: *'Klouékoun Vovo'; 'kolo kpikpa', 'otini Kpoukpa'*

f: *'Otini doundoun' / 'kolo doundoun'*

g: *'Otini fifin'*

h: *'Otini fifin'*

Figure 6: Common varieties of pigeon pea cultivated in Benin

Table 9: Local names and characteristics of varieties

Varieties with in bracket the ethnic groups	Meaning of Names	Agro-morphologic traits	Other traits	Distribution and Extent
'Klouékoun wéwé' (Mahi, Fon)	White pigeon pea	White seed, late maturing, Tall plant	long conservation period, Long cooking time	++(Kaodji, Massagbo, Bowe, Oukpa)
'Klouékoun wéwé' (Mahi, Fon)	White pigeon pea	White seed, early maturing (2 harvest per year: 3 months after sowing and 9 to 10 for second harvest), High productivity	Short cooking time	- -(Bowe), not known by many pigeon pea growers yet
'Klouékoun vovo' (Mahi, Fon)	Red pigeon pea	Red seeds, late maturing	Less preferred by consumers because of the seed colour	-- (Logozohè, Massagbo)
'Klouékoun wlanwlan' (Mahi, Fon) *'Kolo olèyiawo'* (Idaatccha)	Spotted pigeon pea	White seeds spotted with purple, late maturing (9-10 months)	Long conservation period, long cooking time, less preferred because of seed colour, become black after cooking	-+(Kaodji, Massagbo, Bowe)
'Kpèdovinonwovo' (Mahi)		Early maturing (7 months), white seeds colour with reddish spots, plant is very short		-- (Lagbavé)
'Klouékoun '(Tchigbé)		Small seeds, late maturing (9-10 months), Tall plant	Medium productivity, Long cooking time	++ (Bayékpa) Only one available cultivar in the village
'Kloui gbali' (Adja, Tchigbé)	Ordinary pigeon pea	Tall plant, small seeds, low productivity, late maturing (9-10 months)	Long cooking time	++(Dékandji, Wéwéhoué) Only one available cultivar in the village
'Adja Kloui' (Adja) Dekpo centre	Pigeon pea from adja area	Tall plant, small seeds, late maturing (9-10 months)	Long cooking time	-- (Dekpo-Centre)
'Carder klui' or '*Tagoudou'* (Adja)		Large seeds, medium height, late maturing (9 months)	Taste good, high productivity, Short time for cooking,	++ (Lagbavè, Aveganmè) Dekpo-centre
'Otini founfoun' (Holli, Nago)	White pigeon pea	White seeds colour, late maturing (9 months), early maturing (6 months), tall plant,	Short time for cooking, taste good (sweet), high productivity, most	++(Issaba, Ahoyéyé, Idigny); +-(Mowodani)

Varieties with in bracket the ethnic groups	Meaning of Names	Agro-morphologic traits	Other traits	Distribution and Extent
			preferred on the market, Susceptible to pests	
'Otini kpoukpa' (Holli, Nago)	Red pigeon pea	Red seeds colour, late maturing (8 months), tall plant, long cooking time	Less preferred by consumers because of the seed colour (Gbede), taste sweet (Idigny), seeds are highly sensitive to pests	--(Issaba: recently introduced with a lot of undesirable traits) ++(Idigni, Mowodani: early maturing)
'Otini doudou' (Holli, Nago)	Black pigeon pea	Black seeds colour, High productivity, long maturing	Long cooking time, highly sensitive to insects, taste sweet	--(idigny: undesirables traits)
'Otini fifin' (Nago)		White seeds spotted with black, tall plant, Very High productivity, late maturing (9 months)	Short cooking time,	--(Mowodani: less preferred on the market)
'Kolo Founfoun' (Idaatcha)	White pigeon pea	White seeds, late maturing, Tall plant	Taste sweet	++(Magoumi)
'Kolo kpikpa' (Idaatcha)	Red pigeon pea	Red seeds colour, late maturing, Tall plant,		--(Gbede)
'Kolo èko' (Idaatcha)		Red seeds colour; late maturing	Not preferred by consumers	No more cultivated in the Magoumi village (Municipality of Glazoué)

++ varieties cultivated by many households on large plots; - - variety cultivated by few household on small plots.
- + variety cultivated by few households on large plots.
Early or late maturity in the distribution and extent of varieties were used in conformity with farmers' perception.

4.3. Variability and relatedness in the collection

4.3.1. Variability in qualitative characters

4.3.1.1. Growth, leaf, stem and floral characteristics

Growth habit was classified in three classes, namely erect, semi-spreading and spreading. In the collection, 79% of the accessions had a semi-spreading growth habit while 21% were erect and compact (Table 10). None of the accession showed spreading growth habit. Compact and erect and semi-spreading accessions are particularly adapted to intercropping systems.

Two classes, narrow-elliptic and broad elliptic, were recorded for leaflet shape. 87% of the accessions had broad elliptic leaflet while 13% of the accessions showed narrow-elliptic leaflet shape.

Stem colour was classified into four classes, namely green, sun red, purple and dark purple.

Leaf hairiness showed no variation across the various accessions. All the accessions had dark green leaves and the leaves were pubescent.

The base flower colour which is the main colour of the petal was classified in five classes (light yellow, yellow and orange-yellow and mixture of yellow and orange yellow). Yellow base flower colour was dominant (64%) followed by orange yellow (26%) (Table 10).

Of the four classes of the pattern of streak (sparse streaks, medium amount of streaks; dense streaks; uniform coverage of second colour), dense streaks was dominant (62%) followed by uniform coverage (15%) and medium amount of streaks (13%), in that order (Table 10).

The second flower colour which is the colour of streaks on dorsal side of the vexillum and second colour of the wings and keel was categorized into three classes (no flower streak colour, red and purple) with some combinations of these classes. Red was dominant (51% of accessions in the collection).

Figure 7: Second flower colour and streak pattern
(A): Purple; (B andC): Red, (D): No flower streak colour; (A): Uniform coverage; (B): Dense streak, (C): Medium amount of streaks, (D) Sparse streak

Flowering pattern was recorded in two classes, namely determinate, semi-determinate and intermediate (Figure 8). Most of the accessions showed indeterminate pattern (51%). None determinate flowering pattern was recorded in pigeon pea germplasm collected in Benin.

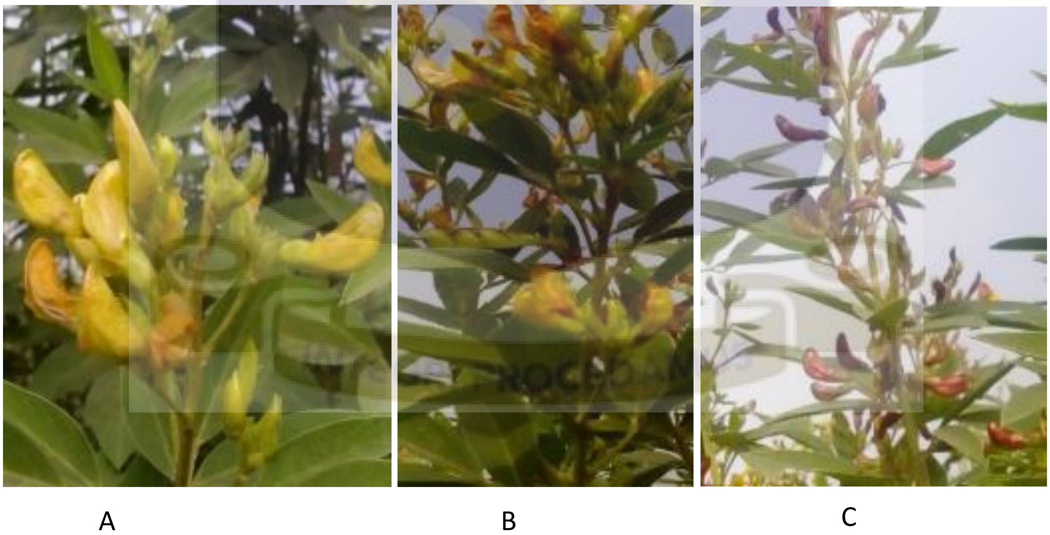


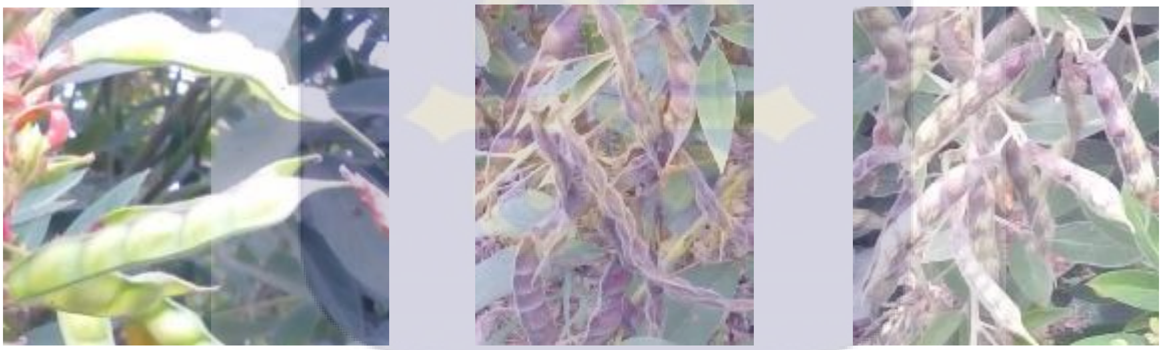
Figure 8: Flowering pattern
(A): Determinate; (B): Semi-determinate; (C): Indeterminate

Vigor at 50% flowering was recorded into two classes, namely intermediate and high. 97% of the accessions notably the medium and late maturing showed high vigor while the early maturing accession 38 showed low vigor (Table 10).

