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Effect of Adoption of Climate-Smart-Agriculture Technologies on Cereal Production, Food Security and Food Diversity in Central Mali

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Abstract: Over a period of two years, this study analyzes the effect on food security of introducing new technologies through farmer field schools in the project "Adapting Agriculture and Livestock to Climate Change" (ACC). A household survey was conducted to compare 125 households in villages that were part of the project to 79 households in villages that were not part of the project. These two groups were compared regarding cereal surplus production, the number of food-secure months and food diversity. The data were analyzed using analysis of variance, a two-sample t-test and boxplots. The project was implemented in the semiarid regions of Segou and Koulikoro in Mali. The technologies introduced were microdosing of mineral fertilizer, seed priming, new cereal varieties, horticulture, poultry and goat production, assisted natural regeneration and ridging. Microdosing of mineral fertilizer and seed priming was adopted by more than 85% of the households in the ACC villages. Grain yields of pearl millet, sorghum and maize increased by 418, 429 and 673 kg/ha, respectively, ($p < 0.0001$) due to seed priming and microdosing. This resulted in a cereal surplus of 756 kg in the ACC households, while the surplus in the non-ACC households was 161 kg. In addition, the ACC households were food secure for two months longer than the non-ACC households and consumed food from one more food group than the non-ACC households. This study shows that, despite the difficult situation in Mali, it is possible to improve food security by introducing improved technologies.

Keywords: microdosing; seed priming; adoption of agricultural technologies; cereal surplus; number of food-insecure months; food security; food diversity sustainability

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1. Introduction

Mali is facing enormous problems related to food security; the country ranks 186th of 191 countries according to the UNDP Human Development Index. Mali has a population of approximately 21 million and a population growth rate of 2.9%. According to the World Food Program (WFP), 4.3 million people needed humanitarian assistance in 2020 in Mali [1].

The past decade has been very turbulent in Mali, owing to a protracted armed conflict between the government and rebel groups in northern and central Mali. This has led to high numbers of internally displaced people. Despite this difficult situation, there are some positive development signs regarding food security and agricultural development. According to the Food and Agriculture Organization (FAO), the percentage of children with stunted growth decreased from 40% in 2000 to 25% in 2020, and the percentage of undernourished people decreased from 16.2% in 2000 to 9.8% in 2020 [2]. However, undernourishment has worsened in recent years, probably as a result of the internal problems in Mali.

Agricultural production has increased, as evidenced by an increase in average dietary energy supply adequacy from 111% in 2000 to 131% in 2020. Improved water and sanitation have also likely contributed to the improved food security situation during the last 20 years [2].

However, food security is still a major development challenge in Mali. Food production is constrained by low soil fertility, access to seeds, erratic rainfall, pests and diseases, postharvest losses, access to agricultural mechanization, agricultural input, credit, volatile markets, agricultural extension services, access to land and gender issues in accessing resources [3–5].

Climate change is an additional threat to food security in Mali. Temperatures have increased by one degree Celsius during the past 120 years, while there is no clear trend for rainfall during this period [6]. According to the Intergovernmental Panel on Climate Change (IPCC) [7], the temperatures will continue to increase, whereas a slight reduction is predicted for rainfall. More extreme weather events are expected.

The main crops for ensuring food security and income in southern Mali are maize and cotton, whereas sorghum and pearl millet are the key crops for food security in central Mali. Rice is cultivated along the major rivers, while pastoralism is the main economic activity in northern Mali.

This research was conducted to assess to which degree an integrated approach focusing on the introduction of improved technologies, diversification of food production, training of farmers and institutional building can improve food security. The effect of agricultural technologies on yields in the Sahel is well known [3,8], but much less is known about how such an integrated approach can improve food security and nutritional quality. The objective of this study was therefore to assess the impacts of introducing the technologies of seed priming and microdosing, the use of a planter for sowing, improved sorghum and millet varieties, fruit production and improved poultry production on food security and food diversity.

2. Materials and Methods

This research was undertaken as part of the project "Adapting Agriculture and livestock to Climate Change" (ACC), which was a research and development project initiated in 2011. The ACC project was led by the Institute d'Economie Rurale (the national agricultural research institute of Mali) in collaboration with Malian NGOs. The project promoted technology development related to rainfed agriculture, livestock production, agroforestry, horticulture and human nutrition.

In this paper, we analyzed the effect of introducing improved agricultural technologies on food production and food diversity in the regions of Ségou and Koulikoro. In each region, we compared villages where the project had been implemented to neighboring villages outside the project area (Table 1) (Figure 1). In the villages of M'pola and Fambugou, the activities started in 2012, while activities were initiated in 2017 in the other villages. In the villages included in the project, approximately 30% of the households were randomly selected to assess the impact of the project. In total, 204 households were randomly sampled. Of these, 125 households were from villages participating in the project, and 79 were from households not participating in the project (Table 1). The villages selected in both regions were part of the Sudano-Sahelian agroecological zone.

The technologies were introduced through the Farmers Field School (FFS) approach. Voluntary farmers hosted the FFS in the selected villages, and neighboring farmers took part in the trainings to get hands-on experience with the new technologies. By participating in the FFS, the farmers not only became aware of the new technologies, but they could also evaluate their merits. Farmers participating in the FFS were encouraged to train 10 other farmers. The technologies introduced included microdosing of mineral fertilizer, seed priming, animal-drawn planters, ridging, improved pearl millet and sorghum varieties, natural regeneration of trees on farmland, poultry production, Sahelian goats, and training on improved nutrition. Microdosing consists of mixing seeds and fertilizer (NPK 16:16:16) in a one-to-one ratio before sowing and applying this mixture in the planting hole. This corresponds to 7.5 kg of NPK per hectare when planting density is 25,000 hills per hectare. Seed priming consists of soaking pearl millet and sorghum seeds in water for 8 h prior to sowing.

