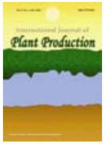

International Journal of Plant Production 6 (3), July 2012
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

GUASNR

Are investments in an informal seed system for cowpea a worthwhile endeavour?

P. Christiaan Biemond[a,b,*], T.J. Stomph[b], A. Kamara[a], T. Abdoulaye[c], S. Hearne[c,d], P.C. Struik[b]

[a]*International Institute of Tropical Agriculture (IITA), Kano, Nigeria.*
[b]*Centre for Crop Systems Analysis, Wageningen University, Wageningen, The Netherlands.*
[c]*International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.*
[d]*Current address: International Maize and Wheat Improvement Centre (CIMMYT), Mexico D.F., Mexico.*
*Corresponding author. E-mail: christiaan.biemond@wur.nl

Received 14 February 2012; Accepted after revision 9 April 2012; Published online 20 June 2012

Abstract

High seed quality is a critical component for realising yield potential. For smallholder cowpea farmers in northern Nigeria the informal seed system is a major supplier of genetically high-quality seed, but the physiological quality of farmers' produced seed remains unknown. The project "Promoting Sustainable Agriculture in Borno State" (PROSAB) trained and supported farmers in seed production in Borno State, Nigeria. We analysed the quality of farmers' produced cowpea seed based on standard quality testing criteria, and evaluated its field emergence as a proxy for non-genetic seed quality. We carried out a survey among seed producing farmers about their production and storage practices, and tested seed quality of samples from these farmers, from seed companies and compared these to foundation seed. Field emergence of farmers' produced seed was not significantly different from that of foundation seed (P=0.47) or seed company samples (P=0.12). Cowpea seed quality, however, was inadequate in both the formal and informal seed systems. Five out of six foundation seed samples, 79 out of 81 samples of farmers' seed, and six out of six seed company samples failed to meet standards for foundation and certified seeds of the National Agriculture Seed Council (NASC), the seed industry regulatory agency in Nigeria. Multiple regression analyses predicting field emergence showed that projects like PROSAB can improve seed quality. Especially proper storage and reducing seed damage can increase field emergence significantly. Our findings suggest that it is worth to invest in improving the informal seed system of cowpea.

Keywords: Cowpea; *Vigna unguiculata*; Seed systems; Seed quality; Northern-Nigeria.

Introduction

Seed is a crucial input for agricultural production, and the most affordable external input for smallholder farmers. The genotype of the planting material affects the plant's ability to cope with harsh weather conditions, diseases and pests, and determines the potential yield of a crop. Seed is the only way for farmers to benefit from investments in crop improvement. High physical quality of seed is essential to establish a sufficient plant stand, directly affecting the yield (McGuire, 2005). High-quality seed should be free from diseases to avoid seedling mortality or introduction of diseases (Haque et al., 2007).

Farmers' access to seed is organized in seed systems (SS), which involve all actors in breeding, seed production, quality control and dissemination. The formal SS consists of public institutions and private companies specializing in their own role in the seed value chain. They apply defined methodologies to meet national and international standards, and in many countries are supported by national legislation and oversight. The formal SS usually controls seed multiplication to assure sufficient quantities of breeder, foundation and certified seed of guaranteed quality. The informal SS, also called the farmers' SS, is operated solely by farmers involved in local seed selection, production and diffusion. Production and dissemination takes place at farmer and community level (Louwaars, 2007). In developing countries, 60-100% of the farmers depend fully on the informal SS for their planting material, despite all investments in the development of a formal SS. Smallholder farmers in general request relatively small quantities of seed, live in remote areas, and have very limited budget for seed purchases. As a market oriented business, the private sector does not tend to offer a wide range of varieties for crops, it does not provide seed for minor crops due to limited demand, and it is not able to distribute small quantities of seed to remote areas (Almekinders and Louwaars, 2002).

Cowpea (*Vigna unguiculata*) is an important legume in West and Central Africa, providing vital proteins for human consumption and fodder for livestock (Uzogara and Ofuya, 1992). The grains are utilized in a wide variety of local dishes and have great potential to fortify food. Alene and Manyong (2006) suggested that adaptation of improved varieties can further enhance cowpeas' impact on rural live. Nigerian farmers planting improved cowpea varieties were more food secure and had higher income compared with farmers growing local varieties. However, the availability of seed is still a bottleneck for adoption of these new varieties. In Sub Saharan Africa, due to issues described above, farmers cultivating cowpea depend largely on the informal SS as the source of their cowpea seed (DeVries and Toenniessen, 2001). Almekinders et al. (1994) suggested that a combined approach of strengthening the informal SS along with creating and enhancing linkages with the formal SS may act as a vehicle for addressing the issue of availability of improved germplasm. A recent study of cereal SS in Syria showed that improving seed delivery systems can only be successful when actors understand the functioning of the whole SS and know farmers' motivations to choose for certain varieties and seed sources (Bishaw et al., 2011).

