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SEED SYSTEM AND SEED QUALITY OF KERSTING'S GROUNDNUT IN BENIN

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ABSTRACT

Swift delivery of quality seeds to farming communities is a fundamental step in mainstreaming the value chain of orphan crops. The objective of this study was to characterise seed production and delivery systems of the orphan Kersting's groundnut (KG) [*Macrotyloma geocarpum* (Harms) Maréchal & Baudet] and their influence on seed quality in Benin. A survey was conducted among 305 farmers from the major KG growing areas in Benin. A total of 60 seed samples were collected from different sources (farmer own seed, local markets and agro-dealers) for quality tests. The results showed that seed sources, acquisition modes and perceived quality differed significantly (P<0.01) among gender groups and with farming experience. Majority of farmers (74.93%) perceived seeds acquired from the local markets and seed stored in non-hermetic conditions as of poor quality compared to seeds sourced from their own stock and stored in hermetic conditions. Yet, the seed quality analysis revealed no differences (P<0.05) among the sources and storage methods. Less than 20% of the tested samples met the national quality standards suggesting an important quality constraint in the current system which may justify the reported low yield and crop failure.

Key Words: Farmer' perceptions, *Macrotyloma geocarpum*, orphan crops

RÉSUMÉ

L'accès aux semences de qualité est une étape fondamentale dans l'intégration de la chaîne de valeur des cultures orphelines. L'objectif de cette étude était de caractériser les systèmes de production et de distribution de semences de la lentille de terre [*Macrotyloma geocarpum* (Harms) Maréchal & Baudet] au Bénin et leur influence sur la qualité des semences. Une enquête a été menée auprès de 305 agriculteurs de la principale zone de production de la lentille de terre au Bénin. Au total, 60 échantillons de semences ont été collectés auprès de différentes sources (agriculteurs, marchés locaux et les vendeurs d'intrants agricole) pour des tests de qualité. Les résultats ont montré que les sources de semences, les modes d'acquisition et la perception des répondants par rapport à la qualité des semences différaient significativement (P<0,01) avec le genre des répondants et leur l'expérience de production. La majorité des répondants (74,93%) perçoivent les semences acquises sur les marchés locaux et les semences stockées dans des structures non hermétiques comme étant de mauvaise qualité par rapport à celles provenant de leur propre stock et stockées dans des structures hermétiques. Cependant, l'analyse de la qualité des semences n'a révélé aucune différence significative (P<0,05) entre les sources et les méthodes de stockage. Moins de 20 % des échantillons testés répondaient aux normes de qualité en vigueur au Benin, ce qui suggère une contrainte de qualité importante dans le système actuel et pourrait justifier le faible rendement et l'échec des récoltes enregistrées.

Mots Clés : Cultures orphelines, perceptions des agriculteurs, *Macrotyloma geocarpum*

INTRODUCTION

Kersting's groundnut [*Macrotyloma geocarpum* (Harms) Maréchal&Baudet] is an important orphan legume crop in West Africa, that has regained considerable attention due to its palatability, nutritional and market values and potential to thrive in harsh and water scarce growing conditions (Bampuori, 2007; Aremu *et al.*, 2011; Agoyi *et al.*, 2019). As a priority, though neglected crop species (NCS) in Benin, Kersting's groundnut (KG) is listed among the 101 African orphan crops promoted by the African Orphan Crops Consortium (http://africanorphancrops.org/meet-the-crops). Kersting's groundnut is grown across the west African savanna belt, mostly by smallholder farmers, and used for food, feed, cultural and medicinal purposes (Pasquet *et al.*, 2002; Ayenan and Ezin, 2016).

In Benin, its production has recently declined, from 1849 to 820 metric t per year (INSAE, 2018). Similar decline in production has been reported in other growing countries, including Burkina Faso (Tamini, 1997), Ghana (Padulosi *et al.*, 2007), Nigeria (Amujoyegbe *et al.*, 2007) and Togo (Mergeai, 1993). The principal reasons associated with this decline are the low yield due to lack of improved varieties, disease pressure on farm, and lack of affordable and good quality seed (Ayenan and Ezin, 2016; Akohoue *et al.*, 2018; Agoyi *et al.*, 2019). Daouda *et al.* (2020) was emphatic on the farmers' perspective that the quality of KG planting materials acquired from open markets is uncertain, leading to frequent crop failure. Unfortunately, there has been no in-depth analysis of KG seed system and seed quality in particular in West Africa.

As a core input of crop production, seed conveys the genetic potential required for high productivity and resilience (McGuire and Sperling, 2016). Seed quality contributes up to 20% increase in crop productivity (Mondo *et al.*, 2016; Ashok Gaur *et al.*, 2020); hence quality seed is essential for achieving a sustainable food system (Van Etten *et al.*, 2017). Furthermore, the availability of functioning and market-driven seed systems is fundamental to ensure farmers' access and adoption of improved varieties (Ojiewo *et al.*, 2018; Maredia *et al.*, 2019). Consequently, the promotion of the cultivation of KG requires understanding and support a reliable seed system. The objective of this study was to characterise seed production and delivery systems of the orphan Kersting's groundnut (KG) (*Macrotyloma geocarpum* (Harms) Maréchal & Baudet) and how they bear on seed quality in Benin.

MATERIALS AND METHODS

Study area. The study was conducted across the major KG production areas in Benin (Fig. 1), located in the Guinean and the Sudano-Guinean ecological zones (Achigan-Dako and VodouheÌ, 2006). The Guinean ecological

