African Journal of Rural Development, Vol. 5 (2): April-June 2020: pp.141-155. ISSN 2415-2838

Seed yield and quality of three foundation seed models under the formal seed system

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ABSTRACT

In Mali, smallholder farmers are generally not involved in foundation seed production which is dominated by the conventional public sector based models. These dominant models have so far failed to avail sufficient quantities of foundation seed especially for non-irrigated rice systems, groundnut, and cowpea. During 2018 and 2019 cropping seasons, field trials were conducted to test three models of foundation seed production, namely: Research Institutions Model – RIM, Seed Companies Model – SCM, and Smallholder Farmers Model – SFM. Single varieties of five crops vital to food security in Mali (rice, millet, sorghum, groundnut, and cowpea) were used in a randomized complete block design with three replicates. The objectives were to identify the best performing models in terms of seed quantity, quality and model efficacy in realizing the yield potential of each crop variety. Significant differences were detected between models and crop performances ($P \leq 0.05$). Owing to the trainings and technical backstopping provided to smallholder farmers, the SFM realized the best performance in terms of seed quantity and seed yield; followed by SCM, while the RIM realized the lowest performance. No quality issue was reported for millet, sorghum, and cowpea even for the seed produced by smallholder farmers. Among crops, millet realized the best performance for seed quantity and seed yield and differed significantly from the two legume crops. None of the three models realized the yield potential of the rice variety used in the trials. In addition, there was problem with rice seed quality for all models due to variety contamination. These two factors combined with large seeding rate (60 kg per ha) may explain the unattractiveness of upland rice seed production and the large deficit of certified and foundation seed in Mali. Further studies are needed to shed more light on the challenges observed in the present research.

Keywords: Foundation seed, Mali, seed yield, seed quantity, seed quality, Seed production models, smallholder farmers

RÉSUMÉ

Au Mali, les petits agriculteurs ne sont généralement pas impliqués dans la production de semences de base qui est dominée par les modèles conventionnels basés sur le secteur public. Ces modèles dominants n'ont jusqu'à présent pas réussi à disposer de quantités suffisantes de semences de base, en particulier pour les systèmes de riz non irrigué, l'arachide et le niébé. En 2018 et 2019, nous avons mené des essais sur le terrain pour tester trois modèles de production

Cite as: Dagnoko, S., Camara, F., Sangaré, N., Aoga, A., Baltissen, G., Niangaly, O., Traoré, A. B.M. and Fofana, B. 2020. Seed yield and quality of three foundation seed models under the formal seed system. *African Journal of Rural Development* 5 (2):141-155.

Received: 14 January 2020
Accepted: 30 April 2020
Published: 30 June 2020

de semences de base, à savoir: le modèle des institutions de recherche - RIM, le modèle des entreprises semencières - SCM et le modèle des petits exploitants agricoles - SFM. Une seule variété de cinq cultures indispensables à la sécurité alimentaire (riz, mil, sorgho, arachide et niébé) a été testée sur le terrain en utilisant un dispositif en blocs complets randomisés en 3 répétitions. Les objectifs étaient d'identifier les modèles les plus performants en termes de quantité de semences, de qualité et d'efficacité du modèle pour réaliser le potentiel de rendement de la variété utilisée pour chaque culture. Des différences significatives ont été détectées entre les modèles et entre les cultures (P 0,05). Grâce aux formations et à l'appui technique fournis aux petits exploitants, le SFM a réalisé les meilleures performances en termes de quantité de semences et de rendement; suivi de SCM, tandis que le RIM a réalisé les performances les plus faibles. Aucun problème de qualité n'a été signalé pour le mil, le sorgho et le niébé, même pour les semences produites par les petits producteurs. Parmi les cultures, le mil a réalisé les meilleures performances en termes de quantité de semences et de rendement et différait significativement des deux légumineuses. Aucun des trois modèles n'a pu réaliser le potentiel de rendement de la variété de riz utilisée dans les essais. En outre, il y avait un problème de qualité des semences de riz pour tous les modèles. Ces deux facteurs combinés à une dose de semis élevée (60 kg/ha) expliquent le manque d'attractivité de la production de semences de riz pluvial de plateau et l'important déficit en semences certifiées et de base au Mali. D'autres études sont nécessaires pour éclairer davantage les résultats de la présente recherche.

