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An Economic Assessment of Sorghum Improvement in Mali

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An Economic Assessment of Sorghum Improvement in Mali

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International Crops Research Institute for the Semi-Arid Tropics

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Executive Summary

Since the Sahelian droughts of the 1970s and 1980s, raising sorghum productivity through development of higher-yielding varieties has been a policy priority for the Government of Mali, in partnership with ICRISAT. ICRISAT's involvement in sorghum improvement in the Sahel dates to 1975. Sorghum is one of the two main dryland cereals (the other is pearl millet) produced in Mali, and is both a food staple and ready source of cash for majority of the country's predominantly rural population.

This report consists of two analytical components, (a) a census of sorghum variety and hybrid seed use in 58 villages in the Cercles of Dioila, Kati, and Koutiala, where new sorghum materials have been tested in farmers' fields; and (b) an assessment of the economic impact of major varieties of improved sorghum released since the study by Yapi et al. (2000), including recently released sorghum hybrids, based on an economic surplus model. The report also presents an ex post assessment of returns to research investment.

The village survey of 2,430 households across 58 villages reveals that 83% grew sorghum in the 2013 main growing season. Considering all plots listed for this season, 24% planted sorghum, 21% groundnut, 16% maize, 9% millet, and 10% cotton. Gender-related changes are worth noting: 13% of sorghum plots were managed by women (87% by men), and women managed 51% of groundnut plots (with younger men managing 49%). Thus, women were more heavily represented among groundnut plot managers and less represented among sorghum plot managers. Secondly, 25% had grown varieties classified as improved (including hybrids) at least once during the past five years (2009-2013). However, adoption of improved materials is "clustered" at household level. That is, when one member of a household grows a new variety, other members are also likely to do so on the plots they manage. Newly released hybrids were grown on 3.5% of all sorghum plots planted from 2009 to 2013. Including these, 28.5% (25 + 3.5) of all sorghum plots were planted with improved materials. Use-rate of hybrid seed, by plot, were 4.9% over the period (2009-13) for sorghum plots in Koutiala, as compared to 2.8% in Kati and 2.9% in Dioila. On the other hand, use of improved varieties in Kati was across 43% of the sorghum plots, as compared to 23% in Dioila and only 10% in Koutiala. Moreover, over the five-year period, the percentage of sorghum area planted with hybrid seed, grew from 1.75 - 2.53 ha, fluctuating slightly between the years. All improved varieties and hybrids represented 32% of sorghum area by 2013. Farmer seed-producers represented 11% and 7% of seed sources for improved and hybrid seed respectively, but other farmers in the same village (family or non-family) are the dominant sources of sorghum seed for all types, including improved germplasm. This suggests that farmers also acquire seeds from other farmers by payment of cash. Farmers' unions, merchants, input dealers, seed fairs and extension services, each represent relatively minor sources of sorghum seed relative to obtaining them from other farmers.

However, the data must be interpreted with caution, given the difficulty of differentiating origin from seed sources during farmer interviews. In addition, improved varieties or hybrids are not likely to be "inherited," but are likely to be transferred within households among family members, such as from male household heads or work team leaders to women or younger men.

Considering the period spanning 1997-2013, this report estimates a net present value (NPV) of US$ 16 million from investing in sorghum improvement in Mali. The internal rate of return (IRR) is estimated at 36% per year with a benefit–cost ratio of 6:1. Moreover, the gender-related changes are worth noting: as per survey results, 13% of sorghum plots is managed by women (87% by men), and women managed 51% of groundnut plots (men-particular the younger generation, managing 49%).

Overall, the use-rates reported here are similar to those reported by Yapi et al. (2000), though the materials used by farmers are different today, than at the time of their study. Yapi et al. (2000) analyzed the use-rates for purified landraces and exotic sorghum germplasm, while in the current assessment, all materials are bred by the national program and ICRISAT, including the first Guinea-race hybrids. Thus, while the percentage of sorghum area with new materials appears to be the same over the past few decades, it does not imply that advances have not been made in the use of improved seed. Changes in the composition of seed types (toward nationally-bred, Guinea-race materials), seed acquisition practices (cash purchases), and women's roles in sorghum production appear to be substantial.

It is also worth noting that the assumptions invoked in the baseline estimates of returns to research investment, are conservative. Increasing the yield advantage to 31%, with no change in other parameters, generates an internal rate of return of nearly 60% and benefit cost ratio of 63:1. Across a broad range of management conditions on farmers' fields, the estimated average yield advantage associated with newly released sorghum hybrids is 30%. These estimates compare favorably with the more conservative estimates generated in other global studies, and should be understood as a lower bound on our overall estimates of gains from Mali's sorghum improvement program.

Introduction

Sorghum is believed to have been domesticated thousands of years ago in multiple locations scattered across the region that was then savannah and is now known as the Sahel (Harlan 1992). Archaeological evidence indicates that economies based on sorghum, pearl millet, cattle and goats were established along the southern fringe of the Sahara 3,000 to 5,000 years ago (Smith 1998).

Today, south of the Sahara, five major morphological forms or "races" of sorghum are recognized (Olsen 2012). These include caudatum sorghum (originating in eastern Africa), durra (found in the Horn of Africa and other arid regions), kafir (subequatorial eastern Africa), bicolor (broadly distributed). The fifth form is the Guinea-race, which dominates the West African savannah, where most of the continent's sorghum is now produced.

Guinea-race sorghum possesses several traits that confer unique adaptation to this region. Photo-period sensitivity enables the plant to adjust to the length of the growing seasons, which is important for farmers when rainfall is uncertain; plants of Guinea-race sorghum also have lax panicle and open glumes, which reduce grain damage from insects and mold (see Rattunde et al. 2013 for related references, including Barro-Kondombo et al. 2008; Hausmann et al. 2012).