Table 1. Participating and nonparticipating villages included in the study during the 2019–2020 and 2020–2021 seasons.

Regions	Municipality	Villages	Number of Participating Households
Koulikoro (N = 103)	Nossombougou	M'Polona	10
		Tienkoulou *	17
	Didiéni	Kobana	12
		Monzona *	15
	Dio	Bamabougou	9
		Moussadiébougou *	8
	Ouolodo	Ouolodo	24
		Djekebougou *	8
Ségou (N = 101)	Barouéli	Tingoni	21
		Digani *	22
	Cinzana	Fambougou	9
		Wassadiala *	9
	Dougouwolo	Dougouwolo	19
	Konodimini	Binkébougou	21

* Control villages not part of the project.

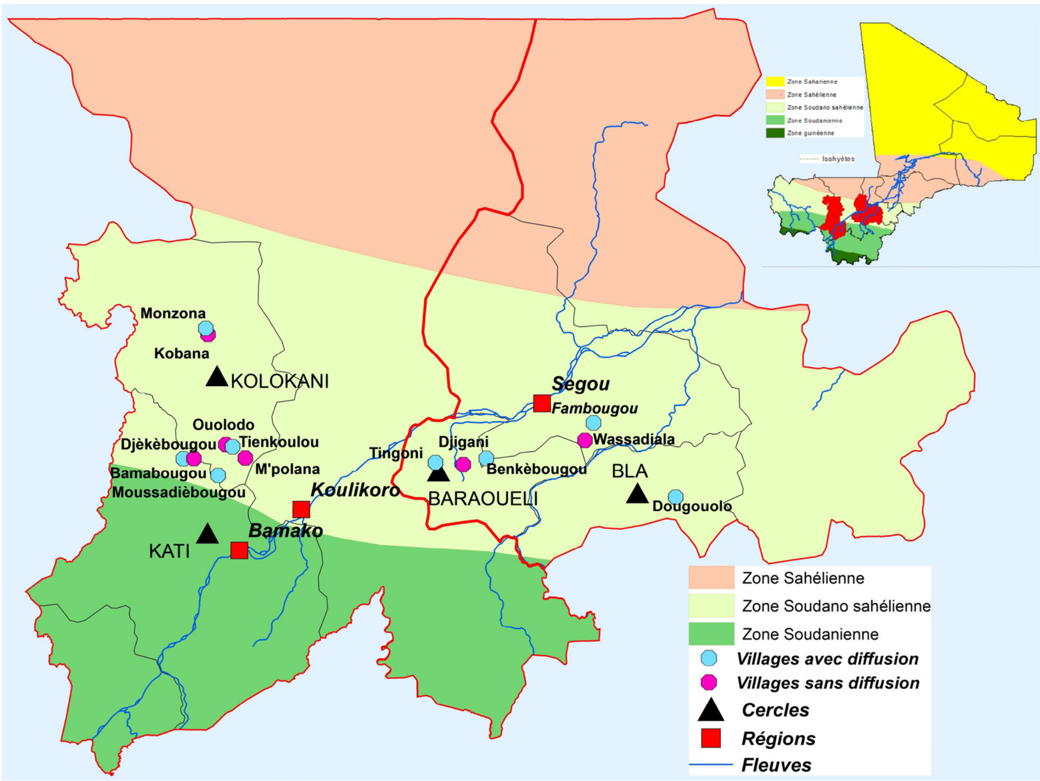

Figure 1. Locations of the ACC- and non-ACC villages in Mali.

Focus group discussions and semi-structured interviews were used to collect data during the 2019–2020 and 2020–2021 seasons. Data were collected on household characteristics, technology adoption, yields, total cereal production, cereal consumption, number of food insecure months, food diversity and households' perceptions of new technologies.

These data were used to calculate the indicators for cereal surplus, cereal coverage index, household dietary diversity score (HDDS) and food consumption score (FCS) [9]. Cereal consumption was considered a good indicator of food security in the project areas because the survey showed that 70% of the food energy intake was in the form of cereals.

The indicator of cereal surplus was calculated as the difference between the household's cereal production and cereal use, where cereal use is the sum of the household consumption, seeds and gifts from the household. Food-insecure months were the number of months the household considered itself to have an insufficient supply of cereals.

The effect of the introduced technologies on food diversity was assessed based on the HDDS and the FCS. HDDS is calculated based on the number of food groups (12 food groups) consumed by at least one of the family members during the last 24 h (Kennedy et al., 2010). The food groups are cereals, grain legumes, legumes, tuber crops, fruits, eggs, fish, meat, milk and milk products, food oils, sugar or honey and species/drinks. The closer the value was to 12, the more diversified the nutrition of the household. The average HDDS was found by adding up the score of HDDS for the households included in the sample divided by the number of families in the sample.

The FCS was based on assessing household consumption of eight different food groups during a seven-day period, as described by the WFP [10]. Each food group was given a weight based on the nutritional quality of the food group and this number was multiplied by how many days per week foods from this food group were consumed (maximum of seven times). The score ranged from 0 to 121, and the higher the score, the better the calorie supply and the quality of nutrition.

The data were analyzed using analysis of variance, a two-sample t-test and boxplots. The box inside each boxplot, shows the range where the middle 50% of the observations are found (the data between the 25th and the 75th quartile). The line inside each box gives the median. Data were analyzed using SPSS 2.3 and the R-software package.

