academicJournals

Vol.10(1), pp. 1-10, January 2018
DOI: 10.5897/JAERD2017.0907
Articles Number: 3EDE73C67061
ISSN 2141-2170

http://www.academicjournals.org/JAERD

Journal of Agricultural Extension and Rural Development

Full Length Research Paper

Assessment of on-farm storage of Bambara groundnut (*Vigna subterranea*) and roselle grains (*Hibiscus sabdariffa*) in Niger

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Received 10 August, 2017; Accepted 24 November, 2017

The objective of this study was an assessment of on-farm storage practices for Bambara groundnut and roselle grains in Niger. It is based on a random sample of 164 farmers producing both crops in the Dosso and Maradi regions using a semi-structured questionnaire. Analysis of the data used Probit regression and budgeting. Fifty four percent of respondents use some type of potentially hermetic container for storage of Bambara groundnut and 46% use that type of container for roselle. Potentially, hermetic containers include metal drums, plastic jugs, and single, double and triple layer plastic bags. About 67% of the quantity of Bambara groundnut stored was in potentially hermetic containers and 58% of roselle. Triple layer Purdue Improved Crop Storage (PICS) bags were used mainly by Bambara groundnut farmers storing larger quantities. While only about 10% of the respondents reported storing Bambara groundnuts in PICS bags. The quantity stored by those respondents is quite large, so about 39% of the total quantity of Bambara groundnut stored by the respondents was stored in PICS bags. For roselle, PICS bags were used by 4% of respondents for only 3% of quantity stored. Profitability of using PICS bags for one or two years is comparable to that achieved with the common practice of storing in woven bags with insecticide. While PICS bags use does not increase profitability substantially compared to insecticide use, it does allow the producer to reduce pesticide exposure and the associated health risks.

Key words: Adoption, Bambara groundnut, hermetic storage, profitability, roselle.

INTRODUCTION

While agriculture in much of the world has focused on a few crops, African agriculture has a diversity of locally and regionally important crop species. Little research is done on those crops and the post-harvest aspects are especially neglected. This study focuses storage practices and storage economics for two of those

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regionally important crops, Bambara groundnut (*Vigna subterranea*) and roselle (*Hibiscus sabdariffa*). Bambara groundnut is mainly grown as a subsistence crop, mostly by women and generally on abandoned or fallow land.

Roselle is a versatile broadleaf plant that is often intercropped with cereals. Roselle leaves are used as a vegetable, the flowers are used for herbal tea and the seeds are used as a high protein ingredient in sauces. Bambara groundnut and roselle are important food security crops in West Africa and add resiliency to the food system. In sub-Saharan Africa, Bambara groundnut ranks third among cultivated legumes after peanuts (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) (Hampson et al., 2000). Bambara groundnut cultivation has several advantages in that it can give acceptable yields on poor soils and with a low rainfall. Nutritionally, it is superior to other legumes and is a preferred food source by many individuals. In addition, the plant has the ability to capture and fix atmospheric nitrogen contributing thus increasing yields of subsequent crops.

Bambara groundnut has potential for industrial processing and increased use for derived products. However, dry seeds are very difficult to cook, requiring more time (45 min for fresh seeds; 1 to 3 h for dry seeds) and energy (Berchie et al., 2010) than other grain legumes. Grain yields are estimated between 650 and 850 kg ha^{-1} with significant variations between the different countries in sub-Saharan Africa (Ajayi and Lale, 2001).

In Niger, the Bambara groundnut is usually grown as a monocrop in small areas or in combination with cereals in family fields. It is in most cases harvested before the grains ripen and consumed fresh by the farmers after being boiled or sold directly at the weekly markets, while the remainder is dried and stored for later use as seed, for consumption or for sale. There is a renewed interest by farmers in Niger for Bambara groundnut production. In the year preceding this study (that is, 2012), the production was estimated at 32,228 tonnes against 22,447 tonnes, an average for the five previous years, that is to say an increase of 46% (DSA/MA, 2012). Area planted in 2012 was 70,342 ha.