The current evidence on farmers' seed production indicate that seed production and storage methods need to be improved to increase seed quality. Nigeria's National Agricultural Seed Council (NASC) published certification standards for cowpea seed. Samples should consist for minimal 98% of cowpea seed, maximal 10 off-type seeds per kg sample, and should have a minimum germination rate of 85%. One of the most important traits is the seeds' ability to create a uniform field stand of the desired plants (Van Gastel et al., 2002), which is mostly referred to as seed vigour. Especially under the suboptimal environmental conditions of most smallholder farmers, vigorous seeds are required to achieve high field emergence and a uniform crop stand (Ghassemi-Golezani and Mazloomi-Oskooyi, 2008). Cleaning cowpea seed samples had a positive effect on field emergence, especially when small and broken seeds were removed (Asiedu et al., 2003). A specific threat for cowpea is the storage pest *Callosobruchus maculatus* F., commonly called weevil. Weevils cause characteristic holes in cowpea, affecting seed weight and viability whilst enabling the introduction of pathogenic fungi and bacteria into the seed. Farmers traditionally store their seeds in polyethylene bags, but storage pests forced them to look for alternatives like metal drums, double bagging and the Purdue Improved Cowpea Storage (PICS) bags (Moussa et al., 2011). Although airtight storage technologies like the PICS bags can successfully suppress weevil damage, most farmers are still using inferior storage bags (Sanon et al., 2011).

The project "Promoting Sustainable Agriculture in Borno State" (PROSAB) addressed the seed quality problem from 2004-2008. The project identified the lack of quality seeds as a major constraint for agricultural production, contributing to food insecurity in Borno State, Nigeria. PROSAB tried to strengthen the informal SS of cowpea by introducing improved varieties, in combination with initiatives and incentives to enhance local seed production. A community-based seed scheme was implemented by training farmers in seed production. Farmers participated in a workshop to be trained in all relevant aspects of seed production including plot selection, land clearing, pest and weed control, removal of off-type and diseased plants, harvesting and storage methods. Project staff assisted farmers with selecting appropriate plots to avoid outcrossing or mixing with other varieties, or problems with witch weed or drainage problems. Furthermore, farmers received foundation seed and were registered as seed producers by the National Seed Council (NSC). NSC officers inspected the field for certification twice a season, and made sure that farmers implemented the required procedures for seed production. The project turned out to be successful in terms of an increased seed availability of improved varieties (Amaza et al., 2010).

The projects' success in terms of cowpea seed quality remains unevaluated. An assessment is crucial for stakeholders and donors targeting to invest in the cowpea SS. This research analysed whether the PROSAB seed producers can match the formal SS in terms of seed quality, and identified the most successful elements of the project approach. The first objective of the study was to evaluate the quality of farmer produced seed. A comparison was made between farmer's seed, samples from seed companies and as a benchmark with samples of the foundation seed that farmers received to start up the seed production. The second objective of the study was to evaluate the effect of individual project elements on cowpea field emergence to establish the most important characters contributing to uniform emergence and optimised crop establishment.

Materials and Methods

General approach

Seed samples were collected from seed producing farmers, seed companies and foundation seed in Borno and Kaduna State, Nigeria. Farmers were interviewed during seed collection about factors that might influence seed quality, including inputs, storage and certification. The seed quality parameters assessed included physical purity, germination rate and field emergence. A multiple regression model was used to analyse the relation between farmer practices and field emergence. In the following sections, we will describe the plant material used, and the methodology of the field experiments and the survey in detail.

Table 1. Overview of cowpea seed samples collected from farmers. Farmers received foundation seed between 2001 and 2009, and multiplied their seed for 1-9 seasons until our sampling in 2009 or 2010.

Variety	Number of multiplications by farmer	No. of samples taken	
		2009	2010
IT89KD288	1	2	0
	2	2	2
	3	2	2
	4	2	2
	5	2	1
	6	0	1
IT89KD391	1	3	3
	2	3	3
	3	3	3
	4	3	3
	5	0	1
IT93K452-1	1	3	0
	2	3	3
	3	3	3
	4	2	3
	5	3	2
	6	2	3
	7	0	2
	8	3	0
	9	0	3
Total		41	40

Plant material

In May 2009 and April 2010, 2-3 months prior to planting, 41 and 40 samples of between 2.5-5.0 kg each were collected, respectively, from seed producing farmers in Borno and Kaduna State (Table 1). Kaduna State is located in Northern Nigeria comprising the Southern and Northern Guinea Savanna zone. Borno State forms the most north eastern part of Nigeria, and also includes the dryer Sudan Savanna zone. Three improved cowpea varieties were selected based on their maturity type and popularity among farmers. The late-maturing variety IT89KD288 and medium-maturing IT89KD391 were most popular in Borno State, the former PROSAB area. The very early maturing variety IT93K452-1 was the most preferred variety in Kaduna State. From 2001-2009, farmers received foundation seed only once, and kept multiplying the seed until the year we collected the seed samples. The number of seasons that farmers multiplied their seed on farm was indicated by “multiplication”. Comparing multiplication 1-9 within a variety showed the effect of seed recycling on seed quality. Six samples were purchased from seed company outlets in Kano, Borno and Kaduna State; two samples in 2009 and four in 2010. Foundation seed from each variety included in the study was collected from the International Institute of Tropical Agriculture (IITA). All seed samples were stored at room temperature between collection and planting time to mimic storage conditions of farmers buying seed from their colleagues.

Table 2. Descriptive summary of regression variables.