Mots clés: semences de base, rendement, quantité de semences, qualité des semences, modèles de production de semences, petits agriculteurs

INTRODUCTION

The benefit of sowing quality seed is tremendous and include low seeding rate which helps farmers save time, money and labor; fast uniform emergence which is crucial under rain fed conditions; more vigorous seedlings; high uniformity in the field (growth and maturity); high return per unit area; high quality of the harvest; and high market value. It is estimated that the use of quality seed of a variety having high genetic potential (as for the improved varieties) can increase yield by 20 – 25% (AgriQuest, 2020). Other authors reported that the use of quality seed can increase yield by 5-20% (Afzal *et al*., 2019). In China, the World Development Report (2008) reported that rice yield was increased by 50% from 1975 to 1990 mainly due to the use of quality seed of rice varieties with high genetic potential (hybrid rice). In 2012, the Food and Agriculture Organisation (FAO) and partners helped create 29 seed businesses in Central America involving smallholder farmers. This enabled them to produce 6192 and 754 MT of high quality bean and maize seed, respectively, and double yield in the field of farmers who planted those seeds. This brings about the need, among other things, for having crop areas covered mainly by improved varieties, but also the seeds sown being of good quality for both the formal and informal seed systems in order to increase yield. Dagnoko *et al.* (2016) referred to this as « Theoretical demand for certified seed (TDCS) ».

Production and commercialization of quality seed of improved varieties involve multiple stakeholders formally organized around the value-chain of a particular crop. Within the value chain in West Africa, breeders at the National and International Agricultural Research Institutes and agricultural universities develop new improved varieties and release them through the National Seed Committees who then register the released varieties in the official national and regional seed catalogues.

As highlited by Dagnoko and Asiedu (2016), for newly released varieties, the available nucleus seed that emerged from the process of plant breeding must undergo a systematic seed multiplication scheme comprising three or four generations as follows: (i) Breeder, Foundation and Certified Seeds, or (ii) Breeder, Foundation, Registered and Certified Seeds. Foundation seed is thus, the second generation in the multiplication scheme, the so called "semi-raw product". Certified seed is the latest generation seed class and is the "end product" destined for commercialization and for planting by grain producing farmers. The higher the quantity of foundation seed, the higher the quantity of the resultant certified seed and the more likely the TDCS will be met. In that situation, all areas are likely to be covered by quality seed, provided that seed affordability by smallholder farmers is not an issue.

Despite the known importance of quality seed in increasing agricultural production, the seed industry is barely taking off in Mali and West Africa generally. Furthermore, smallholder farmers, especially women farmers, are yet to exploit the benefits of sowing and selling quality seed as a means to diversify their activities and generate income. This is suspected to be mainly due to insufficient quantity of early generation seed, especially foundation seed, low return from investment in foundation seed notably for low value-crops, high seed prices, but also inadequate extension services to farmers due to poor or inadequate training in entrepreneurship, seed production, conditioning and storage (ISSD, 2013).

Indeed, the development of a commercial seed market depends heavily on the supply of quality foundation seed stocks in sufficient quantity and at all time. Therefore, one way to ensure the take-off of the seed industry in Mali and West Africa is to increase the supply of foundation seed and enhance their accessibility (physical and financial) to all seed companies for them to produce certified seed. Other authors also reported the need to avail on a regular basis, stocks of foundation seed of suitable varieties in adequate quantities to meet the annual certified seed demand for all the areas planted in each country for both formal and informal seed production (Rubyogo *et al*., 2007).

To produce adequate quantities of foundation seed, different approaches were practiced in West Africa. They include the conventional approach (as in Burkina Faso and Mali) that is to have breeders maintain the released varieties, produce foundation seed and distribute to private sector actors who then multiply it into certified seed. An alternative to the conventional approach was the creation in Mali, of the Foundation Seed Unit at the Institute of Rural Economy (IER) under the West Africa Seed Alliance (WASA) project. This unit obtains breeder seed from public research institutions and multiplies it into foundation seed and then distributes to the private sector. The Foundation Seed Unit in Mali is comparable to the case of Ghana, where a public body (Grains and Legume Development Board) receives breeder seed from the National Agricultural Research Institutes (NARIs), multiplies it into foundation seed, and then supplies it to the private sector seed actors (E. Asiedu, Pers. Comm).

The conventional approach and its alternatives are comparable to the "public sector dominant archetype" reported by a study commissioned by the Bill and Melinda Gates Foundation (BMGF and USAID, 2015) and which applies to low profit and minor crops (sorghum, millet, cowpea, common bean, teff). The same study also identified the "private sector dominant archetype" approach that works well for high value crops as in Nigeria where the private sector seed actors are involved in the production of all seed classes in the case of hybrid and open-pollinated maize.