3. Results

Results are presented on household characteristics, adoption rate of new technologies, yields, number of food-insecure months, cereal surplus, cereal coverage and food diversity, and perceptions of households regarding new technologies.

3.1. Characteristics of the Households

The survey showed that 88% of the households were led by men. The dominant ethnic groups in the study sites were Bambara and Fulani. Crop and livestock production was the main economic activity for 84% of the households (Table 2). The average cultivated area per household across the regions was 9.0 ha, with 6.2 ha of this land under cereal crops. Only 0.2 ha was used for the cultivation of horticultural crops. The livestock numbers differed between the regions. In Koulikoro, the households possessed five cattle on average, while in Ségou, the corresponding number was 20. Sheep and goats were also more numerous in Ségou than in Koulikoro. Approximately 56% of the households participated in FFS.

3.2. Adoption of Technologies in Project Areas

The ACC project promoted a range of technologies to diversify and increase agricultural production. The adoption rate of the technologies in the project villages varied from 10 to 95% (Figure 2). The technologies mostly adopted in project villages across the regions were microdosing and seed priming (above 85% adoption rate). Improved cereal varieties and food transformation methods were adopted by approximately 60% of the households, while the animal-drawn planters, Sahelian goat and ridging were adopted by less than 25% of the households. The adoption rates of the technologies were generally higher in the Koulikoro region than in the Ségou region.

Table 2. Household characteristics in the Koulikoro and Sego regions.

Characteristics	Sites		
	Koulikoro (N = 103)	Ségou (N = 101)	Average (N = 204)
Sex household head (%)			
Man	91	85	88
Women	9	15	12
Major ethnicity (%)			
Bambara	97	71	84
Fulani	0	16	8
Main activity (%)			
Agriculture (crops and livestock)	96	92	94
Crops	4	7	5
Participation in FFS (%)	53	58	56
Cultivated area (ha)			
Total cultivated area	8.0	10.1	9.0
Area cereals	4.8	7.6	6.2
Area horticulture	0.4	0.1	0.2
Area agroforestry	0.2	0.1	0.1
Livestock number			
Traction animals	3	3	3
Cattle	5	20	12
Sheep	4	7	6
Goat	8	11	9

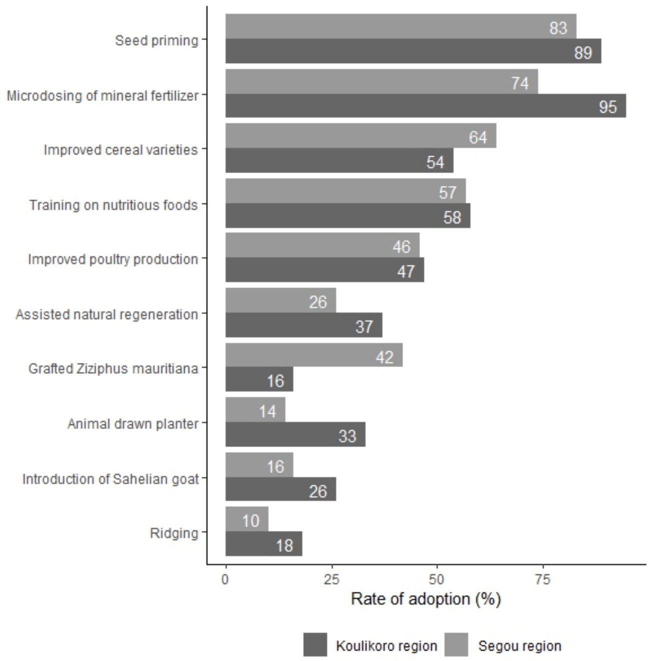

Figure 2. Adoption rate of different technologies (%) in project villages in Koulikoro and Segou regions.

3.3. Effect of Project Interventions on Crop Productivity

The ACC households participating had higher yields than the non-ACC households (Figure 3). The average yield increase for pearl millet, sorghum and maize was 418, 429 and 673 kg/ha respectively ($p < 0.0001$). There was no major difference between the years regarding yield levels. Maize had generally higher yields than sorghum and pearl millet. Figure 3 also shows that the maize yield differed more than the yields of pearl millet and sorghum.