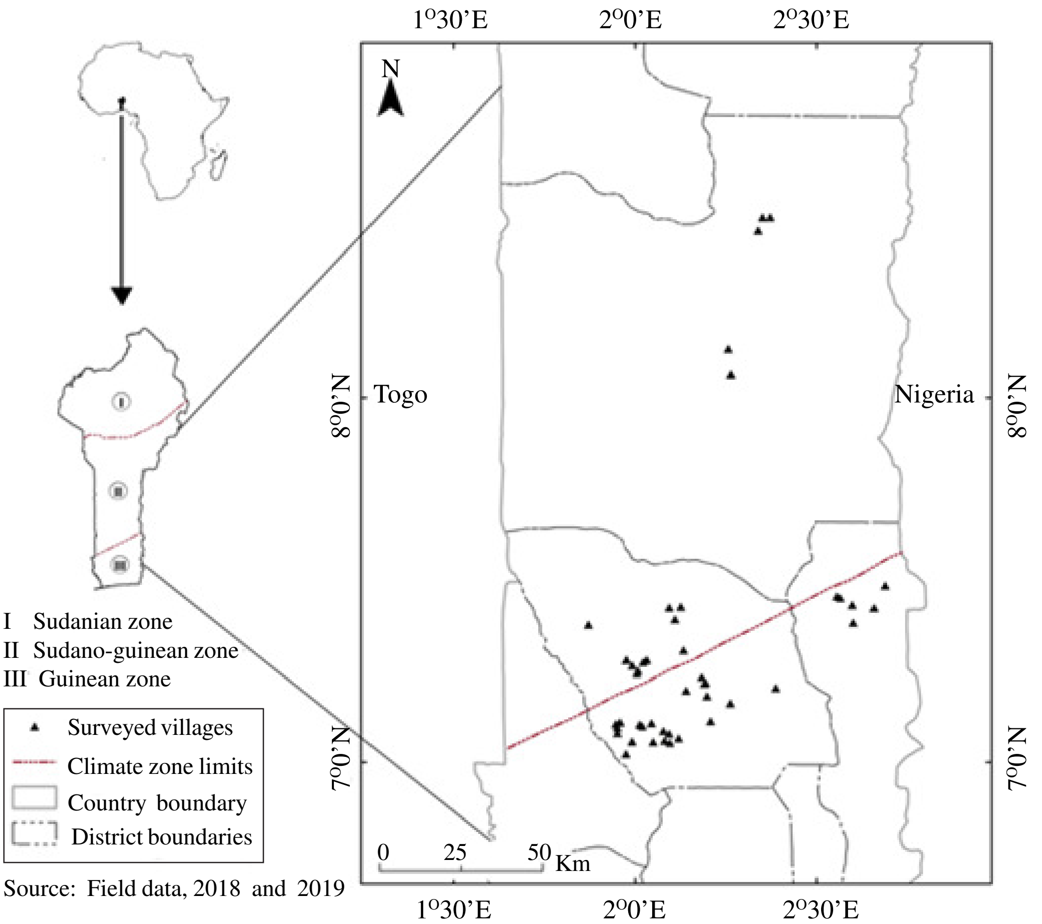


Figure 1. Map of Benin showing the study areasactive in the Kersting's groundnut value chain.

zones exhibit abimodal rainfall patterns with an annual precipitation, temperature and relative humidity ranging from 900 to 1100 mm, 25° to 29 °C, and 31 to 98%, respectively (Adomou, 2005). The Sudano-Guinean zone is a transitional and sub-humid zone with bimodal rainfall regime, gradually turning into unimodal northward from the latitude of Savè (Höllermann *et al.*, 2010). The mean annual rainfall varies from 1100 to 1300 mm (Adomou, 2011).

Sampling design and socio-demographic characteristics. A multi stage sampling procedure was used to select the respondents as follow. Kersting's groundnut production districts (Zogbodomey, Bohicon, Za-Kpota, Djidja, Agbangnizoun, Zangnanado, Kétou, Glazoué, and Ouèssè) were purposively selected with the help of agricultural extension staff and local farmer organisations. In each district, the surveyed population size was determined by conducting, a rapid rural appraisal with 50 farmers randomly selected to assess if they grew or had ever grown KG. The proportion (p) of positive responses was then used to calculate the sample size (n) for the considered district, following the normal approximation of the binomial distribution (Dagnelie, 1998):

$$n = \frac{U_{1-\alpha/2}^{2} \times p(1-p)}{d^{2}}$$

Where:

n = the number of KG producers to sample in a selected district; $U_{1-\alpha/2}$ = the value of the normal random variable corresponding to a probability value of 1- $\alpha/2$ (for $\alpha = 0.05$, $U_{1-\alpha/2} = 1.96$); and d = the margin error fixed at 8%.

Thus, 305 respondents (Table 1) were interviewed using a structured questionnaire and with the help of an interpreter whenever needed. Information collected included respondent's socio-demographic characteristics, farmer association membership, seed sources and acquisition modes, traditional seed quality assessment methods; farmers' perceptions on quality of the acquired seeds (poor, medium, good), and seed management and conservation practices.

For the information related to the formal seed sector, regulations and seed laws, a snowball technique was used (Biernacki and Waldorf, 1981) to interview key informants' in the concerned agricultural organisations. Additionally, secondary information was sought from both published and unpublished sources.

Seed sample collection and quality analysis. Sixty seed samples were collected during the 2018 - 2019 growing seasons and tested in the laboratory to assess their quality against the national seed certification standards and farmers' perceptions. For each sample, seed sources, storage techniques and storage duration were recorded. Seed samples were kept in triple Ziploc slider polyethylene freezer bags at 5 °C. All tests were carried out following the International Seed Testing Association rules (ISTA, 2018) in a completely randomised design (CRD) at the Laboratory of Applied Ecology, University of Abomey-Calavi, Benin.

Seed purity test. From each sample, three replicates of 60 g seeds were taken, sorted and categorised into fractions (pure seeds, inert matter, insect damaged seeds, seeds of other landraces and seeds of other species). Each fraction was then weighed and its percentage determined (ISTA, 2018).

Moisture test. Seed moisture content (MC) was determined using the low constant temperature oven method (103°±2 °C for 17 hr±1) (ISTA, 2018). Four replications of 5 g of seed were taken from each sample and oven dried. The moisture contents were then determined gravimetrically (ISTA, 2018).