Roselle is a multipurpose plant with the flowers, leaves and seed used for human consumption and animal feed. This study focuses on the seed. In Niger, the seeds are used to prepare the "Soumbala", an important condiment used to flavor sauces, especially in rural areas. The seeds have a high oil content (16.8%). In some countries, such as Uganda, the seeds are eaten roasted (FAO, 1990). In Niger, the roselle area in 2012 was estimated at 174,857 ha and production of roselle seeds at 32,056 tons. Boureima et al. (2015a, b) describe the cultivation, utilization and research base for both Bambara groundnut and roselle in more detail.

Both Bambara groundnut and roselle are damaged by storage pests. Bambara groundnut seeds are consumed fresh, but a large quantity are stored for later consumption during the year. Grain prices are relatively high in the post-harvest period because demand exceeds supply. However, the major constraint to an increased and sustainable consumption of Bambara groundnut remains high with losses due to pest infestations during storage (Ayamdoo et al., 2013). According to Golob et al. (1996), the destruction of the seed by insects starts in the fields, but takes place mostly during storage.

Weevils (Coleoptera: Bruchidae) are the most important destructive insects for stored grain legumes in the tropics (FAO, 2009). Various weevils also damage roselle grains in storage. These insects infest seeds in the field and continue to multiply during storage (White, 2001). Losses caused to stored grains by these insects are very important and can reach 100% in the case of a *Callosobruchus maculatus* F. infestation, the most common weevil in hot regions (FAO, 2009). Experimental studies under controlled conditions showed that female weevils can lay more than 100 eggs and a generation of only one month causes infestations to increase exponentially until the complete destruction of the stock in a few months (Dick and Credland, 1984). In an experimental study, Maina et al. (2011) reported that the severity of damage caused by *Callosobruchus subinnotatus* is higher starting from the third month of Bambara groundnut seeds storage and reports that the longer the storage term is, the more important the damage is because of the increase spawning and adult emergence of *C. subinnotatus*. Damage by bruchids in the field before harvest has rarely been reported. For Bambara groundnut, Amuti and Larbi (1981) recorded an average loss of 3.7% after 5 months of storage in Ghanaian local conditions, while Golob et al. (1998) reported Bambara groundnut seed losses exceeding 20%. Baoua et al. (2015) reported losses of 61.8% for Bambara groundnuts and 83.9% due to *C. maculatus* and *C. subinnotatus* in Niger after 7 months of storage without treatment. In Niger, farmers and traders traditionally use indigenous methods for the storage of Bambabra groundnut, often storing smaller quantities in pod form. Compared to large farmers and traders who use jute bags and granaries, small farmers use drums and jars for their stocks (Chougourou and Alavo, 2011).

During the harvest period, the supply of both Bambara groundnut and roselle is high compared to the demand, which leads to lower prices, but after the harvest season the supply of both grains is erratic and prices fluctuate. In general, the price fluctuations between periods of harvesting and consumption allow farmers and buyers to capture gains from storage investment (Jones et al., 2011a, b). However, many small farmers do not take advantage of price seasonality in marketing agricultural products because many are obliged to sell some or all of their crop immediately after harvest due to cashflow constraints or to repay debt or simply because they do not have adequate storage systems to protect their harvest until a more favorable sale period (Stephens and

Table 1. Villages sampled in the three regions of Niger.

Village	Longitude	Latitude	Region
Mourin Dan Dounia	7.57	13.60	Maradi
Milli (Madoua)	7.88	13.47	Maradi
Magami	7.54	13.42	Maradi
Kore	7.95	13.79	Maradi
Debi	8.20	13.78	Maradi
Zigaya	9.23	13.76	Zinder
Fotoro Bougaje	9.20	13.76	Zinder
Baoure	9.23	13.56	Zinder
Angoual Anne	8.94	12.92	Zinder
Ara	8.94	13.00	Zinder
Guesse Beri	3.14	13.23	Dosso
Saboudey	3.39	13.25	Dosso
Carre Roubouki	4.08	13.48	Dosso
Kiria	3.85	14.05	Dosso
Angoual Saoulo	3.96	13.67	Dosso
Darogi Dambo	3.93	13.49	Dosso

Barrett, 2009). Delaying sale of agricultural products to the post-harvest period when prices are rising forces farmers to cover current expenses from alternative sources of income (Jones et al., 2011a).

