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Research article

Effects of low-cost agricultural technology package on income, cereal surplus production, household expenditure, and food security in the drylands of Mali

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Abstract: This study assessed the effects of introducing a technology package consisting of seed priming and microdosing of mineral fertilizer on sorghum and pearl millet yield, cereal production, net value of cereal production, household expenditure, adoption rate of technology and household food security in the millet and sorghum producing areas in Mopti, Segou and Koulikoro regions of Mali. Three different surveys were undertaken to collect the data during the period from 2013 to 2015. The first survey assessed the farmers practices (360 households), the second survey assessed production, household expenditure and food security in the households (54 households) and the third survey assessed the adoption rates of the technologies (108 households). The surplus cereal production was in average 1155 kg/household for adopting households while non-adopting households had a surplus of only 196 kg/household. The monetary surplus increased from 31.2 Euro for non-adopting households to 215.6 Euro for adopting households. Households using the package spent 167.8 Euro on health, children's education, and other necessities while non-adopting households spent only 29.5 Euro. Furthermore, households using the package spent 55.9 Euro on fertilizer against close to zero for non-adopting households. Finally, the number of food insecure months were significantly reduced from 3.57 months for the adopting households to 1.24 months for non-adopting households. The technology package initiated positive development pathways characterized by increased production and income, surplus grain production, investments in livelihood assets and yield-enhancing technologies and improved food security. This link from technology introduction to improved food security is very important from a development perspective, but there is a lack of research that clearly demonstrate this effect in the drylands of West Africa. Future interventions to ensure a more broad-based development should focus on continued investment in yield-enhancing technologies, diversification of production to ensure better access to high quality food, strengthening the role of women, and building institutions to support farmers' livelihood and agency.

Keywords: intensification; dryland farming; microdosing fertilizer; seed priming; cereal surplus; household expenditure; food security; development pathway

1. Introduction

The World Food Summit in 1996 defined food security as follows: "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." Originally food security included the dimensions of availability, access, utilization and stability [1], but the High-Level Panel of Experts on Food Security and Nutrition (HLPE) also added the dimensions of agency and sustainability [2]. Agency is included to ensure people's empowerment over the food system and inclusiveness of all groups in the decision processes. Sustainability ensures that the food needs of present and future generations are achieved without compromising the environmental, economic, and social bases on which the food systems depend.

There are multiple causes of low food security in Africa. Key factors contributing to low food security are high population growth, low yields, poor soil fertility and soil degradation, small farms, climate variability, diets not sufficiently diversified, poorly developed infrastructure, limited access to sanitation, insufficient health services, weak institutions, and policy failures [3–5]. Poor families also have limited capital assets on which they draw in times of hardship [6].

Food and nutrition security is also a significant development challenge in Mali. According to the World Food Program, 30.4% of the children in Mali are stunted and average number of food insecure people per year is 3.6 million [7]. Important factors explaining the high number of food insecure people are political insecurity, civil unrest, recurrent drought, land degradation and lack of access to inputs like seeds and fertilizer [7].

Interventions to improve food security in Mali need to consider the great variability in livelihood opportunities across the country and that interventions may not be equally efficient in reaching the poor households [8]. Nomadic livestock production dominates livelihood activities in the northern parts of Mali while mixed crop–livestock production is practiced in central Mali. Crop production here is dominated by pearl millet (*Cenchrus americanus* (L.) Morrone and sorghum (*Sorghum bicolor* (L.) Moench. In southern Mali, people mainly rely on cotton and maize production for food and income generation. Rice production is key for income generation along the Niger river.

Access to production resources varies greatly between the households, and production-oriented activities will mostly reach households with access to land and livestock. The poorest segments of population have limited access to land and livestock and depend on selling their labor to secure an income [8].