One thousand seeds weight. One thousand seeds weight (TSW)was determined by randomly counting eight replicates of 100 seeds from the sorted seed fraction. Each replicate was weighed and the variance, standard deviation and coefficient of variation were calculated. Whenever the coefficient of variation exceeded 4.0, a further eight replicates of 100 seeds were counted and weighed, and the standard deviation calculated for the 16 replicates. The average weight of one thousand seeds were then calculated using the following formula (ISTA, 2018):

$$TSW = \frac{\sum \text{Weight of 100 seed replicates}}{\text{Number of 100 seed replicates}} \times 10$$

Seed germination test. Seed germination was assessed using the top-of-paper seed germination method (ISTA, 2018). From each sample, four replicates of 50 seeds were tested in Petri dishes (90 mm diameter) on four layers of non-toxic paper towel moistened with 5 ml distilled water and kept at ambient conditions (25°± 2 °C, 70% ± 5% RH, 12 hr photoperiod). A seed was considered germinated as the radicle emerged and reached 30% of the seed length (Bewley *et al.*, 2012). Data were collected every 24 hr for 8 days and the final germination percentage (FGP) was determined. Seedlings were then sorted into normal or abnormal based on the proper development of shoot and root systems (ISTA, 2017) and the percentage of normal seedlings

TABLE 1. Socio-demographiccharacteristics of the Kersting's groundnut study population in Benin

Characteristics	Ecological zones		Overall		χ^2	df	P-value
	Sudano-Guinean (N=138)	Guinean (N=167)	(N=305)	(%)			
Sociolinguistic groups							
Fon	70	154	223	73.11			**<0.001** #
Mahi	68	0	68	22.30			
Nago	0	13	13	4.26			
Gender							
Female	80	77	152	49.84	30.72	2	**<0.001**
Male	58	90	153	50.16			
Age categories							
<30 years	25	33	58	19.27	4.31	4	0.366
30-60 years	22	18	203	67.44			
> 60 years	91	116	40	13.29			
Household size							
≤5 persons	43	34	75	24.59	3.88	6	0.690
6-8 persons	11	31	110	36.07			
9-12 persons	46	62	69	22.62			
> 12 persons	34	37	51	16.72			
Formal education level							
None	105	124	229	75.08			0.640 #
Primary	20	30	50	16.39			
Secondary	13	13	25	8.20			
University	0	1	1	0.32			
KG farming experience							
<6 years	45	59	105	34.43	30.00	6	**<0.001**
6-10 years	41	32	81	26.56			
11-15 years	22	19	42	13.77			
>15 years	26	57	77	25.24			
Membership to a farmer association							
No	129	134	262	85.90	11.23	2	**0.004**
Yes	9	33	43	14.10			

Fisher's exact test

(NS) computed for each sample. Seed germination index (GI) and mean germination time (MGT) were calculated using the formula proposed by Maguire (1962), and Ellis and Roberts (1980), respectively:

$$GI = \frac{n1}{d1} + \frac{n2}{d2} + \cdots + \frac{ni}{di}$$

Where:

ni= number of seeds newly germinated at *di*; *di*= days from the beginning of the germination test.

$$MTG = \sum n.t / \sum n \; ;$$

Where:

n= number of newly germinated seeds at time t; t = days from when seeds were set to germinate, Σn = total number of seeds germinated.

Seed vigour tests and classification

Vigour indexes (SVC). Ten normal seedlings were randomly selected from each replicate at the final germination count, and measured for shoot (SL) and root (RL) length; and their averages computed (ISTA, 1987). Seedlings were then oven dried at 80° ± 1°C for 24 hr; weighed and the average seedling dry weight (SDW) was calculated. For each sample, two vigour indexes (Index 1 and 2) were calculated using the formula of (Abdul-Baki and Anderson, 1973):

Seedling vigour index 1: $SVi(1) = FGP \times TSL$

Seedling vigour index 2: $SVi(2) = FGP \times SDW$

Where:

FGP = final germination percentage, TSL = average seedling length and SDW the average seedling dry weight.

Electrical conductivity (EC). Four replications of 50 seeds were taken from each sample and weighed prior to testing. Each replicate was rinsed once and placed in 150-ml beaker, with 75 ml of distilled water. Two beakers with the same quantity of distilled water were used as blanks. All beakers were kept on a laboratory bench at room temperature (25°± 2°C) at which the cell was calibrated and covered to avoid contamination and evaporation of water. After 24 hours of soaking, samples were stirred using plastic spoon and specific leachate conductivity was measured using FE30 Mettler Toledo FiveEasy™ conductivity meter. The average conductivity values of the control beakers (blanks) were subtracted from the readings of the seed samples. Conductivity was calculated using the following formula (ISTA, 2018):

$$EC\ (\mu S\ cm^{-1}\ g^{-1}) = \frac{\text{Conductivity reading} - \text{background reading (control)}}{\text{Weight (g) of replicate}}$$

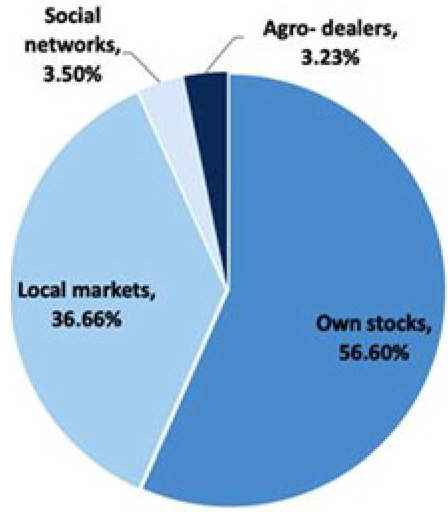
Seedling vigour classification (SVC). Normal seedlings were classified as vigorous or low vigour seedlings. Vigorous seedlings were normal seedlings with all the organs (root system, hypocotyl, cotyledons, epicotyl and primary leaves) well developed; while low vigour seedlings were normal seedlings with short or stunted plumule or coleoptile with limited damage (Don and Ducournau, 2018). The SVC was expressed as percentage of vigorous seedlings.

Data analysis. Data were analysed using ANOVA in R software version 4.0.2 (R Core Team, 2020). Descriptive statistics and other statistic tests (Chi^2, t-test and Fisher's exact test, when appropriate) were used to assess the socioeconomic background of the surveyed population, farming experience, level of education, seed sources, conservation practices and perceived quality. A multiple correspondence analysis (MCA) was performed to assess the relationship between farmer-perceived seed quality, seed sources, production areas and conservation techniques. The Least Significant Difference (LSD) was used for significant mean comparison. One sample t-test was used to assess the analytical quality of the collected samples against the national standards. Pearson correlation was performed on seed vigour indicators to confirm their validity and accuracy to predict seed ability to produce vigorous and uniform seedling stands.