Sorghum is one of the world's five most important cereals in terms of total production, following rice, wheat, maize, and barley. The largest single country producer is the USA, where sorghum is grown primarily for livestock feed. Yet, some of the world's poorest people depend on sorghum as both a primary staple food and ready source of cash. An example is Mali, which ranks 182 out of 187 countries on the Human Development Index (UNDP 2013). The vast majority (almost 80 %) of Malians farm and cultivate under drylands conditions (Bureau Central du Recensement Agricole 2006). The most economically important drylands cereals are millet and sorghum. Key food security crops, sorghum and millet are primarily for consumption by farmers who produce them, in various forms including as a stiff porridge called "tô," gruel, couscous, floury and fermented beverages, and fried dough.

Given its central role in the agricultural economy of Mali, raising sorghum productivity has been a major policy goal. During the Sahelian droughts of the 1970s-1980s, national and international research systems accelerated efforts to enhance sorghum productivity, including the introduction of improved germplasm. ICRISAT's senior economist in the region during that period, Matlon questioned the yield advantages of introduced cultivars, which were largely caudatum races (Matlon 1987). Early breeding programs, along with the increasing impacts of drought, led to a gradual elimination of the local materials with photoperiod-sensitivity, in favor of varieties with short, fixed cycle lengths (Vaksmann et al. 1996). Recognizing the limitations of this approach, national and international researchers have since focused on breeding a range of sorghum materials, with emphasis on Guinea-race materials.

Estimates of adoption rates for improved sorghum differ markedly by source, measurement approach, and scale of analysis, although there is little doubt that it continue to rise. Matlon's (1990) estimate for use of improved seed in the West African Sahel was about 5%. The 2006 Agricultural Census indicated that nearly 10% of area under drylands cereals was planted with improved seed, compared to over 89% of the area in industrial crops (in which rice was included). Using the amounts of certified (R2) seed produced as an indicator, and assuming replacement in the fourth year of use, Diakite et al. (2008) estimated that the area planted with improved sorghum seed had doubled from about 8% in 1996 to 16% in 2006. Diakité's (2009) analysis of farm surveys conducted in the areas around San and Sikasso showed that 20% of farmers grew improved sorghum.

In an assessment commissioned by ICRISAT, Yapi et al.'s (2000) found that nearly 30% of sorghum area was planted using improved seed in major sorghum-producing zones of Segou, Mopti and Koulikoro. Yapi et al. (2000) differentiated between two breeding approaches pursued by the national sorghum improvement program: (1) selection and "purification" of superior landraces, and (2) crosses with exotic germplasm and pedigree selection. They found that despite the greater farm-level impacts of exotic germplasm in terms of yield advantages, farmers preferred the superior landraces. The net present value (NPV) associated with varieties bred from exotic germplasm was greater, but the internal rate of return to research investment (IRR) for improved landraces was higher because of the shorter time lag to adoption. The study by Yapi et al. (2000) measured the overall rate of return to investment to be 69%.

Findings from the Yapi et al. (2000) study laid part of the foundation for the directional changes in Mali's sorghum improvement program. Subsequent research also documented that although introduced cultivars had yield potential, their grain quality was not well appreciated. Improved sorghum cultivars from this period lacked resistance to insects and mold, jeopardizing the food security of farm households. Overall, achieving more than marginal yield changes has been difficult without hybrid vigor. The tremendous variation in climate, soils and farming systems means that the degree of plant stress is not only high, but also highly variable within and among fields in close proximity. Farmers need observation over seasons and across plots to recognize whether or not a new variety has predictable advantages. This is a strong argument for farmer-managed trials early in the research and development process.

The objective of this report is to update the analysis conducted by Yapi et al. (2000), with additional focus on two recent directions in Mali's sorghum breeding program. The first is a participatory approach to sorghum improvement, based on a network of multi-locational, farmer-managed field trials. The second is the development of the first Guinea-race, photoperiod-sensitive sorghum hybrids. Our analysis consists of two components, (1) an assessment of the economic impact of major varieties of improved sorghum released since the study by Yapi et al. (2000), including recently released sorghum hybrids, based on an economic surplus model; and (2) a census of sorghum variety and hybrid seed use, covering 60 villages where farmers have tested materials. Future research will also contribute a detailed analysis of the determinants and impacts of adoption on the well-being of sorghum-growing households.

The following two sections of this report provide contextual information. In Section 2, we use secondary data sources to summarize the role of sorghum in the Malian economy. A brief history of the sorghum improvement program and a synopsis of relevant findings from previous studies about sorghum seed use are presented in Section 3. We summarize the methodology for our analysis in Section 4. Findings are presented in Section 5, followed by conclusions in Section 6.

Sorghum in the Malian Economy

Historically, millet and sorghum were of much greater importance in Mali than they are today in terms of volume and value produced. The top 10 agricultural products in 1961 and 2012 are shown in Figure 1 and 2, respectively. The rank of the top cereals is the same whether computed according to production or when compared in terms of its value, in UD dollars each year. The major difference between the two years is that in 2012, among cereals, rice now assumes the highest rank in terms of either production of value of production, and maize ranks third, above sorghum (FAOSTAT, last accessed December 15, 2013)

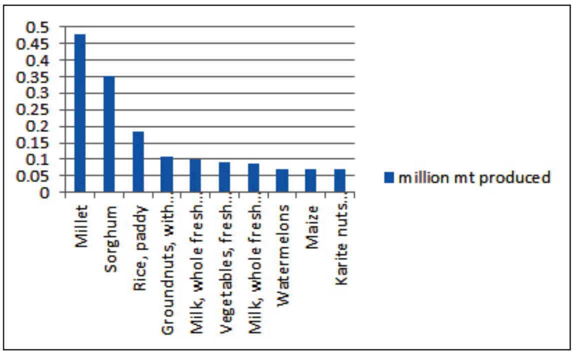

Figure 1. Top 10 agricultural products in Mali (million tons) 1961

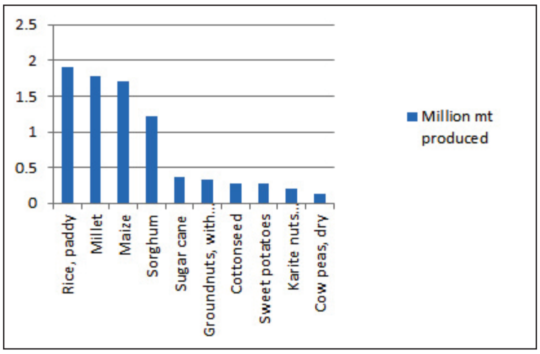

Figure 2. Top 10 agricultural products in Mali (million tons) 2012

Table 1. Decadal-average cereal area ('000 ha), production ('000 t), consumption (kg/capita/year), and imports ('000 t) in Mali