Mali has faced and continues to face a tremendous challenge to produce enough food for its population. The population increased from 5 million in 1960 to currently about 20 million representing a quadrupling of the population in 50 years. The annual population growth is currently 3.0% [9] implying that the population will double in 23 years. Mali has been successful in promoting cereal production in the last decades as production has quadrupled from 1980 to 2020. This increased cereal production can mainly be explained by a tripling of the cropping area during this period [10].

The relationship between food production and household food security is complex and has been most intensively studied in the southern parts of Mali. Here, it has been found that despite sufficient cereal production, malnutrition still prevails. The reasons that have been advanced to explain this anomaly are women's high workload, low education level of women, women's limited control over income from cotton production and low diversification of the diet [11]. In addition, the fertilizer subsidy program in Mali mostly reaches men because only the head of the household can get access to subsidized fertilizer. Women are therefore dependent on negotiation with their husbands to get access.

The justification of this study is the dire need to increase food production and improve food security in the pearl millet- and sorghum producing areas of Mali. We assess how agricultural technologies can increase household income and improve food security. The technologies introduced were seed priming (soaking seeds in water prior to sowing) and microdosing of mineral fertilizer which are technologies with a proven effect on cereal yield in the drylands of West Africa [12–14], but it has not previously been studied how these technologies can improve farmers income, surplus grain production and food security. These technologies have previous been identified as entry points for agricultural intensification in the drylands of West Africa [15] since the cost and labor demand of using these technologies are very low. This makes technology adoption possible despite unfavorable external conditions.

The objectives of this study were to assess farmers' production constraints, study the adoption rate of new technology, and to explore the effect of introduction of new farm technologies on yield, surplus cereal production, net farm income, household expenditure and household food security. The hypothesis of the study is that the improved agricultural technologies can improve income and food security in the pearl millet- and sorghum producing areas in Mali.

2. Materials and methods

The study was undertaken in the regions of Koulikoro, Segou and Mopti which are located in the Sudano-Sahelien and Sahelian zones of Mali (Table 1). In each of the three regions three villages were selected.

Table 1. Characteristics of the regions included in the study.

Regions	Villages	Rainfall mm	Agro-climatic zone
Koulikoro	Nossombougou, Didiéni, Koloko	600–850	Sudano-Sahelien
Ségou	Konobougou, Niono, Cinzana	500–700	Sahelian
Mopti	Bandiagara, Bankass, Koro	400–600	Sahelian

The farmers in these villages were introduced to the new technologies from 2007 by researchers from the national agricultural research institute, Institute Economie Rurale (IER) in Mali. The project used the lead farmer approach by training 10 farmers in their individual plots in each village. These plots were demonstration plots for training of five other farmers. The two main technologies introduced to the farmers were seed priming and microdosing, but they also received training on good general crop husbandry. Seed priming was undertaken by soaking the seeds in water at ambient temperatures for eight hours followed by air drying of the seeds under shadow for one hour to reduce the stickiness of the seeds. Soil was tilled according to farmers' preferences. The sandy soils of Mopti and Segou regions were generally not plowed prior to sowing. Farmers generally plant pearl millet on the sandy soils while sorghum is preferred on heavier soils with higher clay and silt content. The latter soils are leached ferralitic soils. Microdosing consisted of mixing seeds and fertilizer in a one-to-one ratio prior to sowing and this mixture gives about 0.2 g NPK per hill. In the Mopti region farmers sow at a density of 10,000 hill ha^{-1} (inter-row 1 meter and intra-row 1 meter) and here 0.2 g NPK per hill gives an application rate of 2 kg NPK ha^{-1}. Planting density in Segou and Koulikoro regions is normally 25,000 hill ha^{-1} (inter-row 0.8 meter and intra-row 0.5 meter) corresponding to 5 kg NPK ha^{-1} if 0.2 g NPK is applied per hill. The NPK fertilizer used was 15-15-15 equivalent to 15 N%, 15% P_2O_5 and 15% K_2O.