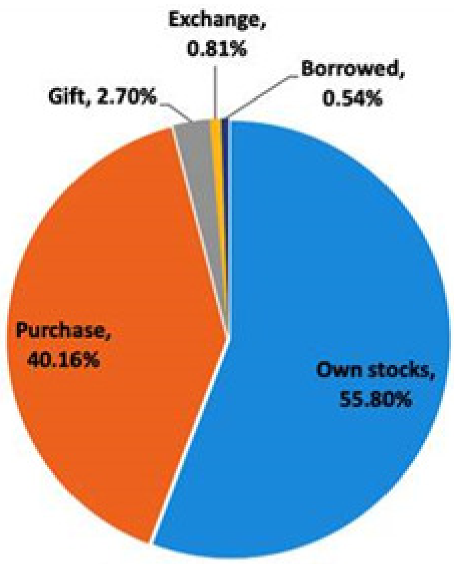
RESULTS

Kersting's groundnut seed sources. Kersting's groundnut (KG) seed production and delivery systems were traditional, thus characterised by the absence of commercial seed growers and formal regulation system. Kersting's groundnut seed value chain comprised of few key actors, including farmers, agro-dealers, grain merchants and farmer's relatives, friends and neighbours (Fig. 2). Farmers grew and saved a portion of their production for the next planting season, but also participated in the dissemination of planting materials through their networks (relatives, friends and neighbours). At village level and in the local markets (village markets and nearby city markets), agro-dealers and grain merchants purchased KG grains at harvest and stored them for trading to neighbouring farmers at the start of the growing season. Farmers' own stocks (56.60%) and local markets (36.66%) were the major sources of planting materials, followed by the social network (3.50%) and agro-dealers (3.23%) (Fig. 2).

Irrespective of the age categories, formal education level, membership to a farmer association and location (agroecological zones) of the respondents, the seed sources used differed significantly among gender (P=0.008), and farming experience (P=0.01). Female respondents relied more on their own saved



Seed sources



Acquisition modes

Figure 2. Kersting's groundnut seed sources and acquisition modes by smallholder farmers in Benin.

stocks, while men tended to source seed from input-dealers and social network. For farming experience, the most experienced (over 15 years) producers relied more on their own saved seed stocks; while the less experienced KG farmers (less than 6 years) used both own saved and market sourced seeds. Farmers also acquired seed from a third party by different mechanisms (Fig. 2), such as purchase from either local markets, agro-dealers and other farmers. Seed acquisition as gifts, exchange or through borrowing, were also practiced but seldomly.

Seed management and quality assessment. There was no separate plot and management for the production of grain and seed for KG in all the surveyed production areas. Kersting's groundnut grains were harvested, dried and threshed as whole, and the distinction between grain and seed were sometimes made only when the need to store for the next planting arose. For 79.57% of the respondents, KG grains stocks for planting were treated differently (in terms of chemical compound and seed handling) from the grains kept for households' consumption. Almost all respondents threshed and cleaned their seeds before storing, but a few (0.79%) preferred keeping unshelled seeds to protect them from insect pest damage. Over eighty percent (81.82%) of the respondents stored less than 10 kg of their seeds, 14.73% stored between 10 and 25 kg, 3.13% between 25 and 50 kg, and the rest stored over 50 kg of seed. Although some respondents (4.32%) stated that KG seeds can be kept in good conditions for more than 24 months, all of them planted seeds that were stored for less than 8 months.

To maintain seed viability and control insect activity until usage, farmers emphasised on proper drying and keeping seeds in ambient room conditions. All the respondents practiced ambient storage using two different storage methods, namely hermetic (78.64%) and non-hermetic (21.32%) storage. The hermetic storage conditions were achieved by using air tight storage containers, including metal drums (2.59%), plastic bottles (70.02%), glass bottles (2.88%), insecticide boxes (2.01%) and buckets with sealable lid (1.15%).The non-hermetic storage containers used were calabashes (2.30%), polypropylene bags (12.96%), wooden basket (1.72%), and clay jars (4.32%).

There were significant differences among sociolinguistic groups (P=0.004), age categories (P=0.02), for the storage containers (Data not shown). The Nago sociolinguistic groups, as well as the younger respondents (<30 years), reported only plastic bottles as storage containers; while the other groups were diversified.

Insect repellents (34.12%), chemical treatments (32.01%), sand (16.66%), wood ash (12.69%) and lamp kerosene (3.70%) were also used as control measures against storage insect pests in both hermetic and non-hermetic conditions. Among the insect repellents used, *Capsicum frutescens* fruits (29.62%) remained the most cited material, in addition to *Citrus sinensis* zests (2.38%) and *Azadirachta indica* leaves and oil (2.11%). Chemicals used by smallholder farmer to protect KG seeds before storage included fumigant (aluminium phosphide tablets: sofagrain, topstoxin), cotton and horticultural crops protection pesticides (CYP&DIM: Cyprodinil and 3,32 - Diindolylmethane, Lambda Super 2.5 EC), and naphthalene balls. Seed stockists reported only fumigation as means of pre-storage treatment. For non-hermetic storage, farmers (12.16%) reported that periodical drying was also done to maintain seed moisture content low and reduce insect proliferation.

To ensure good quality of planting materials, farmers (69.07%) used an array of traditional quality tests, including visual and physical examination of the seed lots (based on the size, weight, colour and hardness of the seeds, and insect proliferation in the seed lots) and seed germination test. Most of the respondents (74.93%) ranked the quality of the seeds they use as good. Seed germination (pre-sowing germination or emergence in the field) remained the major reasons associated with this ranking, but the yield performance was also reported by few respondents (1.63%). No statistical difference (P>0.05) was found among agroecological zones, sociolinguistic groups, age categories and formal education levels regarding the farmer perceived quality. However, farmer's perceptions on seed quality varied significantly with their gender (P<0.01) and farming experience (P<0.001). The female and experienced farmers reported that the planting materials used were of good quality. There was a significant association between farmer' perceived quality and seed sources ($\chi^2 = 27.43$; P<0.001) and the type of storage used ($\chi^2 = 6.70$; P<0.05). Multiple correspondence analysis indicated that seeds from social networks and agro-dealers, and seeds stored under non-hermetic condition were often of medium quality (Fig. 3). In contrast, farmers strongly perceived planting materials sourced from their own stocks and stored under hermetic conditions as having the best quality attributes.