4.3.1.2. Maturity, pod and seed characteristics

The accessions were classified based on pigeon pea maturity group defined at ICRISAT as extra early (<80 days to 50% flowering), early (81–100 days to 50% flowering), medium (101– 130 days to 50% flowering), late maturity (>130 days to 50% flowering) groups. Three per cent (3%) of the characterized accessions in this study belonged to extra-early maturing group, 3% was medium maturing and 94% was late maturing. The extra early maturity accession was collected from the farm manager at IITA station in Benin. It was previously obtained from IITA Ibadan.

Out of the four pod colour classes (green; purple; mixed green and purple; dark purple) recorded for the main colour of pod, mixed green and purple was dominant (69%), followed by green pod colour (15%) (Figure 9).



A B C

Figure 9: Pod colour

(A): Green, (B): Dark Purple, (C): Mixed purple and green

Pod shape

Flat and cylindrical were the pod shape categories observed in the collection. Most of the accessions (92%) in the collection had cylindrical pod shape.

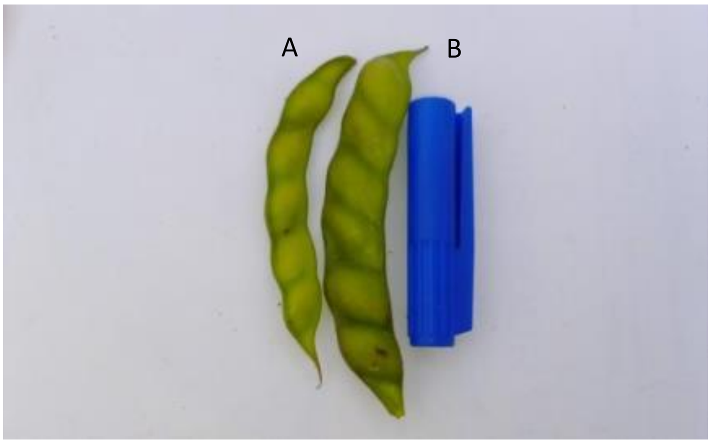


Figure 10: Pod forms

(A): Cylindrical, (B): Flat

Pod hairiness was monomorphic with all the accessions having hairy pods.

Four classes (Plain, Mottled, Speckled, Mottled and Speckled) of seed colour pattern were observed. The most abundant seed colour pattern was plain (69%) and mottled (13%).

In the collection, 5 primary seed colour (white, cream, orange, light grey and dark purple) were observed. Accessions with cream (41%) and white (33) primary seed colour were prevailing in the collection.

Four classes of secondary seed colour (none, orange, purple, dark purple) were recorded. Absence of secondary seed colour (56%) was dominant followed by orange seed colour (23%).

Out of the four categories of seed eye colour (orange, light grey, purple, dark purple), 56% of the accessions had orange seed eye colour.

Narrow, medium and wide were the category of seed eye width recorded. 59% and 38% of the accessions having narrow and medium seed eye width.

Table 10: Distribution of qualitative descriptor status

Traits and category	Proportion (%)	Traits and category	Proportion (%)
Growth habit		**Pod shape**	
1-Erect and compact	21	1-Flat	8
2-Semi-spreading	79	2-Cylindrical	92
Stem colour		**Pod hairiness**	
1-Green	15	2-Pubscent	100
3-Purple	64	**Seed colour pattern**	0
4-Dark purple	21	1-Plain	69
Leaflet shape		2-Mottled	13
2-Narow elliptic	13	3-Speckled	8
3-Broad elliptic	87	4-Mottled and speckled	10
Base flower colour		**Seed eye width**	
2-Ligh Yellow	5	3-Narrow	59
3-Yellow	64	5-Medium	38
4-Orange yellow	26	7-Wide	3
3+4-Mixture of yellow and orange yellow	5	**Seed shape**	
Pattern of streak		2-Globular	92
3-Sparse	3	3-Square	3
5-Medium	13	4-Elongated	5
7-Dense streaks	62	**Primary seed colour**	
9-Uniform coverage of second colour	15	1-White	33
3+5	3	2-Cream	41
5+9	3	3-Orange	5
7+9	3	6-Light grey	18
Flower streak colour		9-Dark purple	3
0-Plain	15	**Secondary seed colour**	
1-Red	51	0-Plain	56
2-Purple	8	3-Orange	23
1+0-Red+plain	21	8-Purple	13
1+2-Red+purple	5	9-Dark purple	8
Flowering pattern		**seed eye colour**	
2-Semi-determinate	46	3-Orange	56
3-Indeterminate	51	6-Light grey	13
3+2 (Mixture of semi and indeterminate)	3	8-purple	15
Vigor at flowering		9-Dark purple	15
5-Intermediate	3	**presence of strophiliole**	
7-High	97	1-Presence	95
Pod colour		0-Absence	5
1-Green	15		
2-Purple	3		
3-Mixed green and purple	69		
1+3 Green+mixed green and purple	10		
2+3Purple+Mixed green and purple	3		

Even though the four classes of seed shape, namely oval, globular; square; and elongate were observed in the collection, 90% of the accessions had globular seed shape while 5% of them showed elongate seed shape.

Seed strophiole was present in 95% and absent in 5% of the accessions (Table 10).

4.3.1.3. Shannon-Weaver Diversity Index (H')

The Shannon-Weaver diversity Index (H') ranged from 0 (pod hairiness) to 1.88 (flower streak colour). The mean diversity was moderate (H'=1.059±0.536). Flower streak colour (H'=1.88), primary seed colour (H'=1.86), pattern of streak (H'=1.77) were the most polymorphic traits in the collection while pod hairiness (H'=0), presence of strophiliole (H'=0.29) and pod shape (H'=0.39) show less polymorphic variation (Table 11).

Table 11: Shannon-Weaver Diversity Index (H') of traits in pigeon pea germplasm from Benin

Traits	**Shannon-Weaver Diversity Index**
Growth habit	0.73
Stem colour	1.3
Leaflet shape	0.55
Base flower colour	1.35
Pattern of streak	1.77
Flower streak colour	1.88
Flowering pattern	1.14
Vigor at flowering	0.17
Pod colour	1.39
Pod shape	0.39
Pod hairiness	0
Seed colour pattern	1.37
Seed eye width	1.12
Seed shape	0.46
Primary seed colour	1.86
Secondary seed colour	1.62
Seed eye colour	1.68
Presence of strophiliole	0.29
Mean H'	1.06 ± 0.54

4.3.2. Phenotypic variability in quantitative characters

Restricted Maximum Likelihood (REML) analysis revealed that the difference in genotypic variance was significant among the accessions for all the quantitative traits. Pod yield, seed yield, number of pod per plant showed high variability in the germplasm. On the other hand, pod length and number of seed per pod showed the lowest variability (Table 12).

Table 12: Range, mean and variation in quantitative characters of pigeon from Benin

Traits	Range	Mean	Standard error	F test	CV%
Plant height	110-281	256.4	4.2	***	10.1
Primary branches	12-27	15.0	0.4	***	16.9
Secondary branches	6-44	27.4	1.04	***	23.4
Number of raceme	28-154	100	3.6	***	22.5
Pod bearing length	53-194	161.6	3.5	***	13.6
Days to 50% flowering	59-195	173	3	***	11.9
Days to 75% maturity	96-226	210	3	***	9.8
Pod yield per plant	64-539	313.5	15.9	***	31.4
Seed yield per plant	33-296	167.0	9.5	***	35.1
Shelling percentage	36-73	53.0	1.2	***	13.8
Number of pods per plant	125-1112	713.0	35.4	***	31.0
Pod length	4-7	5.6	0.06	***	7.1
Number of seed per pod	3-4	3.8	0.04	***	7.3
100 seed weight	7-14	10.7	0.18	***	10.7
Leaf area	20-33	27.9	0.46	***	10.2

CV: Coefficient of variation; *** significant difference among accessions for the trait

4.3.2.2. Relative importance of quantitative traits

Principal component analysis revealed that the first four principal components captured 78.96% of the total variation. The first component accounts for 49.39% of the total variation. The first component is positively correlated with phenological traits (days to flowering and days to maturity), most of the yield components (pod bearing length, pod yield, seed yield, pod length, number of seed per pod and 100 seed weight), plant architecture (plant height and secondary branches). This component contrasts accessions 11 and 13 with accessions 38, 40, 42, 44, 45, 46, 47 and 48 (Figure 11). The latter group of accessions is made up of early maturing and dwarf breeding materials obtained from IITA.