The study included three different household surveys that were undertaken in the period from 2013 to 2015:

1. The first survey of 360 households was based on selection 40 households in each of the nine villages included in the study. These nine villages (three in each region) were among the villages included in the project promoting the improved technologies. This survey assessed the farming system and identified farmers' production constraints
2. In the second survey 18 households were selected from each of the three regions giving a total of 54 households. Of these households, 33 were practicing full scale microdosing and seed priming while 21 households were using the traditional technologies. The criteria for being selected as an adopting farmer was that the farmers had practiced the technologies on all of their land for at least five years. The survey assessed farmers' yield, production surplus, income, expenditures, and food security.
3. The third household survey assessed the adoption rate of the technologies and was based on randomly selecting 12 households from each of the nine villages, giving in total 108 households.

In each of these surveys the head of household was interviewed, and they accepted the participation in this survey. The data were analyzed statistically using Microsoft Excel and SPSS 20.

3. Results

Results are presented on farm characteristics and effect of improved technologies on yield, surplus production, net value surplus production, household expenditure and food security.

3.1. Characteristics of the farming household and the farming system

Data on the farming system was obtained from the household survey including 360 households in the project regions. An average household had 22 people of whom 10 people can be characterized as active labor. Only 33% of the household members were alphabetized. Food security was a major issue in all the sites, as 35% of the households experienced shortage of cereals for consumption every year while 28% experienced shortage every second year.

The farming system in the study areas was a rainfed mixed crop–livestock system with pearl millet and sorghum as the major crops. Most farmers can be considered subsistence oriented as 70% of the farmers are not selling their cereal production. The households cultivated on average 12 ha of which 8 ha was under pearl millet. The households were poorly equipped with farm equipment and only 15 and 19% of the households possessed plows and planters respectively.

Monocropping was practiced on 69% of the millet fields and 84% of the sorghum fields while the rest is under intercropping with cowpea. Crop rotation with maize (Zea Mays (*Zea Mays* L.), groundnut (Arachis hypogea L.), fonio (*Digitaria exilis* (Kippist) Stapf) and cowpea (*Vigna unguiculata* L. Walp.) was frequently practiced. About 55 % of the farmers used the plow to make ridges while 35% practiced flat cultivation. Manual sowing was practiced by 74% of the farmers while 22% used planters. Planters were not in use in the Mopti region. Traditional varieties were used by 81% of the farmers and 58% used seeds from own production. Manual weeding was practiced by 51% of the farmers while 49% practiced mechanized weeding using oxen or donkeys as animal traction. Farmyard manure and organic waste was used by 24% and 19% of the households respectively while 66% used mineral fertilizer.

The households assessed their major farming constraints as being drought (87%), low soil fertility (68%), lack of agricultural equipment (60%), low use of fertilizer (52%) and low use of improved varieties (23%) (survey 1). Less than 10% of the households observed problems with insects and birds. Low rainfall was particularly considered to be a problem in the Mopti region as this is the region with the lowest rainfall (Table 1). There was no clear trend since the 1980s with regard to yearly rainfall and annual yield of pearl millet and sorghum [16].

3.2. Effect of introduced technologies on yields, total cereal production, surplus cereal production, household expenditures and food security

The second survey compared farmers who practiced the technologies on a large scale (microdosing and seed priming) against households not practicing these technologies. There were no major differences between these two groups regarding cultivated area, number of active workers per household and hectares per active persons (Table 2). Average pearl millet and sorghum yield for farmers using traditional practices was 444 and 631 kg ha^{-1} respectively while the corresponding yield was 1456 and 1114 kg ha^{-1} for farmers using the improved technologies (Table 3). Total sorghum/millet production was 1869 kg for the households using traditional practices and 5957 kg for the households using improved technologies (Table 3). The main cause for the large difference in cereal production was a higher yield in the household using the improved technologies. In addition, the area under cereal production was also slightly higher for the farmers using improved technologies. Households practicing improved technologies assessed that they had an auto-consumption of 4802 kg while the corresponding figure for farmers not using improved technologies was 1674 kg. There was a higher consumption in the households using improved technologies, resulting from increased cereal availability. It is likely that auto-consumption also included using part of the harvest as animal feed. The cereal surplus (deducting the auto-consumption from the total production) was 195 kg for farmers using traditional technologies while farmers using improved technologies had a surplus of 1155 kg.