While traditional storage methods are often ineffective for Bambara groundnut and Roselle grain, and have loss rates up to 100% in some cases, improved storage techniques, especially hermetic methods, allow a significant reduction in storage losses. Purdue University's project for improved cowpea storage (PICS) has implemented the wide dissemination of the triple bagging method since 2007. This technique has proved to be very effective for the conservation of cowpea and economically profitable for small farmers. These farmers were ahead of researchers testing hermetic methods with products other than cowpea, particularly in this case with Bambara groundnut.

The overall objective of this study was an assessment of the on-farm storage methods used by farmers producing Bambara groundnuts and roselle in Niger. The specific objectives were to: (i) describe how these seeds are currently being stored and sold; (ii) identify seasonal price fluctuations of Bambara groundnut and roselle seeds and whether these changes are significant enough to justify storage; (iii) assess the added value of the use of Purdue Improved Crop Storage (PICS) bags compared to the common storage methods, and (iv) determine key factors influencing the PICS adoption decision.

METHODOLOGY

To achieve the objectives of this study, surveys were conducted in three regions of Niger, namely Dosso, Maradi and Zinder, during the month of July 2013. Over 80% of the production of Bambara groundnut and roselle in Niger occurs in these three regions. In the region of Dosso, 6 villages belonging to three different rural communities (Arewa, Dogondoutchi and Dosso) were targeted while in Maradi, 5 villages belonging to three rural communities (Gazaoua, Aguié and Tessaoua) were covered by the survey. In Zinder, 5 villages spread in two rural communities (Mirriah and Magaria) were selected. A total of 164 respondents were interviewed: Dosso, 65; Maradi, 50; and Zinder 49.

A 5 part questionnaire was developed. The first part concerns general information (region, town, site, etc.), the second is related to socio-economic characteristics of farmers (name, sex, age, status, experience, etc.), the third part deals with planted areas and production, the fourth part is concerned with the varieties used, and the fifth part focuses on storage methods.

In each region, villages were randomly selected based on the list of villages producing both Bambara groundnut and roselle (Table 1). An exhaustive list of all Bambara groundnut farmers was established in village and the survey sample was drawn randomly on the basis of this list. Ninety seven percent of the 169 farmers randomly selected responded to the survey. The data collection method was personal interviews conducted with the respondents based on a questionnaire written in French. Few Nigerien farmers are literate, so the interviewers asked the survey questions in Hausa and Djerma. Because these languages are primarily oral, the questionnaires were not written out in each language. Questions related to Bambara groundnut and roselle were asked of all respondents. The collected data was used to calculate the percentage of farmers using each storage method, shelf life and amount of Bambara groundnut seeds stored using each method. Microsoft Office Excel 2007 was used for the calculation of the descriptive statistics (that is, means, percentages).

To test the effect of quantity of Bambara groundnut and roselle produced, membership in a village association, gender and other factors on adoption of PICS bags binary probit analysis was used. Probit was used because the cumulative normal distribution curve is like the "S" shaped curve often used in analyzing adoption. Greene (2012) provides an overview of probability models including logit, probit, and tobit. Feder and Umali (1993) review the early uses of probability models. Mercer (2004) reviews the use of these models for forestry and agricultural. Factors such as age, gender,

education, sources of information, participation in farmer's organizations, and farm area often are statistically significant in these models depending on the product produced, technology, ethnic group, gender roles, etc.

The dependent variable was 1 if PICS bags were used and zero if other storage techniques were employed. The independent variables included in the Probit equations were based on experience with adoption equations for hermetic storage of cowpea (Moussa et al., 2014; Ibro et al., 2014). The independent variables used were: region, Dosso = 1 and otherwise zero; sex, 1 if male and zero otherwise; experience, number of decades of experience producing the crop; village association, 1 if member of a village association and zero otherwise; production, the larger of quantity produced in 2011 or 2012 in 100 kg units.