Analytical quality *versus* national seed certification standards

Physical quality. The physical quality characteristics of the KG seed samples are presented in Table 2. The pure seed fraction (PS) of the tested seed lots ranged from 83.36 to 99.17%; while the inert matter (IM) contamination and insect damaged (IDS) seed fractions ranged from 0.26 to 10.87% and 0.25 to 10.87%, respectively. Concerning landrace and species purity, the other crops seed fraction (SoC) ranged from 0 to 8.21%, with an average of 0.05; while the other landrace seed fraction (SoV) ranged from 0 to 5.30%.

Moisture content of the samples ranged from 5.19 to 12.76%.Whereas the weight of thousand seeds (TWS) ranged from 74.33 g for seeds sourced from village seed merchants, to 145.85 g for seeds obtained from farmer's own stocks (Table 2). All the physical quality parameters tested showed no significant differences among means for seed sources, agroecological zones and type of storage, except seed moisture content. The seed moisture content (MC) varied significantly among seed source (P=0.05), agroecological zones (P=0.013) and type of storage (P=0.05), with the highest values recorded in grower own stocks, Guinean Zone andnon-hermetic storage containers.

Physiological quality. Seed germination characteristics of the samples are presented in Table 3. The final germination percentage (FGP) ranged from 44.67 to 99.33%, with a mean of 80.62%; while the normal (NS) and abnormal (AbS) seedlings percentage ranged from 3.33 to 90% and 3.33 to 50.67%, respectively. The germination index (GI) and mean time germination (MGT) ranged from 9.86 to 29.44 and 1.83 to 2.79, respectively. There was no significant difference (P>0.05) in the germination parameters assessed, among seed sources and type of storage. However, there were significant differences among agroecological zones with the highest values recorded in the Guinean zone.

The results of the different seed vigour tests are presented in Table 4. The seedling vigour (SVC) ranged from 0 to 44.74%. The seed vigour indexes 1 (SVi1) and 2 (SVi2) varied, respectively, from 184.79 to 876.66 and from 17.87 to 67.95. Electrical conductivity (EC) ranged from 98.26 to 308.27 $\mu S\ cm^{-1}\ g^{-1}$ with an average of 177.36 $\mu S\ cm^{-1}\ g^{-1}$.

No significant differences were found among seed sources, agroecological zones and type of storage for the seed vigour classification and seed vigour index 1 (SVi1); while the electrical conductivity and seed vigour index 2 (Svi2) were significantly different among agroecological zones (P=0.007), (P=0.018). The highest electrical conductivity was found the Sudano-Guinean zone; while the highest seed vigour index 2 (Svi2) in the Guinean zone. Highly significant correlations (P<0.001) were observed between the final germination percentage (FGP), normal seedlings (NS), germination index, mean germination time (MGT), seed vigour classification (SVC), both vigour indexes (SVi1 and SVi2), and electrical conductivity (Fig. 4).

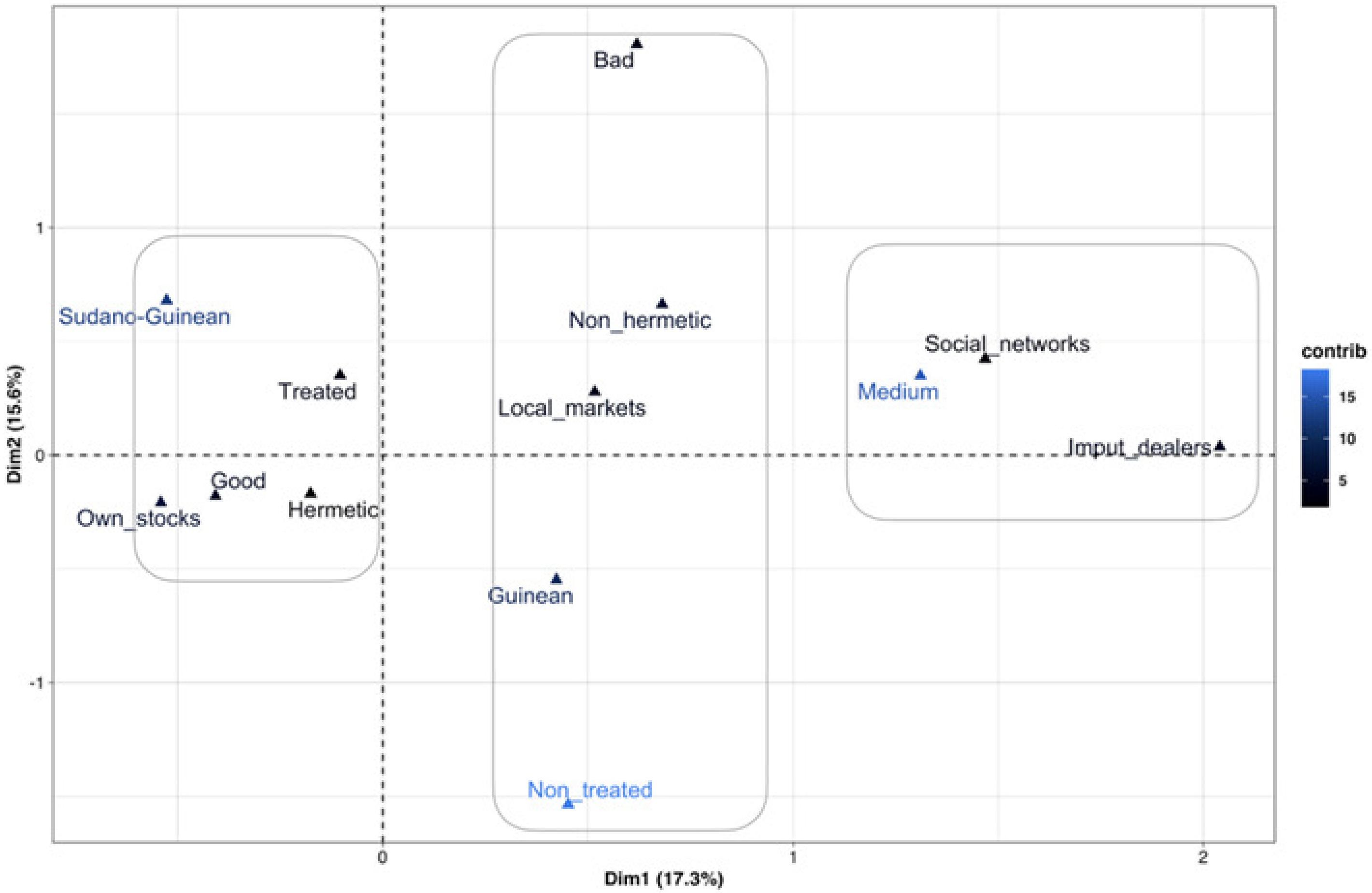


Figure 3. Bi-Plot of the multiple correspondence analysis, performed on farmers' perceived Kersting's seed quality, seed sources, conservation techniques and production areas in Benin.