Table 2. Difference between farmers using tradition technologies and farmers using improved technologies.

	Households using traditional technologies (N = 21)	Households using improved technologies (N = 33)
Average cultivated area millet/sorghum (ha)	3.46 ± 0.96	4.33 ± 0.99
Active laborers per household	8.4 ± 1.68	8.3 ± 1.45
Cultivated area per active laborer (ha/active)	0.51 ± 0.14	0.54 ± 0.25

Table 3. Effects of traditional and improved practice on yield, production, auto-consumption, and surplus production.

	Households using traditional technologies					Households using improved technologies				
	Area Ha	Yield kg/ha	Prod. Kg	Autocons. Kg	Surplus Kg	Area Ha	Yield kg/ha	Prod. Kg	Autocons. Kg	Surplus
Millet	2.36 ± 0.82	444 ± 127	1049 ± 325	934 ± 289	119 ± 40	3.31 ± 0.95	1456 ± 240	4820 ± 1339	3929 ± 1083	892 ± 169
Sorghum	1.30 ± 0.83	631 ± 319	820 ± 326	744 ± 296	77 ± 35	1.02 ± 0.44	1114 ± 229	1137 ± 513	874 ± 370	263 ± 166
Total cereal	3.66 ± 0.97		1869 ± 228	1674 ± 635	195 ± 32	4.44 ± 0.99		5957 ± 1177	4802 ± 953	1155 ± 258

Table 4. Net value of surplus production of millet and sorghum for farmers practicing traditional and improved practices respectively. Values are Euro per farm.

	Households using traditional technologies			Households using improved technologies		
	Millet	Sorghum	Millet/ sorghum	Millet	Sorghum	Millet/ sorghum
Surplus production (kg)	119	77	196	892	263	1155
Grain price Euro/kg	0.23	0.19	-	0.23	0.19	-
Value surplus production	27.1 ± 9.1	14.6 ± 6.6	41.7 ± 7.0	203.4 ± 61.7	50.0 ± 31.6	253.3 ± 57.7
Production costs	6.4	4.1	10.5	29.8	7.9	37.7
Net value millet/sorghum surplus production per farm	20.7 ± 6.6	10.5 ± 6.6	31.2 ± 6.6	173.5 ± 53.7	42.1 ± 3.2	215.6 ± 38.9

The increased surplus of cereal production for the farmers practicing the improved technologies also gave them an economic benefit. The surplus for millet and sorghum per household increased from 196 kg to 1155 kg (Table 3) and the corresponding net value of surplus production increased from 31.2 Euro to 215.6 Euro per household (Table 4). The households practicing the improved technologies therefore had more funds to cater for their daily needs, as well as the possibility to make investments for increasing farm productivity. The fertilizer cost was very low at 2 kg NPK ha^{-1} corresponding to 0.68 Euro ha^{-1} and about 3.0 Euro per household for a farm of 4.33 ha (Table 2).

Table 5. Distribution of household expenditure for households practicing and non-practicing improved technologies in pearl millet and sorghum production. Expenses are in Euro.

Expenditures	Farmers using traditional technologies (N = 21)		Farmers using improved technologies (N = 33)	
	Expenses	% of total expenses	Expenses	% of total expenses
Health	6.2	20%	44.7	20%
Education	7.8	25%	55.9	25%
Taxes	3.1	10%	22.4	10%
Construction	6.2	20%	22.4	10%
Weddings	6.2	20%	22.4	10%
Purchase of fertilizer	1.6	5%	55.9	25%
Total expenses	31.6	100%	223.7	100%

The improved technology package allowed the households to increase their expenditures (Table 5). Households using the improved package spent 223.7 Euro while those not using the package could only spend 31.6 Euro. Households using improved technologies spent far more on health, education, taxes, construction, and weddings compared to those not practicing the technologies. In addition, those who practiced microdosing spent 55.9 Euro on fertilizer while non-adopting households only spent 1.6 Euro.