All the independent variables are hypothesized to have positive effects on PICS bag adoption. Region is expected to be positive because Dosso region has an active PICS bag dealer. Sex is expected to be positive because male farmers in Niger often have been access to information about new technologies and to inputs need to use those technologies. Experience is expected to be positive because experienced farmers are more likely to have had problems with storing these grains in the past and consequently are more likely to seek alternatives. Village association is expected to be positive because village association members should have been information about new technologies. Production 2012 is also expected to be positive because farmers with more grain to store have more incentive to seek out improved storage methods.

Because the Bambara groundnut and the roselle grains are both high protein foods and the storage choices are being made by the same individuals, those decisions are probably subject to some common influences, but chosing a given storage method for one crop does not directly affect the choice for another crop. Consequently, seemingly unrelated regression (SUR) is chosen for the two Probit equations. SUR was first proposed by Zellner (1962) and assumes that the error terms of equations are correlated.

The Probit SUR was estimated using the Stata (StataCorp, 2015) command "biprobit" which uses maximum-likelihood. An introduction to bivariate Probit models is given by Greene (2012). The correlation between error terms in the two equations is measured by "ρ" which is not directly estimated in maximium likelihood process, but atanh ρ ((1/2)ln ((1+ ρ)/(1- ρ)) is. Atanh ρ is used to test whether there is a significant correlation between the two equations.

Interpretation of the estimated probability model focuses on the sign and significance of the coefficients. The magnitude of the coefficients cannot be directly linked to changes in probability. To explore the magnitude of effects, marginal values are estimated. The marginal value is defined as the change in probability that results from a small change in the independent variables holding continuous variables at their sample averages and discrete variables at modal values. Because the two equations in an SUR bivariate probit are correlated, the total marginal effects include a direct or univariate effect from each equation and an indirect effect from the other equation. To focus the discussion on results by crop, only the direct or univariate marginal effects will be discussed. More information on estimation and interpretation of binary models can be found in Greene (2012).

RESULTS AND DISCUSSION

The continuous variable demographic statistics for the sample are shown in Table 2. Discrete variables are explained in the text. The average age of respondents was 48 years (Table 2), 59% male, 89% currently married and 11% widowed. Eighty nine percent had no formal education and most of the rest only had some primary school. The respondents were primarily farmers, but 39% reported livestock production and 30% small scale commerce as secondary activities. With respect to sources of information, 47% reported belonging to a village association and 50% owned a radio. Consistent with the intensive PICS extension effort for cowpea storage in Niger, 73% came from villages which have had PICS cowpea storage demonstrations. About 40% of the Bambara groundnuts were marketed and about 50% of roselle grains.

Fifty four percent of respondents reported using some type of potentially hermetic container for storage of Bambara groundnut and 46% use that type of container for roselle (Table 3), sometimes with the addition of insecticide, sand or ash as a protectant. About 22% of respondents used some type of plastic bag for Bambara groundnut and 24% for roselle. Ten percent of respondents used the triple layer PICS bags for Bambara groundnut and 4% for roselle. Plastic jugs were the single most commonly reported hermetic container, with 27% of respondents using them for Bambara groundnut and 18% using plastic jugs for roselle. Woven sacks, sometimes with insecticide, sand or ash added at a protectant were in common use. About 28% respondents used woven sacks for Bambara groundnut storage and 44% for roselle storage. About 17% of all respondents used storage insecticide for Bambara groundnut and 13% for roselle.