Also there are mixed public/private foundation seed production models for crops that are highly demanded by consumers but require high investments in seed production and that are at the same time risky in terms of demand forecasting, post-harvest losses, or require a lot of efforts and investments for processing. The joint intervention of both sectors in foundation seed production helps each other mitigate the risks related to investments in producing this seed class. This is the case for rice, cowpea, groundnut, cassava, sweet potato, among others. In such cases, the production of early generation seed is unattractive to the private sector and to the public sector. As a result, both sectors are much more tempted to invest in the production and commercialization of the "end product" rather than the « semi raw product » (early generation seed), thus creating shortages of foundation seed and poor quality of the resultant certified seed produced in the countries. In Mali, the West Africa Seed Program of the CORAF/WECARD, implemented a public/private foundation seed model in which WASP served as a broker while the private sector actor contributed 20-30% of the cost of the seed produced by the public sector partner. This model enabled access of the private sector actors to breeder seed of rice, maize, sorghum, groundnut and millet for the purpose of production of foundation seed (Dagnoko and Asiedu, 2016).

Looking at these early generation seed production models, one must admit that a lot of efforts were deployed by the public and private sectors to avail foundation seed of many different crops. However, in most cases, these different models of foundation seed production have not been successful in a long term in meeting the foundation seed demand. For instance in Mali, the West Africa Seed Program estimated the Theoretical Demand for Foundation Seed (TDFS) at 215 MT for maize, 1,785 MT for rice, 41 MT for sorghum, 89 MT for millet, 230 MT for cowpea and 2231 MT for groundnut. The foundation seed supplied in the cropping season 2014/2015 (LABOSEM, 2014) was sufficient only to meet 0.36 – 20.57 % of the foundation seed need. Thus the deficit of foundation seed ranged from 79.43% to 99.64% depending on the crop, the largest deficit being observed for groundnut (99.64%); followed by cowpea (97.9%), rice (95.82%), and millet (95.6%). In the cropping season 2019/2020, the foundation seed production for maize was 58.6 T (LABOSEM, 2020) which is low compared to the total theoretical foundation seed demand of 215 MT.

The case of rice in Mali hides large disparities depending on the production system, the level of supply of foundation seed in 2014/2015 being 0% for rice produced under the traditional flooding system, 0.29% for rain fed lowland rice, 3.13% for rain fed upland rice, and 57.87%, for irrigated rice production systems as per the statistics of the LABOSEM (2020).

Rice, maize, millet, and sorghum are the major staple crops and cowpea and groundnut the major food legumes crops. Among the rice production systems, the flooding system occupies the majority of rice areas (45%) followed by lowland rice (25%). These are facts that cannot be ignored when developing and disseminating improved technologies such as improved varieties and quality seeds. Unfortunately, the foundation seed production models practiced in Mali have so far failed to avail sufficient quantities of foundation seed for these vital cereal and legume crops.

To our knowledge, very limited research has been done on the quantitative and qualitative performance of different seed production models and/or crops in Mali. The national seed certification agency of this country (LABOSEM) publishes annually statistics on the quantity and quality of all the seeds produced under the formal systems. In the cropping season 2014/2015, 168 tons of foundation seeds were produced across all crops, out of which 82% were certified. In 2015/2016, 8 713 tons of foundation seeds were recorded out of which 90.3% passed the certification process. The subsequent croopping season of 2016/2017 recorded 11 052 tons of foundation seed but with 11.5% rejection at certification. In this paper, we report on the performance of three different foundation seed production models for five crops in terms of seed quantity, yield, and quality.

MATERIALS AND METHODS

Genetic materials. Breeder seed of sorghum (*Sorghum bicolor* L. Moench), millet (*Pennisetum glaucum* L. R. Br.), rain fed upland rice (*Oryza* sp), groundnut (*Arachis hypogaea* L.), and cowpea (*Vigna inguiculata*) was used to test three models of foundation seed production. A single and popular variety of each crop was used in each model (Table 1). We tested three foundation seed production models: the Research Institution Model (RIM), the Seed Companies Model (SCM) and Smallholder Farmers Model (SFM).

Research Institution Model (RIM). The RIM is based on the national agricultural research institutions which are public entities and are characterized by: i) availability of large land areas often not improved ; ii) high level of education for the staff ; iii) use of paid day laborers ; iv) high technical capacity ; v) adequate use of inputs ; vi) low number of plant breeders ; vii) aging of the plant breeders, viii) heavy work load as breeders must handle simultaneously multiple tasks such as variety development and registration, variety maintenance, germplasm management, breeder and foundation seed production and distribution, fund raising, among others. In this model, the foundation seed is produced by the research institutions on their own lands using paid day laborers. Technical supervision is provided by the researchers themselves whereas the project supplied the needed agricultural inputs and support for seed quality control and certification. Mali has only one national research institution which is the Institut of Rural Economy (IER) with different experiment stations. The IER regional experiment station of Longorola in Sikasso region was used to conduct the RIM model on rice and the sub station of Cinzana in Segou region was used to host the RIM model for millet, sorghum, groundnut and cowpea.

