Market Access of Small-Scale Farms and Biodiversity Management of Food Crops. The Case of Sorghum and pearl millet in Mali.

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Summary: Several studies carried out in different countries (and various ecosystems) show that varietal diversity has generally reduced with the integration of farms into markets. In Mali, farms sell an increasingly larger share of their cereal production in order to meet the rapid growing urban demand. The question raised here is whether or not this has had an influence on the diversity of sorghum and pearl millet landraces. Different index of diversity were computed using data collected from surveys conducted in 2010 in 120 Malian farms in two different villages. An econometric model is estimated to assess the different significant explanatory factors of these different indexes. Factors are related to the farm and the household characteristics and especially its sales of cereals. We show that farms in the village better connected to the market manage more sorghum and pearl millet cultivars than those of the remote village. However, in this same village, farms that sell proportionately more sorghum and pearl millet tend to reduce the number of landraces. These results suggest that there are two contradictory trends related to the connection of markets on crop biodiversity: one is a positive effect of opening up farms and the other a negative effect of the specialization and simplification of crop systems for sale.

Key words: Agrobiodiversity, genetic erosion, on-farm conservation, Mali, food security, cereals.

1. Introduction and problem: Why is agrobiodiversity important and threatened by the development of consumer markets in the world, in the Sahel and in Mali?

The diversity of crops or agro-biodiversity is relatively specific in relation to general plant biodiversity. Indeed agro-biodiversity is directly related to the actions of humankind, which has grown, multiplied, selected and exchanged their crops for millennia. It is also the indispensable basis of our diet and food security. Goods and services provided by agro-biodiversity are endless. Beyond the biological and economic potential it represents, agro-biodiversity is also invested with symbolic, cultural and identity values (Coulibaly, 2011).

It is a stabilizing factor in agricultural production because it can limit failures related to disease or pests. The specialization of cropping systems makes the plants – all identical – all the more fragile to biological pests and abiotic stress (Heal *et al,* 2004), which can lead to major environmental disasters. The best-known example of this is the Irish potato famine (1846–1851) with the appearance of late blight on potato crops, which resulted in a loss of 25% of the population in 10 years. Several studies have already demonstrated the economic and productive value of agro-biodiversity (Di Falco and al, 2007, Di Falco and al, 2010, Meng, *et al,* 2003). Nevertheless, the results cannot necessarily be generalized because they are specific to a location, a given period, and a system of culture (Drucker *et al,* 2005). In addition, the current agro-biodiversity is also a reservoir of genetic resources for the future. It helps maintain the evolutionary ability of plants to adapt to changing agroclimatic, socio-economic and/or cultural environments. These considerations apply to the three levels of biodiversity: infra-specific, specific and eco-systemic.

Despite its many interests, agro-biodiversity is threatened (Araujo *et al*, 2008; Van de Wouw *et al*, 2009). However, quantified evidence of worldwide genetic erosion is not easy to find. FAO (1997) reports the extent of the loss of genetic diversity in crops based on reports from 143 countries. Almost all countries report genetic erosion in terms of species and cultivated landraces. 81 countries reported that the main cause of genetic erosion was the replacement of traditional landraces by improved landraces (Drucker *et al*, 2005). If this relationship "more improved landraces/less agro-biodiversity" is really true, then the causality is more complex than a simple replacement of former multiple and varied landraces by a small number of new landraces. Indeed, genetic erosion is also associated with the transformation of agricultural production itself and its inclusion in chains that are becoming longer and more organized, both upstream and downstream of farms. Farmers progressively buy their seeds from seed specialists. They practice crop systems "framed" by the firms and research, with "packages" including seeds and other agricultural inputs. They sell their products to the food industry and/or to distributors who have specific requirements in terms of standards. According to Daviron (2002), standardization is a process that was supported by states so as to protect producers from traders who potentially "benefit" more from one market where the products are heterogeneous. This standardization is partly related to the marketing of products. Also, on a certain scale, the trade of agricultural products with the organization of producers and the defense of their interests (Daviron and Vagneron, 2011) is the major cause of standardization. This standardization, in order to sell in the markets, is potentially one of the main forces reducing the number of species and cultivated landraces. As diversity of crops can be considered as a voluntary mechanism to reduce economic and natural risks (Di Falco *and al*, 2007), technologies, policies or institutions that limit the various risks faced by producers (irrigation and water control, storage facilities, insurance schemes, price stabilization schemes for example) may also promote the loss of diversity.

Sorghum and pearl millet are the main cereals grown in West Africa and the Sahel. In five Sahelian countries (Burkina Faso, Mali, Mauritania, Niger and Senegal), about 15 to 16 million hectares are cultivated each year. The countries of West and Central Africa are among the main pearl millet producers in the world (FAO data cited by Udher *et al*, 2011). Udher *et al* (2011) identified three major sorghum and pearl millet production areas in West and Central Africa for the 2003-2007 period: the largest centre is in northern Nigeria and Cameroon (for sorghum and pearl millet), the second is based in Burkina Faso (for sorghum) and Burkina Faso and Mali (for pearl millet) and the third is in Senegal and Gambia (for sorghum and pearl millet).

West Africa is a also major centre of pearl millet and sorghum diversity. It is here that the varietal diversity of pearl millet is the greatest in the world (Hamon *et al*, 1999), while the maximum biodiversity of sorghum is rather found in East and Central Africa. Like for many plants, it is not easy to know exactly whether or not this plant biodiversity is declining, and if it is threatened. Kouressy *et al* (2003), for example, noted that, in Mali, "60% of sorghum cultivars collected in 1978 could not be found in 1999." According to the authors – as well as Bazile and Soumare (2004), whom they cite – this disappearance of traditional landraces is linked to "*the intensification of agricultural practices and the subsequent development of maize that cause the marginalization of traditional cereals on poor soil*." Other authors who have worked in Niger and compared sorghum collections in 1976 and 2003 show on the contrary that there was no erosion of varietal (Bezançon *et al*, 2008) or genetic (Deu *et al*, 2010) diversity. These authors emphasize the ability of producers to "*conserve biodiversity despite periods of drought and recurring and major social changes*." (Bezançon *et al*, 2008).

In Mali, agriculture is the main activity. Cereals account for 75% of the utilized agricultural area (Soumare *et al*, 2008). Among the cereals, pearl millet and sorghum are the most important, as much in area (67% of area under cereals) and production (55% of the total cereal crop production) as their place in the local diet. They represent over 50% of the calories consumed in Mali (Coulibaly, 2011). The seeds are processed into flour and then usually cooked into a thick paste called *tô*, which is the staple food in this part of west Africa. Cereals are also eaten as porridge or couscous. Finally, they are the basis for the production of *dolo* (traditional beer), and many by-products are fed to poultry and livestock (Alary *et al*, 2009).

Between 1982 and 2007, cereal production (pearl millet, sorghum, maize, rice) tripled in West and Central Africa (Udher *et al*, 2011), both in response to the increasing population (which doubled over the same period) and following the liberalization of its trade (Egg, 1999). In Mali, for example, grain production went from about one million tons in the early 80s, and about 2.5 million tons in the late 90s, to over three million tons in the year 2000 (Samaké *et al*, 2008; Egg, 1999). The population also increased significantly over the same period (Mali went from 7 million inhabitants in 1980 to about 10 million in 2000), but at a slower pace so that the per capita availability has improved (Egg, 1999). The output growth was particularly marked for maize and rice, but less so for pearl millet and sorghum. Sorghum has been relatively stagnant since the mid 90s, with production ranging from 500 to 800,000 tons according to the year. Average food consumption of pearl millet and sorghum is estimated at about 130 kg per person per year (Bocoum, 2011), with significant disparities between the rural and urban populations (in Bamako in 2001, consumption was estimated as 55 kg per person per year, while in the rural area in the Koulikoro province the average reached 161 kg/year/person). Most of the rural population consumes their own production whereas the urban population buys sorghum and pearl millet. Urban markets represent about 20% of the total consumption of sorghum and pearl millet in West Africa; the rest is essentially home consumption in rural areas (Udher *et al*, 2011). In Mali, urban consumption is about 12% of total consumption (DNSI, 2003, our calculations). From this data, and for want of more accurate data (particularly on exports, which are hardly measured), it is estimated that the Malian producers generally sell between 10 and 25% of their sorghum and pearl millet production. Sorghum thus contributes to producers' incomes.

The progressive commercialization of so-called “traditional” cereals, is an ongoing phenomenon. As mentioned before, this is linked to a growing urban demand, but also to various economic and institutional crises and instabilities that have affected the historical cash crops (cotton). The producers are looking for alternative sources of income and thus sell part of their cereals.

Does the sale of sorghum and pearl millet reduce their diversity?

Our aim is to determine whether the ongoing development of consumer markets affects the biodiversity of these cereals at the farm- and village-level. Beyond the multiple determinants of biodiversity, we want to assess whether the act of selling more sorghum and/or pearl millet affects the producers’ choice to cultivate one or more species or landraces.