TABLE 2. Physical quality characteristics of Kersting's groundnut seeds in Benin

Physical quality	PS (%)	IM (%)	SoC (%)	SoV (%)	IDS (%)	TSW (g)	MC (%)
Seed sources							
GOS[1]	94.77±0.66[†]	3.52±0.40	0.02±0.01	0.62±0.16	1.38±0.44	105.41±2.44	9.00±0.29a[#]
VSM[2]	95.63±0.58	2.74±0.36	0.10±0.05	0.69±0.32	0.36±0.13	105.81±3.29	7.89±0.35b
MiC[3]	97.34±0.63	1.98±0.28	0.14±0.14	0.00±0.00	0.12±0.08	112.28±3.74	7.79±0.57b
P-value	0.44	0.35	0.25	0.15	0.66	0.66	0.05*
Agroecological zones							
Guinean	95.07± 0.61	3.05± 0.30	0.07± 0.03	0.75± 0.18	1.22± 0.39	107.0± 2.21	8.96± 0.27
Sudano-Guinean	95.44± 0.67	3.55± 0.64	0.01± 0.01	0.26± 0.16	0.51± 0.35	103.61± 3.39	7.76± 0.34
P-value	0.845	0.522	0.272	0.118	0.348	0.405	0.013 *
Storage containers							
Hermetic	95.33±0.53	3.25±1.70	0.03±0.04	0.50± 0.34	0.92±0.31	104.11±2.04	8.31±0.24
Non-hermetic	94.31±1.14	3.05±0.72	0.10±0.10	1.05±0.82	1.48±0.89	112.93±4.42	9.51±0.52
P-value	0.172	0.906	0.332	0.225	0.665	0.089	0.05*

[†] Mean ± SE; [1] Grower Own Stocks; [2] Village Seed Merchant; [3] Market in City; PS = Pure Seeds; IM = Inert matter; SoC = Seeds of other crops; SoV = Seeds of other varieties/cultivars; IDS = Insect Damaged Seeds; TSW= Thousand seed weight; Mc = Moisture content; Significant at P<0.05 *; [#]Mean comparisons within each column by LSD

TABLE 3. Germination characteristics of Kersting's groundnut seeds in the current seed system in Benin

Germination characteristics	FGP	NS	AbS	GI	MGT
Seed sources					
GOS[1]	80.79±1.88[†]	55.68±3.55	20.17±1.94	19.35±0.66	2.24±0.03
VSM[2]	78.08±3.39	49.84±5.31	21.73±2.50	18.99±1.16	2.22±0.06
MiC[3]	89.83±1.00	67.00±6.56	17.83±5.69	21.46±0.32	2.18±0.02
P-value	0.297	0.337	0.777	0.573	0.821
Agroecological zones					
Guinean	83.29 ± 1.78	59.16 ± 3.04	17.67 ± 1.44	20.36 ± 0.63	2.20 ± 0.03
Sudano-Guinean	74.41 ± 2.82	44.56 ± 5.49	26.96 ± 3.16	17.11 ± 0.84	2.32 ± 0.04
P-value	0.012 *	0.015 *	0.009 **	0.005 **	0.044 *
Type of storage					
Hermetic	80.09±1.91	53.74±3.29	20.77±1.74	19.23±0.64	2.24±0.03
Non-hermetic	82.89±2.82	58.78±6.10	19.56±3.20	20.20±1.11	2.21±0.07
P-value	0.777	0.780	0.926	0.695	0.620

[†] Mean ± SE; [1] Grower Own Stocks; [2] Village Seed Merchant; [3] Market in City; FGP = Final Germination Percentage; NS = Normal Seedling; AbS = Abnormal Seedlings; GI = Germination Index; MGT = Mean Germination Time. Significant at $P<0.01$ **; $P<0.05$ *;[#]Mean comparisons within each column by LSD

Although the formal seed system of KG is not operational due to the neglected status of the crop, and the absence of registered variety, the institutional framework exists with roles and regulations for the production and marketing of planting materials clearly stated (MAEP, 2011a, 2015). As Economic Community of West African States (ECOWAS) member State, Benin is subjected to the regional seed regulation (C/REG.4/05/2008) governing quality control, certification and marketing of plant seeds and seedlings. To comply with this regulation, a national seed law was enacted in 2010 to set the overall conditions for seed production and marketing (MAEP, 2011b), and minimum certification standards for many species including KG (MAEP, 2011a). In the absence of certified seed in the system, these standards were used to get insights in the quality trends of the planting materials used by KG growers to grow their crop.

Table 5 presents the quality attributes of the tested KG seeds lots assessed against the standards of the lowest seed class in the certification scheme (Certified seed R2). Despite the absence of formally registered and released varieties for the crop, 76.66% of the samples (N=60) were pure in terms of landraces mixture. The landrace purity was significantly higher (P=0.002) than the minimum national standard for varietal purity. In contrast, only 18.33% of the samples met the national standard for seed purity (PS), and the inert matter (IM) fraction of the samples had largely contributed to that result (77.77% of samples had more than 2% inert matter). For parameters such as insect damaged seed (IDS), seed of other crops (SoC) and moisture content (MC), over 70% of the collected

TABLE 4. Seed vigour characteristics of Kersting's groundnut seedlings in the current seed system in Benin