	1992 - 2002	2003 - 2013
All cereal crops		
Area	2,620	4,356
Production	2,583	6,674
Consumption	2,386	3,579
Imports	245	273
Sorghum		
Area	702	1,245
Production	517	1,212
Consumption	700	900
Imports	5	2.5
Sorghum share of all cereal crops		
Area sown	0.27	0.29
Production	0.20	0.18
Consumption	0.29	0.25
Imports	0.02	0.01

Source: CILSS 2012, SPAA 2013, CPS-DR 2013

Mali's population has grown at a rate of 3.6% annually, contributing to the expansion of area cropped in sorghum. Data shown in Table 1 demonstrate that between the two decades 1992-2002 and 2003-2013, area planted with sorghum expanded by an average of 77% and production rose by 134%. These figures suggest an overall increase in total consumption of 28%. Imports represented under 1% of supply in the first decade, and only 0.2% in the second decade.

Yields reported by FAOSTAT for 2009 through 2012 seasons are particularly erratic. Excluding 2009-2012, the average growth rate in sorghum yields from 1961 to 2012 is 0.35%; including the series from 1961 through 2012, the average growth rate is considerably higher (0.49%). FAOSTAT data are based on statistics provided by the Cellule de Planification Statistique (CPS). Examining the CPS data more closely for the period beginning 2000, we see that the variability in area, production and price is pronounced from 2007 to 2014 (Figure 3). A combination of external and internal shocks contributed to this variability. In 2007, during the global food price crisis, the Government of Mali decided to subsidize seed and fertilizer in some crops in order to stimulate production and reduce food prices in 2008. Prices declined from 2009 to 2011. A dry spell occurred during the 2011/2012 season. Prices rose. At the end of the year, Mali experienced a military coup which favored invasion by jihadists, affecting 2/3 of the country. Many farmers left their villages and migrated south. As a consequence, production declined and prices increased two folds (Mwangi et al. 2014). With the liberation of the country from jihadists in 2013, sorghum prices again decreased.

Trends for maize and rice are much more impressive overall, compared to sorghum. For purpose of comparison, average national yields in Mali were 1 ton/ha for sorghum, as compared to 0.8 for millet, 0.7 for fonio, and about 2.5 tons/ha for rice and maize over the 3-year period 2009-2011 (Cellule de Planification et du Statistique 2014). Rice and maize (via its production with cotton) have benefited from well-organized, subsidized value chains that ensure a steady supply of improved seed and fertilizer, and are grown in areas with better moisture. Maize occupies an increasingly important role in consumption and in the growth of cereal production, and is grown primarily in rotation with cotton, where growing conditions

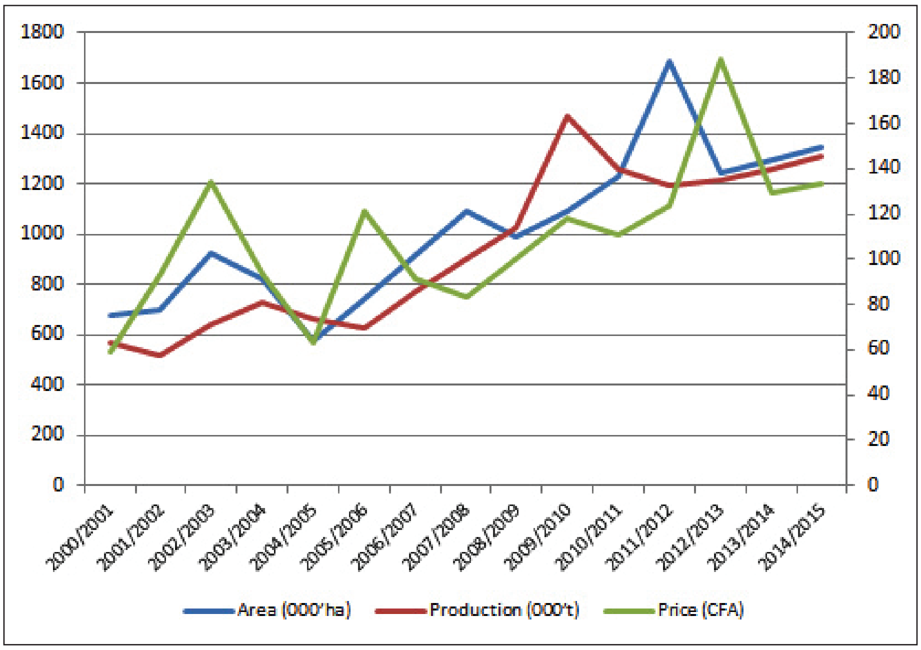

Figure 3. Sorghum cultivated area, production and price in Mali from 2000 to 2014
Source: CPS-SDR, OMA 2014

are favorable and producers benefit from support services that provide fertilizer and high-yielding seed. Rice is a major cereal crop produced under irrigated and recession agriculture, and minor areas are also planted with fonio and wheat.

The major constraint to sorghum commercialization in Mali is that, farmers and agricultural services generally continue to view this cereal as a subsistence crop. There is no organized marketing or trade association for sorghum. The crop has a strong demand in local markets, held weekly in villages throughout the rural areas. Often, farmers sell sorghum grain in small quantities to generate cash for festivals, marriages or baptisms, or to meet acute needs for health or school fees. Farm women in some areas are also part-time traders, selling grain from their stores to purchase other ingredients for the sauces that accompany the staple dish, or to provide supplementary cash to meet specific needs for themselves and their children (Smale et al. 2008). Thus, although sorghum grain is a form of "currency", farmers do not have an organized strategy that enables them to benefit from preferential prices, larger volumes, or premiums that consumers are willing to pay for higher quality grain. Professional grain traders, on the other hand, do. A second constraint has been the state-managed seed system, which is now in the process of transition (Diakité et al. 2008).