One hypothesis concerns the segmentation of demand: consumers and processors may have specific expectations *vis-à-vis* certain landraces, and through various chain intermediaries, processors and traders, this demand could be passed on to producers. Tallec and Egg (2009) worked on this issue and found that the main quality criteria used and valued by retailers, consumers and processors are essentially the criteria relating to lot cleanliness. In addition, they showed that the quality "bonus" (cleaner lots are sold at slightly higher prices than less clean lots) is relatively small and vanishes in times of high prices. Their surveys show that there is no demand, in Mali in any case, for a particular landrace of sorghum or pearl millet. Our interviews with

Malian grain traders in 2010 – as well as the work conducted on fonio, another cereal (Dury and Meuriot, 2010), and Alfonso Becares (2008) results – lead us to the same conclusion: sorghum and pearl millet buyers are not looking for one or many specific landraces. Cleanliness (no straw residue, dust), the absence of weevils, the freshness (previous year) and some geographic origins are the main criteria of quality. Aside from the sorghum's color – and eventually its grain size in some cases, but this is very controversial – market stakeholders are not interested in the special traits of different landraces[1]. Traders-collectors mix cereal lots from several producers, thus mixing landraces. This has been observed by us and the authors mentioned above, from small traders-collectors to wholesalers who trade over long distances between the countries of West Africa. In their seed bags, the collectors mix the small quantities coming from multiple sellers, such as women who bring a few kilograms. Wholesalers make lots out of bags coming from various origins in the same area. Also on a truck that goes from the area of Koutiala to Abidjan or Accra, which are several thousand kilometers away, there are bags from several producers with no regard for the landrace. However, there is a specific market for red sorghum, which is used specially to make the traditional beer. For example, we met a trader from Koutiala who regularly sent a truck of red sorghum to traditional beer (*dolo*) manufacturers located in Ghana and Ivory Coast. But in this case, there is no interest in one particular variety or landrace of red sorghum.

Also, if we place ourselves in a perspective where the market grows with the rise in demand, a "landrace" effect on producers is not to be expected soon. If there is an effect of demand on the management of biodiversity at the producer level, only the "volume" effect – the increase of quantities sold by the producers could exist – and not the "quality" effect.

The increase in the quantities sold by the producers can take many forms both in terms of technical choices and in terms of the distribution of these choices. Producers have various strategies according to their material and immaterial resources and their different levels of constraints and needs. They will choose to move more or less towards a business strategy. In some cases, they can increase their production by using more inputs, including labor per unit area and/or increasing their cultivated areas. In Mali and Burkina Faso, it seems that both strategies have taken place. If the "area growth" strategy is most often cited (Udher *et al*, 2011, p 87), and seems to be consistent with FAO statistics for Mali were yields did not vary very much between the 60' and present. These data tell a different story in Burkina Faso, which is so close from our studied sites. The output per hectare has increased two- or threefold between the 80s and the 2000s. The cause of this increase is unknown, but it is possible that it is linked to the abandonment of intercropping and the transition to pure cropping in line with mechanization (c.p. Eric Vall, CIRAD). Udher *et al*, *2011* consider that the increase in yields is "*essentially attributable to land management (erosion control, lowland crops).*" The relationship between increase in area or yield (kg/ha) and the biodiversity of sorghum and pearl millet is not mentioned in the empirical work we are familiar with on West Africa. One can imagine that extension in area will not affect the crop system – farmers just "extend" their farm- while intensification (increase of yield) may be linked to changes in crop system and choice of specific varieties or landraces.

The commercialization of this extra production could be understood as negatively impacting diversity in the fields. In leaving the sole logic of home consumption, farmers could change their crop rotation strategies by specializing in one of the most productive landraces of sorghum (Nagarajan *et al*, 2007).

The connection to the market is simultaneously made in several directions. Producers can sell but also buy products. They are theoretically less obliged to insure a production covering their basic living needs, and can (still theoretically) specialize in the most "profitable" production and then buy their food. Several studies have already shown a negative relationship between agricultural biodiversity on farms and economic development indicators such as market integration and infrastructure development (Birol *et al*, 2004). The greater the distance to a road, the more remote the market and the more households depend on their own farms to access a wide range of crops and landraces to meet their own dietary needs. Conversely, when the market is available, farmers replace their diversity against the more standardized market products (Nagarajan *et al*, 2007). A review of the articles cited above shows that many other factors (Table 1) explain, or at least are related to, the diversity of landraces grown by farmers. It is a matter of the "agricultural" characteristics of farms (livestock size, cultivated area, for example), the sociological characteristics of households (age, gender of household head, number of people and the farmers' education level) and the economic characteristics (income levels and non-agricultural sector origin).

2. METHODOLOGY

The idea is to compare the biodiversity of farms based on their level of sales and market access, while controlling for other variables that may affect biodiversity. 120 farms were surveyed in two villages in the same small region, one being on a road and the other isolated. We conducted qualitative individual interviews and closed question surveys on a measured sample at both the village and farm levels.

2.1. Sampling

Measured choice of two villages: "isolated" and "connected"

Our study area Koutiala – 300 km east of Bamako and 100 km west of the border of Burkina Faso – is located in both major sorghum and pearl millet production areas, although in a non-central position. The surveys were conducted in two villages located within a 100 km radius around Koutiala in the administrative region of Sikasso, one of the three largest producing areas of Mali and West Africa.

The villages were chosen according to experts so that the main difference between them would be the distance to a road and a market. This is Sougoumba (Koningue Commune, Koutiala district) and Zandieguela (Municipality of Yorosso, Yorosso circle). The first village ("C" for connected) is crossed by a paved road, while the second ("I" for isolated) is located one hour away by motorbike and 15 km from a paved path. It is inaccessible by car.

The populations of the two villages are the same ethnicity (Mynianka) and speak the same language. The villages share similar climatic and soil conditions, without going as far as to say that they are identical. The main crop species are the same: primarily cotton, pearl millet, sorghum and maize. All farms grow cotton and maize.

These two villages have not experienced any interventions for the introduction and promotion of improved sorghum landraces. They represent the majority of Malian villages where few "new" landraces have been proposed, much less accepted (Smale *et al*, 2011).

Random selection of farm households

Each farm is typically, in this area, an agricultural household (in the sense of Singh *and al*, 1986) and consists of a farming unit and represents one or several consumption units closely linked together. Each of these farms is a unit of residence, a unit of agricultural work and a unit of resource sharing (Bazile, 2001; Gastellu, 1979). All members of the farm sow seeds, monitor the crop, harvest, cut own their grain together and share the results of the harvest. The agricultural production decisions regarding cereals in these villages (which is not the case everywhere in Mali) are entirely made by men. Farm household leaders responsible for all assets and food security were interviewed according to their availability on agricultural issues related to the agricultural decisions they are responsible for. For processing criteria and organoleptic or nutritional qualities, we interviewed one of the farm household head's wives. Sixty different farms in each village have been surveyed. About 22% and 36% of the farms present in the villages C and I, respectively, were surveyed. The farms were chosen randomly. The statistics and regressions presented below are not weighted by the sampling rate of the farms.

2.2. Surveys

The surveys were conducted between October and December 2010. They focused on the landraces of sorghum and pearl millet grown the previous year (planted in 2009). The agricultural season actually extends over two calendar years. Seedlings are produced between June and July, the seeds are harvested at the end of the year (November to December) and consumed and/or sold between December and the following year.

All the data (area, production, etc.) was reported by the producers. Plots have not been measured nor have the productions been weighed, the animals been counted, etc. As this data has a margin of error associated with the memory of producers (they were interviewed, however, in a single year) and with conversions. Harvesting wheelbarrows were converted to kilograms from an estimated average weight of the wheelbarrow.

2.3. Definition of landraces by producers and their spouses

Here, we use the sorghum landraces' common names as given by the farmers themselves. We asked each producer (man) to tell us the main agronomic traits (early or late landrace) and morphologies (grain color and glumes) of the landrace they grow. Women gave us the technological attributes of processing (ease of threshing and flour yield) for these landraces. For each of the selected characteristics, there are between two and three modalities. We estimated the level of consensus for the two villages to ensure that the producers gave the same name to the landraces they described the same way. Even though it is difficult, the rate of agreement, between 40% and 100%, is rather good (Table 2).

A landrace is not a pure landrace as defined by breeders and geneticists. This is really an issue of landrace populations, which are neither homogeneous nor stable over time (Deu *et al,* 2010). It is thus possible that two seemingly identical landraces are genetically different. However, in this study we only consider the phenotypic variability between landraces as managed by the farmers to build up their seed lots. Like other authors (Isakson, 2011, Smale, Bellon, Von Dusen, etc.) we consider that the producers' decisions in the management of landraces depend on their own performances and, in this sense, using their own categories to better understand their mode of management.