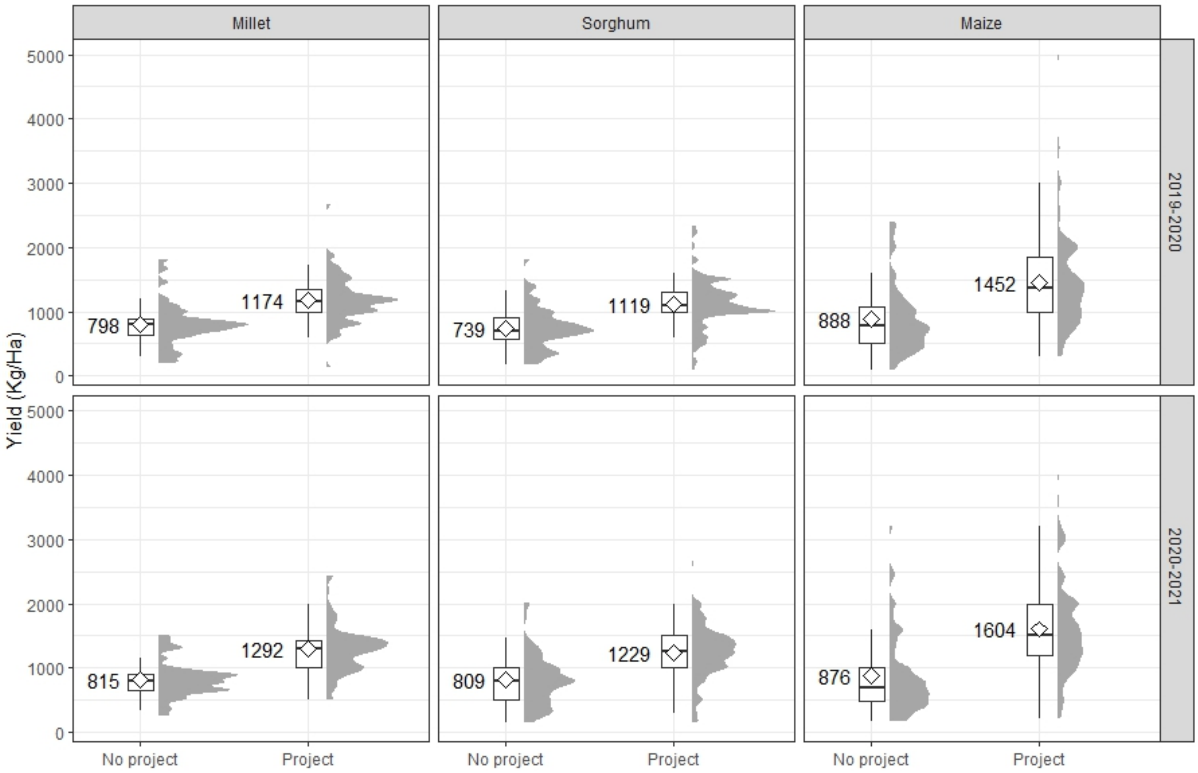

Figure 3. Boxplot/distribution plot showing yields of millet, sorghum, and maize in the years 2019–2020 and 2020–2021 with and without projects. The numbers presented in the boxes represent the means (also indicated by the diamond inside each box). The line inside each box represents the median.

3.4. Effect of the Project on the Number of Food-Insecure Months (Production Increase and Food Security)

The food security situation improved in households included in the ACC project compared to households not included. For the seasons 2019–2020 and 2020–2021, the average number of food-insecure months were reduced by 1.70 and 2.05 months, respectively ($p < 0.0001$ for both years) (Figure 4). The percentages of ACC households that were food secure (zero months of food insecurity) were 66.4 and 78.5% for the 2019–2020 and the 2020–2021 seasons, respectively, while the corresponding numbers for non-ACC households were 30.7 and 27.8%. Less than 2.5% of the ACC households were food insecure for five months and beyond (severe food insecurity) in both years, while the corresponding number for non-ACC households was approximately 20%.

3.5. Effect of the Project on the Surplus Cereal Production

Cereals are the cornerstones of food security in rural Mali. The non-ACC households had a cereal surplus of 161 kg, while the ACC households had a cereal surplus of 756 kg (Figure 5). Only 26.6% of the non-ACC households were able to generate a cereal surplus, while 66.4% of the ACC households achieved this. The cereal surplus was particularly apparent for millet. The maize surplus was low because this crop is only produced on small plots in the project areas, and most of the maize is consumed by households.

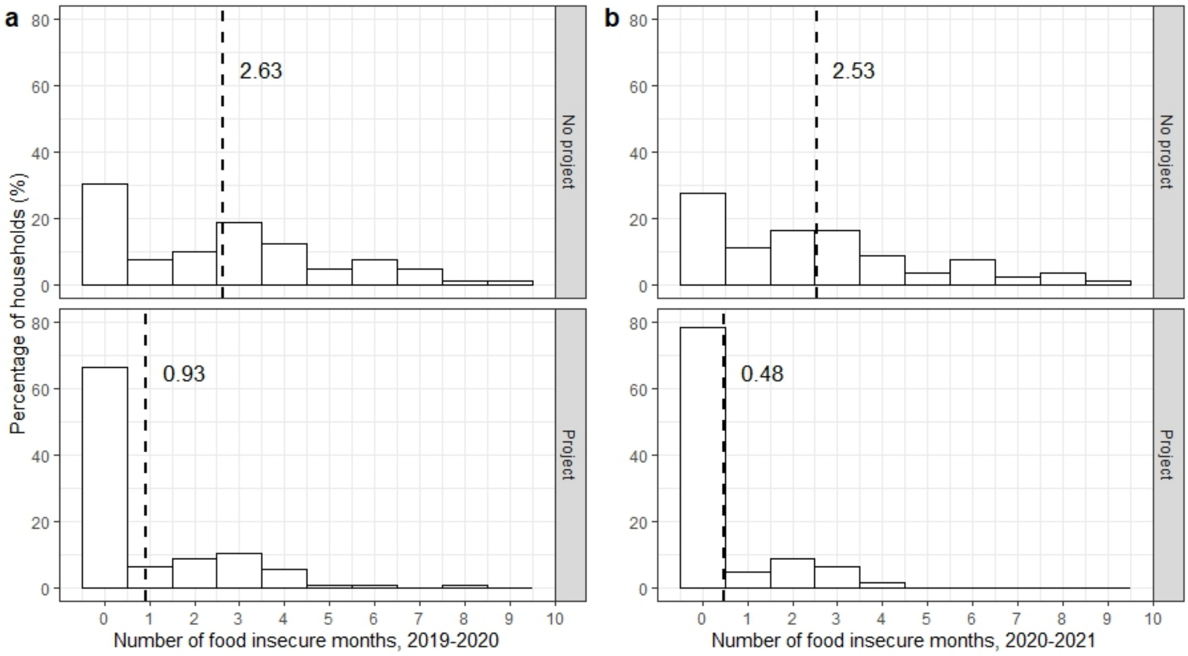

Figure 4. Number of food insecure months in non-participating households ("No project") compared to participating households ("Project"). The number inside each figure shows the mean. Figure (**a**,**b**) present results for 2019/2020 and 2020/2021 respectively.