Seed Company Model (SCM). The SCM refers to private seed companies operating in Mali, 41 in total (Witaka *et al*., 2018). The key features of the Malian seed companies include, among others : i) dearth of information on the available land area per company and their level of improvement ; ii) dearth of information on the quantity and level of education of the human resources employed by the SC ; iii) the level of use of input fertilizer not well known ; iv) weak technical capacity ; v) low access to financing ; low access to improved technologies including the genetic materials developed by the RI ; and high capacities in seed conditioning, packaging and marketing. In the SCM, the foundation seed is produced by the seed companies on their own lands using paid day laborers. Technical supervision is provided by the seed companies through paid technical staff. The project supplied the needed agricultural inputs and provided support for seed quality control and certification. The seed companies used as SCM in this research were Camara Semences eshtablished at Kasséla for rice, millet, sorghum and groundnut and Faso Kaba Seed Co established at Tamala, for cowpea.

Table 1. Plant genetic materials used in the field tests (2018 and 2019)

Crop	Variety	Yield potential (tons/ha)	50% Maturity (days)	Adaptation zones (mm of rain)
Sorghum	CSM 63-E	2	60	400 - 700
Millet	Toroniou C1	2	105-110	450 - 600
Rice	Nerica 8 ML	4	90	800 - 1000
Groundnut	Fleur11	1.2	90-95	400 - 700
Cowpea	Wilibali	1.5	65-70	600 - 800

Smallholder Farmers Model (SFM). The SFM refers to individual seed producing farmers or seed cooperatives / associations. During the 2018/2019 cropping season, the National Seed Laboratory (LABOSEM) which is the seed quality control and certifcation agency in Mali registered a total of 133 smallholder farmers among which were 24 individual producers and 109 seed cooperatives / associations (Witaka *et al*., 2019). The key features of the SFM comprise: i) Cropping of small land areas often varying between 0.5 to 6.1 ha (SAA baseline survey, 2020) which are often not improved; ii) low level of education (SAA Covid19 Impact survey, 2020); iii) low use of input fertilizer; iv) weak technical capacity; v) low access to financing; vi) low access to improved technologies including the genetic materials developed by the research institutions. In the SFM, the foundation seed is produced by the farmers on their own lands using unpaid family labor. Technical supervision is provided by the SAA technical staff and the State extension agents. The project supplied the needed agricultural inputs and provided support for seed quality control and certification. The groundnut seed production plots were hosted by a women group of 69 members in the village of Foloda at Monzomblena PHTC (Production, post Harvest and Trade Center). The PHTC is an extension model of Sasakawa Africa Association that puts farmers at the center of their learning process to fast track technology adoption, farmer access to markets and premium prices. It is composed of 10 villages consisting of one central village and nine satellite villages all within a radius of 35 kilometers (SAA, 2019). Cowpea, rice, millet and sorghum plots were assigned to individual farmers, at a rate of 1-3 replicates per farmer for each crop, depending on their capacities. Rice plots were established at the PHTC Siranikoto while the plots of millet, sorghum, and cowpea were established at the PHTC Dacoumani.

Experimental design, plot design and management. Field experiments were established during two years (2018 and 2019) at different model specific locations (Table 2). A randomized complete block design with 2 factors (3 models and 5 crops) was used. For each crop, each model was replicated three times. The plot size of each model was 0.75 ha (0.25 per replicate) for a given crop. Across models and crops, each replicate was planted with the same variety (Table 1) and same quantity of breeder seed following the recommended practices (6 kg/ha for sorghum and millet; 60 kg/ha for rice and groundnut, and 20 kg/ha for cowpea). Smallholder farmers, research insttutions and seed companies managed their respective trials using the recommended field management practices.

All seed production fields were subjected to quality control and certification procedures employed under the formal seed system and the seed produced submitted to the official seed quality control agency (LABOSEM) for certification.

Data analysis. For each crop and under each model, we collected data on quantity of seed produced, the quantity of seed certified, the quantity of seed rejected (not certified), and seed yield (SY). The yearly agronomic data were analysed using the GLM procedure of the Minitab software (Minitab Inc). The Least square means were then used for combined analysis using the following statistical model: $Y_{ij} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon$ where Yij is the mean performance of the ith crop in the jth model, μ is the overall mean, i is the effect of the ith crop, β_j is the effect of the jth model, β_{ij} is the interaction effect of the ith crop with the jth model, and ε is the pooled experimental error. Crop and model effects were considered as fixed.

A 95% Bonferoni confidence interval was used to detect significant differences between means. The efficacy of each model in terms of SY was assessed by comparing the SY of each model for a given crop relative to the yield potential of the variety used in the test. Models' efficacy in terms of seed quality was assessed by comparing the proportion of seed certified relative to the total seed quantity.