2.4. Several indexes of biodiversity

There are several indexes making it possible to characterize diversity (Van Dusen *et al*, 2007, Nagarajan *et al*, 2007, Major *et al*, 2005; Mafhoud, 2009) according to the importance given to the richness, abundance, or dominance of elementary entities, here the farmers' landraces. We have calculated five different indexes (see table 1*): the number of sorghum landraces, the Simpson index and Shannon index, and the Berger-Parker index and an index of scarcity. The indexes are calculated from the area cultivated by landrace. The indexes have been calculated for each farm. They have also been calculated separately in each village. Scarcity is defined in the two villages surveyed. It was determined that the landraces were "rare" when they occupied less than 2% of the total of all the 120 surveyed farms' plots and that they were grown in less than five farms (4% of farms). We then identified the farm that cultivated at least one of these rare landraces and thus created the rare landrace variable that takes the value zero if none of the rare landraces are grown on the farm and one if it cultivates at least one of them. For the Shannon and Simpson indexes, the more they are, the greater the number of landraces and the more homogeneous the area occupied by each landrace. If there is only one landrace, the Simpson index is 0 and the Shannon index cannot be calculated. These two indexes are similar, but the Shannon index is more "spread out" than the Simpson index. For example, for three landraces grown in equal proportion (33%, 33%, 33% of the area), the Simpson index equals 0.667 whereas the Shannon index = 1.099. For three landraces grown in different proportions (0.1%, 0.1%, and 98.8%, for example), they are respectively equal to 0.004 and 0.016. Also, the Shannon index gives more weight to rare landraces. The Berger Parker index corresponds to the size of the dominant landrace in the total area. It allows us to account for any specialization in a particular landrace.

2.5. Statistical processing and modeling

. We conducted[2] several types of econometric models to assess the relationship between biodiversity indicators and the explanatory variables. For richness, which corresponds to a count, we used the Poisson model and the logit model. For the Simpson, Shannon, and Berger Parker indexes, we used Tobit models (censored data). Finally, for the "rare landrace" indicator a logit model was estimated (Greene, 1990). To avoid any autocorrelation problems, we performed chi^2 tests to check the relationships between the qualitative variables. For the quantitative variables, we performed a correlation test and retained all variables because the correlation rate was always less than 0.5.

3. RESULTS AND DISCUSSION

The results are presented in three parts. The first concerns landrace traits and their distribution between villages and farms, as well as the calculation and discussion of biodiversity indexes on the scale of the two villages surveyed and that of farms. The second part concerns the description of potentially explanatory variables of biodiversity also at two levels, the village and the individual. The third part presents the results of econometric regression models estimates and their interpretation.

3.1 Landrace Traits

In the two villages, twelve landraces of sorghum were planted in 2009: seven landraces in the village I and nine in the village C. Ten landraces are named and precisely described, while two landraces are classified as "other", or unnamed. Six landraces of pearl millet were planted, five of which are named and described, and one is unnamed. There were four landraces in the isolated village and four in the connected village. There were also five ha of sorghum and 36 ha of pearl millet, corresponding to a mixture of landraces. Three landraces dominate and occupy 60% of the sorghum and pearl millet planted area: *Manyo wulé* and *Seguetana fima* for sorghum and the *Kéna* landrace for pearl millet. In fact, this landrace of pearl millet takes center stage in the village C (26% of planted area), while it occupies less space in the village I (14% of sorghum and pearl millet planted area).

Color and processing characteristics of sorghum landraces

Two landraces have red grain (*Kalagnika* and *Gnoblé*), which are traditionally used for sorghum beer, and all the others have white grain. The glumes are white, black, or red, but they have no connection with the grain color. The processing traits are significantly different between certain landraces. For example, most women believe that the early landraces are easier to hull compared to the late landraces. In contrast, the late landrace's flour yield seems to be better than the early landrace.

Early and late sorghum

The sorghum landrace *Manyo wulé* is "early", whereas the *Seguetana fima* landrace is "late". The two types of landraces, early and late, are photoperiodically sensitive (Vaksmann *et al*, 1996). The flowering, or more precisely the floral initiation, of the early landrace is triggered by longer days (early in the rainy season) than the late landrace. For example, it could be a 13-hour-day for the early landrace (around August 15) and a 12-and-a-half-hour day for the late landrace (about September 1). Therefore, regardless of the planting date, the early landrace will flower before the late landrace. The early landrace is more flexible in regards to crop calendars and can be sown late because it will flower early, when the last rains and especially the soil water reserves will be sufficient enough for it to complete its cycle, that is to say, to fill its panicles. The late landrace, which flowers late in the rainy season, can only perform well when planted early because in this case its root system has had time to grow to its full extent, and thus makes the most of the soil water reserve, allowing it to fill its panicles (P.C. Gilles Trouche, Cirad). Vom Brocke *et al* (2010) explain the complexity of differences in understanding and interpreting this term of earliness according to farmers and crop breeders or agronomists, and the consequences this may have in terms of selection. Ultimately, the most important for producers is the flowering date, and not the cycle duration. Most improved sorghum landraces in the 70s-80s do not have this photoperiod character and flower too early or too late compared to the rain distribution. This is one explanation for the lack of success seen in the improved landraces. According to these authors, the earliness criterion is cited as one of the most important criteria by farmers during the participatory selection process. Nevertheless, nuances in this result may be dependent on the particular rainfall of the previous year. Lacy *et al* (2006) or Kouressy *et al* (2008) emphasize that associated early and late landraces are found in most environments. The former say that farmers prefer long-cycle (late) landraces because they taste better and have a better yield, thus they are grown as soon as the rain and resources permit. "Short-cycle" or "early" landraces are associated with "flexibility" in regards to the rainfall and labor available for planting and weeding, while "long-cycle" or "late" landraces are associated with "best yield potential" (if there is adequate rainfall) and "a better taste".

Yields : no difference for the major landraces in 2009/2010.

Our study focuses on a single year and does not capture the variability of landrace production according to the year and different climatic conditions. Moreover, the yields are reported and have a margin of error linked to memory and conversion. Finally, for some landraces there is a single observation, which can hardly be compared to landraces with 20 or 30 observations. Nevertheless, a few salient points can be highlighted. In total, if you take all the farms of the two villages and the yields (production per unit area), the means are not significantly different from one landrace to another: For the two main sorghum landraces, the yields are quite similar: the average is around 950 kg/ha and the standard deviation around 70 kg/ha. Other landraces of sorghum have quite varying yields, but the number of observations is too limited to draw a conclusion. The main pearl millet landrace (*Kéna*) has an average yield of 900 kg/ha.

Sorghum and Pearl millet yields vary greatly from one village to another. In the connected village, yields in 2009 were an average of 1.2 tons per ha in sorghum and 1 ton per ha in pearl millet. In the isolated village, yields are lower at respectively 0.9 and 0.8 ton/ha (Table 4). Most landraces found in both villages have greater yields in the village C. However, the magnitude of this difference varies: the sorghum landrace *Manyo wule* has a 1.6 times higher yield (1.1 t/ha versus 0.69 t/ha). The sorghum landrace *Segetana fima*, on the other hand, has an almost identical yield in the two villages (0.9 to 1 t/ha). Finally, the pearl millet landrace *Kéna* produces an average three times more per hectare in the village C than in the village I (1.1 t/ha versus 0.37 t/ha).

Landrace prices

On average sorghum is sold cheaper than pearl millet (106 CFA francs/kg and 130 CFA francs/kg respectively). Prices vary slightly from one landrace to another and from one village to another. The differences are not significant. Depending on the month, there are small differences (figure 1) between the prices of main sorghum and pearl millet landraces. This seems true even if the number of observations is not large enough to perform a statistical test in the months following the harvest (from January to June), while these differences disappear during the other months (July to October). Tallec and Egg (2009) established a similar result on the assessment of quality depending on the season. In the lean season, the premium quality fades. These price differences reveal consumer preferences, as we have described them among the producers' wives interviewed. Pearl millet is "preferred" to sorghum, and long-cycle sorghum is "preferred" to the short-cycle landrace. Pearl millet can make more revenue. Long-cycle sorghum has "a better taste" than short-cycle sorghum.

Sales:

Sales for most take place right after the harvest. Most producers make just one sale of a small amount of pearl millet or sorghum, or both. Some producers make multiple sales throughout the year. Moreover, women also sell small quantities (several kilograms) to buy condiments (salt, spices, vegetables, dried fish) accompanying the sauce. These sale quantities are really small, and thus not included in the presented data. In total, over the studied year, the 117 farms sold 90 tons of cereals, 67% sorghum and 33% pearl millet.

About 10% of the total grain production was sold (Table 5). Among the three main sorghum landraces, *Manyo wulé* is the most sold: 12.11% of production is commercialized. The sorghum landrace *Seguetena Fima* is sold relatively less (5.49% of production) and the pearl millet landrace *Kéna* is somewhere in between (9.19%). Commercialization rates are different between the villages, but in both cases, the commercialization rate of *Manyo wulé* is higher than for the other two landraces.
The producers did not, however, say that they preferred to sell one landrace to another. They said that it was a matter of convenience: they sold the landrace that at the top of their silo. It is also conceivable that some of them sell the early landrace, as they have not yet harvested the late landraces and are in urgent need of cash.