The second component explains 11.78% of the total variation. This component contrasts large number of pod per plant, number of primary branches, high pod yield and seed yield with small pod length, low leaf area and low 100 seed weight. This component contrasts accessions 41 and 43 with accessions 27 and 29 (Figure 11).

The third component explains 9.93% of the total variation and contrasts high seed yield, high pod yield, high shelling percentage and large leaf area with low number of primary and secondary branches.

The fourth component accounts for 7.88% of the total variation and defines pod characteristics. This component discriminates accessions having high shelling percentage and accessions having low number of seed per pods.

Overall, plant height, number of raceme per plant, pod bearing length, days to 50% flowering, days to 75% maturity, pod yield, seed yield, number of seeds per pod, number of pod per plant and 100 seeds weight are the traits contributing the most to discriminate the 48 accessions. These traits were retained for the clustering analysis.

Only PCA with Eigen Value higher than 1 were presented. Values in bold indicates a coefficient whose absolute value is greater than half the maximum coefficient (in absolute value) for the relevant PC.

Table 13: Coefficients from principal component analysis of 15 traits of pigeon pea

Traits	PC1	PC2	PC3	PC4
Plant height	**0.95**	-0.18	-0.12	-0.03
Primary branches	0.35	**0.38**	**-0.43**	0.19
Secondary branches	**0.57**	0.28	**-0.45**	0.03
Number of raceme	**0.84**	0.08	-0.20	0.16
Pod bearing length	**0.88**	-0.24	-0.15	-0.12
Days to 50% flowering	**0.93**	-0.24	-0.15	0.01
Days to 75% maturity	**0.93**	-0.24	-0.15	0.01
Pod yield per plant	**0.83**	**0.38**	**0.30**	-0.11
Seed yield per plant	**0.80**	**0.35**	**0.41**	0.16
Shelling percentage	0.16	-0.02	**0.47**	**0.80**
Number of pods per plant	**0.63**	**0.67**	0.18	0.00
Pod length	**0.66**	-0.29	0.15	-0.15
Number of seed per pod	**0.49**	0.10	**0.42**	**-0.60**
100 seed weight	**0.61**	**-0.55**	-0.10	0.21
Leaf area	0.16	-0.47	**0.51**	-0.01
Eigen value	7.41	1.77	1.49	1.18
Variability (%)	49.38	11.78	9.93	7.88
Cumulative %	49.38	61.15	71.09	78.96

4.3.2.3. Relatedness of the accessions

Non-hierarchical clustering (Tocher' method based on the Euclidean distance) produced 10 groups (Table 14). The characteristics of each cluster based on means of quantitative traits of the accessions were presented in Appendix 4.

The most contrasting clusters were cluster 1 and cluster 3 with an inter-cluster distance of 7.85. The lowest inter-cluster distance (2.5) was recorded between cluster 2 and cluster 10.

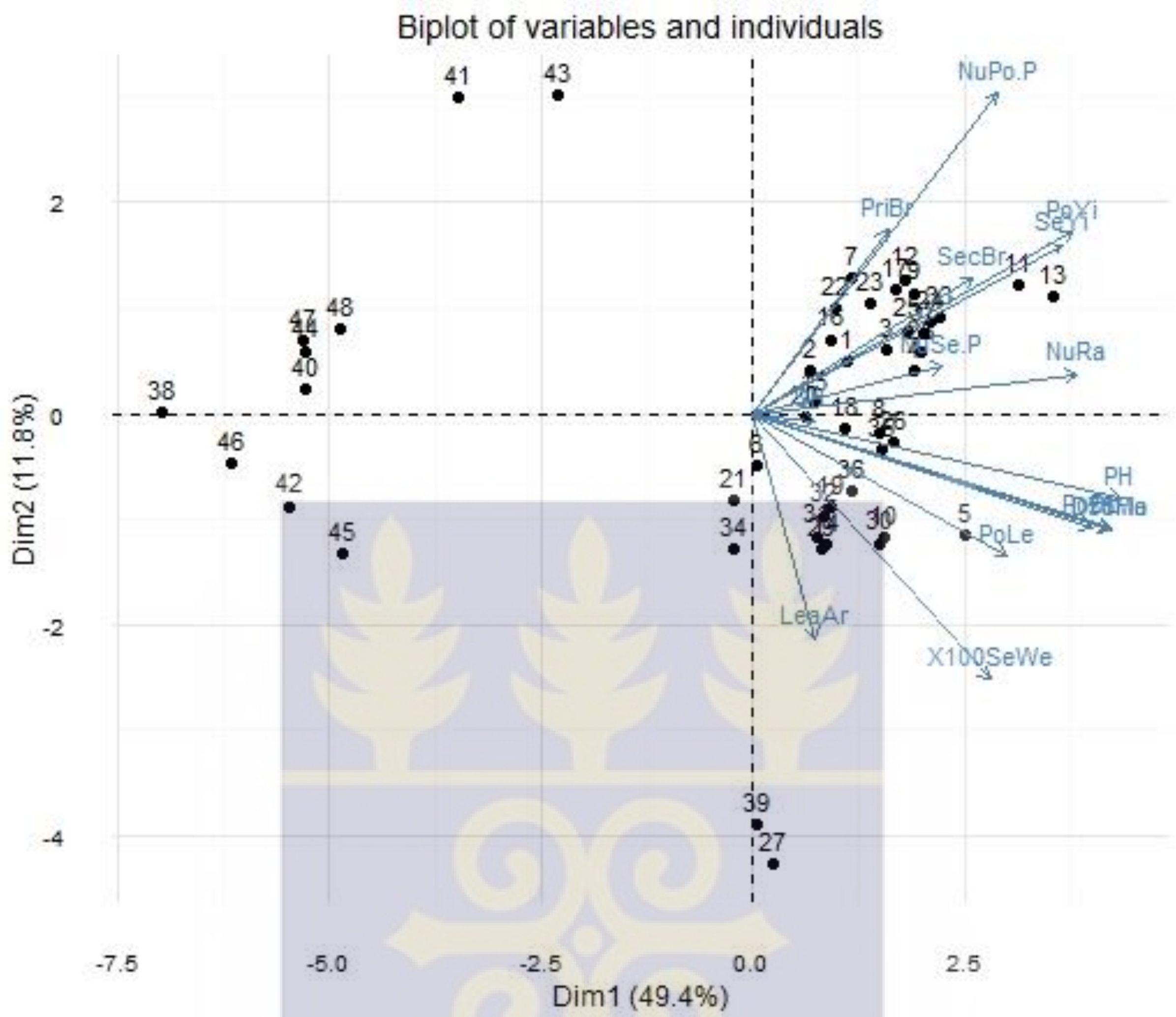


Figure 11: Biplot of first two dimensions of PCA involved 15 traits of pigeon pea

PH: Plan Height, PriBr: Primary Branches, SecBr: Secondary Branches, NuRa: Number of Racemes, PoBL: Pod Bearing, D50Flo: Day to 50% Flowering length, D75Ma: Days to 75% Maturity, PoYi: Pod Yield, SeYi: Seed Yield, NuPo/P: Number of Pod per plant, PoLe: Pod Length, NuSe/P: Number of Seed Per pod, 100SeWe: 100 Seeds Weight, LeaAr: Leaf Area

Table 14: Distribution of 49 accessions of pigeon pea in Benin into clusters

Clusters	Accessions
1	40; 44; 47; 48; 45; 38; 46 and 42
2	29; 36; 32; 35; 18; 3; 10; 22; 23; 1; 19; 30; 14; 21; 6; 2; 15; 16; 28; 17; 8 ; 24; 31 and 12
3	13 ; 33 ; 25 ; 11 and 26
4	41 and 43
5	27 and 39
6	7 and 9
7	4 and 37
8	5
9	20
10	34

Cluster 1 grouped 8 accessions (breeding materials from IITA) with short stature (123.9 ±5.4), early maturing (107±2), very low seed yield (42.3±3.8 g/plant), lowest number of raceme per plant and low 100 seed weight (8.7±0.2g). This cluster included an accession introduced and grown at IITA station in Benin.

Cluster 2 was composed of 24 accessions. These accessions showed high plant height (258.3±2 cm), high pod bearing length (167±2.5 cm), late maturing (213 days to 75% maturity), low seed yield (42.3±3.8), low number of seed per pod (3) and low 100 seed weight (8.7±0.2).

Cluster 3 was made up of five accessions characterized by high plant height (261.8±4.3 cm), high number of raceme per plant (107.4±4.3), late maturing (213 days to 75% maturity), high seed yield (227.4±19.5g/plant), high number of pod per plant (935.8±67.2) and the highest number of seed per pod (4) in the pigeon pea collection.