There was a statistically significant reduction in number of food insecure months from 3.57 [2.43–4.80] months for households practicing the traditional technologies to 1.24 [0.74–1.74] months for households using the improved technologies.

3.3. Adoption of technologies

In order to have an effect on food security beyond the targeted households, widespread adoption of the technologies is needed. This study showed that microdosing and seed priming was adopted by 73% and 39% of the farmers respectively. Other technologies adopted included improved varieties (49%), composting (33%), use of farmyard manure (30%), early sowing (26%) and mechanized sowing (26%). There was no subsidy or financial support from the project to promote the technologies.

4. Discussion

4.1. Effect of the technologies on yield, surplus cereal production and expenditures

The introduced technologies increased yield, cereal surplus, household income and household expenditures. Average pearl millet was increased from 445 kg ha^{-1} for households using traditional technologies to 1459 kg ha^{-1} for households using improved technologies while the corresponding numbers for sorghum were from 631 kg ha^{-1} to 1137 kg ha^{-1}. These technologies have also been found to increase yields in on-farm experiments in Mali and Niger [12,17].

The cereal surplus increased from 196 kg for households not practicing the improved technologies, to 1155 kg for households practicing the improved technologies, and the corresponding value of the surplus production increased from 31.2 to 215.6 Euro. The adopting households compared to the non-adopting farmers had 7 times (223.7 against 31.0 Euro) more funds to spend than non-adopting farmers. The adopting farmers spent more on education, health, housing and farm inputs than non-adopting farmers. Adopting farmers spent 55.9 Euro on fertilizer while the non-adopting farmers only spent 1.6 Euro which shows their willingness to invest in yield-enhancing technologies.

Other studies in the same regions confirm that the farmers who practice microdosing make investments to improve farm productivity. A qualitative study in Mali [18] showed that farmers who practiced seed priming and microdosing purchased more farm equipment such as carts, ploughs and planters and purchased livestock. Outmigration of young people also decreased resulting from improved food security in the households. Furthermore, the households purchased solar panels for lighting and watching TV. In the cotton production zone in southern Mali, it has also been found that the surplus from cotton production allowed the farmers to purchase input and farm equipment [19].

4.2. Effect on food security

There was a statistically significant reduction in the number of food insecure months from 3.57 months for households practicing the traditional technologies to 1.24 months for households using the improved technologies. A study by in the same regions in Mali showed that the number of food insecure months was reduced from 4.1 months before the farmers started to use the technologies to 1.3 months after the adoption of the technologies [20]. This also confirm the hypothesis that the improved agricultural technologies improve income and food security in the pearl millet- and sorghum producing areas in Mali.

The improvement in food security was likely the result of strengthening all six dimensions of food security (availability, access, utilization, stability, agency, and sustainability). Food availability was increased resulting from an increase in surplus cereal production. Food access was increased because of higher income. Another study across different regions in Mali found that increased farm income was positively although weakly related to better child health and that increased income from agriculture allowed for more investment in local health centers [21]. Furthermore, it is also likely that there is an effect on food utilization as the farmers increased their expenditure on health, education, and housing. Food stability is improved as these technologies have been shown to reduce the probability of a low income in Mali [22]. Stability is also enhanced resulting from a shortening of the growing cycle and improved crop establishment [17]. This reduced the need for resowing the crops. Agency is improved because the farmers received training on improved production methods and particularly because their net income increased which allowed them to increase their expenditures according to their preferences as Table 5 shows. Yet, farmers’ freedoms are still severely curtailed owing to high levels of poverty, poorly developed institutions, and low status of women. The dimension of sustainability was enhanced resulting from farmers’ accumulation of financial capital, increased access to production resources like farm input and livestock and reduced probability of a low economic return [12]. Finally, the technologies increase the sustainability of the livestock systems as straw production is increased. Another study in Mali confirmed the importance of building capital assets to increase resilience of the household. The study showed that increased resilience of the households in the form of cultivated area, livestock ownership, quality of housing, sanitation, access to electricity, household characteristics (dependence ration etc.) and family health reduced the probability of child malnutrition [6].