RESULTS

Performance of crops, models, and crop x model interaction for seed yield. Significant differences were detected between crops, but also between models but crop x model interaction was not significant (Table 3). Seed yield (SY) was highest for millet but was not significantly different from the other cereals (Table 4). Cowpea and groundnut had the lowest SY which differed significantly from millet, but not from rice and sorghum. The SFM recorded the highest SY but was significantly different only from the RIM. The SY recorded for SCM and RIM were not significantly different from each other (Table 5). Overral, millet out-performed the potential of the variety used (111.5%). Sorghum, groundnut, and cowpea realized 93.25, 95.42 and 69%, respectively, of the potential yield of the varieties used; whereas rice achieved less than 50% of the potential of the variety used (Table 6).

Table 2. Characteristics of the trials per crop and per model

Crop Variety	Model	2018			2019		
		Sowing	Days to harvest	Total rain fall (mm)	Sowing	Days to harvest	Total rain fall (mm)
	RIM	July 6	116	1397.5	July 8	104	965
Rice	SCM	June 29	91	823.5	July 8	79	1023.5
Nerica 8	SFM	July 14	139	998.3	July 11	101	976.78
	RIM	July 8	140	738.6	July 9	127	925
Millet	SCM	July 3	130	823.5	July 10	86	1023.5
Toroniou C1	SFM	July 10	129	690	July 10	138	833
	RIM	July 6	103	738.6	July 15	98	925
Sorghum	SCM	July 3	97	823.5	July 10	86	1023.5
CSM63E	SFM	July 9	127	690	July 9	129	833
	RIM	July 4	99	738.6	July 9	106	925
Groundnut	SCM	July 5	97	824.5	July 8	88	1023.5
Fleur11	SFM	July 17	95	696	July 13	106	952
Cowpea	RIM	July 16	72	738.6	July 16	94	925
Wilibali	SCM	June 28	69	579	July 22	NA	1117.4
	SFM	July 23	108	690	July 26	81	833

RIM : Research Institution Model ; SCM : Seed Company Model ; SFM : Smallholder Farmer Model; NA: Not Available

Table 3. Analysis of variance for seed yield (SY) combined across 2018 and 2019

Source	DF	Seq SS	Adj SS	Adj MS	F statistics	P
Crop	4	6263511	6263511	1565878	60.2	0.005
Model	2	4246622	4246622	2123311	8.16	0.004
Crop*Model	8	4478478	4478478	559810	2.15	0.1
Year	1	33912	33912	33912	0.13	0.724
Error	14	3643523	3643523	260252		
Total	29	18666047				

Table 4. Comparisons of different crops for seed yield as measured in the test plots (0.25 ha) combined across 2018 and 2019

Crop	Yield (kg/ha)
Rice	1821.11 ab
Millet	2223.56 a
Sorghum	1862.67 ab
Groundnut	1143.22b
Cowpea	1025.78b

Means with similar letter in a column are not significantly different from each other (P 0.05)

Table 5. Comparisons of different models for the efficacy of seed yield as measured in the test plots (0.25 ha) for the data combined across 2018 and 2019

Model	Yield (kg/ha)
Research institutions	1190.67b
Seed companies	1549.87ab
Smallholder farmers	2105.27a

Means with similar letters in a column are not significantly different from each other (P 0.05)

Table 6. Overall yield performance of the crops used compared to the potential of their respective varieties pooled across models and years

Crop	Variety	Overall seed yield (t/ha) of the project	Yield potential of the variety (t/ha)	Overall percent achievement of the yield potential (%)
Rice	Nerica 8	1,82	4	45.5
Millet	Toroniou	2,225	2	111.25
Sorghum	CSM 63E	1,865	2	93.25
Groundnut	Fleur11	1,145	1,2	95.42
Cowpea	Wilibali	1,035	1,5	69

Performance of each model and crop in term of seed quality. In 2018 and 2019, there was 0% rejection during the certification process for the three models for millet, sorghum and cowpea. In 2018, smallholder farmers had one third of their rice seed rejected and 100% of their groundnut seed rejected. In 2019, all the three models had 100% of their rice seed rejected due to non acceptable numbers of red seeds in the samples. Regarding groundnut, 100% of the seed produced by the RIM and SCM were rejected wheras SFM had zero percent rejection (Table 7).

Efficacy of each model in foundation seed production. The efficacy of the foundation seeed models was measured as the level of achievement of the potential yield of each crop variety used in the experilents. Although crop x model interaction was not significant, RIM realized the lowest achievement of the yield potential of each crop variety except for cowpea for which the SCM realized the lowest performance (Table 8). The smallholder farmer model performed well for all cereals and for cowpea. It was generally followed by seed company model except for cowpea where the RIM performed well. The greatest concerns in achieving the yield potential of the crop varieties were related to the RIM model for rice and the SCM for cowpea. These two models x crop combinations realized less than twenty percent of the yield potential of the varieties leaving huge yield gaps greater than 80% (Table 8).