Compared to previous studies in other parts of West Africa, this study finds a much higher proportion of Bambara groundnut farmers using hermetic storage. Bediako (2000) found that farmers in Ghana used mainly mud brick granaries, baskets and woven bags to store grain legumes. Berchie et al. (2010) found that most farmers surveyed in Ghana stored Bambara groundnut in woven bags: 90% in the Guinea savannah, and 67% in the forest transition area. Ayamdoo et al. (2013) found most farmers in the Upper East Region of Ghana storing Bambara groundnut in either clay pots or woven bags. Ayamdoo et al. (2013) study estimated that about 23% of the farmers stored in potentially hermetic containers (that is glass bottles, plastic containers or plastic bags). Tinkeu et al. (2016) found that most farmers in the Adamawa region of Cameroon stored Bambara groundnut in clay jars or bags. Tinkeu did not specify what type of bags was used. The percentage of farmers using hermetic storage for Bambara groundnut and roselle in Niger is similar to that of cowpea (Moussa et al., 2014; Ibro et al., 2014). The common use of hermetic grain storage in Niger can probably be linked to the extension efforts by non-governmental organizations (NGOs) and the PICS project to inform farmers about the use of this type of storage and facilitate access to plastic jugs, drums, and bags containers.

Use of storage insecticide for Bambara groundnut in Niger is in the range found by previous studies in other

Table 2. Continuous demographic variables in the sample of Bambara groundnut and roselle farmers in Niger in 2013.

Item	Mean	Max.	Min.
Age	48	95	20
Household size	12	43	1
Experience producing Bambara nuts	11	45	5
Experience producing roselle	10	45	0
Bambara groundnut production (kg)	243	3000	0
Roselle grains production (kg)	170	1300	1
Bambara groundnut stored (kg)	168	3000	0
Roselle grains stored (kg)	98	1283	0
Bambara groundnut stock later sold (kg)	101	1798	0

Table 3. Storage methods used for Bambara groundnut and roselle grains in Niger (% of respondents).

Item	Bambara groundnut	Roselle grains
Plastic jugs	21.5	14.1
Plastic jugs with insecticide	3.5	2.1
Plastic jugs with sand or ash	2.1	1.4
Metal barrel	0.7	2.1
Metal barrel with insecticide	1.4	0.0
Metal barrel with sand or ash	0.0	0.7
Jar or Canary	5.6	4.9
Jar with insecticide	0.0	0.0
Jar with sand or ash	1.4	3.5
Granary	7.6	0.7
Granary with insecticide	2.1	0.0
Granary with sand or ash	1.4	0.0
Woven bag	20.1	26.8
Woven bag with insecticide	6.9	7.7
Woven bag with sand or ash	1.4	9.9
Single layer plastic bag	0.0	7.0
Single layer plastic bag with insecticide	0.0	0.0
Single layer plastic bag with sand or ash	0.0	2.8
Double bag	8.3	6.3
Double bag with insecticide	2.8	2.8
Double bag with sand or ash	0.0	0.7
Triple bag	10.4	4.2
Triple bag with insecticide	0.0	0.0
Other	2.8	2.1
Total	100.0	100.0

West African countries and similar to that of cowpea in Niger. Bediako (2000) indicates that none of the farmers interviewed used storage insecticides for Bambara groundnut. Berchie et al. (2010) found that 37% of farmers were using storage insecticides for Bambara groundnut. Ayamdoo et al. (2013) indicate that 10% use storage insecticides. Golob et al. (1998) state that very few farmers use storage insecticides for Bambara groundnut.

In terms of percentage of overall quantity stored, most Bambara groundnuts and roselle grains are stored in potentially hermetic containers (Table 4). About 84% of Bambara groundnut is stored in such containers and 91% of roselle. While only about 10% of respondents reported storing Bambara groundnuts in PICS bags, the quantity stored by those respondents is quite large, so about 39%

Table 4. Percentage of Bambara groundnut and roselle grain quantity stored in Niger by storage method.

Item	Bambara groundnut	Roselle grains
Plastic jugs	7	5
Plastic jugs with insecticide	1	0.1
Plastic jugs with sand or ash	0.2	1
Metal barrel	1	1
Metal barrel with insecticide	3	0
Metal barrel with sand or ash	0	1
Jar or canary	1	0.4
Jar with insecticide	0	0
Jar with sand or ash	0.3	1
Granary	11	1
Granary with insecticide	2	0
Granary with sand or ash	2	0
Woven bag	0.04	1
Woven bag with insecticide	0	0
Single layer plastic bag	15	35
Single layer plastic bag with insecticide	7	19
Single layer plastic bag with sand or ash	0.4	15
Double bag	7	10
Double bag with insecticide	3	2
Double bag with sand or ash	0	0
Triple bag	39	3
Triple bag with insecticide	0	0
Other container with insecticide	0	0
Other container with sand or ash (plastic bag)	0	3
Other	1	0.3
Total	100	100

of the total quantity of Bambara groundnut stored by the respondents was stored in PICS bags. About 16% of the quantity of Bambara groundnut was stored with insecticide and about 21% of roselle.