A study from Niger also confirmed that introduction of new agricultural technologies can improve the different dimensions of food security [23]. Here it is was found that the introduction of stone bunds, tree planting, manure application and integrated soil fertility management increased pearl millet yield by more than 30%, enhanced the caloric per capita food intake and improved household food diversity.

Our study showed that the improved technologies did not completely remove food insecurity as the adopting households were still on average food insecure for 1.2 months. The improved technologies increased surplus production, but households are still food insecure despite the surplus in cereal production. One reason for this anomaly is that households may forego cereal consumption in some months to have sufficient funds to cater for other needs. Furthermore, food security is not only about cereal production, but the households also ensure their food security through cultivating other rainfed crops, livestock production, horticulture, small businesses, artisanal activities, selling their labor, income from migrated family members and finally liquidizing capital assets. Despite these activities, cereal production remains their largest source of income as in the pearl millet and sorghum producing areas in southern Mali where farmers generated 70% of their income from crop production [24]. It is very common in Mali that farmers need to purchase part of their food supply, particularly the poorest segments of the population [8].

Other similar development initiatives have also showed an effect on food security in Mali. A study of the fertilizer subsidy program in the rice and cotton producing areas in Mali showed that the subsidies increased food production, income, and household expenditures [25]. However, women benefited less than men because, to a large extent, they got access to fertilizer through their husbands. There are similarities between a subsidy program for fertilizers and the introduction of improved technologies (seed priming and microdosing). As found in our project, both types of interventions will reduce fertilizer cost owing to better fertilizer-use efficiency in the case of introducing technologies, while the subsides on fertilizer reduce fertilizer costs directly. A study of maize production systems in southern Mali also showed that the use of improved technologies (organic fertilizer and early varieties) improved household food security [26].

However, addressing food security through promoting yield enhancing technologies in cereal production has its limitations because a focus on cereal production will not sufficiently address the problems of poor nutritional quality. There is particularly a need to diversify production to addresses deficiencies in nutrition related to micronutrients such as vitamin A and C, iron, and Zn [21]. These deficiencies can be corrected by production and consumption of mango, yellow fleshed sweet potato, green leafy vegetables like Moringa oleifera, milk and eggs.

4.3. Adoption of technologies

This study showed that microdosing and seed priming was adopted by 73% and 39% of the farmers respectively. Another study in the same regions found that 68.1% of the farmers adopted microdosing, while 51.3% adopted seed priming [18]. Furthermore, adoption rate increased with increasing numbers of people in the household and was reduced with increasing distance to the fertilizer market. A study by [16] showed that all of the 102 farmers who started to use the technologies in 2009 continued to use the technologies in 2015, three years after the completion of the project.

The use of the technologies has also spread to villages that have not been part of the project. In one study [18] it was reported that microdosing and seed priming had spread to 51 villages that were not included in the project while another study reported that the use of the technologies had spread to most of the villages in the project areas of Koulikoro, Segou and Mopti regions of Mali [18].