Cluster 4 was composed of two accessions that are breeding materials obtained from IITA. The accessions in this group were characterized by medium plant height (169.7±20.5 cm), earliest maturing (105±7), highest number of pod per plant (1010.42±81.25) in the collection but medium seed yield per plant (127.21±2.04 g/plant) and the lowest 100 seed weight (8.48±0.32g).

Cluster 5 was composed of accessions 27 and 39. They showed high plant height (269.17±1.61 cm), highest pod bearing length (174.48±6.11 cm), highest seed weight and very late maturity (221 days to 75% maturity). Accessions of this group may be of great importance when using in breeding programme for improving seed size. The lowest seed yield (40.22±6.67 g/plant) in the collection was recorded for accessions in this group. 27and 39 may be duplicate accessions.

Cluster 6 comprised two accessions (7 and 9) which were mainly characterized by high plant height (261.5±18.5 cm), high number of raceme per plant (145±9), late maturing (220±6), medium seed yield (130±11.7 g/plant) and high number of pod per plant (797±115.5).

Cluster 7 grouped accessions (4 and 37). These accessions had high plant height (261.5±18.5 cm), late maturing, high pod bearing length (152.6±25.8 cm) and high number of pod per plant (911±81). The highest seed yield (261±21.6 g/plant) was recorded in this group. Accessions in this group can be potentially used for yield improvement.

Cluster 8 was composed of the accession 5 which showed very high plant height (269 cm), highest number of raceme per plant (152), late maturing (213 days to 75% to maturity), high seed yield (191.4 g/plant) and high 100 seed weight (11.4±01 g).

Accession 20 was classified in cluster 9. This accession showed high plant height (258.7 cm), low number of raceme per plant (66), high seed yield (200.7 g/ plant), high number of pod per plant (772), medium maturity 162 days to 75% maturity). This accession was the earliest maturing accession collected from farmers' field.

Cluster 10 comprised one accession (34) with the highest plant height (269.3 cm), the highest pod bearing length, late maturing (215 days to 75% maturity), medium seed yield (92.5 g/plant) and low 100 seed weight (9.8g).

Accessions collected from farmers' field were grouped in 8 clusters. This revealed a relatively high diversity in Benin pigeon pea collection.

Besides the cluster 5 which groups two accessions Couffo Department, no geographical pattern was observed in the grouping of the accessions collected in Benin. This may be due to exchange of seeds among farmers across the growing areas.

4.3.2.4. Association among traits

Except leaf area which showed no significant correlation with any other trait, significant association was recorded among most of the other traits. Biologically significant associations (r>0.71) were recorded between plant height and number of racemes (r=0.77), plant height and pod bearing length (r=0.94), plant height and days to 50% flowering (r=0.96), plant height and days to 75% maturity (r=0.96), number of racemes and days to 50% flowering (r=0.79), number of racemes and days to 75% maturity (r=0.79), pod bearing length and days to 50% flowering and days to 75% maturity (r=0.92), pod yield and seed yield (r=0.94), pod yield and number of pod per plant (r=0.83), seed yield and number of pod per plant (r=0.8). Days to 50% flowering and days to 75% maturity showed perfect correlation (r=1) (Table 15). These associations among different traits showed that indirect selection can be applied to select for many traits at once and significant resources (time and money) can be saved.

Table 15: Correlation matrix of 15 quantitative traits in characterized pigeon pea collection

PH	**PriBr**	**SecBr**	**NuRa**	**PoBL**	**D50Flo**	**D75Ma**	**PoYi**	**SeYi**	**SH.**	**NuPo.P**	**PoLe**	**NuSe.P**	**X100SeWe**	**LeaAr**
PH	0.31*	0.53***	**0.77*** **	**0.94*** **	**0.96*** **	**0.96*** **	0.69***	0.65***	0.08ns	0.47***	0.61***	0.40**	0.65***	0.19ns
	PriBr	0.40***	0.37**	0.18ns	0.28ns	0.27ns	0.28ns	0.26ns	-0,03	0.32*	0.13ns	-0.01	0.08ns	-0.11
		SecBr	0.58***	0.48***	0.46**	0.46***	0.37**	0.34*	-0.02	0.46***	0.25ns	0.19ns	0.25ns	-0.15
			NuRa	0.67***	**0.79*** **	**0.79*** **	0.64***	0.63***	0.13ns	0.56***	0.47***	0.23ns	0.50***	0.04ns
				PoBL	**0.92*** **	**0.92*** **	0.60***	0.54***	0.01ns	0.40**	0.52***	0.40**	0.61***	0.13ns
					D50Flo	**1.00*** **	0.65***	0.61***	0.10ns	0.39**	0.61***	0.35*	0.65***	0.16ns
						D75Ma	0.64***	0.61***	0.09ns	0.39**	0.61***	0.34*	0.65***	0.15ns
							PoYi	**0.94*** **	0.12ns	**0.83*** **	0.48***	0.57***	0.28ns	0.10ns
								SeYi	0.43**	**0.80*** **	0.46**	0.48***	0.31*	0.13ns
									SH.	0.13ns	0.11ns	-0.09	0.20ns	0.16ns
										NuPo.P	0.20ns	0.38**	0.05ns	-0,07
											PoLe	0.46**	0.51***	0.22ns
												NuSe.P	0.14ns	0.18ns
													100SeWe	0.22ns
														LeaAr

PH: Plan Height, PriBr:Primary Branches, SecBr: Secondary Branches, NuRa: Number of Racemes, PoBL: Pod Bearing, D50Flo: Day to 50% Flowering length, D75Ma: Days to 75% Maturity, PoYi: Pod Yield, SeYi: Seed Yield, NuPo/P: Number of Pod per plant, PoLe: Pod Length, NuSe/P: Number of Seed Per pod, 100SeWe: 100 Seeds Weight, LeaAr: Leaf Area

4.4. Heritability estimates

The estimated heritability ranged from low (H=0.38 for shelling percentage) to high (0.99 for days to 50% flowering and days to 75% flowering) (Table 16). Except shelling percentage, all the traits showed medium or high heritability. With a selection intensity of 10%, when coupling the genetic advance and the genetic advance expressed as a percentage of the population mean, the highest responses to selection were recorded for seed yield (GA%=48.83%), pod yield (GA%=47.17%), number of pod per plant (GA%=44.61%) and number of raceme (GA%=32.83%). Not surprisingly, the phenotypic coefficient of variation was higher than the genotypic coefficient of variation for all the traits. As already showed by the coefficient of variation, the genotypic coefficient of variation revealed that seed yield (28.32%), pod yield (26.14%) and the number of pod per plant (25.68%) presented a high variability in the collection.

Table 16: Genetic parameters of quantitative traits in Benin pigeon pea germplasm

Traits	σ^2_g	σ^2_P	H	GA%	GCV (%)	PCA (%)
Plant height	595.93	673.68	0.885	18.45	9.52	10.12
Primary branches	3.13	6.01	0.521	17.50	11.76	16.29
Number of racemes	362.45	517.33	0.701	32.83	19.04	22.75
Pod bearing length	327.93	495.92	0.661	18.76	11.20	13.77
Days to 50% flowering	392.11	395.37	0.992	23.49	11.45	11.50
Days to 75% maturity	386.78	387.85	0.997	19.30	9.38	9.40
Pod yield per plant	6715.71	8748.38	0.768	47.18	26.14	29.83
Seed yield	2237.35	3193.94	0.700	48.83	28.32	33.84
Shelling percentage	16.29	43.35	0.376	9.61	7.61	12.41
Number of pods per plant	33536.83	47165.83	0.711	44.61	25.68	30.46
Pod length	0.10	0.16	0.601	8.88	5.56	7.18
Number of seeds per pod	0.06	0.08	0.766	11.69	6.48	7.41
100 seeds weight	1.17	1.35	0.860	19.28	10.09	10.88

σ^2_g: Genotypic variance, σ^2_P: Phenotypic variance, GA: Genetic advance, GA%, Genetic advance as a percentage of the mean, GCV: Genotypic coefficient of variation, PCA (%): Phenotypic coefficient of variation

CHAPTER FIVE

5. DISCUSSION

5.1. Farmers' knowledge of cultivation and utilization of pigeon pea

Pigeonpea is an important crop integrated in cropping systems in growing areas in Benin. The crop is mainly grown by adult and experienced men. This observation suggests that farmers have accumulated knowledge related the crop through years of cultivation and exchanges with elders and other farmers (Dixit and Goyal, 2011). The socio-economic data about the pigeonpea growers is of great importance to identify those to be included in a participatory varietal selection or participatory plant breeding programmes.

Pigeon pea is used in various ways. Boiled whole dry seeds were the main form of consumption. Pigeon pea seed boiling was shown to be important in reducing anti-nutritional factors notably trypsin and increasing digestibility of protein and carbohydrate (Rani *et al.*, 1996). The important place of pigeon pea in home consumption is due to the fact that it is used to make up for the shortage of cowpea, maize and other staple foods during lean season (May-June). The use of immature seeds as vegetable was not reported in Benin conversely to what is observed in Eastern African countries and other parts of the world (Silim *et al.*, 2005; van der Maesen, 2006; Odeny, 2007; Manyasa *et al.*, 2009; Saxena *et al.*, 2010a). Besides home consumption, marketing was the second major purpose for growing pigeon pea in all the surveyed villages. Income generated by the sale of pigeon pea grains is used to pay labour at the onset of the cropping season (March-April). This finding underscores the strategic role played by pigeon pea in the production system.