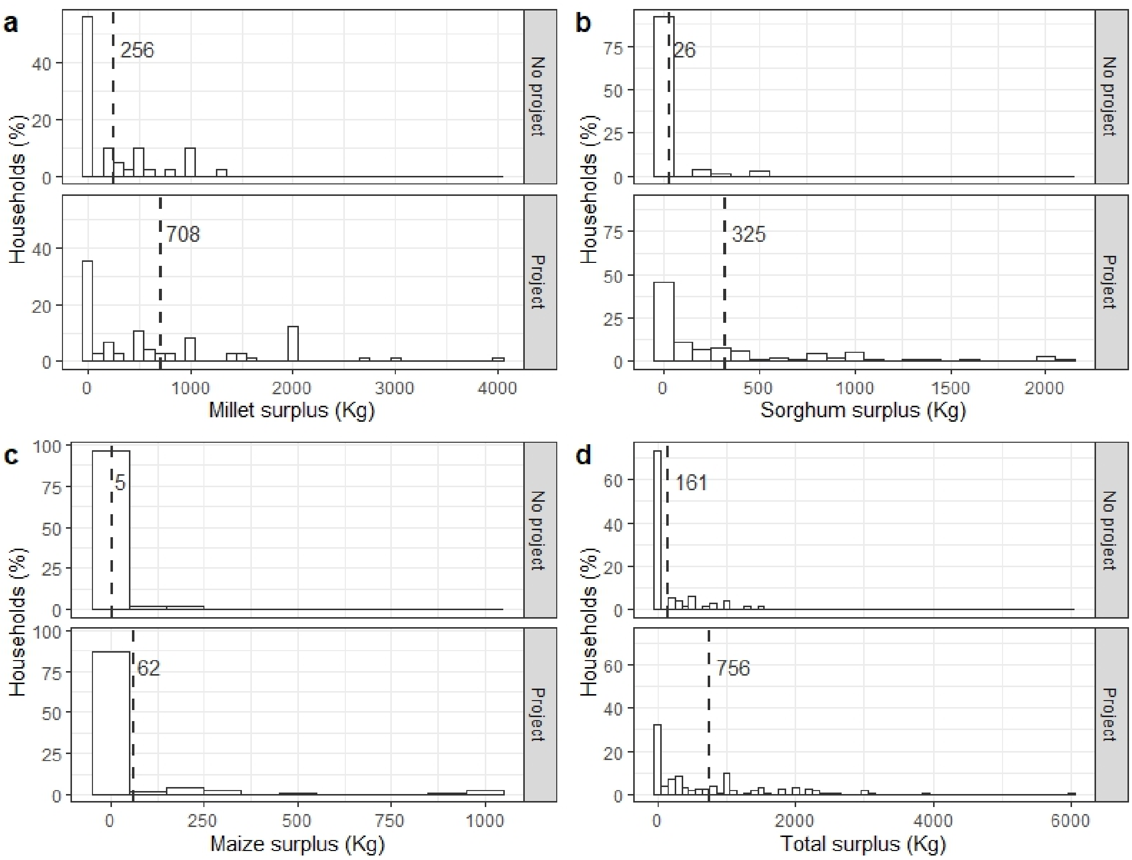

Figure 5. Surplus production of millet (**a**), sorghum (**b**), maize (**c**) and total cereal surplus (**d**) in household participating in the project and households not participating. The number inside each figure is the mean.

3.6. Effect of the Project on Food Diversity

Food diversity is strongly associated with food quality. In general, the households had a fairly good food diversity. The average HDDS was 8.9 in the ACC households, while it was 7.6 in the non-ACC households (Figure 6). This means that the ACC household consumed food from at least one additional food group compared to the non-ACC households during the last 24 h prior to the interview. There is no international consensus for assessing HDDS, but an HDDS of 6 and above is high, according to [9].