Sorghum as a proportion of cereal calories (kcal/capita/day) consumed has also declined considerably over time (from 35% in 1961 to 20% in 2009), but remains higher as a proportion of protein from cereals than as a share of calories (Figure 4). In the last year reported (2009), sorghum provided an average of 14% of the total kcal in the food consumed per capita per day in Mali. In absolute terms, the 1961 figure for sorghum kcal per capita per day is 408, as compared to 357 in 2009. Corresponding figures are 12 grams of protein in 1961 from sorghum and 10.5 in 2009. Nationally, sorghum ranks second after millet in terms of its contribution to calories and protein among all cereals grown in Mali, and is followed by rice and maize.

Sorghum improvement in Mali

Agro-ecological context

Sorghum is cultivated across Mali's agroecologies, from the border with Ivory Coast (1400 mm annual rainfall) to the border of the Sahara desert, where rainfall is too low to support crop cultivation (Figure 5).

Adaptation requirements for new sorghum varieties are specific to each ecology, and no single variety can perform over a major share of the sorghum area cultivated in Mali. This simple fact differentiates the context for crop improvement from that of crops such as wheat and rice in South Asia, the historical locus of the Green Revolution.

A compilation of research published in 2008 explores this theme in detail. In that special issue, Bazile et al. (2008) demonstrate how farmers differentiate their crops, varieties and agronomic varieties by soil type. The authors found that farmers defined soil type according to the position of the field in the toposequence, or profile characteristics related to local topography. Farmers distinguished the shallow soils of the plateaus or higher areas from medium-depth soils and alluvial, low-lying soils ('bas-fonds'). Observed within and among farms, soil differentiation provided one explanation for growing multiple varieties or ecotypes per farm and across a landscape.

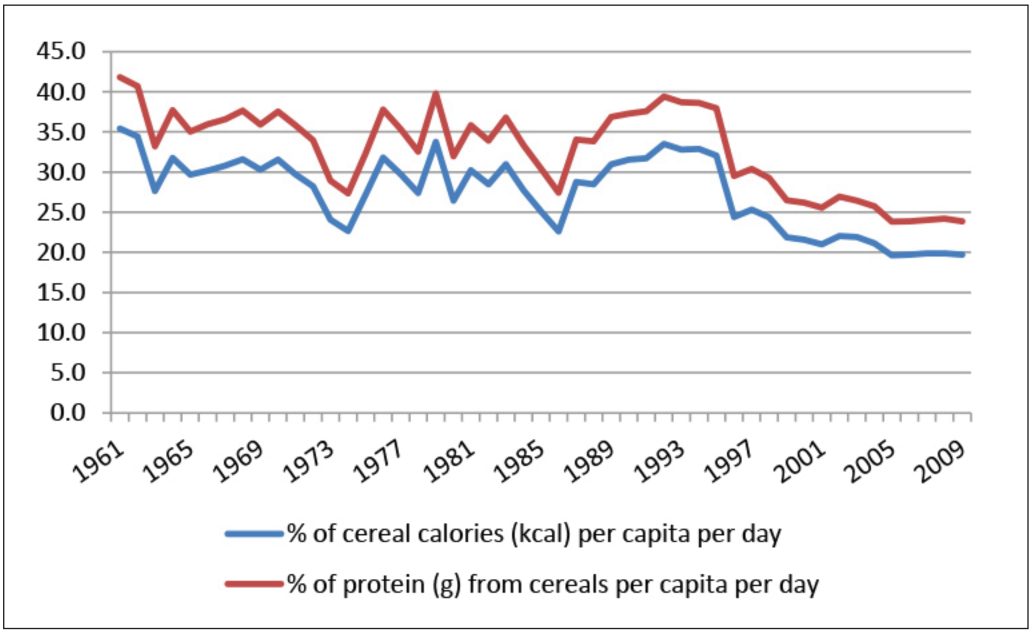

Figure 4. Sorghum as average % of calories and protein from cereals consumed in Mali, 1961-2009.
Source: FAOSTAT, accessed December 17, 2013.

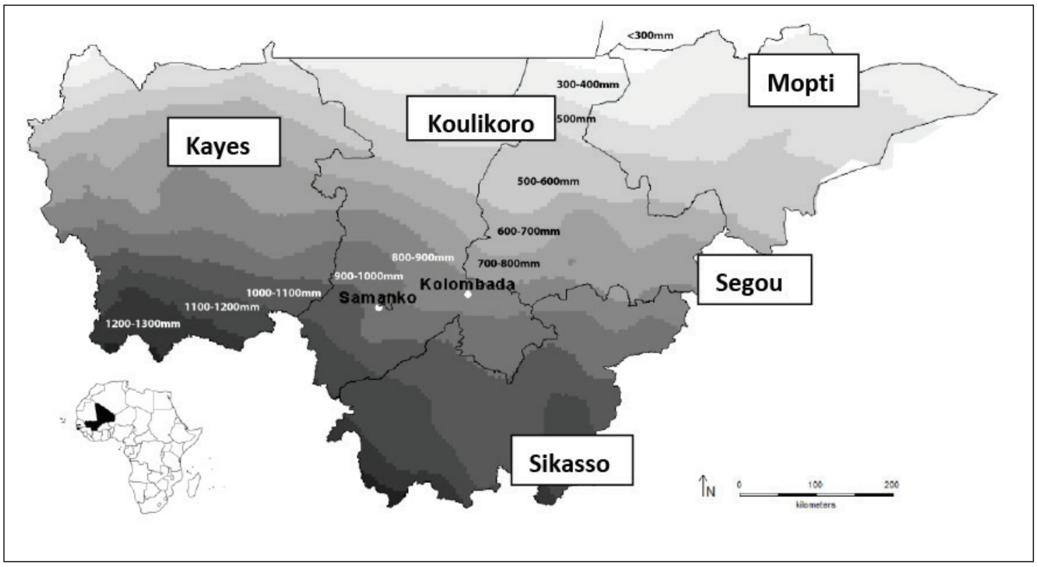

Figure 5. Rainfall isohyets and regions of southern Mali
Source: Rattunde et al. (2013)