Overall, the average quantity of Bambara groundnut stored per respondent was 168 kg and for roselle it was 98 kg. Respondents with larger quantities of Bambara groundnut or roselle to store tended to use metal drums, woven sacks, granaries or multilayer plastic storage bags, while those with smaller quantities reported storing in plastic jugs, canary jars, or single layer plastic bags (that is, shopping bags) (Table 5). For Bambara groundnut, the storage method with the highest average quantity stored was the PICS bag at 500 kg per respondent. For roselle, the storage method with the highest average quantity stored was the woven bag with insecticide at 260 kg per respondent.

Profitability of alternative storage technologies

For the estimation of storage losses, the budget calculations used the Baoua et al. (2015) data showing Bambara groundnut grains losses at 61.8% and roselle losses at 83.9% after 7 months of storage using traditional methods. For the analysis of the sensitivity, gains on storage were calculated by considering ±5% of the storage loss rate. For PICS bags, losses were considered at 0.6% as recommended by Jones et al. (2011b). Estimation of returns to storage used the budget approach described by Jones et al. (2014). To calculate the gain on investment, the price of the PICS bag was estimated at 1000 FCFA and a negligible cost in terms of storage infrastructure used by the farmers.

Tables 6 and 7 show the return on storage estimates for Bambara groundnut after eight to nine months and roselle grains after seven months of storage with opportunity costs of 25 and 35%. The storage period for each crop corresponds to a strategy of marketing in the lean season when prices are typically in highest, in May for roselle and July for Bambara groundnut. Average harvest time and lean season prices are those reported in the survey. Roselle prices are reported by farmers to rise from an average of 81 FCFA/kg at harvest to an average of 213 FCFA/kg in the lean season, a seasonal price increase of 142 FCFA/kg. Bambara groundnut prices are

Table 5. Amount of Bambara groundnut and roselle grains stored per respondent by storage method (kg per respondent).

Item	Bambara groundnut	Roselle grains
Plastic jugs	43	41
Plastic jugs with insecticide	36	5
Plastic jugs with sand or ash	12.1	59
Metal barrel	100	54
Metal barrel with insecticide	303	0
Metal barrel with sand or ash	0	75
Jar or canary	35	8
Jar with insecticide	0	0
Jar with sand or ash	29	35
Granary	189	138
Granary with insecticide	126	0
Granary with sand or ash	206	0
Woven bag	100	144
Woven bag with insecticide	153	260
Woven bag with sand or ash	42.5	189
Single layer plastic bag	0	5
Single layer plastic bag with insecticide	0	0
Single layer plastic bag with sand or ash	0.0	9
Double bag	113	150
Double bag with insecticide	132	74
Double bag with sand or ash	0	88
Triple bag	501	87
Triple bag with insecticide	0	0
Other	67	13
Overall sample	135	105

Table 6. Profitability of Bambara groundnut post-harvest alternatives (harvest October and sold in July).

Parameter	Sell at harvest	Storage in woven sacks		PICS storage bags	
		Without insecticide	With phostoxin	1 year	2 years
Initial stock (kg)	100	100	100	100	100
Storage loss (%)	0	61.8	1	0.6	0.6
Commercial quantity (kg)	100	38.2	99	99.4	99.4
Selling price (CFA/kg)	165	449	449	449	449
Total revenue (FCFA)	16550	17164	44484	44663	44663
Bag cost	0	250	250	1000	500
Insecticide cost	0	0	450	0	0
Total cost of storage	0	250	700	1000	500
Net cashflow (FCFA**)**	16550	16914	43784	43663	44163
Return on storage (%) with 25% opportunity cost of capital	NA	-17%	139%	136%	143%
Return on storage (%) with 35% opportunity cost of capital	NA	- 24%	135%	134%	138%

NA: Not applicable.

reported by farmers to rise from an average of 165 FCFA/kg at harvest to an average of 449 FCFA/kg in the lean season, a season price increase to 284 FCFA/kg. Based on the literature review, average storage losses

Table 7. Profitability of roselle post-harvest alternatives (harvest in November).