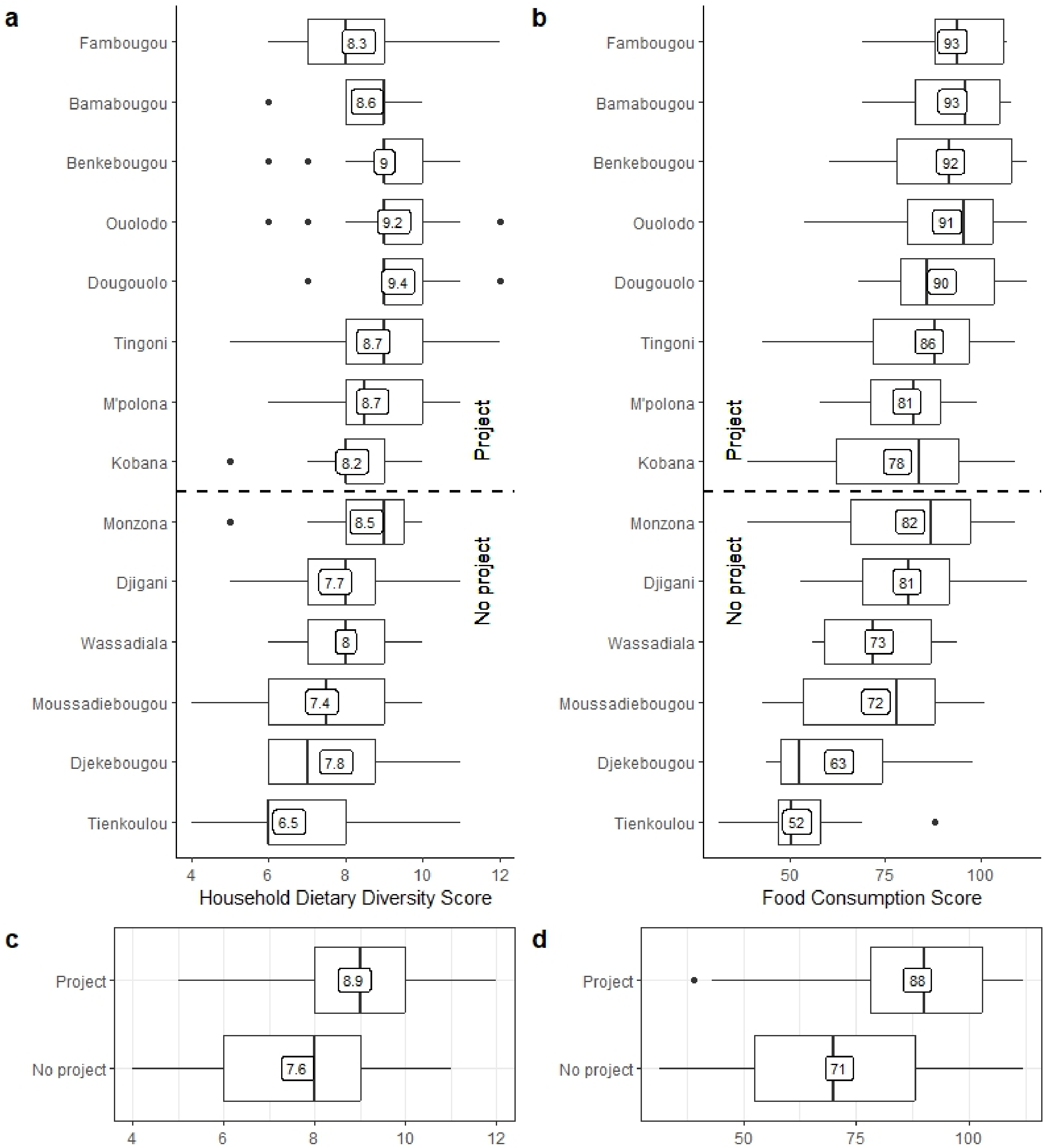

Figure 6. Household dietary diversity score (HDDS) and food consumption score (FCS) in all the ACC villages and the non-ACC villages. The numbers in the boxes represent the mean value for each village. The figures (**a**,**b**) present the HHDS and FSC for all the villages while the figures (**c**,**d**) show the mean for all the villages and the variability between the villages in HHDS and FSC. The dotes present the outliers.

The FCS, which measured calorie intake and food diversity during the last 7 days, also showed that the households had reasonably diversified nutrition. Households included in the project had an FCS of 87.9, whereas households outside the project area had a score of 70.4. An FCS above 35 is considered acceptable [10].

3.7. Households' Perceptions of the Improved Technologies

Farmers have adopted the new technologies for different reasons (Table 3). Microdosing is appreciated for its increased yield and reduced fertilizer cost, while seed priming is valued for its positive effect on crop establishment. The introduction of improved production methods for poultry is particularly important for income generation, while the introduction of grafted *Ziziphuz mauritiana* Lam. contributes to food diversity and income. The food transformation activities improve infant nutrition and increase food diversity.

Table 3. Perceived benefits of the different technologies.

Benefits	Sites		
	Koulikoro (N = 55)	**Ségou (N = 70)**	**Average (N = 125)**
Microdosing mineral fertilizer mineral			
Increased agricultural production	87%	66%	76%
Reduced costs of mineral fertilizer	55%	41%	48%
Improved growth at crop establishment	49%	33%	41%
Seed priming			
Fast germination	65%	56%	61%
Cleaning and sorting of seeds	9%	14%	12%
Poultry production			
Diversification of chicken breeds	47%	42%	45%
Improved income	42%	44%	43%
Enriching the diet	26%	28%	27%
Grafted Zizipus Mauritania			
Diversification of nutrition	16%	36%	26%
Income	11%	38%	24%
Assisted Natural Regeneration			
Improved soil fertility	37%	20%	28%
Wood for heating	37%	18%	27%
Protection of crops against wind	21%	14%	18%
Food transformation			
Improved child nutrition	58%	57%	58%
Food diversification	53%	48%	50%

The farmers' challenges related to the use of these technologies in the project villages were high labor use, limited access to fertilizer and financial constraints. A problem regarding seed priming was how to store the primed, unused seeds. Mechanization was constrained by machine costs and access to equipment. In poultry production, gaining access to sufficient feed was demanding. Access to irrigation and protection of young plants against grazing animals were difficulties experienced when introducing grafted *Ziziphus mauritiana*. Challenges in relation to food processing were the seasonal availability of crops and a lack of access to equipment.

4. Discussion

The discussion focuses on the adoption of technologies, their effect on food security and the sustainability of the approach.