3.2 Biodiversity traits

3.2.1 Biodiversity indexes at the village scale

For the sixty farms studied in each village, 252.5 ha of sorghum were grown in the isolated village compared to 224.5 in the connected village, and 114 ha of pearl millet in the isolated village versus 284.5 in the connected village. Thus, the main difference between the two villages is a larger pearl millet crop (twofold) in the village C. (Fig. 2)

Richness: 13 versus 11 landraces

In the village C, more landraces of sorghum are grown compared to the village I, while both have the same number of pearl millet landraces. There are landraces of sorghum (*Manyo wulé*, *Seguetana fima*, *Seguetana djema*, and *Kalagnika*) and pearl millet (*Kéna*), as well as specific landraces, common to both villages.

Rare landraces: 6 versus 4

In the village C, there are five "rare" landraces (less than 2% of all cultivated area) of sorghum and one of pearl millet (*chotogo*), while in the village I, there are four rare landraces of sorghum and none of pearl millet.

Distribution indicators:

The indicators vary somewhat depending on the village because they are heterogeneous. The effect of "increasing the number of landraces" (for sorghum) is offset by the "homogenization" effect, or better distribution. The Shannon index is more sensitive to rare landraces and varies a little more between sorghum and pearl millet (1.39 and 1.25 for village I sorghum and pearl millet, and 1.42 and 1.28 for the village C) and between villages than the Simpson index, which is virtually identical (0.68 to 0.69 for pearl millet and 0.68 for sorghum in the two villages).

3.2.2 Biodiversity indexes at the farm level

For the entire sample, the farms grow an average of 1.37 sorghum landraces and 0.97 pearl millet landraces. If we compare these figures with those of biodiversity at the village level, it is clear that the magnitudes are not comparable. The vast majority of farmers grow in fact between one or two landraces of sorghum and none or one landrace of pearl millet. They may have more landraces reserved in their silos, but the one-year cultivation concerns a limited number of landraces.

Two-thirds (64%) of farmers across the two villages grew just one sorghum landrace and 84% of them grew just one pearl millet landrace for the observed year. In total, 54% of the sample grew one sorghum landrace and one pearl millet landrace. The Chi^2 test shows independency between the number of pearl millet and sorghum landraces grown.

The majority of producers said they always grew the same landraces, and that they got them from their parents. They usually have several landraces in their silos and, according to the rain and the time available for planting; they choose one or the other. For example, if the rains are late, they plant an early landrace. If the rains arrive "on time", as in 2009, they plant a late landrace. If they do not have enough time, enough available labor to do the planting and weeding, then they plant the early landrace.

For the sorghum and pearl millet evaluated together and for sorghum and pearl millet evaluated separately, the farm average varietal richness and distribution indicators (Shannon and Simpson) were significantly higher in the connected village than in the isolated village (with the exception of the Simpson index for pearl millet, whose average is not significantly different). This means that the landraces are more evenly distributed within each farm in the connected village. The Berger Parker index is symmetrically higher in the isolated village for pearl millet and sorghum and for sorghum alone, but not significantly for pearl millet alone (Table 6). The rare landraces are more often found in the village C farms than those in the village I.

Beyond the number of landraces, the portfolio of landraces also changes between the two villages: in the connected village, the early sorghum landraces are grown more than in the isolated village: 54% of farms cultivate early landraces (*Manyo wulé* and *Gnoblé*) in the isolated village while they are 66% to farm in the connected village. In addition, the areas cultivated in early landraces are larger in absolute terms and in relation to the cultivated area of sorghum (92/252 ha = 36% of the sorghum cultivated area in the isolated village and 111/224 ha = 50% of the sorghum cultivated area in the connected village.

3.1.3 Biodiversity conclusion

Thus, at the village level like at the farm level, biodiversity is higher in the connected village than in the isolated village. In the village I, there are a greater number of farms that grow only one landrace of sorghum, and this landrace is usually a late landrace. When farms have two landraces in the isolated village, the "second" landrace is sown in smaller quantities than in farms with two landraces in the connected village, where the two landraces are better balanced. Similarly, in terms of pearl millet, more producers grow it in the connected village than the isolated village (86% versus 79% of farms respectively).

One may expect that the connected village will exhibit a lower biodiversity because of the specialization induced by commercialization. But the connected village is not specialized in a few crops. On the contrary they keep growing a wide range of cereals and species. Such behaviors are well explained by the theory of farmers decisions under uncertainty, devoting resources to self consumption and diversifying products sold on the markets to minimize risks (Binswanger and Rosenweig, 1986)

3.2 Explanatory variables

The averages of the different socio-demographic characteristics (age of farm leaders and work leaders, number of households, number of people) are not statistically different between the villages, with the exception of a higher educational level in the connected village: 68% of the farms have a literate work leader versus only 33% in the isolated village (Table 8). The farms of the connected village have more diverse incomes than those of the isolated village: they more often have off-farm income, external income, and they more often practice market gardening, which has more than one income source than for food. They own or operate greater holdings in terms of livestock than the total cultivated area – on average 16 hectares versus 12 hectares (Table 8). Agricultural systems are often much more diverse in the connected village with 58% of the farms practicing market gardening compared to only 16% in the isolated village.

Agriculture is distinguished by increased mechanization and the presence of a greater amount of draft animals (data not shown) in the connected village. Thus, even though the number of adults (supposed as working) per farm is the same, although they are more often employed outside of agriculture, the area cultivated by farms is larger in the connected village. The sorghum-cultivated area is slightly lower in the village C, but the standard deviation is so large that the difference between the means is not significant. Farms in the village C are market gardening and have more pearl millet than the farms of village I. The pearl millet-cultivated area corresponds to an average of more than 3 ha (4.91 ha versus 1.97 ha). We have no details for the cultivated areas of cotton and maize, which are crops also grown by all producers, but it is likely that the cultivated areas are slightly lower per farm in the village C. About four tons of sorghum is produced in each farm.

In sales, the village C has higher indicators than the village I (quantity sold per farm, the relationship between quantity sold and quantity produced, and sale/person). The "availability" measured as the difference between production and sale of sorghum per person for food (the quantity produced minus the quantity sold) is somewhat lower for the connected village (171 kg/person for the village C versus 203 kg/person in the village I), but it appears that most producers remain cautious *vis-à-vis* the production of these cereals. Cereals are primarily intended for domestic consumption for all, including the largest producers and the biggest sellers.

The farms in the connected village are on average wealthier and more diverse than those in the isolated village. They are most diverse on at least three different levels: they have more non-farm income, they have more agricultural speculations (market gardening and animals), and their sorghum occupies less space in their farms. Their sorghum landraces are on average more numerous and better distributed (less risk of extinction) than in the isolated village farms. Moreover, the connected village farms sell on average more sorghum than the village I: an average of 23% of the sorghum production is sold versus 7% in the village I. Furthermore, the cross between "number of landraces" and "farm sales volumes" shows a statistical link between these two variables. The farms that sell the most sorghum also grow more landraces. But this statistical link is not necessarily a causal link, on the one hand, and the "sale of sorghum" variable may actually hide an explaining variable to which it is connected. Also, after this first step, it is difficult to establish a causal relationship between the different potentially explanatory variables and biodiversity. A multivariable model will test the effect of each of the endogenous variables, "all things" being equal.

3.3 Results of regressions on farms

The variables used in the regressions should not be too numerous nor be too correlated or redundant. They must also be easily interpreted. So we have selected the following variables for the explanatory variables:

Sociodemographic variables:

Age of work leader in years.

Work leader's education level: 0 = never attended school, 1 = reached primary level or took literacy courses

Number of elderly people (over 60 years old)

Use of labor

Number of adults (20 to 60 years old) (it does not retain the total number of people because it is very strongly correlated to the number of adults)

Off-farm activities practiced: 0 = no, 1 = yes

Income indicator (level and diversification)

External income: 0 = no, 1 = yes

Wealth and agricultural system indicator

Market Gardening 0 = no, 1 = yes

Number of animals indicator = calculated as the weighted sum of cattle, horses, and donkeys.

Total farm-or farm- cultivated area (in hectares)

Sorghum and pearl millet cultivated area (in hectares), or sorghum cultivated area, or pearl millet cultivated area, according to the regressions

Sorghum and pearl millet production (in metric tons), or sorghum production, or pearl millet production

Sales indicators

Sorghum and pearl millet sales (in metric tons) or sorghum sales, or pearl millet sales according to the regressions. As the cultivated area and production are kept in the regressions, the level of sales is enough; and the share of sales must not be put with production.

The richness (number of landraces per farm), the presence of rare landraces and the indexes of distribution are explained by these different variables. [3]

Richness:

The Poisson regressions do not reveal a variable that is statistically related to richness (number of landraces grown by each farm). No coefficient is significantly different from zero. In contrast, the logit models (in two modalities) reveal variables that are related to the number of landraces. For sorghum, it concerns the village, the sorghum cultivated area, the volume of sorghum sold, and the constant. For pearl millet, this model cannot be estimated because there is not enough variation. For sorghum and pearl millet together, the sorghum "effect" is found again, which dominates and the significant variables are similar: the village, the sorghum and pearl millet cultivated area, sorghum and pearl millet sales, and the constant. All things being equal, the farms from the connected village have significantly more often two landraces of sorghum than those from the isolated village. The sorghum-cultivated area increases the likelihood of growing two landraces instead of one. Finally, selling more (at a constant cultivated area and production among others) has a negative effect on the number of sorghum landraces.