Adoption of new agricultural technology is related to farmers' socio-economic environment, household conditions and agro-ecological conditions. The socio-economic barriers to adoption of new technologies in Africa include access to financing, supportive policy and regulatory environment, infrastructure, access to extension services and prices of input and output [25]. The household conditions are related to the household's access to capital, land and labor, education level, gender issues and technological competence. The new technologies must also be well adapted to the existing agro-ecological conditions (climate, soils, and predators). It is likely that the high adoption rate of the new technologies is due to low capital requirements of the technologies, the low labor demand, and the high return on investment [26]. On this basis we suggest that the following rule of thumb for technology adoption can be formulated: The more demanding a technology is terms of access to credit, labor, and knowledge, the more difficult it is for the poorest segment of the households to adopt new technologies.

4.4. Development impacts

The introduced technologies set in motion a positive development pathway characterized by increased yield, cereal surplus, increased net income, increased expenditures in farm input and other necessities, and increased food security in terms of the number of food secure months (Figure 1). Each of these positive changes has been documented in this study. This link is of great interest from a development perspective, but there is a lack of research that clearly demonstrate this effect for the drylands of West Africa. The only exception is the study by the International Food Policy Research Institute (IFPRI) in Niger that showed that increased uptake of improved technologies improved food security [23]. The technologies used are attractive because the input costs are very low and the return on the investment is high as the value cost ration (VCR) has been above 4 for sorghum in southern Mali and above 12 for pearl millet in central Mali [12]. The low cost of the technologies and the high VCR also reduces farmers' risk.

This improvement in food security took place during a period characterized by great political instability and armed conflicts in central and northern parts of the country. This may indicate that if a technology is well adapted to the prevailing conditions and in line with farmers' priorities, farmers are willing to adopt new technologies despite unfavorable external conditions.

The technologies introduced in this study increased land productivity without much effect on labor productivity. However, recent research has shown that application of primed seed and microdosing can also be mechanized by using a planter [17,28]. In Mali, such an approach increased sorghum yield by 44% and reduced labor by 64% demand while in Niger, the corresponding figures were an increase in yield of 56% and a reduction in labor of 71%. This double intensification in terms of land and labor productivity can make this approach to intensification even more attractive for the farmers. In general, adoption rate of the new technologies in the Sahel has been low and it is likely that one of the factors that has contributed to this is the increased labor demand. Technologies like compost production, manual manure application, intercropping, mulching and tree planting can all increase yield [27], but at the same time there is an increase in labor demand, particularly at the onset of the rainy season when labor is in high demand for land preparation, sowing and weeding.