4.1. Adoption of Technology

As the result section shows, the households that were included in the ACC project had a high adoption rate of the new technologies, increased cereal production, more cereal surplus, a lower number of food-insecure months and a more diversified diet. The adoption rate of the technologies varied from 10 to 95%. The most adopted technologies were microdosing and seed priming, which, on average, were adopted by more than 85% of the households. An adoption rate above 85% must be considered particularly high since farmers are known to differ greatly in their propensity to adopt new technologies [11]. Some farmers are early adopters, while others are more conservative (laggers). Seed priming is easily adopted because there is no capital cost connected with this method, while microdosing has a cost of approximately 1650 FCFA per hectare (7.5 kg per hectare * 220 CFA per kg fertilizer), corresponding to 2.5 EUR. Furthermore, these technologies have a very low labor demand because mineral fertilizer and seeds are mixed in a one-to-one ratio before sowing and the mixture is applied in one operation. Application of fertilizer through this method, therefore, does not, to any significant degree, increase the labor demand when sowing. The technologies of planters, Sahelian goats and ridging had low adoption rates. This was not because they are less suited to the Sahelian environment, but rather because they demand more capital and skills and are therefore less likely to be adopted without support.

The use of FFS greatly facilitated adoption in the ACC project because it allowed the farmers to discover the new technologies, learn the skills of the new technologies and evaluate the technologies according to their own criteria [12]. Adoption of the new technology normally follows a gradual process from the observation and discovery stage to the evaluation stage and finally the trial stage [13].

The adoption rates found in the ACC project are similar to the adoption rates of technologies found in two other studies in Mali [13,14]. In central Mali, adoption rates of climate-smart technologies varied from 39 to 77% [4]. Microdosing was adopted by 70% of households in this study, which is slightly lower than the adoption rates found in the ACC project. A study across several regions in southern and central Mali found that 61% of the farmers had adopted at least one climate-smart technology and that the poorer households benefited relatively more from these technologies than the richer households [14]. Factors that promoted the adoption of new climate-smart technologies included access to credit, contact with extension agents, participation in training, access to information and membership in organizations. A study from Niger found that the use of modern inputs such as mineral fertilizer was positively correlated with household wealth, education level, access to labor and easy access to the market [15]. The high adoption rate in the ACC project and in the other projects in Mali shows that technology adoption is possible despite the security problems and the low level of support for households. Conducive socio-economic conditions will promote adoption, but these studies clearly show that farmers will adopt new technologies if they see a clear benefit. Hence, a positive development in agricultural productivity and food security can be achieved, even though the political and economic conditions are far from optimal.

Seed priming and microdosing, along with improved varieties, were promoted as a technology package. Other studies also indicate that adoption is increased if technologies are presented as a package instead of as "stand-alone" technologies [4,15].

4.2. Food Security

Food security increased in the project areas as a result of higher food production and more diversified nutrition. Yields of the cereal crops were significantly higher in the project areas than in the villages outside the project area. Average yields across two years for pearl millet, sorghum and maize increased by 418, 429 and 673 kg/ha, respectively. This corresponds to a yield increase for pearl millet, sorghum and maize of 50.9, 56.0 and 77.2%, respectively. This yield increase is mainly related to the use of the technologies of seed priming and microdosing of mineral fertilizer. Research conducted in Mali, Niger and

Sudan also confirms similar yield effects of these technologies [16–18]. An experiment conducted over four years in the Mopti region of Mali showed that the combined effect of seed priming and microdosing increased millet yield by 424 kg ha^{-1} [16]. The technologies adopted in this study cannot close the yield gaps as the input use is too low, but they can be considered as entry points for agricultural intensification.

The increased production allowed the households participating in the project to increase their cereal surplus. Households not included in the project had a cereal surplus of 161 kg, whereas participating households had a cereal surplus of 756 kg on average. This surplus in cereal production makes it possible for the farmers to cover their expenses and invest in their own farms. This increase in surplus production in households participating in the project is very likely related to the increase in cereal yields.

The participating households greatly improved their access to food. Households that were part of the project were food insecure for only 0.7 months per year, whereas the period of food insecurity for households not participating in the project was 2.6 months. The major reason for this improved food security is likely to be increased cereal production, as the cereal yield-enhancing technologies were widely adopted and the productivity gains were high for these technologies. Other technologies, such as the production of legumes, fruit, poultry and goats, may also partly explain this improvement in food security, but their contribution to improving food security is less due to lower adoption rates (below 50%). We think that the improved food security is a result of the uptake of new technology, as we see a plausible link from the uptake of new technologies to increased yield, the generation of a cereal surplus and finally, a reduced number of food-insecure months. One of the perceived benefits of microdosing was improved cereal production (Table 3), which supports the argument that the increase in food security can be traced back to the introduction of new technologies.

Food security is not only about supplying sufficient calories; nutritional quality is of equal importance. A nutrition study conducted in Mali showed that 84% of children younger than five years were anemic, 35% of schoolchildren suffer from vitamin A deficiency, and 9.4% of children aged 6 to 59 months are wasted [19]. Nutritional deficiencies have many causes. A study from Niger found that pregnant women particularly suffered from a lack of iron, iodine, zinc, folate, and vitamins A and B_{12} [20]. The current project has addressed nutritional quality through the diversification of food production by stimulating the production of legumes, fruits, poultry, and goats. As a result, the HDDS increased from 7.65 for households not participating in the project to 8.76 for participating households, while the corresponding increase in the FCS was from 70.4 to 87.6. The HDDS was improved by more than one unit, which implies that the ACC households consumed food from one more food group than did the non-ACC households. The increase in FCS indicates an increase in energy intake and a more diversified diet. These changes in indicator scores are likely to suggest improved nutrition since a similar study in Mali found that dietary diversity is a good indicator for nutrient adequacy [21]. In the project villages of Helen Keller International in Burkina Faso, it was found that stimulating homestead production and building competence in nutrition and health reduced anemia, wasting, and diarrhea among children [22]. A study from Mali showed that HDDS also differed between seasons, as the average HDDS was 6.84 in the hunger season in rural areas and 7.45 in the post-harvest season [23]. This also shows a slightly lower food diversity than what was found in our study.