Besides the consumption of boil dry seeds, which was the primary usage, local populations use dry stems and leaves for several purposes (food, firewood, fodder, medicines). This multi-purpose characteristic of pigeon pea, reported across its growing areas worldwide (Mula and

Saxena, 2010), is particularly due to the perennial nature of most of the genotypes (Daniel and Ong, 1990). The use of pigeon pea leaves to treat various diseases such as malaria was reported by farmers in many countries and substantiated by pharmacological or antiviral tests (Aiyeloja and Bello, 2006; Nwodo *et al.*, 2011; Oladunmoye and Kehinde, 2011). These observations give a scientific support to indigenous knowledge in the identification of plants for treating diseases. The treatment of eye infections and vertigo reported by farmers is confirmed by previous studies (Mula and Saxena, 2010). Use of pigeon pea leaves to treat snake bite has not been reported elsewhere. Further researches on the biologically active or the properties of pigeon pea responsible for curing snake bite are needed. The use of pigeon pea leaves in treatments of some diseases was locality-dependent. This finding showed that pigeon pea farmers in Benin did not have the same knowledge on the use of pigeon pea and specific knowledge related to the plant uses might be kept and transmitted within communities in some areas as a result of vertical knowledge transmission (Jarvis *et al.*, 2000; Leclerc and Coppens, 2012). No specific pigeon pea variety was associated with folk medicines conversely to previous findings on *Macrotyloma geocarpum* (Harms) Maréchal & Baudet) (Achigan Dako and Vodouhè, 2006; Assogba *et al.*, 2015) in Benin and on rice (Rana *et al.*, 2007) in Nepal, showing that some landraces were specifically used for medicinal purposes. These results suggest that usage of crop varieties in folk medicine depends on the crop species and the cultural background of local communities. Furthermore, the fact that no particular cultural and religious use was associated to a given variety may be a threat for the conservation of grown varieties when new varieties are introduced in the farming systems. In fact, traditional values associated with varieties increase their chance of survival in farming systems (Rana *et al.*, 2007; Bellon *et al.*, 2015).

Pigeon pea is an important crop integrated in cropping systems in growing areas in Benin. The crop is mainly grown by adult and experienced men. Farmers have accumulated knowledge related to the crop through years of cultivation and exchanges of their knowledge with other farmers. For instance, farmers perceive nonoccurrence of harmattan as a factor leading to yields reduction. In fact, absence of harmattan during a year is translated by high temperature and under constant and high day temperature there is high flowering abortion and therefore a low pod setting which ultimately reduce the yields (Turnbull, 1986).

Pigeon pea is grown in association with various crops species due to its slow growth during the 2-3 months after sowing (van der Maesen, 2006). Thus, depending on the growing area, pigeon pea was mainly associated to maize, cassava, cowpea, groundnut and vegetables. Similar finding was reported in Southern Benin where pineapple cropping systems is locality-dependent (Achigan-Dako *et al.*, 2014). Couffo Department recorded the highest number of crops combined with pigeon pea. This Department is characterized by degraded soil and a high pressure on agricultural land (Edja, 2001) and pigeon pea has been promoted to cope with depletion in soil fertility (Versteeg and Koudokpon, 1993; Aihou *et al.*, 2006). The association of pigeon pea with maize, cassava was reported in other pigeon pea growing countries for instance in Nigeria (Egbe and Vange, 2008), Uganda (Manyasa *et al.*, 2009) and Kenya (Mergeai *et al.*, 2001). However, intercropping with sorghum and finger millet observed in Uganda and Nigeria (Manyasa *et al.*, 2009; Egbe and Vange, 2008) was not reported in this study. This might be explained by the fact that the major growing area of pigeon pea in Benin does not overlap with the major growing area of sorghum and finger millet. Cultivation of pigeon pea in the Northern Benin, which is a semi-arid region, is marginal (MAEP, 2013). Its cultivation is then more social-cultural than linked to agro-ecological conditions mostly climatic conditions since pigeon pea is known as a crop adapted and most produced in semi-arid regions of the world (Mula and Saxena, 2010). This observation may be an opportunity to expand the cultivation to these areas, which are more prone to drought. However, socio-cultural factors limiting the cultivation of the crop in the semi-arid regions of Benin need to be assessed for the success of an introduction of the crop. Few pigeon pea producers planted the crop in pure stand. Similar result was observed in Tanzania, Uganda and Kenya (Kimani, 2001; Silim *et al.*, 2005; Manyasa *et al.*, 2009). The primary reason given by farmers was that pigeon pea has a long life cycle and its cultivation in sole crop occupies land that should be used for other crops. As such, farmers may be more willing to grow in pure stand early or extra early pigeon pea cultivars since they can harvest within a short period and allocate the land for other crops. In crop rotation system, pigeon pea was reported to control weeds and improve soil fertility for subsequent crops notably maize. This observation was consistent with findings of similar studies (Adjei-Nsiah, 2012; Odeny, 2007). In fact, as a legume, pigeon pea fixes atmospheric nitrogen in its various parts and the leaves drop forming litter and root residues enhance soil fertility (Myaka *et al.*, 2006; Høgh-jensen, 2011).

Both male and female pigeon pea producers are involved in decision-making regarding farming activities and income management. To perform labour intensive operations such as land preparation (clearing, plowing), weeding, harvesting and threshing, households often hired labour or get involved in mutual aid groups. This observation was in agreement with finding on fonio (*Digitaria spp*) in Togo (Adoukonou-Sagbadja *et al.*, 2006). The relatively low proportion of female involved in pigeon pea production as compared to other crops may be explained by its long life cycle and then its cultivation requires access to land over long duration. Such condition is difficult to fulfill by female farmers who, in Benin, are rarely landowners (Achigan-dako *et al.*, 2014). Popularization of early or extra-early maturing cultivars may make the cultivation of pigeon pea more attractive to female farmers. In Benin, women are more involved in pigeon pea commercialization conversely to some regions in Tanzania (eg. Babati) where men played the major role in pigeon pea grains commercialization; this may be explained by the fact that in this region, pigeon pea is grown as cash crop (Høgh-jensen, 2011).

Several constraints affect pigeon pea production. As reported elsewhere, these constraints include among others, poor agronomic practices, lack of improved varieties, no formal seed system to supply quality seeds to farmers and pest attack (Odeny *et al.*, 2007; Mutegi and Zingore, 2008, Adjei-Nsiah, 2012). Facing with these constraints, farmers adopted mitigation strategies. However, the coping strategies developed by farmers cannot boost pigeon pea production to ensure food and nutritional security to local farmers. Thus, incentive measures such as introduction and evaluation of cultivars and their release for popularization, development of pigeon pea technological packages including sustainable inputs (seeds, fertilizers, insecticides) system to make available inputs to producers, increase market access notably international markets.

Most of the farmers used no product to conserve pigeon pea grains. Nevertheless, some farmers use chemical products and indigenous products to conserve their grains. The chemicals products used by farmers to conserve pigeon pea grains are not registered for such use. Consumption of pigeon pea grains treated with these products with residual and toxic ingredients is detrimental to consumers' health [World Health Organization, (WHO), 1990].

The majority of pigeon pea producers saved seed for planting next season. This was observed in other countries mainly in developing countries and for many other crops as well (Silim *et al.*, 2005; Manyasa *et al.*, 2009; Mula *et al.*, 2013) where most farmers saved seed for the next planting season and few farmers purchased seeds. To some extent, this situation is the result of a non-existing formal seed system, an unaffordable cost of seeds in formal seed systems where they exist (Odeny, 2007; Mutegi and Zingore, 2008; Bioversity International, 2014). The informal seed system involving seed exchanges among farmers and among villages favor the introduction of new varieties or help to spread existing cultivars across villages (Almekinders and Louwaars, 1999; Mula, 2014). The viability of seed exchange network is important for long term availability, diversity and maintenance of cultivars (de Haan, 2009). However, farmer-saved seed and seed acquisition from market do not guarantee physical and genetic purity and an acceptable germination percentage (Almekinders and Louwaars, 1999; Saxena, 2006). Currently, apart from sporadic seeds distribution to farmers by extension services, there is no formal seed supply system for pigeon pea in Benin. It is important to make available to farmers good quality seed in order to increase productivity of pigeon pea (Saxena, 2006). Hence, farmers should be trained in seed production of crops that are not covered by private companies. Support organisations including research institutes, universities, farmers' associations and Non-Governmental Organisations (NGO) should design and implement an integrated seed system to ensure timely availability of quality seeds (Louwaars *et al.*, 2013; Mula *et al.*, 2013).