Parameter	Sell at harvest	Storage in woven sacks		PICS bags storage	
		Without insecticide	With phostoxin	1 year	2 years
Initial Stock (kg)	100	100	100	100	100
Storage loss (%)	0	83.90	1	0.60	0.60
Commercial quantity (kg)	100	16.10	99	99.40	99.40
Selling price (FCFA/kg)	81	213	213	213	213
Total revenue (FCFA)	8100	3435	21120	21205	21205
Bag	0	250	250	1000	500
Insecticide cost	0	0	450	0	0
Total cost of storage	0	250	700	1000	500
Net cashflow	8100	3185	20420	20205	20705
Return on storage (%)	NA	-73%	125%	118%	123%
Return on storage (%)	NA	-79%	120%	113%	115%

NA: Not applicable.

were estimated for both crops at 1% after a phostoxin insecticide treatment (3 tablets per 100 kg of grain). Because seasonal price changes storage was very profitable for Bambara groundnut and roselle farmers. Estimated returns with PICS bags were comparable to storage with insecticide and substantial better than unprotected storage in woven sacks without insecticide.

With an opportunity cost of 25%, a Bambara groundnut farmer who chooses to store his or her production with PICS bags could have doubled annual revenue with a 136% return on resources invested in storage when the bag was used for a season and 143% if the PICS bag was reused for a second season (Table 6). With 35% opportunity costs, the returns were slightly lower. In both cases, the profitability of using the PICS bag was comparable to that obtained with an insecticide treatment (Phostoxin), while unprotected storage shows a loss. While use of PICS bags did not provide a large monetary gain compared to insecticide use, it did allow the farmer to reduce pesticide exposure and the associate health risks.

With an opportunity cost of 25%, a roselle farmer who chose to store his or her production with PICS bags would have more than double their money. With a 25% opportunity cost the returns to storage investment was 118% when the PICS bag was used for one year and it was 123% if it was used two years. With a 35% opportunity cost the returns to storage were slightly lower, but still close to those achieved with insecticide in woven bags.

Probit analysis of PICS bag adoption

The SUR Probit estimate identified factors that are important for the adoption of PICS bags by farmers who store Bambara groundnut and roselle (Table 8). The overall Wald Chi Square was statistically significant at the 5% level indicating the Probit model explains an important portion of the overall variability in adoption. The estimated correlation between errors in the two equations (that is, ρ) was 0.81. The atanh ρ was estimated at 1.1318 and was statistically different from zero at the 1% level indicating statistically significant correlation between the error terms in the equations and supporting the use of SUR.

The estimated coefficients indicate that for Bambara groundnut the most important factors predicting adoption of PICS bags were being in the Dosso region, experience in production and membership in a village association. Dosso region had a very active PICS vendor and consequently the positive coefficient for that region probably reflected greater availability of the bags. The sex of the respondent and whether or not PICS demonstrations had been done in the village for cowpea were not significant. Estimated univariate marginal values indicated that farmers in the Dosso region are about 13% more likely to adopt PICS bags than those in other regions. A decade of experience increased probability of PICS adoption by about 10% and membership in an association by about 11%.

For roselle, the most significant variable in the Probit estimation was the quantity produced. With a probability of 10.8%, the village association membership coefficient was almost significant at the 10% level. For roselle, sex of the respondent, PICS cowpea storage demonstrations in the village and experience producing roselle were not significant at any conventional level. For roselle marginal effects, none of the variables were significant at conventional levels. The univariate roselle production marginal effect had a P value of 0.11 and indicated that each 100 kg of roselle grain produced increases the probability of adoption of PICS bags by 9%.