Variables	Description
Measured variables	
Off-types	Seeds visibly different from expected variety (colour/shape)
Broken seeds	All seeds that are broken, or missing an embryo
Weevil damage	All seeds damaged by cowpea weevils
Other damage	All damaged seeds except broken seeds and seeds with weevil damage
Germ2	Germination rate after 2 days
Total germination	Germination rate after 7 days
Femergence	Field emergence after 14 days
Survey variables	
Year	Year of seed sample collection (2009/2010)
State	State where sample was collected (Borno / Kaduna)
Multiplications	Number of on-farm seed multiplications
Field inspection	Field inspection by extension agents for certification
Selection	Farmers selected good cowpea pods before or during harvest to provide seed
Storage	Method and location to store cowpea seed from harvest until sale or planting
Drum	Metal, tightly closed drum, used to store cowpea seed or grains
Polybag	A single-layer polypropylene bag
Double bag	One inner high density polyethylene bag surrounded by an outer polypropylene bag
PICS bag	Purdue Improved Cowpea Storage (PICS) bag; two inner high density polyethylene bags surrounded by an outer polypropylene bag
Store	Storage location only used for storage activities
Room	Storage location also used for non-storage activities

Experiments

Physical purity was measured by sorting 1 kg of each seed sample. The composition of the seed lot was divided into categories of pure seed, other seeds and inert matter as described by the International Seed Testing Association (ISTA) standards for pure seed (Mannino et al., 2010). Instead of two separate analyses for physical purity and other species count as described by ISTA, all analyses were done on one sample of 1 kg. The procedure for seed damage, off-types and hundred-seed weight deviated from the ISTA standards to analyse the effects on field emergence in detail. Off-types were removed by visually observed differences in shape and colour. Damaged seeds were divided into broken seeds, weevil damage, and other damage. Off-type seeds with seed damage could belong to both categories, but were always categorized as off-type. Inert matter and other crop and weed seeds were also measured separately. Hundred-seed weight was measured from the total sample prior to sorting, but inert matter, broken seeds and other crop seeds were replaced with intact seeds from the sample. The definitions of the various categories used in the sorting process are shown in Table 2. The results of farmers, seed companies and foundation seed samples were compared and tested for significance with the two-sided t-test in MS Excel®.

Germination rate was determined based on unsorted seeds with the exclusion of materials farmers would not plant: broken seeds, very small seeds and other crop and weed seeds. Broken seeds are considered to be inert matter by the NASC, and very small seeds are not suitable for use in germination tests. Germination rate was determined with the paper towel method on 400 seeds as described by ISTA. Fifty seeds were rolled in one paper towel and put vertically in a cup. The cups holding the eight paper towels were filled with 1 cm water and placed into an incubator at 27 ^{o}C. The paper towels were unfolded every 24 hours to count and remove the germinated seeds, up to 7 days after initiation of testing. Although ISTA germination standards for cowpea only require observation on day 5th and 8th, all non-germinated seeds appeared to be disintegrated after 7 days, making observation at day 8th unnecessary. Germinated seeds were counted daily instead of only twice to allow analysis of germination speed as a parameter for seed vigour.

Field emergence was tested in two seasons with 41 samples in 2009, and 35 samples in 2010. Although 40 samples were collected in 2010, some samples had to be omitted due to insufficient seed delivery of five farmers in 2010. Field was measured under rain fed conditions at Minjibir farm (12808.9970 N, 8839.7330 E) in Kano State, Nigeria. The field was planted in July, the time that most farmers planted cowpea. The farm lies in the Sudan Savanna agro-ecological zone (Boukar et al., 2011). The field was harrowed and ridged with inter ridge space of 0.75 m. The field was divided in three replicates, containing 50 plots of 5.0 m × 4.5 m. Three seeds were planted per hole on an intra-ridge space of 20 cm. The number of planted seeds was estimated by multiplying number of seeds per hole and planting holes. Field emergence was determined by counting the emerged seedlings after 14 days, divided by the number of planted seeds times 100%. To improve plant stand, the number of seeds per hole was increased from three to four in 2010.

Survey

The 40 farmers contributed 81 seed samples. Thirty-two farmers delivered one sample in 2009 and one in 2010, while four of them could even provide seed of a second variety. One farmer delivered three samples, and eight farmers only 1 sample. Only the 14 farmers who lived in Borno State participated in the seed production workshop and benefited from the support of the PROSAB project. The other 26 seed producers from Kaduna State lived outside the project area. The survey consisted of 22 multiple choice questions divided into three categories: farmer's personal information, background of the seed, and the seed production and storage process. Farmer's personal information included the farmer's name and village, including the State and agro-ecological zone the village was situated. To determine the number of on-farm multiplications, farmers were asked the source and year they received "fresh" seed from PROSAB, IITA or another source. Seed production questions included field clearing, fertilizer and agrochemical application. Farmers were asked whether they removed off-type and diseased plants prior to harvest to maintain seed quality or whether they carried out "selection at harvest" by selecting the best pods during harvest to obtain seed. Most farmers received extension agents for "field inspection" as part of a certification program. Farmers also indicated which storage method they used, as well as placement of storage bags in a separate store solely meant for storage, or in a room in the house that was also used for non-storage activities.

Analysis

The relation between field emergence and germination on day 1-7 was analysed with the Pearson r correlation coefficient, calculated with MS Excel®.