Seed vigour characteristics	SVC(%)	SVi1	SVi2	EC (µS cm^{-1} g^{-1})
Seed sources				
GOS[1]	14.70±1.82[†]	556.48±29.99	42.31±1.93	180.86±7.86
VSM[2]	16.49±3.12	511.87±52.79	40.60±3.67	175.3±11.47
MiC[3]	23.41±3.91	721.92±62.96	53.52±2.77	151.76±6.00
P-value	0.341	0.0873	0.192	0.6149
Agroecological zones				
Guinean	38.32±3.29	585.84±28.09	45.17 ±1.82	167.38±6.88
Sudano-Guinean	32.64±5.18	482.61±50.79	36.50 ±3.21	200.64±10.79
P-value	0.353	0.116	0.018 *	0.007 **
Type of storage				
Hermetic	15.51±1.81	549.19±30.83	41.35±2.01	180.76±7.60
Non-hermetic	16.38±3.09	584.05±46.40	46.02±2.80	164.90±8.21
P-value	0.918	0.822	0.391	0.588

[†] Mean ± SE; [1] Grower Own Stocks; [2] Village Seed Merchant; [3] Market in City; SVC = Seedling Vigour Classification; SVi1 = Vigour index 1; SVi2= vigour index 2; EC = Electrical Conductivity.
Significant at P<0.01 **; P<0.05 *; [#]Mean comparisons within each column by LSD

samples met the standard (76.66, 96.66 and 70%, respectively). However, the mean SoC and MC were significantly lower than the maximum standards (P<0.001), (P=0.041); while the mean IDS was higher than the maximum accepted. Concerning the seed germination, though the mean final germination percentage (FGP) percentage of the tested samples was significantly higher than 75% (minimum standard for germination), only 20% of the samples were within that range for normal seedling (NS) percentage.

DISCUSSION

The predominant dependence of KG farmers on own saved seed and local markets as seed sources in Benin may be attributed to the lack of improved variety and certified seed production. With the increasing attention on the crop, local seed businesses can be set up in the production areas with the help of rural development organisations (e.g. NGOs) to supply good quality seed to farmers and leverage the uptake of improved varieties. For the marginalised legume crops, decentralised and community-level seed entrepreneur models have been advocated for as suitable option of seed business (Bishaw *et al.*, 2009; Monyo and Varshney, 2016) with proven economic viability and profitability for individual farmers or farmer-groups (Akpo *et al.*, 2020). Moreover, famers willingness to pay for planting material is a prerequisite for setting up successful local seed business (McGuire and Sperling, 2016). It was established that 40.16% of farmers acquired seed by purchasing, which could be presumed as an indicators of their willingness to purchase commercial seed (Ojiewo *et al.*, 2018; Maredia *et al.*, 2019). Furthermore, no seed voucher or subsidy was undertaken for KG as reported

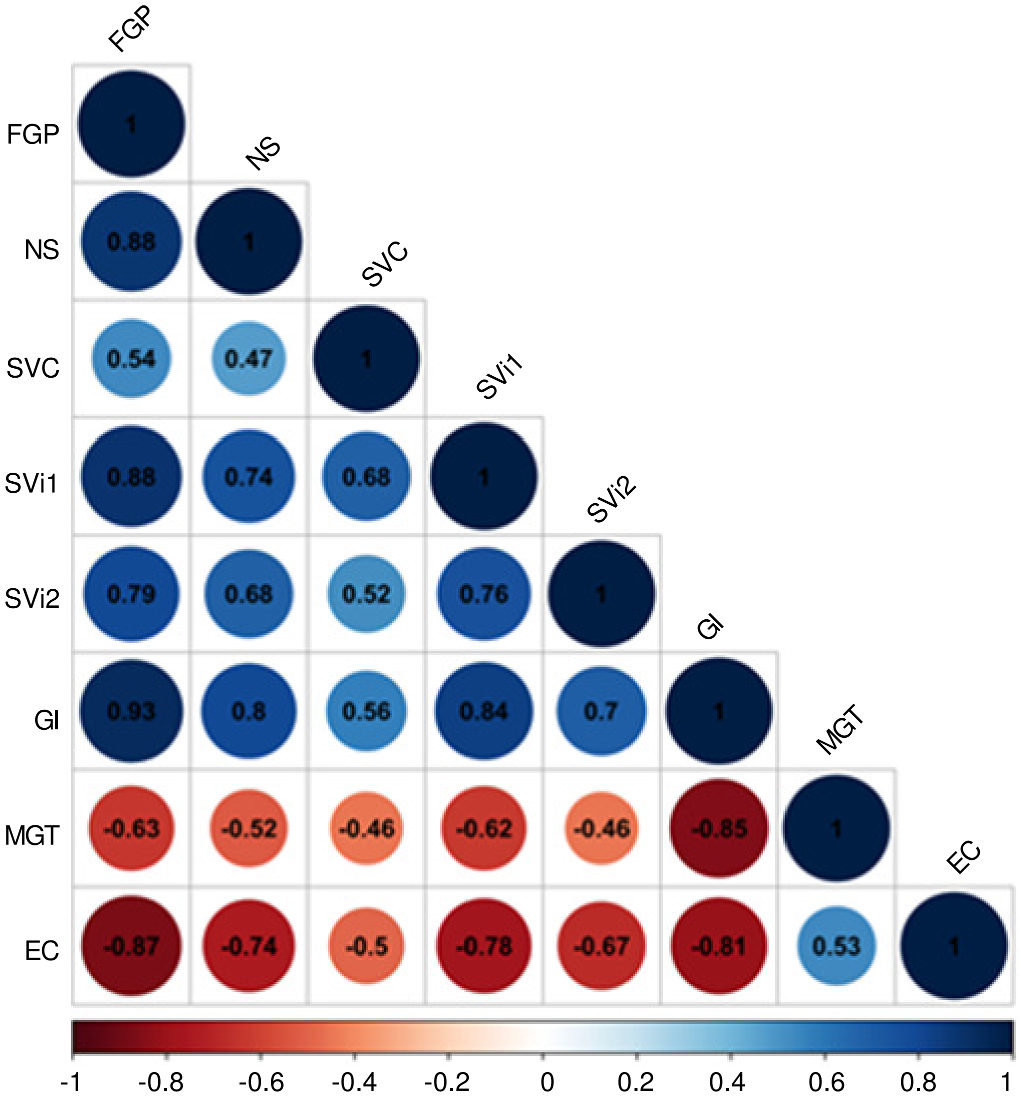


Figure 4. Correlogram of seed germination characteristics and vigour indicators of Kersting's groundnut in Benin.

for other crops (Achigan-dako *et al.*, 2014), leaving room for local seed businesses to be viable. Additionally, to make it more resilient, KG seed business can be leverage where possible through existing seed platforms and seed production facilities of other legume crops such as soybean. For instance, in the locations where both crops are grown, the already established soybean (*Glycine max* [L.] Merr.) seed producers (Ayenan *et al.*, 2017) can be encouraged to incorporate KG seed into their seed business plan.