DISCUSSION

In this study, significant differences were detected between crop species for yield. But generally, researchers tend to avoid comparisons between crop species. Comparison is rather done between varieties within crops. The between crop species comparison done in this study was needed to shed light on the challenges stakeholders of the seed value chain face in terms of sufficient quality seed to fullfil the seeding requirement per hectare of some species such as rainfed rice, groundnut, and cowpea due to their yield potential. The yield potential of the rice Nerica 8 ML, Millet Toroniou C1, Sorghum CSM63E, Groundnut Fleur11, and Cowpea Wilibali are respectiviely 4, 2, 2, 1.2, and 1.5 t/ha (Anonymous, 2016). On another hand, the seeding rate per hectare of rice, millet, sorghum, groundnut, and cowpea are 60, 6, 6, 60, and 20 kg/ha, respectively (according to the breeders of the RIM models). Thus, the ratio seed sown:seed harvested is 1:67 for rice; 1:333 for millet and sorghum, 1:20 for groundnut and 1:75 for cowpea. These ratios make millet and sorghum the crops with the highest value because one can harvest 333 kg from sowing only 1 kg. Following the same analysis, groundnut and rice are the crops with the lowest values whereas cowpea is a crop with intermediate value in terms of seed sown:seed harvested ratio of 1:75.

Table 7. Seed rejection by the national certification agency per crop, year and per model (% of total seed lot)

		Rate of seed rejection at certification (%)			Reasons for seed rejection
Crop	Year	RIM	SCM	SFM	
Rice	2018	0	0	33	Red seeds
Rice	2019	100*	100	100	Red seeds
Groundnut	2018	0	0	100	Purity of seed variety
Groundnut	2019	100	100	0	Purity of seed variety

Source : National Seed Laboratory (2018 and 2019). *Downgraded from foundation to certified seed class

Table 8. Achievement of the models for the yield potential of the varieties used in the trials combined across 2018 and 2019

Crop the	Variety	Model	Yield potential of the variety (t/ha)	Seed yield of the model (t/ha)	% achievement of model relative to the yield potential
Rice	Nerica 8	RIM	4	0.74	18.50
Rice	Nerica 8	SCM	4	1.96	49
Rice	Nerica 8	SFM	4	2.23	55.75
Millet	Toroniou C1	RIM	2	1.79	89.50
Millet	Toroniou C1	SCM	2	2.37	118.5
Millet	Toroniou C1	SFM	2	2.23	111.50
Sorghum	CSM63E	RIM	2	1.48	74
Sorghum	CSM63E	SCM	2	1.71	85.50
Sorghum	CSM63E	SFM	2	2.04	102.00
Groundnut	Fleur11	RIM	1.2	0.76	63.33
Groundnut	Fleur11	SCM	1.2	1.52	126.67
Groundnut	Fleur11	SFM	1.2	0.9	75
Cowpea	Wilibali	RIM	1.5	1.31	87.33
Cowpea	Wilibali	SCM	1.5	0.22	14.67
Cowpea	Wilibali	SFM	1.5	1.45	96.67

The fact that significant differences were detected between crops was not surprising since we are dealing with different species. This merely reflected the genetic potential of the crops and their respective varieties used in this research. Nerica 8 ML rice variety was the crop with the highest yield potential (4 t/ha). However, its poorest performance (1.82 t/ha) compared to the other cereals (millet and sorghum) was quite surprising but comparable to the results of Kotchi *et al*. (2010) who obtained yields of 1.2 – 1.9 t/ha for five rainfed rice varieties grown on acid soils of Cote d'Ivoire after phosphate treatment. On the contrary, Sanogo *et al*. (2020) reported higher yields for Nerica rice varieties (2.7 – 3.5 t/ha) also in Cote d'Ivoire. The low rice yield observed in this study was due mostly to the poor performance of the RIM which realized only 18.5% of the potential of the rice variety and to a lesser extent by the SCM which realized only 49% of the potential of the variety. Smallholder farmers did better by realizing 55.75% of the potential of the Nerica 8 ML rice variety. Generally speaking, rice was the least performing crop for all the three models in terms of seed yield which is quite the opposite of the expectations. Worth noting here is the highest requirements of Nerica 8 ML rice variety in terms of precipitations (800 – 1000 mm) compared to the other crops and their respective varieties used in this research (400 – 800 mm) and this could explain in part the yields obtained, but not all of the poor performance observed for rice since there was enough rains for all the RIM (1397.5 mm in 2018 and 965 mm in 2019).