Presence of rare landraces

For rare landraces, the regression is of lower quality (Prob> $Chi^2 = 0.31$). Only age had a significant and negative impact on the cultivation of one or more rare landraces. The younger the work leaders are, the more likely they are to cultivate a rare landrace. Regression for pearl millet cannot be reached due to a lack of data. When considering the sorghum and pearl millet simultaneously, the village has a very significant effect, the same for the cultivated area of sorghum and pearl millet. In addition, the amount of sorghum and pearl millet sold has a negative effect. The presence of rare pearl millet and sorghum landraces is negatively related to age and cultivated farm area, and positively to sorghum and pearl millet cultivated areas, and positively to sorghum and pearl millet sales. The more sorghum and pearl millet are sold, the better the chance to grow a rare landrace.

Index distribution

The Shannon and Simpson indexes for sorghum increase with the change of village, the sorghum cultivated area, the sorghum production (Shannon only), and decrease with the volume of sorghum sold. Symmetrically, the Berger Parker index decreases with the change of village and the sorghum-cultivated area, and increases with the volume of sorghum sold. Thus, in the connected village, the distribution is more regular between the landraces. The farms selling more sorghum have a less regular distribution. The Shannon and Simpson indexes for pearl millet are positively linked to livestock. The Shannon and Simpson indexes for both species were significantly related to the village and the sorghum and pearl millet cultivated area. To test the robustness of these results, we also conducted regressions (not shown here) for the villages separately. It is found that the volume sold effect is significantly and negatively related to diversity only in the connected village.

4. DISCUSSION AND CONCLUSION

Contrary to our initial intuitions, there is more varietal diversity in the connected village compared to the isolated village: there are more sorghum landraces and more rare sorghum landraces; the distribution indexes at the farm level are on average higher. Pearl millet is grown on much larger surface area and by more producers in the connected village. There is more landrace in this village. Richness is greater there, but the distribution indicators are not systematically different. Thomet *et al* (2010) found in southern Chile that the villages most connected to the market also had more biodiversity. They explain that these are projects that have increased the cultivated diversity of quinoa. In our study, we cannot attribute the greater diversity to the influence of a development project because the study villages were not part of such projects. How then can we explain this result? The other important, and seemingly a bit contradictory, result concerns the effect of volumes sold on biodiversity. The more they increase, the more biodiversity decreases. We had imagined that the farms with the opportunity to sell their sorghum and pearl millet could specialize in one or multiple more productive landraces, and then rely a little more on the market for insurance against various hazards. At this stage, there was no evidence of some landraces being significantly more productive than others, and that this is not the motivation behind the specialization of producers. In addition, late landraces "deemed" most productive are grown less and less according to an isolated village/connected village gradient. The farmers in the more connected village in fact grow more short-cycle landraces and less long-cycle landraces than farmers in the isolated village.

In fact, it seems that two forces act antagonistically: on one hand, the connection to trade or to the road has a positive effect on biodiversity, a very clear and very strong effect. On the other hand, once people are "connected", the act of selling more has a negative effect on biodiversity. This effect is less easy to bring to light, but it is also significant. The act of selling more implies greater varietal specialization and a better distribution between species and landraces.

The "market" is a source of exchange and more opportunities to travel and make contacts, and allows farmers to test new landraces. The producers of the connected village more often have off-farm activities and more often receive income from the outside. The presence of the weekly market in this village is also an opportunity to make contacts and acquire new seeds and new landraces. On the other hand, it is an outlet for the products and encourages those who sell more and who progressively – and carefully, in the case studied – move away from the self-sufficiency model to specialize in a landrace that is both more in demand and with a better price (pearl millet) and/or easier to grow (short-cycle sorghum, *Manyo wulé*).

For all that, the growth of consumer markets in cereals and the increasing integration of Malian producers to these markets do not seem to threaten the diversity of cultivated landraces, and in contrast a better access that goes along with the integration market and exchanges play a rather positive role on the biodiversity of sorghum landraces. This result goes in the same direction as other case studies in Mexico and Guatemala on maize (Bellon and Hellin, 2011, Isakson, 2010). Like these authors, we can say that the market or the market chains of any kind, in themselves, do not stimulate the erosion of biodiversity, and that the market is included in other social regulations. These authors emphasize the cultural motivations for maintaining biodiversity and explain that – depending on the context, the market, and integration into commercial agriculture – it may or may not degrade these values and motivations. Our study has not emphasized this "cultural" aspect on these values and motivations. Other works (such as Kudadje *et al*, 2004) have shown the different attractions of sorghum biodiversity in different African contexts.

Here, we have looked rather at the micro-economic and agronomic motivations that can explain that the sale of sorghum ultimately has a negative effect on the diversity of sorghum landraces. What we have shown in particular is that the level of sales has a small and negative effect on diversity. Integration with markets plays nevertheless a role, and has a positive effect on biodiversity in at least two ways. First, it provides opportunities for the on-farm and off-farm diversification of cultivated products and activities as a whole, and second, it allows access to people and more diverse seeds.

The producers' logics (goals and motivations) do not seem fundamentally dissimilar between the two different studied villages; however, in the case of the connected village, they have more job opportunities in and outside agriculture, particularly with market gardening. They also have less time available to plant cereals and, more often than less diversified producers (without vegetables), they plant two sorghum landraces for lack of time to sow just one late landrace.

Having more exchanges – as more work outside agriculture means more market access – also gives the producers the opportunity to try new landraces from both non-market (Bazile *et al*, 2008) and market (Smale, 2005, Lipper and Cooper, 2009) seed exchange networks.

It is hard to tell from this case study whether the progressive integration of grain producers into the market in the Sahel will continue to have a positive effect on biodiversity at the scale of farms and villages. Nevertheless, this study shows that one should not show blind optimism *vis-à-vis* the farmer management of biodiversity: (i) on the one hand, each individual producer has ultimately few landraces (between 1 and 3), which has been shown elsewhere (Labeyrie *et al*, 2011, for example, in Kenya); (ii) the development of the producers' sale of agricultural products shows its first signs of specialization; and finally (iii) nothing is known about the potential effects of the possible introduction of improved landraces that are well adapted to the producers' conditions. Following this study, it seems that the suppositions of Heal *et al*, (2004) are potentially correct in this case as well: that the producers, whatever their situation, "mechanically" follow a trend toward uniformity as and since, individually, they enter the market exchange. They have "interest" in simplifying their production system and this "interest" surpasses other collective and social forces. This individual interest is certainly short-term, but is usually the best individual solution. It seems that Sahelian farmers follow the same economic baseline laws. In the Sahelian context and elsewhere, and as was clearly shown by Heal *et al* (2004) collective rules should be considered to prevent the adverse effects of the integration of farms into the market economy on biodiversity. This integration is expected to accelerate in Africa and it is wise to anticipate it.

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Table 1: Factors that may influence agro-biodiversity

Factor	Sign of the expected impact	causes
Market integration	-	Market diversity replace on-farm diversity
Education	+ or -	Knowledge of landraces Social networks
Labor availability	+	Traditional landraces require more labor than modern varieties
Wealth	-	Market diversity replace on-farm diversity
Age of the household's members	+	The older persons have a better knowledge of different landraces
Taille du cheptel	+ or -	Facteur lié à la richesse et à la capacité de production
Diversité des parcelles cultivées	+	Hétérogénéité favorise la biodiversité
Niveau des ventes	-	Spécialisation sur une variété pour augmenter les bénéfices

Table 1* : Indexes

Index	Construction	Description	Valeur
Richesse	N	Nombre de variétés	Variable discrète 1,2, 3, 4, 5….
Indice de Shannon	$= - \Sigma pi \ln pi$	Répartition (plus la répartition est équitable, plus l'indice est grand, plus les variétés sont nombreuses plus l'indice est grand)	Variable continue et positive, bornée.
Indice de Simpson	$= 1 - \Sigma pi^2$	Répartition (plus la répartition est équitable, plus l'indice est grand, plus les variétés sont nombreuses plus l'indice est grand)	Variable continue comprise entre 0 et 1.
Dominance inverse (indice de Berger-Parker)	= 1-Smax/A	1-Proportion de la variété dominante	Variable continue comprise entre (1-1/N) et 1
Variété rare si superficie de la variété représente moins de 2% de la superficie mil et sorgho des deux villages	Variable dichotomique =0 si absence =1 si présence d'au moins une variété rare	présence	Variable dichotomique

Si = Surface cultivée de la variété i
N= nombre de variétés
A : Surface cultivée de l'espèce = Σ Si
pi : proportion de la variété i en surface (pi= Si/A)
Smax : Surface de la variété la plus abondante.