The Guinea-race of sorghum has a broad geographic distribution, and scientific studies have suggested that it comprises more genetic diversity than other races (eg, Folkertsma et al. 2005). Currently, sorghum breeding research in West Africa emphasizes the use of genetic diversity within the Guinea-race in order to maintain the required grain quality and array of adaptive characteristics. The spatial structure of genetic diversity is another key characteristic of Guinea landraces grown in this region. Often, the range of adaptation of a landrace is only 30-40 kilometers. Sagnard et al. (2008) found that the genetic structure of Malian sorghum is evident among villages more than 30 kilometers apart.

As noted above, a defining trait of Guinea-race sorghum is photoperiod sensitivity, which means that the plant is able to measure the length of periods of light, allowing it to synchronize flowering dates with the end of the rainy season. Photoperiod-sensitive varieties are specifically adapted to a given geographical zone but can cope with a large variation in sowing date, which is critical for farmers who cope with uncertain rainfall conditions in West Africa (Soumaré et al. 2008). When Kouressi et al. (2008) compared the phenology of Malian sorghum varieties collected in 1978 and 2000, they found that despite major droughts, the average cycle duration changed little. They attributed this finding to photoperiod sensitivity. Moreover, their research indicated that farmers continued to grow combinations of longer- and shorter-duration varieties, attesting to the importance of genetic diversity and a range of ecotypes in supporting farmer adaptation to climatic conditions. With respect to sorghum cultivation, the agriculturally useful ecologies are classified as presented in Table 2.

Table 2. Characterization of the main agroecologies in which sorghum is grown in Mali

Agroecology and rainfall zone	Predominant soil conditions	Predominant uses of sorghum	Main biotic constraints of sorghum
Sahelian (300 – 600 mm)	NA	NA	NA
Western Sahel (Northern parts of Kayes and Koulikoro regions)	Sandy soils with low lying, clayey areas	In low lying areas even later maturing, guinea type sorghums for food, on sand dunes durra type sorghum largely as animal feed	Blister beetles, which mostly attack millet have led to increased cultivation of sorghum, many opportunities for intensification exist.
Central Sahel zone (Northern parts of Segou region)	Highly degraded soils, mostly sandy, with loamy areas near the large river systems	Early maturing guinea type sorghums	Striga is the main constraint, head bugs can occur and can lead to grain mold in case of late rains.
Northern Sahel (Mopti region)	Mostly sandy soils, with some loamy areas	Very large diversity of races, grown in spaces with heavy soils, or water stagnation	Striga is the main constraint. Birds can be serious, especially if sorghum grain matures very early, or very late
Decrue zone (recession farming in areas flooded by the rivers)	Heavier soils with good water holding capacity	Decrue sorghums belong to the durra race, are directly sown or transplanted as flood waters recede	Birds, and stem borers are the main constraints
Sudan savannah (700 – 1000 mm)	Heavier soils, generally degraded, some with tendency for water stagnation	Sorghum the dominant cereal crop, photoperiod sensitive types with Guinea-type grain for human consumption	Striga, headbugs, grain molds, and leaf diseases
Northern Guinea savannah (1000 – 1300 mm)	Heavier soils, tendency for water stagnation	Frequently 'rice'- type sorghum with very hard small grains	Birds, various insects and leaf diseases, as well as smuts

Source: L. Diakité (2009)

In Mali, sorghum is grown across all agroecologies except the driest Sahelian zone (300-600 mm rainfall per annum). In the Sudan Savannah, sorghum is the dominant staple crop and is grown in rotation with cotton, maize and groundnuts or in association with cowpeas or maize. Fertilizer availability in this zone is facilitated by the cotton sector and thus research opportunities on intensification of sorghum production have very high potential, especially in the context of high grain prices.

Sikasso and Koulikoro regions have the largest proportions of agricultural land located in the Sudan Savannah zone, and are thus the priority target areas for sorghum breeding and especially for hybrid development in Mali. In order of area cultivated and total production, these are the dominant sorghum producing regions. As per the 2006 Agricultural Census, the estimated share of crop area planted with sorghum was 31% in Koulikoro and 22% in Sikasso regions. In this zone, research on weed management and profitable options for fertilizer application, as well as integrated pest and disease management, are important interventions. Since sorghum is the primary staple in much of this zone, the nutritional value of sorghum could also contribute to better child nutrition status (ICRISAT 2013).

Other zones also present research opportunities for the national sorghum program. In the Northern Guinea zone, sorghum has high biomass production potential in uses other than grain (eg, fodder, bio-energy and construction material), not prone to aflatoxins like other staples grown in this region, and could play a role as a relay or intercrop to maximize the efficiency of water use. The western Sahelian zone has greater potential for expanding area used for agricultural production and sorghum is the target staple for this region. Soil fertility and water management improvements are crucial for increasing sorghum productivity in the Central Sahel zone. Sorghum is a minor crop in the northern Sahel zone, where breeding of extra early varieties might have an impact on diversification of staples. Sorghum is also a high priority crop in the recession farming areas that flood during the rainy season (ICRISAT 2013).

History of sorghum improvement

Yapi et al. (2000) provide an overview of the sorghum and pearl millet research in Mali from 1962. ICRISAT began work in the region with the United Nations Development Program (UNDP) and the US Agency for International Development (USAID) in 1975. Until then, research was conducted on a contractual basis with French research institutes such as the Institut de Recherche Agronomique Tropicale (IRAT). The West Africa Sorghum Improvement Program at ICRISAT was launched formally in 1988. A year later, CIRAD (formerly IRAT) joined ICRISAT at the Samanko research station. The Sotuba station (in Koulikoro) was also established for sorghum and maize research in the wetter regions, and Cinzana (in Segou) was established for pearl millet improvement in the drier areas.