The fact that rain-fed upland rice such as Nerica 8 is a crop with low value combined with the poor yields observed with the models tested here explains the difficulties encountered by the stakeholders in availing sufficient stocks of rice foundation and certified seeds.This result brings about the difficulties pertaining to the farming of rain-fed upland rice in Mali. Especially one may ask the following questions: Are the environmental conditions (soil characteristics, precipitations, pests and diseases status) of the locations suitable for rice production? Is upland rain-fed rice too much demanding in terms of efforts and investments in production and processsing more than the other crops? Can the producers of the three models afford the needed efforts and investments or is rice foundation seed worth all the needed efforts and investments in terms of economic return from investment? What can be done to improve the yield of rain-fed upland rice in Mali? As long as rain-fed upland rice seed yield is not improved, its seed business shall remain unattractive to stakeholders especially from the private sector.

Regarding millet, the overall yield across the three models was 2.23 t/ha which outperformed the potential of the variety by 111.5%. The RIM was the lowest yielding (1.8 t/ha). Sissoko and LeBailly (2019) obtained lower yields for millet which varied from 1.3 to 1.6 t/ha in the cropping season 2013/2014 and from 1.2 to 1.5 t/ha in the subsequent season in the three main production basins of millet in Mali (Segou, Koulikoro and Mopti regions). Both SCM and SFM obtained higher yields than those of Sissoko and LeBailly (2019).

Sorghum overall yield across all models was a bit smaller than that of millet (1.9 t/ha versus 2.23t/ha). Smallholder farmers were the best (2.04 t/ha) and they outperformed the potential of the variety by 102%. The two models, RIM and SCM, achieved respectively 1.5 and 1.7 t/ha. In the three main production basins of sorghum in Mali (Segou, Koulikoro and Mopti regions), Sissoko and LeBailly reported lower yields raging from 1.2 to 1.6 t/ha.

For groundnut, the overall seed yield across all models was 1.15 t/ha and this was almost the same as the maximum possible seed yield for Fleur11, the variety used in the study(1.2 t/ha). Also SCM realized 1.52 t/ha which was able to beat the potential of Fleur11 by 126.67%. This was similar to the 1.6 t/ha seed yield derived from 2.34 t/ha pod yield obtained by Goalbaye *et al*. (2017) for Fleur 11 sown at a planting density of 125751 plants/ha in Senegal. The RIM (0.76 t/ha) and SFM (0.9 t/ha) yielded lower than the SCM and than the yield obtained by Goalbaye *et al*. (2017). In the RIM, the low yield was due to the stunted appearance and rot due to the occurrence of disease. This considerably affected the normal development of the vegetative cycle of the plants. Regarding the farmer model, average production was mainly due to drought at harvest time. This resulted in pod loss at the ground level.

Cowpea yielded overall 1.04 t/ha in this study. In Cote d'Ivoire, other authors reported higher yields for cowpea ranging from 1.87 to 2.1 t/ha depending on the variety (N'Gbesso *et al*., 2013). The low yield of cowpea observed in this study was mainly attributable to the poor performance of the SCM which realized only 15% of the potential of the variety. This poor performance was due to high rainfall in 2019 (1117.4 mm) recorded in the locality of seed production which caused rotting and discoloration of most of the cowpea seeds. Also, abnormal small pods were observed which were discarded.

When it comes up to quality issues, no rejection was observed for sorghum, millet, and cowpea during the two years of the trials for all the three models. The 2014/2015 cropping season statistics of LABOSEM also recorded zero rejection of the foundation seed of sorghum, millet, and cowpea produced by the research institutions (7.9, 4.7, and 5.05 tons for sorghum, millet and cowpea, respectively). Records of LABOSEM (2015/2016) also revealed zero rejection at certification for the 2.6 tons of sorghum foundation seed produced by the Seed Company Camara Semences. Similar results were also recorded by LABOSEM (2015/2016) for sorghum, millet and cowpea foundation (2.42, 3.35, and 5.82 tons, respectively) produced by the research station of Cinzana. Hence quality performance of sorghum, millet and cowpea seed produced under the formal seed system seems to be of minor concern. This result combined with the quantitative performance of the SFM for these crops shows that smallholder farmers are capable of producing foundation seed under formal seed system for these three crops. On the contrary quality issues were recorded for rice and groundnut with rice recording the highest rates of rejection by the national seed certification agency and / or seed inspectors. The quality issues observed for rice and groundnut were found in all the three models indicating that this is not only a smallholder farmer issue. LABOSEM (2015/2016) recorded 100% rejection of the 2.72 tons of groundnut foundation seed produced by the research institutions. LABOSEM statistics also showed variables results on rice foundation seed quality, with the rainfed rice breeding program showing zero percent rejection in the cropping season 2014/2015 from 16.8 tons produced and only 0.67% rejection out of the 10.5 tons of seed produced in the cropping season of 2015/206. The irrigated rice breeding program had 19.8% rejection in 2014/2015. Once again, one needs to ask the following questions about the source of the red seeds responsible for rice seed failure to pass the certification process: Is the origin of the red seeds environmental or genetic? What can be done to reduce the presence of red seeds? Is rice seed processing and removal of red seeds doable manually? Is it worth to invest time, efforts and resources in rice seed processing to remove red seeds? Are there any technics to identify and remove the off types sources of red seeds in the rice field and have producers of the three models practice those technics? Here, it is worth recalling that Nerica 8 ML rice is an interspecific cross bred variety between *Oryza sativa* and *Oryza glaberrima* released since 2002 (Anonymous, 2016) which may have degenerated and as such needs to be purified to have it come up true to type.