Table 2: Traits of sorghum landraces

Common landrace names	Manyo wulé (early)	Seguetana fima (late)	Seguetana djema	Mayegniozaga	Kalagnika	Kalatigue	Beguene	Kalagnigne	Triban	Gnoblé	Kalafoulo
Agronomic traits											
“Early” or “late” landraces	early	late	early	late	late	late	late	late	late	early	late
% agreement	64	83	67	100	83	100	100	?	?	80	67
Morphological traits											
Grain color	white	white	white	white	red	white	white	white	white	red	white
Glume color	red	black	white	black	red	black	black	black	black	red	black
% agreement	70	98	100	67	83	100	100	100	100	100	100
Processing traits											
Threshing	easy	easy	easy/normal	easy	easy	difficult	easy	normal	easy	easy	normal
% agreement	72	42	40	100	60	100	100	100	100	100	100
Flour yield	good	good	good	good	good	good	good	good	good	good	good
% agreement	73	100	100	100	100	100	100	100	100	100	100
No. of farms growing this landrace	73 (62%)	48 (41%)	6 (5%)	3 (3%)	6 (5%)	1	1	2	1	4	3

Table 3: Number of farmers growing the different landraces and area per landrace in each village

		Isolated village (n=58)				Connected village (n=59)				Total (n=117)			
		No. of farmers growing landrace		Cultivated area		No. of farmers growing landrace		Cultivated area		No. of farmers growing landrace		Cultivated area	
		Count	%	in ha	%	Count	%	in ha	%	Count	%	ha	%
Sorghum	Manyo wulé	26	45%	80.0	22%	39	66%	111.0	22%	65	56%	191.0	21.8%
	Seguetana fima	31	53%	113.0	31%	22	37%	51.0	10%	53	45%	164.0	18.7%
	Sorghum other	1	2%	4.0	1%	8	14%	33.0	6%	9	8%	37.0	4.2%
	Seguetana djema	3	5%	16.0	4%	4	7%	5.5	1%	7	6%	21.5	2.5%
	Kalafoulo	3	5%	17.0	5%	0		.		3	3%	17.0	1.9%
	Gnoblé	5	9%	12.0	3%	0		.		5	4%	12.0	1.4%
	Kalagnika	4	7%	9.0	2%	1	2%	3.0	1%	5	4%	12.0	1.4%
	Mayengniozaga	0				3	5%	5.5	1%	3	3%	5.5	0.6%
	Kalagnigue	0				2	3%	5.5	1%	2	2%	5.5	0.6%
	Mixed landraces	0				2	3%	5.0	1%	2	2%	5.0	0.6%
	Beguene	0				1	2%	3.0	1%	1	1%	3.0	0.3%
	Kalatigue	0				1	2%	2.0	0.4%	1	1%	2.0	0.2%
	Sorghum other 2	1	2%	1.5	0.4%	0		.		1	1%	1.5	0.2%
Total Sorghum	***in ha***			***252.5***	***69%***			***224.5***	***44%***			***477.0***	***54%***
Pearl millet	Kéna	19	33%	52.0	14%	32	54%	134.5	26%	51	44%	186.5	21.3%
	Pearl millet other	3	5%	10.5	3%	12	20%	67.5	13%	15	13%	78.0	8.9%
	Ngongapogo	0				8	14%	45.0	9%	8	7%	45.0	5.1%
	Mixed pearl millet	0				7	12%	36.0	7%	7	6%	36.0	4.1%
	Ninban	13	22%	26.3	7%		0%			13	11%	26.3	3.0%
	Gnignema	11	19%	25.3	7%		0%			11	9%	25.3	2.9%
	Chotogo	0		.		1	2%	1.5	0.3%	1	1%	1.5	0.2%
Total Pearl millet	***in ha***			***114.0***	***31%***			***284.5***	***56%***			***398.5***	***46%***
Total sorghum & pearl millet				***366.5***	***100%***			***509.0***	***100%***			***875.5***	***100%***

Table 4: Yields of different sorghum and pearl millet landraces by village

		village I (n=58)		village C (n=59)		Total (n=117)	
				No. farmers growing the landrace		No. farmers growing the landrace	
	Landraces		yield (kg/ha)(1)	count	yield (kg/ha)	count	yield (kg/ha)
Sorghum	Manyo wulé	26	690.23 ***(76.22)	39	1105.61***(84.93)	65	941.26***(72.22)
	Seguetana fima	31	938.84*** (216.72)	22	1053.59***(150.43)	53	979.16***(73.25)
	Sorghum other	1	1845***(479.44)	8	985.94***(117.77)	9	1022.62***(132.51
	Seguetana djema	3	737.54*** (216.72)	4	2447.43***(564.59)	7	927.14***(217.48)
	Kalafoulo	3	146.56 (ns) (194.39)	0	-	3	71.35 (ns)(206.13)
	Gnoblé	5	730.287** (333.21)	0	-	5	672.30*(356.82)
	Kalagnika	4	442.8 (ns) (383.55)	1	1968***(606.82)	5	846.53**(353.16)
	Mayengniozaga	0	-	3	1557.253***(500.12)	3	1560.35***(565.72)
	Kalagnigue	0	-	2	1198.51**(468.57)	2	1260.12**(528.86)
	Mixed landraces	0	-	2	584.08(ns) (504.90)	2	584.08 (ns)(571.14)
	Beguene	0	-	1	2050***(606.82)	1	2050***(686.43)
	Kalatigue	0	-	1	2029.5**(910.23)	1	2029.5*(1029.64)
	Sorghum other2	1	-	0	-	1	2193.01(ns)(1417.60)
	R^2		*R2=0.85*		*R2=0.91*		*R2=0.86*
	Average Yield of sorghum per farm	58	*895.1035 (83.29)*	*59*	*1203.021 (79.76)*	*117.0*	*1050.378 (639.7867)*
Pearl millet	Kéna	19	372.9043***	32	1103.32***	51	901.7634***
	Other landrace pearl millet	3	694.2201***	12	1131.00***	15	1085.6822***
	Ngongapogo	0		8	1240.46***	8	1240.4605***
	Mixed pearl millet	0		7	780.1456***	7	780.14583***
	Ninban	13	566.8989***		-	13	566.89889**
	Gnignema	11	634.6921***		-	11	634.69212**
	Chotogo	0		1	-5.0745836	1	-5.0745836
	R2=		*0.77*		*0.87*		0.82
	Average Yield of pearl millet per farm	*45*	*793.95(87.66)*	*59*	*1064.061(61.34)*	*104.0*	*947.18 (539.27)*

Comment: yields by landrace are estimated via a linear form model *Production (in tons) of sorghum = Ói (yield of landrace i) * (landrace area size i) + å. R2 shown in the table gives the model's quality adjustment. The estimated coefficients are presented with a normal level of significance (*** significant at 1%, ** 5% ,* 10%, ns not significant) and their standard deviation in parentheses.*

Table 5: Production and sales of different sorghum and pearl millet landraces

	Production (kg and %in column)		Sale (kg and %in column))		Sale/Production (%)
Manyo wulé	179 781	20.46%	21 770	24.51%	12.11%
Seguetana fima	160 582	18.28%	8 820	9.93%	5.49%
Sorghum other	37 837	4.31%	16 432	18.50%	43.43%
Seguetana djema	19 934	2.27%	900	1.01%	4.52%
Kalagnika	10 158	1.16%	3 383	3.81%	33.30%
Mayengniozaga	8 582	0.98%	369	0.42%	4.30%
Gnoblé	8 068	0.92%	250	0.28%	3.10%
Kalagnigue	6 931	0.79%	2 000	2.25%	28.86%
Beguene	6 150	0.70%	2 000	2.25%	32.52%
Kalatigue	4 059	0.46%	35	0.04%	0.86%
Sorghum other2	3 290	0.37%	984	1.11%	29.91%
Mixed landraces	2 920	0.33%	2 858	3.22%	97.86%
Kalafoulo	1 213	0.14%	123	0.14%	10.14%
Total sorghum	*501 030*	*57.03%*	*59 924*	*67.47%*	*11.96%*
Kéna	168 179	19.14%	15 453	17.40%	9.19%
Pearl millet other	84 683	9.64%	4 996	5.63%	5.90%
Ngongapogo	55 821	6.35%	5 671	6.39%	10.16%
Mixed pearl millet	28 085	3.20%	1 445	1.63%	5.15%
Gnignema	16 058	1.83%	1 004	1.13%	6.25%
Ninban	14 909	1.70%	321	0.36%	2.15%
Chotogo	0	0.00%		0.00%	
Total pearl millet	*377 451*	*42.97%*	*28 890*	*32.53%*	*7.65%*
Total sorghum and pearl millet	*878 482*	*100%*	*88 814*	*100%*	*10.11%*