5.2. Farmers' perception of pigeon pea varietal diversity

Varietal taxonomy adopted by farmers is based on ethnic group and farmers' location which may lead to some inconsistency. Therefore, one variety in farmers taxonomy may actually correspond to many varieties (one to multiple) and varieties differently named by farmers may in reality tally to one (multiple to one) (Adoukonou-Sagbadja *et al.*, 2006; de Haan, 2009; Dansi *et al.*, 2010; Gbaguidi *et al.*, 2013). Such a situation may contribute to under or over-estimate the diversity within a species. To elucidate the situation, use of various descriptors through agro-morphological characterization back up with molecular tools are recommended (Kombo *et al.*, 2012; Gbaguidi *et al.*, 2013; Bharathi and Saxena, 2015). However, high consistency between farmers' varietal classification and molecular markers was reported (Bajracharya, 2003; Agre *et al.*, 2015), suggesting that assessing crop diversity based on folk taxonomy is still to some extent reliable.

The absence of significant association between gender and diversity maintained at household level agreed with previous finding of Cromwell and Oosterhout (2000). However, Rana *et al.* (2007) reported that male rice growers maintained more rice varieties, while Prain and Piniero (1994) found that female farmers contribute more to on farm crop diversity management. The absence of association of the respondent age agreed with earlier research (Rana *et al.*, 2007). All these results suggest that gender contribution to crop diversity maintenance and management is context-based.

Use of morphological, physiological, agronomic and organoleptic traits by farmers to discriminate their varieties was reported in various studies (Adoukonou-Sagbadja *et al.*, 2006; de Haan, 2009; Dossou-Aminon *et al.*, 2014). Seed colour, maturing groups and plant height were the predominant criteria used by farmers in the surveyed regions to classify and identify pigeon pea varieties. Manyasa *et al.* (2009) reported seed size and maturity as the most important criteria used by Ugandan pigeon pea producers to discriminate their varieties while in this study seed colour and maturity were the predominant criteria. In fact, farmers use various phenotypic characters to distinguish their varieties and these criteria vary across communities (Jarvis *et al.*, 2000). In this study, eight characters, fewer as compared with internationally described descriptors for pigeon pea, were used by farmers to distinguish the varieties. These criteria may not be enough to effectively differentiate varieties. However, beyond agronomic and morphological traits, farmers used organoleptic and culinary characters, which are not included in the descriptors. Some of the traits (taste of boiled grains) were based on the farmers and consumers preferred characters and they should be considered as breeding objectives.

Varieties with white or cream primary seed colour were the most grown not only in terms of allocated area but also in terms of the number of households cultivating them. Preference to white seeds was observed in South Africa (Gwata and Siambi, 2009). The varieties with red, spotted, black primary seed colour are not preferred by consumers and though some of them have desirable traits for farmers, their production tended to decline. This observation substantiated findings in similar studies showing the abandonment of varieties farmers found less desirable (Mergeai *et al.*, 2001; Silim *et al.*, 2005; Lacy *et al.*, 2006; Achigan-dako *et al.*, 2014; Agre *et al.*, 2015). The abandonment of less preferred varieties could be explained by the act that farmers' preferences lie in their desire to adapt to their biophysical environment, cropping systems (Lacy *et al.*, 2006; Achigan-dako *et al.*, 2014) and meet consumers preferences (eg: preference to white seed colour) (Mergeai *et al.*, 2001; Silim *et al.*, 2005; Høgh-jensen, 2011). Despite some undesirable traits mentioned by farmers as reason for their abandonment, these varieties may have some traits that can be exploited in breeding programmes for further adaptation. In order to avoid their loss, strategies for on farm collection should be designed. In addition, seed exchange between farmers in the various growing areas should be encouraged with the support of extension agents in order to spread their cultivation. In fact, this action lies in the fact that varieties with less preference in some regions may be preferred in others. Furthermore, for ex situ conservation and exploitation of useful traits in Benin pigeon pea germplasm, collection and characterization of the cultivated pigeon pea varieties are advocated.

5.3. Farmers' preferred traits of desired varieties and implications for varietal development

Farmers' varietal preferences are based on their desire to meet socio-economic and agro-ecological conditions (Lacy *et al.*, 2006; Achigan-dako *et al.*, 2014). Failing to take into account these traits may hinder the success of any pigeon pea varietal improvement programme targeting these areas. The preferred traits stated by farmers were early maturity, high yielding, big seed and flood tolerance, resistant to pod borers, short cooking time and grains taste. Farmers' preference for early maturing cultivars is driven by the desire to get quick return on their investments, multiple harvests in one season, to limit competition of pigeon pea with intercropped species and to limit the extent of yield because of drought at the end of the season (Dutta *et al.*, 2011; Saxena *et al.*, 2014). The preferred seeds attributes such as big seed size, short cooking time and taste were probably based on consumers' preferences. In South Africa, Gwata and Silim (2009) reported consumers' preference to white seed colour in pigeon pea which is a driver of the grown varieties. Even though within a given village, varieties preferences criteria may depend on gender, socio-demographic conditions, cropping systems (Defoer *et al.*, 1997), grouping of villages based on the preferences criteria may facilitate variety popularization and seed production. In fact, as advocated earlier, farmers should be trained in seed production. However, the outcrossing rate of pigeon pea is relatively high, up to 50% (Girithi *et al.*, 1991). To cope with this challenge in seed production and maintenance of genetic purity of released varieties, adoption of "seed village", whereby all farmers in a village are encouraged to grow one variety of pigeon pea (Saxena, 2006), is proposed.

Up to now, in Benin none of the grown variety is early maturing and there is no ongoing pigeon pea breeding programme in the country. Thus, the only source of improved varieties is introduction from international research institutes notably the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Varieties to be introduced for evaluation should focused on major traits identified in this study to increase their chance to be adopted by farmers and contribute to increase the production of the crop.

5.4. Variability and relatedness in pigeon pea collection

The preponderance of accessions with white and creamy seed colour agrees with findings previously reported (Shiferaw *et al.*, 2005; Manyasa *et al.*, 2008; 2009). This might result from an intentional selection based on seed colour. This finding confirmed farmers' preferences for white and creamy seed colour as a result of market demand (Manyasa *et al.*, 2008). Besides, white seeds in pigeon pea showed relatively low polyphenols content, which makes them particularly appropriate in conditions where whole seeds are consumed without processing such as de-hulling (Saxena *et al.*, 2010a). All the accessions showed pubescent pods which has been proven to reduce bruchids attacks on mature pods through limiting egg laying (Silim Nahdy *et al.*, 1999) and this revealed an important trait in Benin pigeon pea germplasm which can be exploited to breed varieties resistant to pod insect.

Growth habit was the less polymorphic trait in the pigeon pea germplasm conversely to findings of Upadhyaya *et al.* (2007b); Manyasa *et al.* (2008; 2009) showing that stem colour was the less polymorphic trait in Tanzanian and Ugandan pigeon pea germplasm. However, primary seed colour as the highest polymorphic character was consistent with observations of Upadhyaya *et al.* (2005; 2007b) but different from findings of Manyasa *et al.* (2008; 2009). The fact that the germplasm collections were not made up of the same accessions may explain the difference observed in traits diversity. For instance, when breeding materials which have low traits variability (Rauf *et al.*, 2010), are included in the collection, this may affect the diversity assessed over the whole collection.

The mean diversity of qualitative traits as revealed by Shannon-Weaver Index in Benin pigeon pea germplasm was higher than the one reported by Manyasa *et al.* (2008) for tanzanian collection (H'=0.23) and Manyasa *et al.* (2009) for Ugandan collection (H'=0.32) and for African germplasm (H'=0.464±0.039) held at ICRISAT (Upadhyaya *et al.*, 2005). This relatively high diversity in Benin pigeon pea germplasm could be due to the fact that germplasm has undergone little selection, with low introduction of improved varieties which show more uniformity.

Based on days to flowering and days to maturity, none of the accessions collected from Benin was early maturing conversely to breeding materials which were extra early maturing. This finding confirms that pigeon pea landraces and traditional cultivars are of medium to late maturity duration (Saxena *et al.*, 2010b). Accessions collected from Benin showed among others traits, higher performance in pod yield and seed yield, which are some of the most important targeted traits in pigeon pea improvement (Mula and Saxena, 2010).

Overall, the ranges of observation of the traits fell in the ranges observed in pigeon pea collected from other African countries such as Ghana, Uganda, Kenya, Zambia and Nigeria, held and characterized at ICRISAT (India) (Upadhyaya *et al.*, 2005). However, the maximum seed yield per plant (296.33 g/plant) recorded in Benin collection is higher than the maximum recorded over the African collection (144.9 g/plant). Potential materials from Benin collection could be used in seed pigeon pea yield improvement. In addition, substantial advance can be made when considering the improvement of pod yield, seed yield and number of pod per plant by exploiting Benin pigeon pea germplasm collection. The relatively high variability observed in this study for pod yield, seed yield and pods per plant agrees with findings reported by Manyasa *et al.* (2009). Exploiting this variation may contribute to broaden the genetic basis of pigeon pea. In fact, high variation in agronomically important traits is a precondition for successful plant breeding programme (Upadhyaya *et al.*, 2013).