Two multiple linear regression models were tested with stepwise regression in Genstat 13th edition, using only the data of farmer produced seed samples. The two models explained the variance in germination on day 2 (germ2) and field emergence, respectively. The independent variables were storage, broken seeds, weevil damage, other damage, multiplication, year, variety, inspection, 100 seed weight and State (Table 2). The quality of the models was assessed by the $R^2_{adj.}$ and the Akaike Information Criterion (AIC). The AIC compares the relative goodness of fit of the models as a trade-off between complexity and accuracy. To determine the importance of a single variable, the explained variance was calculated for each independent variable. The explained variance was calculated by dividing the sum of squares of the independent variable by the total sum of squares of the model.

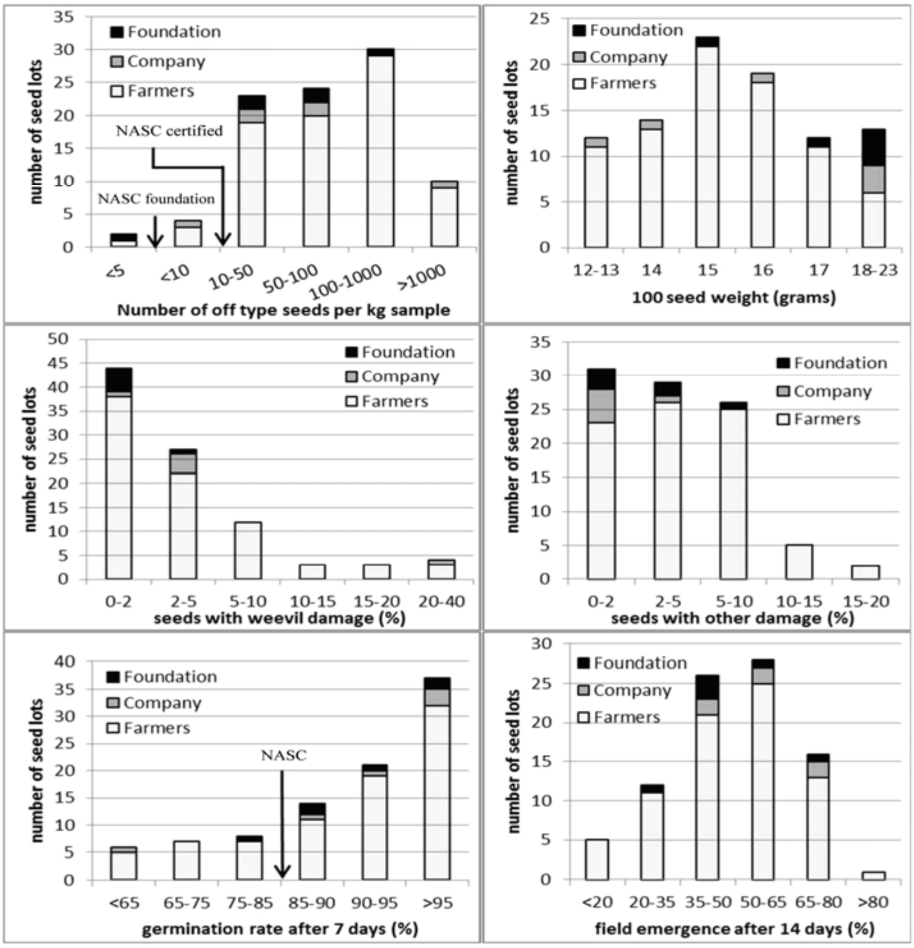

Figure 1. Distribution of farmer produced seed lots, seed company samples and foundation seed for off-type seeds, 100 seed weight, weevil damage, other damage, germination rate and field emergence. Arrows show standards set by the National Agricultural Seed Council (NASC) of Nigeria for the maximum number of off-type seeds and minimum germination rate as indicated for certified and foundation seed.

Results and Discussion

Seed quality

Seed samples from farmers, seed companies and foundation seed were compared for the number of off-type seeds, the percentage seeds with weevil damage and otherwise damaged seeds, 100 seed weight, germination rate and field emergence (Figure 1). Foundation seed had on average the lowest number of off-types (62.2 per kg), followed by seed companies with a mean of 212 per kg and farmers with on average 484 off-types per kg. For comparison, 1 kg of seed with the average 100 seed weight of 15.6 g contained approximately 6400 seeds. On average, farmers' seed had significantly (t-test, P=0.0003) more off-types than foundation seed, but the number of off-types in seed lots of seed companies was not significantly (t-test, P=0.2019) different from that of farmers' seed. The NASC guidelines for seed certification allow a maximum number of off-types per kg seed sample of five and ten seeds for foundation and certified seeds, respectively. Figure 1 shows that only one out of six foundation seed samples met this requirement. The same conclusion is valid for seed companies where five out of six samples exceeded 10 off-type seeds per kg sample. The majority of foundation and seed company samples, four samples each, had between 10-100 off-types per kg seed. One foundation sample had 195 off-types, 39 times the NASC limit, while a company sample exceeded the NASC limit more than 100 times with a total of 1048 off-types per kg seed sample. Only four out of 81 farmers' samples met the NASC guidelines, and 19 samples fell in the next category of 10-50 off-types. Thirty-eight samples had more than 100 off-type seeds. From the ten samples with more than 1000 off-type seeds, nine samples belonged to variety IT89KD288. Seven of these samples had more than 3000 off-type seeds, meaning that approximately 60% of the seeds were off-type.