Sorghum improvement began with the evaluation of new collections of local materials, as well as the introduction of improved genetic materials from other sorghum breeding programs worldwide, such as ICRISAT's program in India, the program in Texas, USA, and the program in France. In response to the devastating droughts and hunger of the 1970s-1980s, the national program focused primarily on raising grain yield. Scientists pursued two main approaches: (1) collecting, testing, "purifying," and selecting superior landraces for re-release to farmers, and (2), introducing exotic germplasm with characteristics thought to be desirable, including short duration, drought tolerance, short plant height, emergence in high temperature, and grain yield. Releases of this period that were still grown when Yapi et al. (2000) conducted their study, and are still grown today, include Seguetana, Tiemarifing, and the CSM series (Guinea type), all of which are photoperiod-sensitive. Several caudatum-type sorghum varieties, which had been originally released in Senegal and Burkina Faso, were also grown in Mali at that time.

Assessment by Yapi et al. (2000), marked a turning point in the strategy for improvement of sorghum in Mali. The authors found that adoption rates were substantially higher for the 'purified' landraces, despite the fact that their yield advantages were often small when compared to yield potential of exotic germplasm. Often, the yield potential of exotic germplasm was not met in the fields of smallholder farmers—in part because it was susceptible to insect damage and molds. In addition, farmers preferred traits associated with Guinea-races, such as grain quality. Over the past ten years or so, in order to overcome some of the constraints identified in that study, the national breeding program has emphasized two new directions, 1) participatory, multi-locational testing of varieties at an earlier phase of development; and 2) linking farmer and community organizations more closely to research (Weltzien et al. 2006).

By 2001, three government departments and two institutes of higher learning were involved in agricultural research and development in Mali (Stads and Kouriba 2004). The main actor has been and still is the Rural Economy Institute (IER, Institut d'Economie Rurale) with its headquarters in Bamako and six regional research stations in the different climatic zones of the country, plus three laboratories and one unit for genetic resources. The national research program collaborates with many international partners like the CGIAR centres (IITA, ILRI, ICRISAT, WARDA), French research institutions (CIRAD, IRD) and regional institutes (INSAH). IER was an active member in the West-African Sorghum Research Network (ROCARS Reseau Ouest et Centre Africaine de Recherche sur le Sorgho), which was coordinated from a base in Mali. Since the phasing out of this network in 2002, collaboration between IER and ICRISAT has been driven by special project funding. The IER sorghum program for Mali now has a range of research partners. Despite the strong reliance on special project funding the IER sorghum breeding group has successfully maintained an effective continuous breeding program.

At the time that Stads and Kouriba conducted their study (2004), no private actor was involved in agricultural research and development in Mali. Over the past decade however, with institutional reform and new seed laws, private sector entrepreneurs have begun to establish themselves in the seed sector where it is linked to the agricultural input business, regional vegetable seed producer groups and farmer's unions that produce grain or specialize in seed production. There is some interest in sorghum because hybrid seed is now available, demand for grain quality in the market is substantial, and sorghum grain prices have been rising.

Data compiled by ICRISAT (2013) indicates that a complementarity has evolved between farmer seed-producer organizations and private enterprises that market the seeds. The total volume of seed sales of sorghum is growing every year and has reached 70 tons (of which 20 tons are hybrid seeds) of seed produced by the farmer organization partnering with ICRISAT or IER, and not including quantities produced by private companies directly, and other farmer organizations. The small private companies produce some of their own sorghum seed, but the increasing volume and numbers of varieties demanded, greatly exceed their capacity. They are thus buying large quantities of seed from farmer seed cooperatives or unions. The IER/ICRISAT program has estimated the certified seed required to cover 20% of the area planted to sorghum, with improved varieties (at a seeding rate of 5 kg/ha), by agro-ecology, and has elaborated a plan that engages functional seed cooperatives, small-scale seed companies, agricultural services in districts and regions, and national and international associations as partners in the development of a decentralized seed supply chain.

As described above, the importance of adaptation to rainfall distributions, soil types and different uses, underscores the need to select varieties in multi-location trials under farmers' conditions. Weltzien et al. (2008a) reviewed changes in participatory breeding approaches in West Africa from 2000. Compared to earlier programs, in which farmers evaluated materials that had been released but not diffused, the more recent generation of programs began experimenting with farmer-breeder collaboration during the variety development stage, followed by joint variety testing. They found that in addition to achieving genetic gains while successfully addressing farmer's preferences and priorities, these programs also addressed other goals, such as farmer empowerment, biodiversity conservation and poverty related issues. Drawing from earlier work by Schell (1982) and Weltzien et al. (2003), they depict variety improvement in terms of 5 continuous, circular stages (Figure 6).

Weltzien et al. (2008b) describe their decentralized breeding strategy as applied in Mali. IER source materials are generally crosses between Caudatum and Guinea-races (about 25%). ICRISAT source materials are derived from Malian and Burkinabe Guinea-races and several high-performing selections