The principal component analysis revealed that plant height, days to flowering and maturity, number of primary and secondary branches, pod and seed yield, pod bearing length and number of raceme per plant were the traits accounting for most of the variation in the characterized pigeon pea collection. Similar results were reported by Upadhyaya *et al.* (2007b), Manyasa *et al.* (2008) and Manyasa *et al.* (2009). Elsewhere, few characters, viz. days to 50% flowering, 100 seed weight, protein content explained the variation in the pigeon pea germplasm collection (Durgesh *et al.*, 2015). Despite this difference, characters which are consistent across studies in explaining variability can be used as reliable trait to characterize germplasm collection.

The grouping of the accessions into 10 clusters using Tocher's method based on Euclidean distance revealed an appreciable level of diversity in the collection. In addition, materials may be selected from clusters for crosses that would result in high genetic gain. Thus, accessions from clusters 1 and 3, which showed the highest inter-cluster distance may be potential sources of materials for breeding varieties combining high yield, high seed weight.

When coupling the cluster analysis and farmers' preferences criteria, early maturing and high yielding varieties were the traits mentioned all over the study area. None of the accession in the collection met these preferences. However, a trade-off could be made to find accessions with acceptable seed yield and maturity duration. Thus, accessions (41 and 43) in the cluster 4 with moderate seed yield and early maturing may be further evaluated in participatory varietal selection. Accession 20, classified in cluster 9 was medium maturing and showed good yield performance. Medium duration maturity varieties are known to be adapted to wide range of environment (Mligo and Craufurd, 2005). This accession may also be advanced for multi-locational trials and participatory evaluation.

As for farmers' preference criteria such as tolerance to flood, tolerance to seed borers attack, organoleptic trait (sweet taste of cooked seeds) and short cooking time for the time, they were not evaluated during this study and in this regards, further evaluations are recommended.

Several correlations with biological interest were identified among the traits. Association between plant height and days to flowering can be explained by the fact that, early maturing accessions are short/dwarf and are breeding materials adapted for pure stand cropping systems and amenable to mechanical harvesting (Upadhyaya *et al.*, 2005). Medium and late maturing accessions had high height since their long growth cycle enabled them to accumulate much more biomass and grew taller (Robertson et *al.*, 2001). Tall accessions bear more racemes, and had higher pod bearing length which are important yield components in pigeon pea. Plant height can be used to predict the level of expression of the number of racemes and pod bearing length. Thus, time and resources can be saved either in a breeding programme through indirect selection for one of these traits or in germplasm evaluation and characterization by measuring only one of these traits. Days to 50% flowering and 75% maturity were strongly associated as reported in previous works (Egbe and Vange, 2008; Upadhyaya *et al.*, 2010; 2013; Bharathi and Saxena, 2013). Thus, indirect selection or early selection for days to maturity can be performed on days to flowering.

5.5. Heritability estimate and potential for varietal improvement through selection

High proportion in variance of seed yield, pod yield, number of pod per plant and number of raceme were attributable to variation in gen6etic factors. Phrased differently, most of the variation in the current population is due to variation in genotypes. Similar observation was reported by Manyasa *et al.* (2008), Upadhyaya *et al.* (2010) and Singh *et al.* (2014). Although heritability is trait, environment and population specific, the heritability of similar traits are often remarkably similar in other populations of the same species, or even across species (Visscher *et al.*, 2008). High heritability in traits revealed that effective selection can be carried out on these traits in single replication or on environment basis (Holland *et al.*, 2003).

Seed yield, pod yield, number of pod per plant and number of raceme per plant, phenotype can be used as a good predictor of the genotype (Visscher *et al.*, 2008). In addition, these traits are easy to measure and significant genetic advance can be made over generations. Considering the high heritability, the variability recorded for these traits, a mass selection as an easy and effective breeding scheme can be used for their improvement.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This study shed light on the production systems and phenotypic diversity of pigeon pea in Benin. Farmers grow pigeon pea in association with a diversity of crops species for efficient land use and to allow other crops to benefit from the ability of pigeon pea to enhance soil fertility. Apart from the use of its grain, pigeon pea has a cultural significance for local populations and the crop is used in the treatment of various diseases.

Poor agronomic practices, difficulty to have access to quality seeds and market are some the factors limiting pigeon pea production in Benin. Both men and women are involved in pigeon pea production. Poverty alleviation and women empowering initiatives in rural areas should seek to promote this crop which plays an important role in food security as home consumption is one of the main reasons for pigeon pea cultivation in the growing areas.

Farmers showed deep knowledge of their grown varieties through the naming and description provided. No socio-demographic factor was found to determine maintenance of varieties at household level. There are some varieties that are being abandoned because of their undesirable (black, red) seed coat colour.

When coupling preferred traits and the existing germplasm, no accession meets farmers' preferences. Introduction of early maturing and high yielding and large seeded varieties is likely to be an incentive for pigeon pea growers. Support also has to be provided to farmers in terms of access to quality seeds by training them in seed production.

Agro-morphological characterization revealed an important diversity in Benin pigeon pea collection especially for seed yield, pod yield, number of raceme per plant, secondary branches and number of pod per plant. Most of those traits showed high heritability along with high genotypic coefficients of variation and genetic gain and hence could be targeted for use in pigeon pea improvement programmes in Benin.

6.2. Recommendations

Based on the findings of this study and for further research on pigeon pea in Benin, the following recommendations are made:

(i) to use molecular markers, which are non-sensitive to environment, to elucidate the actual genetic diversity in Benin pigeon pea germplasm and the status of potential duplicate accessions. In fact, conversely to morphological traits, molecular markers are not subjected to environmental influence. In addition, use of molecular markers is less prone to errors that may occur while observing or measuring traits during morphological characterization;

(ii) to design a conservation plan to avoid loss of pigeon pea genetic resources as some of the varieties are being abandoned for their undesirable traits;

(iii) to select potential genotypes for multi-locational trials and over several cropping seasons to better assess the variation of the quantitative traits and determine the most suitable genotypes within an environment or across environments. This will be a follow-up to potential variability detected from this study that was carried out in one location over one season;

(iv) to implement a participatory breeding approach to develop and select most preferred varieties both by farmers and consumers and

(v) to analyse the trade-off in adopting early maturing varieties and their contribution to soil restoration through biomass production.

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APPENDICES

Appendix 1a: Interview guide

1. Cultivated varieties in your village, their characteristics, meaning of their name

Varieties (local name and meaning)	Characteristics

2. Criteria used to differentiate pigeon pea varieties

3. Status of each variety and reasons for assigning such a status

Varieties	Cultivated by many households on small areas	Cultivated by many households on large areas	Cultivated by few households on small areas	Cultivated by few households on large areas	Disappeared

(define small area and large area, many household and few households)

4. Cultural and ritual significance of pigeon pea in your village

5. Utilization of pigeon pea plants

Part of the plant used	Reasons

5. Constraints

Cite and rank the different constraints encountered in the production and marketing of pigeon pea

Constraints	Coping strategies

6. Farmers 'preference

What are your preferred traits in pigeon pea and why?

Traits	Reasons

Appendix 1b: Questionnaire

Questionnaire No..

Investigator's name:

Department District Village:

1. **Farmer identification**

1.1. Farmer's Name: Age:

1.2. Gender: Male ☐ Female ☐

1.3. Ethnic groups:

1.4. Level of instruction: 1.Illiterate ☐ 2.Primary ☐ 3. Secondary ☐

4. Tertiary 99. Others (specify)

1.7. Size of household:

1.8. Available cultivated land area Cultivated land area

1.9. Cultivated crops:

2. Pigeon pea cropping system and gender

2.1. Since when have you been growing pigeon pea?

2.2. What is on the average cultivated land do you devote to pigeon pea?

2.3. How many pigeon pea varieties do you grow?

2.4. Where did you get seeds to establish your first pigeon pea field?

1. Market ☐ 2.Gift ☐ 3.From my own harvest ☐ 99. Others (specify) ☐

2.5. Where did you source seeds each season for planting pigeon pea?

1. Market ☐ 2.Gift ☐ 3.From my own harvest ☐ 99. Others (specify) ☐

2.5. Which crops do you grow in association with pigeon pea?

2.6. At which position do you grow pigeon pea in the rotation system? (cite the crops grown before and after pigeon pea and say why)

2.7. In your household, who make the decision about pigeon pea production?

Level of decision	Member of the household	Reasons
Choice of varieties		
Land allocation		

Land preparation		
Crop management		
Harvest		
Marketing		
Others (Specify)		

Utilization of pigeon pea

3.1. What are per priority the reasons why you grow pigeon pea?

Reasons	Comment

4. Storage and conservation of pigeon pea grains (consumption) and seeds (planting)

4.1. Where do you store your grains/seeds?

1. Gourd ☐ 2. Sack ☐ 3.Granaries ☐

4. Other (specify) ☐

4.2. What products do you apply to conserve your grains/seeds?

1. Chemical products (specify); ☐ 2. biopesticides (specify) ☐

3. Other (specify) ☐

4.3. How do you apply those products?

4.4. For how long do you store your grains/seeds?

Thanks for your availability.