Seed size of farmers' seed lots were almost normally distributed with 40 out of 81 samples with a hundred-seed weight of 15-16 grams. Foundation seed samples had four samples in the category of heaviest seeds (18-23 g), against three seed company samples. The average 100 seed weight of foundation seed was not significantly (P=0.2438) different from that of seed company samples.

Weevil damage showed a binomial distribution, with 71 out 93 samples having less than 5% seeds with weevil damage. A total of four samples, one foundation and three farmer samples, had no weevil damage at all, while 32 samples had weevil damage between 0.1-1%. Apparently, weevil infestation does not directly have to lead to widespread damage. Foundation seed samples had less weevil damage than seed company samples. One seed company sample even had 31.7% seeds with weevil damage.

Damaged seeds that were not broken or affected by weevils were put into the category "other damage", including heavily damaged seeds as well as seeds with light damage to the seed skin. Other damage ranged from 0-20%, with 60 out of 93 samples having less than 5% other damage. Five out of six seed company samples had less than 2% other damage. Foundation seed samples had more other damage than seed company samples, with even one sample in the category 5-10%. Only farmer seed samples had more than 10% other damage. A comparison with weevil damage showed that the range of other damage was smaller, but that more samples had 5-15% other damage. Foundation samples had less weevil damage compared with seed company samples, while company samples outperformed foundation samples in other damage.

The germination rate ranged from 59-100%, with an average of 89.4%. The germination rate of farmers seed was not significantly (t-test, P=0.4684) different from foundation seed, neither from seed company (t-test, P=0.9746) samples. Germination rate had a binomial distribution with 37 samples having over 95% germination. Five out of six seed company samples met the NASC guidelines of 85% germination, but the remaining sample had a germination rate of only 60%. The only foundation seed sample that failed the NASC standard had a germination rate of 84%, only 1% less than the required percentage. Nineteen out of 81 farmer samples did not meet the NASC standard for total germination.

Field emergence was normally distributed ranging from 8.6% to 88.1%, with an average of 49.5%. Five seed samples of farmers did not have enough seeds to plant, leaving a total of 88 samples. Five farmer samples had less than 20% germination, meaning that only 1 out of 5 seeds could produce a viable seedling. Forty-six of 76 farmer samples had a field emergence between 35-65%. Only 14 out of 88 farmer seed samples had a field emergence of more than 65%. Foundation seed was not significantly (t-test, P=0.7106) different from farmer produced seed, while seed company samples performed a little better. Four out of six seed company samples had more than 50% field emergence, against two out of six for foundation seed. Seed company samples had on average the highest field emergence of 58.2%, but that was not significantly different from that of farmers' (t-test, P=0.1192) or foundation (t-test, P=0.1838) seed samples.

Table 3. Pearson r correlation coefficient between field emergence and germination rate (germ) on day 1-7, and the germination on day 1-7 as percentage of the number of seeds germinated on day 7.

	germ1	germ2	germ3	germ4	germ5	germ6	germ7
Correlation coefficient with field emergence	0.78	0.83	0.75	0.76	0.76	0.76	0.76
Average % of germinated seeds	45.5	88.5	95.8	98.8	99.9	100.0	100.0

The average field emergence of 49.5% was almost 40% lower than the average germination rate. Ellis and Roberts (1980) related the gap between germination rate and field emergence to seedbed conditions and seed viability. Storage time and suboptimal storage conditions increased the time barley seeds needed to germinate, which negatively affected field emergence. Many different factors including seed production conditions, physical purity and seed health affect seed vigour. Tests such as tetrazolium, accelerated ageing and electric conductivity are well described to test seed vigour (Pekşen et al., 2004), but these tests require laboratory facilities. In contrast, germination speed can be easily observed by farmers or extension agents under very basic circumstances. Table 3 showed the correlation coefficients between field emergence and the cumulative germination on day 1-7. The correlation with germination on day 1 was 0.78, which increased to 0.83 on day 2, followed by a decrease to 0.75 on day 3. The correlation with germination rates on day 4-7 remained stable at 0.76. The highest correlation coefficient was with germination rate on day 2 when 88.5% of total germination was reached. The remaining 11.5% that germinated between day 3-7 was of little importance for field emergence. The correlation coefficient for germ1, with only 45.5% of the seeds germinated, was higher for germ3, emphasizing the importance of seed viability over total germination. Germ2 was more important for cowpea field emergence than total germination, because it had the highest correlation coefficient with field emergence. An additional advantage for Nigerian seed producers would be that germ2 can be determined in two days instead of seven, saving time and costs. The NASC is recommended to consider reviewing the standards for certified cowpea seed, and replacing total germination rate by germination on day 2.

Table 4. Two multiple regression models predicting germination rate at day 2 and field emergence with input, production and storage factors. The second and fourth column shows the explained variance per factor as percentage of the total variance in the model. The regression estimates of all factors are presented in columns 3 and 5.