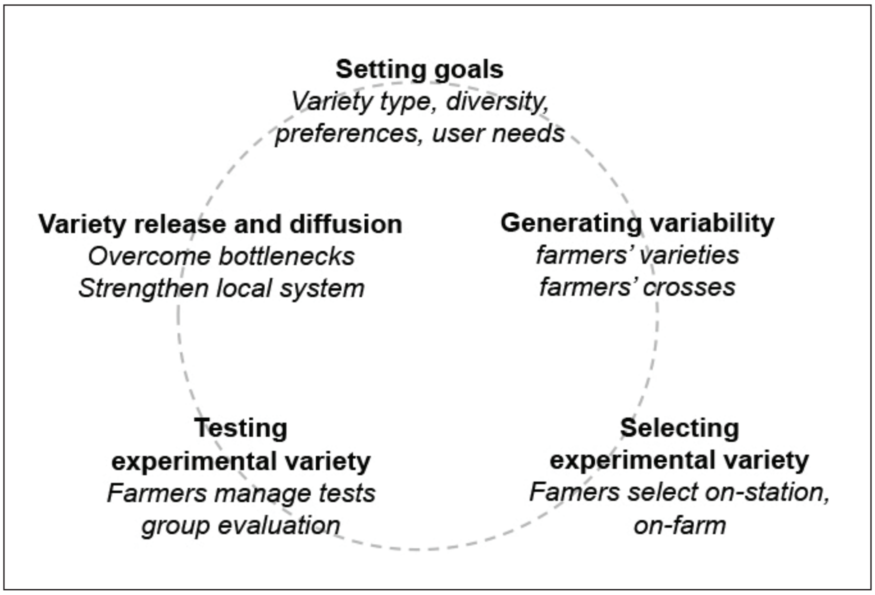

Figure 6. Process of participatory variety improvement
Source: Weltzien et al. 2003.

from landraces. All sites are located in one rainfall zone, but have different cropping systems and socio-economic contexts. In the site of Mandé, Cercle (administrative area) of Kati, fewer farmers grow cotton and use of animal traction is limited. In the Cercle of Dioila, cotton is more extensively grown, farmers utilize more animal traction, and more land is available to expand cultivation of sorghum. Koutiala is an historical center of cotton production, where the supply of cultivable land is limited and most farmers use animal traction. Local partner organizations selected test villages in each of the three sites. The principal partner in Dioila is the Union Local des Producteurs des Cereales (ULPC). In Kati, the Association des Organisations Professionelles des Paysannes (AOPP) is now the primary partner. Initially, testing was supported by another NGO, l'Association Conseil pour un Développement durable (ACoD), and by l'Office pour la Haute Vallée du Niger (OHVN). In Koutiala, farmers engaged in breeding and testing activities were supported by a local NGO, AMEDD (Association Malien pour l'Eveil au Developpment Durable). At first, all farmer-testers were men. When the program recognized that women were more involved in sorghum production than previously believed (Van der Broek 2009), women were brought into the testing and seed production program.

The framework employed for the tests has evolved over the years. From 2003 to 2008, four farmer-testers conducted sorghum trials with 32 test plots in their primary sorghum fields (grand champs, selected by the farmers). The plots were divided into 4 blocks with 8 subplots. Each farmer-tester evaluated 15 varieties and evaluated them for a number of traits. Randomization was prepared by the research organizations and the local partners distributed the seeds and protocols. The field preparation and the seeding, as well as crop management decisions were the responsibility of the farmers. Each village (Mande, Koutiala) or commune (Dioila) has an 'animateur villageois' who acts as a trainer for farmers, facilitates information exchange between farmers and the technically-trained, project personnel. In the Mandé project zone, a farmers' seed cooperative called COPROSEM was established. The cooperative enhances the production of new variety seeds, increased contacts with input dealers outside the project zone and with other projects, and negotiates fertilizer loans. Additional details are provided in Weltzien et al. (2008b).

Rattunde et al. (2013) summarize recent advances of the new breeding approach and hybrid program since 2009. The two major achievements have been the development of well-adapted hybrids and shorter-statured varieties, both possessing photoperiod-sensitivity and good grain quality. The adaptation comes from locally adapted germplasm, with new variability obtained by moderate introgression of introduced germplasm. The first cytoplasmic male-female parents based on West African Guinea-race landraces and

Table 3. List of major improved varieties of sorghum and sorghum hybrids disseminated in Mali.

Name	Type V=OPV H=hybrid, R=restorer	Adaptation zone	Rainfall isohyet (mm)	Photo-period sensitivity class*	Plant height m	Release year
SANGATIGUI	V	Sahelian	500-600	L	3	1992
SEGUIFA	V	Sahelian	500-600	L	2	1995
JAKUMBE (CSM 63E)	V, R	Sahelian	500-800	L	3	1984
NIELENI	V	Sahelian	600-800	L	3	2011
WASSA	V	Sahelian	500-600	M	3.5	2007
SOUMBA	V	Sudanian	600-800	L	2.4	1999
GRINKAN	V, R	Sudanian	700-900	L	2	2002
TIANDOUGOU-COURA	V, R	Sudanian	800-1,000	L	1.8	2011
TIANDOUGOU	V,R	Sudanian	800-1,000	L	1.8	2002
DARRELLKEN	V	Sudanian	700-900	L	3.5	2002
N'TENIMISSA	V	Sudanian	800-1,000	L	3.5	1995
JIGISEME (CSM 338)	V, R	Sudanian	800-1,000	M	3.7	1984
NIATCHITIAMA	V	Sudanian	800-1,000	M	2	2002
SEGUETANA-CZ	V	Sudanian	600-900	M	3.5	1989
TIEBLE (CSM 335)	V	Sudanian	800-1,000	M	3.6	1999
N'GOLOFING (CSM 66660)	V	Sudanian	700-900	M	4	2002
SOUMBA (CIRAD 406)	V	Sudanian	600-900	M	2.5	2002
MARAKANIO CGM 19-1-1	V	Sudanian	700-900	M	2.5	2002
SAKOYKABA	V	Sudanian	800-1,000	M	4	2002
TOROBA	V	Sudanian	700-1,000	M	4	2005
LATA	V,R	Sudanian	800-1,000	M	3	2009
DIEMA	V,R	Sudanian	800-1,100	L	4	2012
BOBOJE	V	Sudanian Savannah	800-1,200	H	3.8	2005
ZARRA	V	Sudanian	800-1,000	M	4	2002
TIEMARIFING	V	North Guinean	1,000-1,200	H	4.5	1984
SOUMALEMBA	V	North Guinean	1,000-1,200	H	4.5	1999
DOUAJE	V	North Guinean	800-1,200	H	3.5	2010
NIELENI	H	Soudanien	700-900	L	3	2011
FADDA	H	Sudanian	800-1,000	M	3	2008
SEWA	H	Sudanian	800-1,000	M	2.5	2008
SIGUI-KOUMBE	H	Sudanian	800-1,000	M	2.5	2008
HOUDÔ	H	Sudanian	800-1,000	M	2	2012
OMBA	H	Sudanian	800-1,000	M	4	2012
PABLO	H	Sudanian	700-1,000	M	4	2012
YAMASSA	H	Sudanian	800-1,000	M	5	2012
CAUFA	H	Sudanian	800-1,000	M	4	2012
NIAKAFA	H	Sudanian	800-1,000	M	4	2012
GRINKAN YEREWOLO	H	Sudanian	800-1,000	M	2	2010

*Class L=Least, M=Moderate, H=Highly. Source: Eva Weltzien-Rattunde.