Kersting's groundnut seed management and quality assessment are guided exclusively by the traditional knowledge and mutual trust. No improved storage technology was alluded to by the respondents, thought the storage facilities used were quite diversified. Despite this diversity, most respondents (78.64%) used hermetic storage containers probably

TABLE 5. Kersting's groundnut seed quality in farmers' seed system *versus* national certification standards in Benin

	Number of samples	Number of samples with						
		PS>98%	IM<2%	SoC< 0.5%	*IDS< 0.5%	MC<9%	FGP> 75%	NS> 75%
Seed sources								
GOS[1]	39	8	11	39	29	22	25	9
VSM[2]	17	2	6	16	13	16	11	2
MiC[3]	4	1	3	3	4	4	4	1
Agroecological zones								
Guinean	42	10	13	40	30	27	31	10
Sudano-Guinean	18	1	7	18	16	15	9	2
Type of storage								
Hermetic	46	10	17	45	36	34	31	8
Non-hermetic	12	1	2	11	8	7	8	4
Overall	60	11	20	58	46	42	40	12
df#	-	59	59	59	59	59	59	59
P-value#	-	1	1	<0.001	0.953	0.041	0.001	1

* *Callosobruchus maculatus.* Source: (MAEP, 2011a)

[1] Grower Own Stocks; [2] Village Seed Merchant; [3] Market in City; VP = Varietal/Landrace purity; PS = Pure Seeds; IM = Inert matter; SoC = Seeds of other crops; IDS = Insect Damaged Seeds; Mc = Moisture content; FGP = Final Germination percentage; NS = Normal Seedling; # One Sample t-test

because it offers good protection against major storage pests including *Callosobruchus maculatus* (Loko *et al.*, 2019). However, additional care is sometimes taken by treating seeds with chemical or organic insect repellents, which often have no proven effect on the pests. Maredia *et al.* (2019) reported that in Tanzania and Ghana, the quality of the planting materials acquired by farmers was an important factor when deciding on where to source seed even for legume crops. To ensure the quality of their planting material, especially when purchasing form markets, most farmers assess KG seed quality. As such, for most of the respondents KG seeds acquired from the local markets and seed stored in non-hermetic conditions are of poor quality compared to those sourced from their own stock and stored in hermetic conditions. This corroborates with Daouda *et al.* (2020) study which reported that the use of seed sourced from market often led to germination failure and ultimately low yield.

Kersting's groundnut being a geocarpic crop with a small seed size compared to peanut (*Arachis hypogaea*) and Bambara groundnut (*Vigna subterranea*), is easily liable to disease and damage causing organisms embedded in the soil when seed cleaning is not properly done (Agoyi *et al.*, 2019). The percentage of impurity was high, especially for inert matter fraction (Table 2), and could not meet the standards. Within the inert mater fraction, an important rate of broken seeds was recorded, which probably resulted from injuries during seed harvesting and threshing. Kersting's groundnut seed is harvested during the dry season by digging-up pods when the soil is dried, and threshed using mortars or beating with sticks. This process may subject the seed to an important stress and result in physically damaged seeds. Though seed physical quality could be improved by further cleaning prior to sowing, physically injured seeds are subjected to microbial attack which exacerbate their deterioration during storage (Kameswara Rao *et al.*, 2017). Besides, seed moisture content, germination and vigour characteristics of the tested samples were alarming. Though the average moisture content was significantly lower than the maximum standard, many samples had as high as 12.76% including those stored in hermetic conditions. Seed moisture content is critical for seed longevity and should not be over looked (Ellis and Hong, 2007). In addition, it plays an important role in the rate and severity of seed injuries during seed processing in many crops (Kameswara Rao *et al.*, 2017).

Coupled with storage temperature and seed treatment methods used, seed moisture content can significantly affect germination and vigour of seed lots. A drop in seed germination and vigour was reported in chickpea (*Cicer arietinum*) and green gram (*Vigna radiata*) when fumigated at moisture content and temperature greater than 12% and 30 °C, respectively (Singh *et al.* (2003).

Concerning the physiological quality of the seed samples, though the mean FGP was 80.62% (Table 3), the mean (NS) was very low and only 20% of the tested samples met the standard (Table 5). This confirmed the seed quality constraint raised by Daouda *et al.* (2020). Though the mean FGP percentage was over 80 %, the MGT and EC were high and negatively correlated with the FGP and other germination characteristics and seedling vigour classification. With an acceptable level of laboratory germination (above 80%), low vigour seed lots result in higher EC and MGT, and low vigour seedlings (Matthews and Powell, 2006; Matthews *et al.*, 2012). Low seed vigour affects seedling emergence rate and uniformity in the field and has indirect impact on the potential yield of the crop (Tekrony and Egli, 1991; Ellis, 1992; Finch-Savage, 2004). With the existing challenge of climate variability, which compromises and creates uncertainties in the time of sowing (Akohoue *et al.*, 2018), the use of low quality KG seeds can definitely undermine the potential establishment of the crop and lead to yield reduction. In contrast with farmers' perceptions on KG seed quality, this could not be attributed to a single source nor to a specific method of conservation, as there were no statistical differences among the various sources and types of storage. As seed production and handling is not undertaken on different plots with the required attention, this could justify such inferior quality. Appropriate moisture content to minimise the mechanical damages and the factors affecting KG seed germination and vigour should be investigated in more controlled conditions.

CONCLUSION

This study has revealed that farmers own stocks and local market are the major sources of seed for KG growers in Benin. Seed storage is a key component of the KG seed production system and is the only stage that introduces a distinction between grain and seed at farmer's level. Hermetic storage containers are the most used by farmers for their ability to mitigate storage insects' proliferation when properly operated. Farmers should be encouraged to undertake seed production on separate plots in order to provide the required care for quality seed production. The viability of the seed lots is satisfactory, but the ability to produce normal seedlings is quite low. Most KG seed lots failed to meet the national seed quality standard. Improving the local storage technologies is essential to guarantee seed viability and vigour until planting.

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