	Model Germ 2			Model Field emergence		
$R^2_{adj.}$	63.1			70.9		
Akaike Information Criterion (AIC)	364			357		
Independent variables:	Explained variance	Regression estimates		Explained variance	Regression estimates	
Constant		99.6			16.6	
storage PICS		0	a		0	a
storage double bag room		1.6	a		-2.8	a
storage double bag store		-2.4	a		-18.6	b
storage polybag room	20.7	-2.3	a	25.4	-17.6	b
storage polybag store		-0.2	a		-11.9	b
storage drum		-14.9	b		-20.6	b
broken seeds	2.4	-0.48		4.4	-0.96	
weevil damage	12.0	-0.53		11.8	-0.65	
other damage	9.6	-0.76		8.6	-0.88	
multiplication 1		0	a		0	ab
multiplication 2		0.7	a		-1.1	a
multiplication 3		-0.9	a		2.9	ab
multiplication 4	11.7	2.9	a	11.6	6.8	bc
multiplication 5		0.7	a		15.7	c
multiplication 6&7		4.7	a		4.2	ab
multiplication 8&9		20.6	b		26.6	d
year 2010	4.7	7.0		5.0	13.6	
variety IT89KD 288		0.0	a			
variety IT89KD 391	8.0	1.1	a			
variety IT93K 452-1		-16.3	b			
inspection	2.6	-9.82				
100 seed weight				7.3	3.5	
state				3.6	-11.0	
Total explained variance	71.7			77.7		

Regression coefficients with different letters differ significanly (P=0.05).

Regression analysis

Field emergence among farmer produced seed samples was poor, considering that 49% of the samples had a field emergence below 50%. Additional analyses were carried out to identify options for improvement. Stepwise multiple linear regression models were analysed predicting germ2 and field emergence with input, production and storage factors. The Akaike

Information Criterion (AIC) was used to select the best model for germ2, and the best model for field emergence. The AIC enables to compare models based on the goodness of fit, but penalizes for over fitting by adding more parameters (Burnham and Anderson, 2002). The selected field emergence model had an R^2_{adj} of 70.9, while the selected Germ2 model had an R^2_{adj} of 63.1 (Table 4).

The single most important factor in the two models was storage, explaining 20.7% of the variance in germ2 and 25.4% of the variance in the field emergence model. The influence of storage might even be underestimated by the model, because the effect of storage methods that suppress weevil damage was captured by the category weevil damage. The traditional cowpea storage in low density polyethylene bags frequently results in severe seed damage due to storage pests, adversely affecting seed viability. Cowpea weevils (*Callosobruchus maculates*) can be killed effectively by insecticides applied during seed storage. However these chemicals have a negative effect on human health if consumed, and the application is therefore limited. Some farmers stored their cowpeas in metal drums that are tightly sealed to create a low oxygen environment suppressing weevils. The double bagging system applies an inner, high density polyethylene bag to create an airtight environment, with an outer polybag to protect the inner bag from damages. Use of only one inner bag might result in penetration of the bag during filling or movement of the bag, allowing oxygen to enter (Moussa et al., 2011). The Purdue Improved Cowpea Storage (PICS) project introduced an airtight storage technology of two high density polyethylene bags, tightly sealed and placed in a nylon bag. The PICS bags effectively arrest insect development, limiting any seed damage while having no impact on germination rates (Sanon et al., 2011). Drums, double bagging and PICS bags are all supposed to be airtight, but drums are more expensive, need to be completely filled to limit the volume of oxygen, and are difficult to transport when filled. Samples stored in drums underperformed in both models with a 14.9% lower germ2 and 20.6% lower field emergence compared with PICS bags. These samples had significantly (P=0.05) lower germ2 than all other storage methods. PICS bags and double bag room outperformed all other methods on field emergence. The superiority of PICS bags over polybags was expected, because it has more protective bag layers reducing the risk of penetration and harm from outside. The significant difference between double bag room and double bag store in field emergence was more remarkable. Room was superior over store for double bag storage, but store was a better location for polybags, although the difference was not significant (P=0.05). On top of that, store was supposed to be more suitable for storage than a room also used for other activities. Additional research is recommended to investigate interaction between storage location and storage method. Farmers are advised to store their cowpeas in PICS bags, because of the poor performance of double bag in store.

Seed damage was represented in the model by the categories broken seeds, weevil damage and other damage. Altogether, they explained 24-25% of the variance in both models. Weevil damage was the most important factor among them, followed by other damage and broken seeds. One percent more weevil damage lead to 0.53% lower germ2 and 0.65% lower field emergence. Remarkably, the effect of 1% other damage was bigger with a regression coefficient of -0.76 for germ2 and -0.88 for field emergence.

Broken seeds were not included in the germination test, and were not supposed to be planted either. However, the possibility that damaged seeds were planted by some less skilled field workers cannot be out ruled. Nonetheless, broken seeds explained 2.4% of the variance in the germ2 model, and even 4.4% in the field emergence model. Broken seeds had a devastating effect on field emergence with a regression coefficient of -0.96. Therefore, broken seeds might be an indication for poor seed processing in general. Seed damage had more effect on field emergence than on germ2, considering that the regression coefficients for all three damage components were lower for germ2 compared with field emergence. Germ2 is mostly depending on the vitality of the embryo, and was tested in paper towels. Field emergence requires the embryo to emerge from the soil, a process that takes several days in which damaged seeds are not protected by the seed skin.

Variety explained 8.0% of the variance in the germ2 model. Variety IT93K452-1 had with 16.3% significantly (P=0.05) lower germ2 than variety IT89KD288. The underperformance is partly compensated by multiplication 8-9, which only contained samples of variety IT93K452-1.