Appendix 2: Accessions, code and area of collection

Code Accessions	Naming	Village
D1C2V2P1	**17**	Issaba
D1C2V2P2	**16**	Issaba
D1C2V1P1	**15**	Ahoyéyé
D1C1V1P1	**8**	Idigny
D1C1V1P1	**9**	Idigny
D1C1V1P3	**10**	Idigny
D1C1V1P4	**11**	Idigny
D1C1V2P2	**13**	Mowodani
D1C1V2P1	**14**	Mowodani
D1C1V2P3	**12**	Mowodani
D2C2V1P3	**24**	Wéwéhoué
D2C2V2P3	**25**	Bayékpa
D2C1V1P1	**18**	Dékpo-Centre
D2C1V1P2	**19**	Dékpo-Centre
D2C1V2P3	**20**	Lagbavé
D2C1V2P3	**21**	Lagbavé
D2C1V2P3	**22**	Lagbavé
D2C1V2P3	**23**	Lagbavé
D2C3V1P2	**26**	Dkandji
D2C3V1P1	**27**	Dkandji
D2C3V1P4	**39**	Avéganmè
D3C1V1P1	**28**	KAODJI
D3C1V1P2	**29**	KAODJI
D3C1V1P3	**30**	KAODJI
D3C1V1P5	**31**	KAODJI
D3C1V2P1	**32**	MASSAGBO
D3C1V2P2	**33**	MASSAGBO
D3C1V2P4	**34**	MASSAGBO
D3C2V1P5	**35**	BOWE
D3C2V2P3	**36**	OUKPA
D3C2V2P3	**37**	OUKPA
D4C2V1	**4**	GBEDE
D4C2V2	**3**	KOKORO
D4C1V2	**2**	MAGOUMI
D4C1V1	**1**	OUEDEME
D4C3V1	**5**	OUESSE
D4C3V2	**6**	OUESSE
D4C3V2	**7**	OUESSE
BL	**38**	IITA-Benin
CITA2	**40**	IITA-Ibadan
TCc4	**41**	IITA-Ibadan
ICPL87	**42**	IITA-Ibadan

Code Accessions	Naming	**Village**
TCc6	**43**	IITA-Ibadan
TCc1	**44**	IITA-Ibadan
TCc8129	**45**	IITA-Ibadan
TCc8127	**46**	IITA-Ibadan
CITA3	**47**	IITA-Ibadan
TCc8126	**48**	IITA-Ibadan
AO78-99	**49**	IITA-Ibadan

Appendix 3: Qualitative and quantitative variables collected and the observed phenotypic classes and evaluation

Descriptors	Observed phenotypic classes	Evaluation phase
Growth habit	1-Erect and compact ; 2-Semi-spreading ; 3-Spreading ; 4-Trailing	Vegetative
Stem colour	1-Green ; 2-Sun red ; 3-Purple ; 4-Dark purple	Vegetative
Leaflet shape	1-Lanceoate; 2-Narrow-elliptic; 3-Broad elliptic; 4-Obcordate	Vegetative
Leaf hairiness	1-Glabrous; 3-Pubescent (lower surface of the leaves)	Vegetative
Base flower colour	Main colour of the petal (1-Ivory; 2-Light yellow; 3-Yellow; 4-Orange-Yellow	Flowering
Pattern of streaks	Pattern of second colour on the dorsal side of the flag (standard petal). 3-Sparse streaks; 5-Medium amount of streaks; 7-Dense streaks; 9-uniform coverage of second colour	Flowering
Second flower colour (flower streak colour)	1-Red; 2-Purple	Flowering
Flowering pattern	1-Determinate; 2-Semi-determinate; 3-Intermediate	Flowering
Vigor at 50% flowering	3-Low; 5-Intermediate; 7-High	Flowering
Life cycle	1-Early; 2-intermediate; 3-Late	Maturation
Pod colour	Main colour of pod (1-Green; 2-Purple; 3-Mxed green and purple; 4-Dark purple	Maturation
Pod shape	1-Flat; 2-Cylindrical	After Maturation
Pod hairiness	1-Glabrous; 3-Pubescent	After Maturation
Seed colour pattern	1-Plain; 2-Mottled; 3-Speckled; 4-Motled and Speckled; 5-Ringed	After Maturation
Base seed colour (primary seed colour)	1-White; 2-Cream; 3-Orange; 4-Light brown; 5-Reddish-brown; 6-Light grey; 7-Grey; 8-Purple; 9-Dark purple; 10-Dark grey	After Maturation
Seed second colour (secondary seed colour)	Second colour of seed coat (same code with Base seed colour)	After Maturation
Seed eye colour	Colour around hilum (same code with Base seed colour)	After Maturation
Seed shape	1-Oval; 2-Globular; Square; 4-Elongate	After Maturation
Presence of seed strophiole	0-Absent; +Presence	After Maturation

Quantitative descriptors

Descriptors	Observed phenotypic classes	Evaluation phase
Plant height	Arithmetic means (cm)	Maturation
Number of primary branches	Arithmetic means of number of primary branches of 3 randomly selected plants per plot	Maturation
Number of secondary branches	Arithmetic means of number of secondary branches of 3 randomly selected plants per plot	Maturation
Leaf size (length and width)	Arithmetic means of measurements of middle leaflet on a secondary branch	Vegetative
Days to 50% flowering	Number of days from sowing to when 50% of plants flower	Flowering
Days to 75% maturity	Number of days from sowing to when to 75% maturity	Maturation
Raceme number	Arithmetic means of the number of racemes from 3 randomly selected plants per plot	Maturation
Seed per pod	Arithmetic means of the number of 5 randomly selected pods from 3 randomly selected plants per plot	After maturation
Pod bearing length	Arithmetic mean of distance between lowest and topmost pod on 3 randomly selected plant per plot	After maturation
Pod length	Arithmetic means of the lenght of 5 randomly selected pods from 3 randomly selected plants per plot	After maturation
Pod per plant	Arithmetic means of the number of pod from 3 randomly selected plants per plot	After maturation
Seed per pod	Arithmetic means of the number of seeds of 5 randomly selected pods from 3 randomly selected plants per plot	
100-seed weigh	Estimated from a random sample taken from 3 plants per plot	After maturation
Seed yield per plant	Arithmetic mean of seed weight of 5 randomly selected plant per accession	After maturation

Appendix 4: Characteristics of each cluster based on means of quantitative traits of the accessions

Traits	PH	NuRa	PoBL	D50Flo	D75Ma	PoYi	SeYi	NuPo/P	NuSe/P	100SeWe
Cluster 1	132.9±5.4	44.2±3.3	76.4±5.1	70±2	107±2	82.1±6.6	42.3±3.8	313.6±29.8	3.4±0.1	8.7±0.2
Cluster 2	258.3±2	96.3±2.6	167.0±2.5	176±1	213±1	312.8±9.4	166.4±7.3	717.3±31.6	3.8	10.5±0.1
Cluster 3	261.8±4.3	107.4±4.3	162.4±1.2	178±1	213±1	458.0±20.6	227.4±19.5	935.8±67.2	4.2±0.1	10.5±0.4
Cluster 4	169.7±20.5	67.7±6.1	101.2±5.3	68±7	105±7	251.7±13.2	127.2±2	1010.4±81.3	3.8±0	8.5±0.3
Cluster 5	269.2±12.6	87.1±7.1	174.8±6.1	183±1	221±0	77.3±13.2	40.2±6.7	176.3±51.2	3.7±0.2	14±0.2
Cluster 6	261.5±18.5	145.4±9.1	148.3±3.7	184±11	220±6	261.7±14.2	130±11.7	797±115.5	3.3±0.1	9.9±0.4
Cluster 7	261±16.6	124±2.1	152.6±25.8	179±1	215±2	406.5±23.3	261±21.6	910.9±81.2	3.5±0.1	11.4±0.1
Cluster 8	269.0	151.7	147.1	176	213	325.6	191.4	607.8	4.0	12.8
Cluster 9	258.7	66.4	151.4	127	162	363.3	200.7	772.9	3.9	11.3
Cluster 10	269.3	92.1	181.3	178	215	179.0	92.5	490.9	3.5	9.8

PH: Plan Height; PriBr: Primary Branches; SecBr: Secondary Branches; NuRa: Number of Racemes; PoBL: Pod Bearing length; D50Flo: Day to 50% Flowering; D75Ma: Days to 75% Maturity; PoYi: Pod Yield; SeYi: Seed Yield; SH%: Shelling percentage; NuPo/P: Number of Pod per plant; PoLe: Pod Length; NuSe/P: Number of Seed per pod; 100SeWe:100 Seeds Weight; LeaAr: Leaf Area.