Comparison of the seed quality of rice, millet and sorghum clearly shows that there is a need for researchers, extension agents, and seed certification agents to work together to improve rice seed quality by reducing the undesirable red seeds which are seeds of the glaberrima parent of the degenerated Nerice 8 rice or those of the wild rice *Oryza barthii*. Seeds of these two rice species are red and the LABOSEM generally refers to them as "red seed". During the certification process, the laboratory technicians look for the seeds of the undesirable glaberrima rice, but most importantly those of the wild rice *Oriza barthii*. Seeds *Oryza barthii* are the reasons of rice failure to pass the certification process. This can be improved by applying the recommended seed production practices such as crop rotation, appropriate weeding, rogging of off-types, and the use of good breeder and foundation seeds.

As long as the questions above are not resolved, shortages of rainfed upland rice foundation seed and certified seed will remain in Mali. These results may explain why former studies have considered rice as a risky crop in terms of investments and efforts and have put it under the mixed public/private model of seed production as a means to reduce risks (BMGF and USAID, 2015).

Like rice, groundnut also exhibited quality issues pertaining to the genetic purity of the variety indicating that the variety Fleur11 used in the trials may have been contaminated with one or more other groundnut varieties. In the first year trials in 2018, only groundnut seed of the women farmers (SFM) was rejected (100%) and the rejection occurred after pod sampling in the laboratory. This could be explained by the fact that these women farmers were involved in seed production for the very first time and were not aware of seed production technics, especially pod cleaning and sorting to remove off-types, small pods, empty pods, etc. These much needed processes were not performed by the women before pod sampling. The successful certification of their groundnut seed in year 2 of the project indicated that they learnt lessons from the failures they experienced in 2018. Also, during year 2, the project provided several quality assurance trainings from the field to the warehouse, to the leaders of the women group and to the extension agent of SAA, in charge of the technical bacstopping of their seed production field. The said trainings were provided by SAA staff in partnership with the National Seed Laboratory and the foundation seed unit of IER.

By contrast with the women farmer's groundnut seed, the seed production fields of the SCM and the RIM were both rejected before harvest in year 2 of the project due to the same reason of varietal purity. The fact that this happened despite the trainings provided by the project to the stakeholders of the RIM and SCM needs explaining. Actors in these two models, in spite of good yield, may have neglected the removal of off-types from the seed production fields and/or may have been less rigorous in the choice of the field which should have been planted with a crop other than groundnut during the previous year to allow crop rotation.

CONCLUSIONS

From the results of this research it can be assumed that rigor is applied by seed inspectors and agents of the National Seed Laboratory in the process of field inspection and seed certification which is good for seed quality assurance and competitiveness of the Malian seed sector in the subregion. Based on the results of this experiment, Foundation seed of millet, sorghum, and cowpea can be produced under the formal seed system by the SHF model with high yields and good quality. Likewise, SCM model can produce foundation seed of sorghum and millet with good yield and high quality. The RIM performed well with cowpea. Thus, policy makers should consider involving seed companies and smallholder farmers together with research institutions in the production of foundation seed as long as they can fullfil all the quality requirements.

Yield performance is not an issue in groundnut production but there are serious issues of quality for all the three models. Regarding rice, there are problems with both yield and seed quality performance. The combination of large seeding rate (60 kg per ha) and poor seed sown, resulted in the low seed harvested ratio (1:67) and this explains the unattractiveness of upland rice seed production and the large deficit of certified and foundation seed produced.

Finally, our results need to be used with caution since the models and crop varieties used were considered as fixed variables. In addition, one needs to assess the economic performance of each model and crop combination to find out which crop is more suitable or less risky for which model. Such information is needed to help actors in decision making relative to the organization, coordination and demand forecasting of the Malian seed sector. Finally, strong involvement of extension services is needed to promote the use of certified seeds.

ACKNOWLDEGMENT

This research was funded by the Food and Business Applied Research Fund – ARF of the Netherlands Organization for Scientific Research (NWO). The authors are thankful to RUFORUM for their technical support.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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