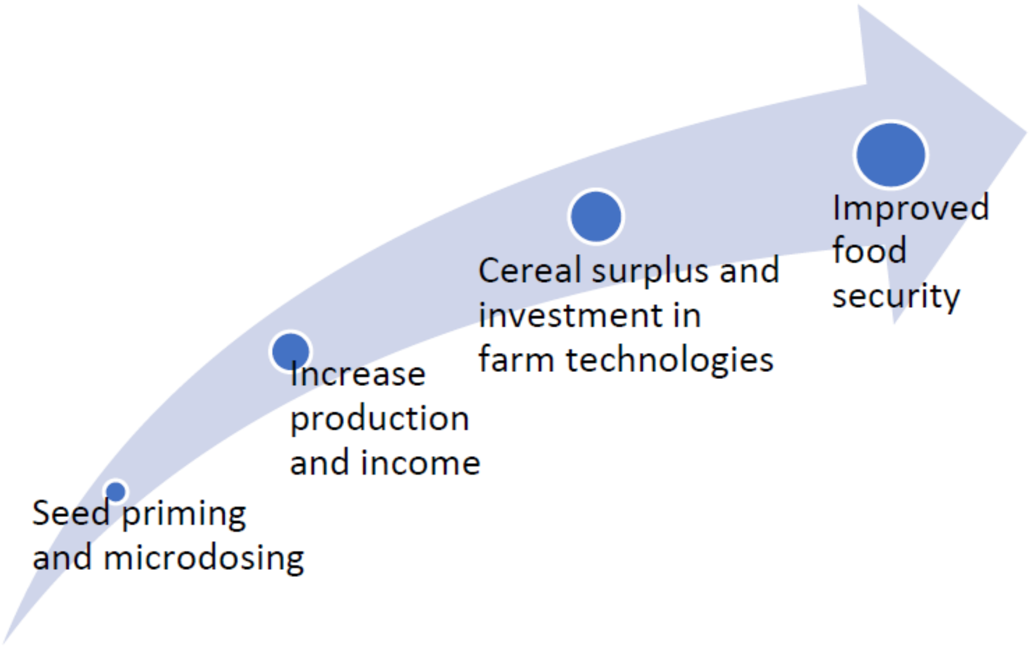

Figure 1. Development pathway from introduction of improved technologies to improved food security.

These technologies were introduced through a research for development project. The cost the technologies is very low, and the technologies can therefore be introduced without a well-functioning credit system. In the beginning of the project, it was difficult for the farmers to get access to mineral fertilizer in their village because of the remoteness from the market for many of the villages. However, this situation has changed, and fertilizer is now easily available in the villages on market days. It was also easy for the farmers to adopt the new technologies as they did not represent any fundamental change to their current farming practices. As Table 5 shows, farmers were willing to spend part of their additional income on purchasing mineral fertilizer and farm equipment. This indicates that they do not wait for the inputs to be given for free, but rather decide to invest in yield enhancing technologies without any external support.

The technologies used in this study can be considered as entry points or low hanging fruits for agricultural intensification. A recent review by research of the CGIAR research system in Africa also conclude that low-tech approaches are most appropriate to improve food security for small-scale farmers in Africa [29]. However, introduction of improved technologies should be accompanied with policies favoring infrastructure development, improving access to agricultural extension, and improving purchasing power of household through better access to credit [30].

These technologies used in this study have been criticized on the grounds that they can lead to nutrient mining that in the long run will impoverish the soil [31]. However, we show in this study that farmers do not only rely on mineral fertilizer; they also apply organic fertilizer and compost and practice crop rotation with grain legume crops. We realize that to achieve a continued growth in crop yields it is important to increase the supply of plant nutrients. These technologies also make crop production less vulnerable to climate change as they improve crop establishment, promote root development, and shorten the growing cycle of the crops. If farmers do not introduce any technologies to adapt to climate change, the effect of climate on the yields can be severe, while if improved technologies are introduced it is possible to increase yield despite climate change [32].

Population growth in Mali is 3% [9], and the national food production should at least keep pace with this population growth. This study shows that intensification of sorghum and millet production can greatly contribute to enhancing food production in Mali.

This study has addressed food security by focusing on low-cost agricultural technologies and positive development pathway was set in motion that increased farmers' income and reduced the number of food insecure months. However, the adopting farmers were still food insecure for more than a month of every year despite the increased production. We therefore recognize the importance of a more broad-based approach to development with more focus on production of nutrient-rich food, gender issues, institutional development, and farmers' agency. Such a broad-based approach can more efficiently address all six dimensions of food security.

5. Conclusions

In this study we have shown that seed priming and microdosing were able to trigger a positive development pathway characterized by increased yield, surplus cereal production, increased farmers' income, increased expenditure on farm input, health and education, and finally, improved food security. The number of food insecure months were significantly reduced from 3.57 months for households using traditional practices to 1.24 months for households using the improved practices. This increase in food security was achieved despite political unrest and limited external support. Seed priming and microdosing were adopted by 39% and 73% of the households respectively. The high adoption rate of the technologies can be explained by the technologies' low cost, the low labor demand, the high return on investment and a low risk. In addition, low soil fertility was identified by the households as one of their most severe farming constraints.

However, the households are still food insecure despite this positive development. We therefore recognize the need for a more broad-based approach that includes the production of nutrient rich food, with an increased emphasis on gender issues, institutional development, and farmers' agency.

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Conflict of interest

The authors declare no potential conflicts of interest with respect to this study.

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