Table 6: Indexes of biodiversity by village

Indexes of biodiversity	village I	village C
Number of pearl millet and sorghum landraces	11	13
Number of sorghum landraces	7	9
Number of pearl millet landraces	4	4
Number of rare MS landraces	4	6
Number of rare sorghum landraces	4	5
Number of rare pearl millet landraces	0	1
Shannon index pearl millet and sorghum	2.00	2.05
Shannon index sorghum	1.39	1.42
Shannon index pearl millet	1.25	1.28
Simpson index pearl millet and sorghum	0.82	0.84
Simpson index sorghum	0.69	0.68
Simpson index pearl millet	0.68	0.68
Berger Parker index sorghum and pearl millet	0.69	0.74
Berger Parker index sorghum	0.55	0.51
Berger Parker index pearl millet	0.54	0.53

Table 7: Biodiversity indicator statistics by farm and by village and total (sample)

Indicator (1)	Village					
	Village I N=58		Village C N=59		Total N=117	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Number of pearl millet and sorghum landraces (***)	2.07	0.59	2.61	.67	2.34	.68
Number of sorghum landraces (**)	1.28	.45	1.46	.54	1.37	.50
Number of pearl millet landraces (***)	.79	.41	1.15	.41	.97	.44
Shannon index pearl millet and sorghum (***)	.59	.31	.75	.21	.67	.27
Shannon index sorghum (*)	.17	.28	.27	.33	.22	.31
Shannon index pearl millet (*)	.32	.05	.30	.08	.31	.07
Simpson index pearl millet and sorghum (***)	.39	.20	.48	.12	.44	.17
Simpson index sorghum (*)	.12	.19	.19	.23	.15	.22
Simpson index pearl millet (ns)	.24	.31	.25	.25	.24	.28
Berger Parker index sorghum and pearl millet (**)	.69	.18	.61	.13	.65	.16
Berger Parker index sorghum (**)	.91	.16	.84	.20	.87	.18
Berger Parker index pearl millet (ns)	1.00	.00	.99	.08	.99	.06

(1) Between parentheses, the test result for equality of means between the two villages: (***) significant difference at 1% (**), at 5%, and (*) at 1%, (ns) no significant difference. The weighting does not change the results.

Table 8: Descriptive Statistics of the possible exogenous variables.

(1)Titre?		Village I Mean	Village I Standard deviation	Village C Mean	Village C Standard deviation	Together Mean	Together Standard deviation
Work leader age (ns)		44.40	12.88	43.17	9.98	43.78	11.47
Education level (***)	*none*	*39*	*67.2%*	*18*	*31.6%*	*57*	*49.6%*
	Primary or literacy courses	*19*	*32.8%*	*39*	*68.4%*	*58*	*50.4%*
Number of elderly persons (ns)		.72	.97	.90	1.05	.81	1.01
Number of adults (ns)		7.71	6.39	9.10	4.76	8.41	5.65
Off-farm activity (*)	no	40	69.0%	31	53.4%	71	61.2%
	yes	18	31.0%	27	46.6%	45	38.8%
External income (***)	no	48	82.8%	36	61.0%	84	71.8%
	yes	10	17.2%	23	39.0%	33	28.2%
Market gardening (***)	no	49	84.5%	25	42.4%	74	63.2%
	yes	9	15.5%	34	57.6%	43	36.8%
Number of animals indicator (***)		18.53	26.77	36.72	42.07	27.55	36.21
Total cultivated area 2010 per household? (***)		11.59	8.99	15.87	7.41	13.75	8.47
Total cultivated area per adult (ns)		1.73	1.13	1.92	.89	1.83	1.01
Pearl millet and sorghum cultivated area (***)		6.3	4.6	8.7	4.5	7.5	4.7
Sorghum cultivated area 2009 (ns)		4.35	3.09	3.81	2.79	4.08	2.94
Pearl millet cultivated area 2009 (***)		1.97	2.17	4.91	2.52	3.45	2.77
Sorghum and pearl millet production in kg (***)		4651	3629	9559	6089	7126	5575
Sorghum production in kg (ns)		3485	3024	4395	3445	3944	3261
Pearl millet production in kg (***)		1166	1196	5163	3808	3182	3462
Pearl millet and sorghum yield kg/ha (***)		791.05	407.97	1099.45	397.70	946.57	429.94
Sorghum yield kg/ha (***)		895.10	634.34	1203.02	612.69	1050.38	639.79
Pearl millet yield kg/ha (**)		793.96	588.06	1064.06	471.18	947.19	539.28
Sorghum and pearl millet sales (kg) (***)		318.20	513.55	1692.92	2361.18	1011.43	1842.20
Sorghum sales kg (***)		173.97	343.05	1002.00	1945.69	591.52	1457.24
Pearl millet sales (kg) (***)		56.51	183.27	587.59	1217.48	324.32	910.36
Sales of sorghum and pearl millet production (%) (***)		.06	.08	.16	.16	.11	.14
Sorghum sales/production (%) (***)		7.19	10.96	23.52	21.29	15.43	18.79
Pearl millet sales from pearl millet production (%) (***)		3.45	10.06	10.67	18.28	7.09	15.16

(1) in parentheses, the test result for equality of means or chi² test between the two villages: (***) significant difference at 1% (**), at 5%, and (*) at 1%, (ns) no significant difference. The weighting does not change the results.

Table 9: Results of the regressions for on-farm Sorghum varietal diversity

N=113	Richness	Richness "2"	Rare landrace	Shannon	Simpson	Berger Parker
Type of regressions	Poisson	Logit	Logit	Tobit	Tobit	Tobit
Village	0.185	1.352**	0.514	0.138*	0.101*	-0.0974**
	(0.227)	(0.633)	(0.788)	(0.0741)	(0.0524)	(0.0451)
Age of work leader	0.00332	0.0150	-0.0741***	0.000417	0.000314	-0.000158
	(0.00812)	(0.0231)	(0.0275)	(0.00260)	(0.00184)	(0.00158)
Work leader's education level	0.117	0.744	-0.743	0.0763	0.0503	-0.0289
	(0.198)	(0.539)	(0.640)	(0.0640)	(0.0453)	(0.0390)
Number of elderly people	-0.0125	-0.108	0.269	-0.0191	-0.0137	0.0119
	(0.0848)	(0.230)	(0.285)	(0.0275)	(0.0194)	(0.0167)
Number of adults	-0.00390	-0.0171	0.0913	-0.00237	-0.00179	0.00262
	(0.0210)	(0.0563)	(0.0708)	(0.00683)	(0.00483)	(0.00416)
Off-farm activities	0.00902	-0.125	-1.094*	-0.0117	-0.00699	-0.00350
	(0.175)	(0.499)	(0.649)	(0.0574)	(0.0405)	(0.0350)
External income	0.00871	-0.0443	-0.424	0.00481	0.00291	0.000925
	(0.191)	(0.539)	(0.702)	(0.0626)	(0.0443)	(0.0382)
Market Gardening	0.138	0.854	0.0674	0.0682	0.0462	-0.0305
	(0.192)	(0.524)	(0.694)	(0.0646)	(0.0457)	(0.0394)
Number of animals indicator	-0.00124	-0.00807	-0.0165	-0.000818	-0.000524	9.29e-05
	(0.00313)	(0.00853)	(0.0177)	(0.00102)	(0.000721)	(0.000622)
Total farm cultivated area	-0.0109	-0.0755	-0.0750	-0.00535	-0.00365	0.00279
	(0.0171)	(0.0496)	(0.0679)	(0.00541)	(0.00382)	(0.00330)
Sorghum production (t)	0.0275	0.188	-0.163	0.0238*	0.0161	-0.0105
	(0.0412)	(0.124)	(0.154)	(0.0139)	(0.00982)	(0.00847)
Sorghum cultivated area (ha)	0.0456	0.328**	0.236	0.0314*	0.0220*	-0.0193*
	(0.0506)	(0.151)	(0.173)	(0.0168)	(0.0119)	(0.0102)
Sorghum sales (t)	-0.0633	-0.443**	0.173	-0.0456**	-0.0316**	0.0264*
	(0.0709)	(0.223)	(0.264)	(0.0224)	(0.0158)	(0.0136)
Constant	-0.0750	-2.925**	2.065	0.0155	0.0108	0.984***
	(0.434)	(1.245)	(1.332)	(0.137)	(0.0971)	(0.0837)
LR(chi^2)	19.82	28,27	14.85	23.18	22.37	19.82
Prob>chi^2	0,008	0,008	0,31	0.0395	0.0499	0.0998

Standard deviations in parentheses*** p<0.01, ** p<0.05, * p<0.1

Table 10: Results of the regressions for on-farm Sorghum and Pearl millet biodiversity