4.3. Sustainability

The introduction of new technologies has set in motion a development pathway characterized by the adoption of improved technologies, increased yield, increased cereal surplus, food security and more food diversity. The technologies contributing the most to improved food security were seed priming and microdosing because these technologies were adopted by approximately 85% of the households and yields were 50% higher and beyond. This allowed farmers to create a cereal surplus and reduce the number of food-insecure months by two months on average for the two seasons. The project also diversified farming by promoting the production of poultry, goats, fruits and vegetables. In addition, the households received training on how to prepare nutrient-rich food by using products that are locally available. As a result, the households consumed food from one additional food group.

A previous study from Mali showed that farmers will use part of the additional income to invest in fertilizer and cover other expenses such as those related to medicines, clothing, schooling, and housing [24]. Consequently, if farmers are convinced of the technologies, they will use part of their meager income to invest in production-enhancing technology, thereby increasing the sustainability of their farms.

The ACC project has focused on introducing agricultural technologies that do not require any fundamental shift in how farming is practiced. This approach was chosen because we believe that the production-enhancing opportunities within the existing farming system are far from being fully exploited. There are still untapped opportunities for improving the existing system by promoting new varieties, improving soil fertility management, mechanizing to improve precision in farm operation, integrating pest management and improving access to climate services [3].

Despite the positive results obtained in this project, we recognize that alternative pathways within and beyond agriculture may produce similar or better outcomes. Within the agricultural sector, it is possible to increase farm income by taking better advantage of seasonal changes in grain prices and by promoting meat production from small ruminants and cow milk production [25]. Young people look for income opportunities outside agriculture, such as gold mining, where better income can be earned [25]. However, most households in Mali still rely on agriculture for their livelihoods, and there is, as documented in this paper, untapped potential within this sector that can draw many people out of poverty.

Projects focusing on adaptation to climate change have been criticized for carrying the risk of elite capture of benefits, shifting vulnerability to other groups of people or areas and introducing new risks [26]. Furthermore, adaptation projects may not sufficiently address the root causes of vulnerability. We realize that the ACC project may not have addressed all the socioeconomic and cultural constraints to agricultural development, such as access to credit, markets, secure land tenure, the inclusion of marginalized groups, and so on. The ACC project approach to these constraints have been to deliberately promote technologies with low financial and labor costs that, to a lesser degree, depend on well-functioning markets and access to credit. These types of technologies are also feasible for the poorest segments of the population and can therefore be considered as low-hanging fruits for agricultural development. An adoption rate above 85% shows that the majority of the households have been able to make use of the technologies, which indicates a low risk of producing new inequalities. Households that derive a large share of their income from livestock will also be able to benefit from these technologies because the higher straw yield resulting from improved fertilization will increase access to fodder. Furthermore, the activities of natural regeneration, poultry and milking goats will also be of benefit to livestock owners. The risk of shifting vulnerability to other people must be considered low, since land use (crops, pastures and forests) will remain the same.

It is essential that the technologies are perceived positively by the farmers if they are to continue using them when the project comes to an end. The technologies with the highest approval rates were seed priming and microdosing, and these technologies were the most widely adopted. Yet, high labor demand may still limit their uptake. The project has addressed the labor constraint by promoting the use of planters, which can reduce labor demand at planting by approximately 90% [27].

There is a need for continued research to identify entry points or "low hanging fruits" for agricultural intensification in the drylands of West Africa. Furthermore, there is a need to study how local institutions, such as innovation platforms combined with new technologies, can stimulate a sustainable development pathway.

It has now been 50 years since Schumacher wrote his famous book Small is Beautiful [28]. Even though our understanding of development has advanced since that time, it is still highly relevant to look for solutions that are within reach of the small-scale farmers in Africa. The low-cost technologies proposed in the project must be in line with the "small-is-beautiful "concept".

5. Conclusions

This study shows that the introduction of improved agricultural technologies increased yields, households' cereal surplus and food diversity, and reduced the number of food insecure months experienced by the households. The technologies that were the most adopted were seed priming and microdosing, which were adopted by 85% of the households. Farmers favored these technologies because they facilitated crop establishment, reduced fertilizer costs, had low capital and labor requirements and increased yields by more than 50%. The risks associated with using these technologies were found to be low. The increased yield allowed the farmers participating in the project to generate a cereal surplus of 756 kg, whereas households not participating in the project had a cereal surplus of only 161 kg. This had the result that participating households were food-secure for two more months than households not participating in the project. The FFS stimulated farmers to diversify their food production, and households who were part of the project consumed food from one more food group on average than households not taking part in the project.

Even though the last ten years in Mali have been difficult due to political instability and high insecurity, it has been possible to introduce new technologies that have improved food security and diversified nutrition. The adoption of new technologies has been high because the technologies have a low cost and a satisfactory return. Under such conditions, farmers will adopt new technologies despite external conditions being far from optimal. The key lesson learned is that it is possible to improve food security through an integrated approach that includes yield-enhancing technologies, diversification of crop and livestock production, training on new farming methods and human nutrition and institution building to improve access to inputs. Agricultural development assistance is challenging because it is unlikely that the same results would be achieved if we focused only on one or two of these factors. An integrated approach should therefore include new technologies, diversification of production, training, and institution building.

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