The difference between planting season 2009 and 2010 explained 4.7-5.0% of the variance in the two models. The 2010 season had a 7.0% higher germ2, and 13.6% higher field emergence than season 2009. The difference in field emergence might be explained by superior field and weather conditions in 2010.

PROSAB implemented a certification system to ensure seed quality. Seed producers were visited by extension agents to observe production conditions and field isolation, and received a certificate at harvest time. Neither germination rate nor physical purity was measured, so certificates were rewarded solely based on field observations. Although extension agents only rewarded non-legume crops with certificates, field inspections of cowpea were still carried out to check seed production conditions. Only 1 farmer in Borno was not inspected, while 8 farmers in Kaduna State were not visited. Field inspection by extension agents was included in the germ2 model as a factor explaining 2.6% of the variance, where visited farmers had 9.8% lower germ2 than non-visited farmers. The implemented certification system of PROSAB failed to guarantee cowpea seed quality. Personal observation during seed collection showed that farmers were not willing to pay for certification either. Moreover, farmers' perception of the certificate was that they were certified as farmers, not for a specific crop or a season. It is unknown whether users of seed requested a certificate, or that they merely relied on the reputation of the farmer, physical observation of the seed, or experience with the seed producer during previous years.

Seed weight and State were only selected in the field emergence model. Hundred-seed weight among farmer produced samples varied from 12.1-20.7 gram with a mean of 15.3 gram. The average 100 seed weight of IT93K452-1 was with 14.4 almost 2 g lower than IT89KD288 (16.3 g) and IT89KD391 (16.7 g). One gram increase in hundred-seed weight led to 3.5% increase in field emergence. These results were consistent with the results of cowpea seed processing with a gravity separator in Ghana. Cleaned cowpea seed had a higher 1000 seed weight, higher germination rate and a higher field emergence (Asiedu et al., 2003).

Regression model 2 showed that farmers in Borno State had 11% higher field emergence than farmers from Kaduna State. State was a minor factor in the regression model with only 3.6% of the explained variance. In contrast with Borno State, farmers in Kaduna did not benefit from the support and training in seed production. So the differences between States are an indication that the PROSAB project had a positive influence on seed quality. Unfortunately, a baseline study of seed quality in Borno State prior to PROSAB was not available to prove the project effect.

The effects from State and variety are partly intertwined. Variety IT93K452-1 is significantly (P=0.05) different from the other varieties in the germ2 model, but absent in the field emergence model. However, variety

IT93K452-1 could only be collected in Kaduna State, which performed significantly worse than Borno State in the field emergence model.

Amaza et al. (2010) considered seed recycling to be one of the problems causing low yields in Borno State, describing that the farmer SS delivered seeds that were "exhausted" after generations of recycling, because the system does not replace the seed frequently with foundation or certified seed. Although the concept of seed recycling is mostly referring to genetics or pathology, it might also affect seed viability and field emergence. Multiplication was the third most important factor, explaining 11.6-11.7% of the variance. Multiplications 6-7 and 8-9 were grouped, because of the small number of samples in these multiplications. In contrast with the expectation that subsequent multiplications would lead to reduced germination speed and field emergence, multiplication 8-9 had a significantly higher germ2 and field emergence than multiplication 1. Multiplication 5 had a significantly (P=0.05) higher field emergence of 15.7% compared with multiplication 1, but this difference did not appear in germ2. Therefore, the results show no evidence for a negative effect of seed recycling effect on seed viability or field emergence.

Multiplication 8-9 was significantly (P=0.05) different from the other multiplications in both models, with a field emergence of 26.6% higher than multiplication 1. The three samples of multiplication 8 were collected in 2009. In 2010, the same three farmers multiplied their seed one more season, resulting in samples of multiplication 9. Multiplication 8-9 could only be collected from variety IT93K452-1 from the same village in Kaduna State, which does not belong to the PROSAB area. Multiplication 8-9 had a 20.6% higher germ2 than the reference level multiplication 1, but this was partly compensated by the negative regression coefficient (-16.3) of variety IT93K452-1. In the field emergence model, the superiority of multiplication 8-9 is partly compensated by 100 seed weight. Variety 452-1 had an average 100 seed weight of 14.4 g, while varieties IT89KD288 and IT89KD391 had a 100 seed weight of 16.3 and 16.7 g, respectively. Two grams lower seed weight corresponds to 7.0% lower field emergence for variety IT93K452-1, but field emergence of multiplication 8-9 was 26.6% higher than multiplication 1.

Conclusions

The PROSAB project trained and supported cowpea farmers to boost the availability of high quality seeds. Further investments in the informal seed system can only be justified if farmers can deliver high quality seed.