Sorghum and Pearl millet N=113	Richness	Richness 2 modalities	Rare landrace	Shannon	Simpson	Berger Parker
	Poisson	Logit	Logit	Tobit	Tobit	Tobit
village	0.181	1.541**	0.428	0.114*	0.0733*	-0.0598
	(0.167)	(0.625)	(0.808)	(0.0621)	(0.0388)	(0.0382)
Age of work leader	0.00215	0.0248	-0.0748***	-0.000448	-0.000530	0.000418
	(0.00621)	(0.0250)	(0.0281)	(0.00224)	(0.00140)	(0.00138)
Work leader’s education level	0.113	0.952*	-0.494	0.0628	0.0247	-0.0168
	(0.151)	(0.559)	(0.665)	(0.0561)	(0.0350)	(0.0345)
Number of elderly people	-0.00371	0.00895	0.132	-0.0192	-0.00921	0.00544
	(0.0630)	(0.243)	(0.280)	(0.0240)	(0.0150)	(0.0148)
Number of adults	-0.00256	0.0374	0.126	-0.00247	-0.00246	0.00230
	(0.0156)	(0.0552)	(0.0802)	(0.00568)	(0.00354)	(0.00349)
Off-farm activities	0.00516	-0.0768	-1.009	-0.0412	-0.0251	0.00893
	(0.134)	(0.525)	(0.643)	(0.0501)	(0.0313)	(0.0308)
External income	0.0103	-0.604	-0.281	0.0170	0.0172	-0.0137
	(0.148)	(0.575)	(0.734)	(0.0550)	(0.0343)	(0.0338)
Market Gardening	0.0939	0.726	0.193	-0.000804	-0.00641	0.0134
	(0.149)	(0.541)	(0.737)	(0.0568)	(0.0354)	(0.0349)
Number of animals indicator	-	-0.00854	-0.0170	-0.000813	-0.000452	0.000263
	(0.00237)	(0.00986)	(0.0175)	(0.000911)	(0.000569)	(0.000561)
Total farm cultivated area	-0.00284	-0.0551	-0.181*	-0.00697	-0.00386	0.00495
	(0.0153)	(0.0609)	(0.108)	(0.00572)	(0.00357)	(0.00352)
Sorghum and pearl millet	-0.00509	0.00776	-0.226*	0.00254	0.000389	0.000225
	(0.0195)	(0.0737)	(0.124)	(0.00759)	(0.00474)	(0.00467)
Sorghum and pearl millet cultivated area	0.0278	0.271**	0.320**	0.0350***	0.0208***	-0.0209***
	(0.0291)	(0.125)	(0.153)	(0.0111)	(0.00692)	(0.00683)
Sorghum and pearl millet sales	-0.0245	-0.446**	0.480**	-0.0121	-0.00650	0.00345
	(0.0425)	(0.208)	(0.199)	(0.0160)	(0.00997)	(0.00983)
Constant	0.490	-4.137***	2.170	0.504***	0.359***	0.719***
	(0.329)	(1.425)	(1.330)	(0.117)	(0.0732)	(0.0722)
LR(chi^2)	6.85	36.49	21.30	30.42	24.86	20.87
Prob>chi^2	0.9099	0.0005	0.672	0.0041	0.0241	0.0756

Standard deviations in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table 11: Results of the regressions for on-farm Pearl millet varietal diversity

PEARL MILLET	Richness Poisson	Shannon Tobit	Simpson Tobit	Berger Parker Tobit
Observations	113	101	101	101
Village	0.279	-0.0125	0.0521	0.00736
	(0.276)	(0.0197)	(0.0754)	(0.0133)
Age of work leader	0.00183	-0.000213	0.00362	-0.000679
	(0.00975)	(0.000693)	(0.00266)	(0.000468)
Work leader's education level	0.113	0.00614	-0.0221	-0.0141
	(0.232)	(0.0162)	(0.0622)	(0.0110)
Number of elderly people	-0.0126	-3.44e-05	-0.0287	0.00450
	(0.0957)	(0.00730)	(0.0280)	(0.00493)
Number of adults	-0.0131	-0.000906	-0.00303	0.00258**
	(0.0256)	(0.00165)	(0.00630)	(0.00111)
Off-farm activities	-0.0212	0.0192	-0.0177	-0.00271
	(0.209)	(0.0149)	(0.0572)	(0.0101)
External income	0.0523	-0.0131	0.0126	-0.00945
	(0.221)	(0.0158)	(0.0606)	(0.0107)
Market Gardening	-0.00821	-0.00734	0.0248	-0.0127
	(0.234)	(0.0174)	(0.0668)	(0.0118)
Number of animals indicator	-0.000362	0.000445*	0.00207**	-0.000950***
	(0.00330)	(0.000245)	(0.000940)	(0.000166)
Total farm cultivated area	0.00919	0.000506	-0.00367	0.00192*
	(0.0209)	(0.00146)	(0.00559)	(0.000984)
Pearl millet production (t)	-0.0509	-0.00173	-0.0137	0.00562**
	(0.0473)	(0.00331)	(0.0127)	(0.00223)
Pearl millet cultivated area (ha)	0.0818	-0.00706	-0.00584	-0.00948***
	(0.0648)	(0.00475)	(0.0182)	(0.00321)
Pearl millet sales (t)	-0.00381	0.00685	0.0149	-0.000678
	(0.117)	(0.00838)	(0.0321)	(0.00566)
Constant	-0.459	0.341***	0.172	1.025***
	(0.514)	(0.0364)	(0.139)	(0.0246)
LR(chi^2)	6.89	12.76	11.88	45.71
Prob>chi^2	0.9095	0.4667	0.5371	0.0000

Standard deviations in parentheses. *** p<0.01, ** p<0.05, * p<0.1

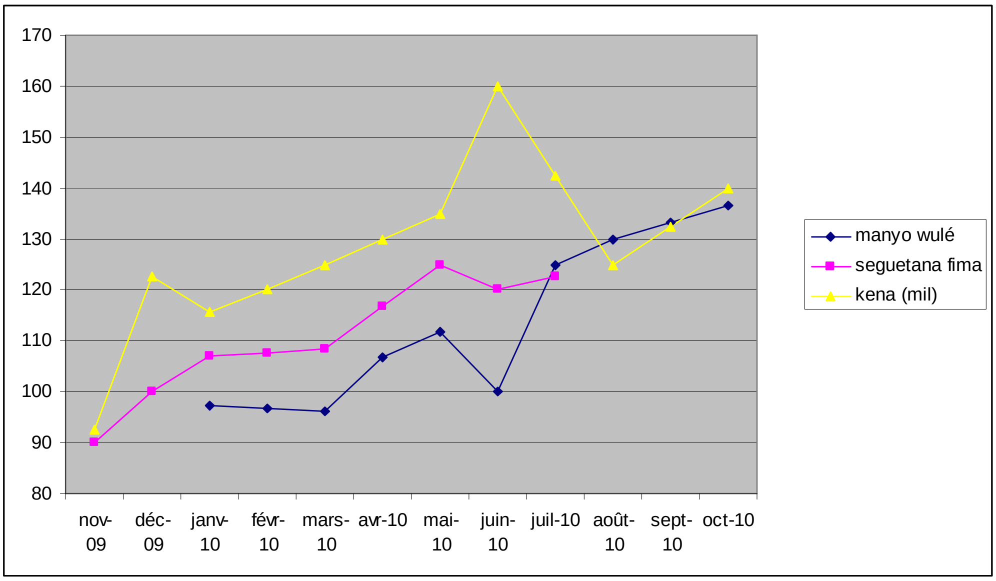

Figure 1: Prices of main sorghum and pearl millet landraces by season

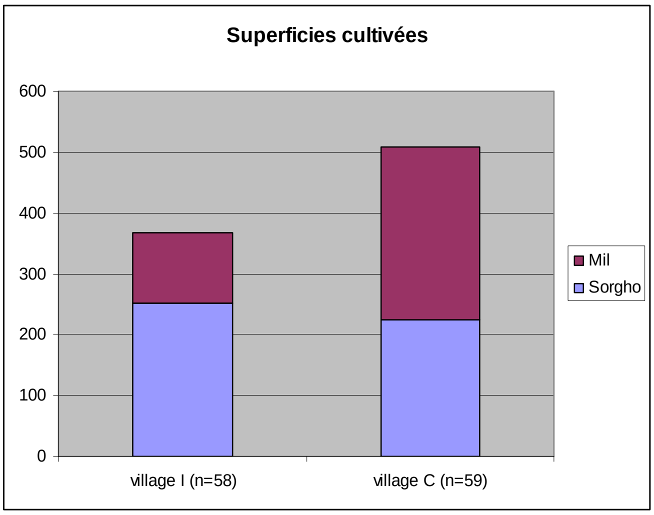

Figure 2. Cultivated area per village and per crop

Notes

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1 A demand for other specific traits can be found when interviewing women from production areas who can describe landraces according to, for example, their suitability for processing through their resistance and the loss rate during pillage or their baking performance (flour swells more in some landraces). But demand is not strong or organized enough and/or the differences between landraces are not significant enough for the organization of landrace-specific chains.

2 The quantitative surveys were entered into a database using the SPSS program version 18 (Statistical Package for Social Sciences). The statistical analyses were made using SPSS version 18 and Stata version 11

3 We have also created a richness variable into two modalities because the observed frequencies for three landraces were low for sorghum (only one farm) and for pearl millet (one). We thus have a second richness variable for sorghum that is set to 0 for one landrace and 1 for two landraces, and for pearl millet, the richness "2" = 0 for no landrace, and = 1 for one, two, or three landraces. Rarity and richness "2" are not estimated for pearl millet because not enough differences and/or not enough observations.