Table 8. Seemingly unrelated probit regression estimates for PICS bag adoption for Bambara groundnut and roselle grain storage.

Parameter	Bambara groundnut		Roselle grains	
	Estimated coefficient	Univariate marginal effects	Estimated coefficient	Univariate marginal effects
Region	0.8313**	0.1285**	NA	NA
Site category	0.3378	0.0457	0.1965	0.0144
Sex	0.2879	0.0410	0.6406	0.0449
Experience	0.6648***	0.0961***	-0.5516	-0.0437
Village association	0.8039*	0.1105**	0.7929	0.0559
Production 2012	0.0353	0.0051	0.1156*	0.0092
Constant	-3.4478***	NA	-2.4398**	NA
Number of obs =157				
Wald $chi^2(11)$ = 22.65**				
Log likelihood = -60.205423				
Athrho = 1.1318**				
Rho = 0.8116				

'*', '**' and '***' indicate statistical significance at the 10, 5 and 1% levels. NA: Not applicable.

Conclusion

This study documents the on-farm storage practices for Bambara groundnut and roselle grains in Niger. It is based on a random sample of 164 farmers of both crops in the Dosso and Maradi regions in 2013. Over half of respondents used some type of potentially hermetic container for storage of Bambara groundnut and 44% used that type of container for roselle. About 22% of respondents used some type of plastic bag for Bambara groundnut and 24% for roselle. Ten percent of respondents used the triple layer PICS bags for Bambara groundnut and 4% for roselle. The use of hermetic storage for Bambara groundnut was found to be much higher than previous studies in other West African countries, probably due to the intense hermetic grain storage extension effort in recent years in Niger by NGOs and other organizations.

About 17% of respondents used storage insecticide for Bambara groundnut and 13% for roselle. The use of storage insecticide for Bambara groundnut was in the range found by previous studies in other West African countries.

While only about 10% of respondents reported storing Bambara groundnuts in PICS bags, the quantity stored by those respondents is quite large, so about 39% of the total quantity of Bambara groundnut stored by the respondents was stored in PICS bags. Respondents with larger quantities of Bambara groundnut or roselle to store tended to use metal drums, woven sacks, granaries or multilayer plastic storage bags, while those with smaller quantities reported storage in plastic jugs, canary jars, or single layer plastic bags.

From an economic perspective, storage of Bambara groundnut and roselle is quite profitable. Farmers could potentially double their revenue from either crop by storing. Profitability of using PICS bags for one or two years was comparable to that achieved with the common practice of storing in woven bags with insecticide.

The Probit analysis indicates that for Bambara groundnut in the Dosso region, with easier PICS sack availability, there was significant production and membership in a village association. For roselle, only production was significant with membership in a village association almost significant at the 10% level. The adoption decision did not seem to be affected by the sex of the respondent or whether a PICS cowpea storage demonstration had been done in the village. Marginal estimates indicate that farmers in the Dosso region are 11% more likely to adopt PICS bags for Bambara groundnut than those in the other regions, probably in part because of the active PICS distributor in that region.

Overall, the data suggest that while many Bambara groundnut and roselle farmers in Niger are using hermetic storage, but only a few have adopted the use of PICS bags. The relatively modest level of PICS bag used for Bambara groundnut and roselle can be linked to: (1) supply chain issues limiting local availability of the bags in villages, (2) lack of a PICS storage extension effort targeted at Bambara groundnut or roselle (PICS training was exclusively for cowpea storage), and (3) technology diffusion lags. It takes time for farmers to learn about, test and adopt any new technology. Those that use PICS bags seem to be among the larger farmers. Because of substantial and relatively predictable seasonal price increase, storage of Bambara groundnut and roselle is quite profitable. While PICS bags use does not increase profitability substantially compared to insecticide use, it does allow the farmer to reduce pesticide exposure and the associate health risks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This work was supported by the Bill & Melinda Gates Foundation, Seattle, WA, USA under the Grant# OPP1009185. Interpretation of the data and opinions expressed are the responsibility of the authors.

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