Farmers' produced seed on average had significantly more off-types (t-test, P=0.0003) compared with foundation seed, but on average germination (t-test, P=0.4684) and field emergence (t-test, P=0.7106) were not significantly different. In comparison with seed company samples, there were no significant differences on these four criteria for farmers produced samples. The major problem is that 97% of the tested samples failed to meet the NASC certification standards, including all seed company samples. Seed quality is therefore a problem in both the formal and informal sector. The regression analysis showed that a project like PROSAB can effectively improve seed quality. The regression model showed that farmers in Borno had 11% higher field emergence, ignoring other effects like seed damage and storage. Field inspection for certification purposes had a negative effect on germ2, and was not selected as a relevant factor for field emergence. Reducing seed damage and proper storage had more success. Ten percent more weevil damage led to 6.5% lower field emergence, and ten percent more other damage reduced field emergence by as much as 8.8%. Storing cowpea seeds in PICS bags increased field emergence up to 17.6% compared to polybags in a room. These results indicate that investments in informal cowpea seed systems yield significant benefits. Seed quality can be improved significantly by training farmers in seed production, emphasising strict seed cleaning and introducing appropriate storage methodologies. Other benefits of projects like PROSAB include the introduction of improved varieties and a dramatic increase of seed production in the region (Amaza et al., 2010). Further research is required to verify the results for other crops and areas. Our recommendation would be for the NASC to review the standards for foundation and certified seed and to enhance testing or certification. Germ2 is a better predictor of field emergence then germination after 7 days, and is faster and therefore cheaper to determine. This could be cost effectively and easily implemented in testing protocols. Further research to assess the effect of multiplication on field emergence in other crops and regions is recommended.

References

Alene, A.D., Manyong, V.M., 2006. Endogenous technology adoption and household food security: the case of improved cowpea varieties in Northern Nigeria. Quarterly Journal of International Agriculture. 45, 207-226.

Almekinders, C.J.M., Louwaars, N.P., De Bruijn, G.H., 1994. Local seed systems and their importance for an improved seed supply in developing countries. Euphytica. 78, 207-216.

Almekinders, C.J.M., Louwaars, N.P., 2002. The importance of the farmers' seed systems in a functional national seed sector. Journal of New Seeds. 4, 15-33.

Amaza, P.S., Udo, E.J., Abdoulaye, T., Kamara, A.Y., 2010. Analysis of technical efficiency among community-based seed producers in the savannas of Borno State, Nigeria. Journal of Food, Agriculture and Environment. 8, 1073-1079.

Asiedu, E.A., Danquah, O.A., Adusei-Akowuah, P., Van Gastel, A.J.G., 2003. Improving maize and cowpea seed quality through seed processing. Tropical Science. 43, 167-169.

Bishaw, Z., Struik, P.C., Van Gastel, A.J.G., 2011. Wheat and barley seed system in Syria: farmers' varietal perceptions, seed sources and seed management. International Journal of Plant Production. 5, 323-347.

Boukar, O., Massawe, F., Muranaka, S., Franco, J., Maziya-Dixon, B., Singh, B., Fatokun, C., 2011. Evaluation of cowpea germplasm lines for protein and mineral concentration in grains. Plant Genetic Resources: Characterization and utilization. pp. 1-8.

Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel interference: a practical information-theoretic approach. Springer science and business media, New York, USA.

DeVries, J., Toenniessen, G., 2001. Securing the harvest: biotechnology, breeding and seed systems for African crops. CAB international. ISBN 0851995640.

Ellis, R.H., Roberts, E.H., 1980. The quantification of ageing and survival in orthodox seeds. Seed Science and Technology. 9, 373-409.

Van Gastel, T.J.G., Gregg, B.R., Asiedu, E.A., 2002. Seed quality control in developing countries. Journal of New Seeds. 4 (1/2), 117-130.

Ghassemi-Golezani, K., Mazloomi-Oskooyi, R., 2008. Effect of water supply on seed quality development in common bean (*Phaseolus vulgaris var.*). International Journal of Plant Production. 2, 117-123.

Haque, A.H.M.M., Akon, M.A.H., Islam, M.A., Khalequzzaman, K.M., Ali, M.A., 2007. Study of seed health, germination and seedling vigor of farmers produced rice seeds. International Journal of Sustainable Crop Production. 2, 34-39.

Louwaars, N., 2007. Seeds of confusion; the impact of policies on seed systems. PhD dissertation, Wageningen, the Netherlands. ISBN 9789085047933.

Mannino, M.R., Taylor, J., Jones, S., 2010. ISTA handbook on pure seed definitions: edition 2010. International Seed Testing Association. www.seedtest.org.

McGuire, S., 2005. Getting genes: Rethinking seed systems analysis and reform for sorghum in Ethiopia. Wageningen University Thesis, ISBN 9085041791.

Moussa, B., Lowenberg-DeBoer, J., Fulton, J., Boys, K., 2011. The economic impact of cowpea research in West and Central Africa: a regional impact assessment of improved cowpea storage technologies. Journal of Stored Products Research. 47, 147-156.

Pekşen, A., Pekşen, E., Bozoğlu, H., 2004. Relationships among some seed traits, laboratory germination and field emergence in cowpea (*Vigna unguiculata* (L.) Walp.) genotypes. Pakistan Journal of Botany. 36, 311-320.

Sanon, A., Dabiré-Binso, L.C., Ba, N.M., 2011. Triple bagging of cowpeas within high density polyethylene bags to control the cowpea beetle *Callosobruchus maculates* F. (Coleoptera: Bruchidae). Journal of Stored Products Research. 47, 210-215.

Uzogara, S.G., Ofuya, Z.M., 1992. Processing and utilization of cowpeas in developing countries: a review. Journal of Food Processing and Preservation. 16, 105-147.