Guinea-Caudatum interracial breeding lines were developed in 2004. New shorter-statured varieties offer potential for significantly enhanced stover quality and new dual-purpose grain/fodder types.

The names and characteristics of sorghum varieties and hybrids that are currently supplied to farmers in Mali are listed in Table 3, according to ICRISAT (2013). Noteworthy improved varieties (Diakité 2009) include several of the CSM series, such as CSM 63E (Jakumbe), Tieble, Jiguisseme, Tiemarifing, Gadiaba, and Seguétana CZ. Additional data culled from the official catalog are included in Annex C.

Previous studies about sorghum seed use and seed systems

Few studies have systematically assessed the adoption of improved sorghum varieties in Mali. Other studies funded by ICRISAT have contributed key insights into the use of sorghum varieties by farmers and their diversity, the role of women in sorghum production, and the contribution of local seed systems to variety diffusion. Below, we begin by summarizing the main findings of previous adoption studies. We then highlight some of the findings from the second set of studies, which have contributed to the strategies and approaches pursued today by IER/ICRISAT. As noted above, current strategies are designed to encourage more widespread use of improved varieties through decentralized breeding, seed production and supply.

Adoption

Research published through 2000, questioned the yield advantages of cultivars introduced in this region by ICRISAT (Matlon 1987, 1990), also emphasizing the need to combine them with soil fertility and water management practices to raise profitability (Sanders et al. 1996). Matlon (1990) reported that, "under normal rainfall conditions, and with low to moderate input levels under farmers' management, the yield advantage of most improved cultivars rarely exceeds 15% and is often negative" (p. 27; see also Matlon 1985). He estimated an overall adoption rate for improved sorghum and millet in the region that did not exceed 5%, citing the region's "enormous agroclimatic diversity" and the poor adaptation of introduced materials, among the primary constraints. However, as noted by Yapi et al. (2000), Matlon's estimates referred only to the introduced varieties, and did not include selections from superior local landraces.

When Yapi et al. (2000) grouped materials by breeding strategy, they found much higher overall rates of adoption in Mali. In their sample survey covering 53 villages, data indicated that 34% of sorghum growers in the Mopti region, 36% in Segou region, and 52% farmers in Koulikoro region grew improved varieties. Most adopted varieties were based on improved selections of local Guinea ecotypes, as compared to crosses based on the introduced, Caudatum types. Adoption rates for improved varieties were higher in the more favorable rainfall zones of the Koulikoro region than in either Segou or Mopti regions, and rose between 1990 and 1995. Notably, less than one percent farmers used chemical fertilizers, although almost all used manure.

The continued popularity of local ecotypes compared with introduced cultivars was explained by preferences for food quality, farmer familiarity with these well-adapted varieties, and their tall stalks, which provided good fodder and other useful materials. In Koulikoro, where sorghum competes with maize, early maturity and higher yield were identified as priority traits. Farmers cited lack of improved seed and related information, as major constraints to adoption. By far the most important source of information about seed in Koulikoro and Mopti regions was other famers within the village; the National Seed Service (SSN) was present in Segou, and seed service and extension agents were more prominent as sources of variety information.

In an assessment of the adoption of improved rice and sorghum varieties, Diakité (2009) found an overall adoption rate of roughly 20% across 10 villages and 1047 farmers in the zones of San and Sikasso. Major varieties included N'ténimissa, CS 388, ICSM 1063, and Malisor 92-1. Comparing the sorghum adoption rate to the adoption rate of improved rice varieties, Diakité estimated that while 87% of rice area and 100% of cotton area in Mali were already planted with improved varieties in 2009, the share of improved varieties in sorghum area was only 18%. He cited the lack of an organized production and marketing channel for sorghum, which is a more traditional food staple, as a principal constraint.

In areas where this study has been conducted, Some (2011) analyzed the determinants of adoption and the varietal diversity of sorghum in the cercles of Kati and Dioila, including 201 production units and 85 women farmers. He found that presence of test activities in the village raised the chances of adoption by 0.29%. Access to purchased inputs increased it by 0.19%, and availability of improved seed had a much smaller effect of 0.08%. The last finding could be explained by the relative strength of the local seed system, in which farmer-to-farmer exchange plays a much stronger role traditionally than other sources of seed.

Farmers appear to change portfolios of sorghum ecotypes frequently, and especially following a drought. Ehret (2010) analyzed changes in sorghum diversity in three of the villages of the Mandé region. She found that variety diversity at the village scale increased in all three project villages from 2004-2010, and that variety diversity per farm clearly increased in two of the three villages. Ehret concluded that the process of varietal choice over the years is dynamic; most farmers in the three villages she studied decided to experiment varieties with different cycle lengths and with a different number of varieties on the field. Few farmers retained the same portfolio over the period. Some et al. (not dated) found that after a drought season, most farmers shifted toward cultivation of a higher number of varieties, emphasizing on improved materials with a short growing cycle. Diversification was more intense in villages with more active selection programs. Social relationships seem to have an influence on farmers' information exchange and consequently on the diversity of sorghum varieties cultivated by households (Ehret 2010). Rietvield (2010) reported that testing activities by IER/ICRISAT and partner associations increased the number of varieties present in the target area, as well as the frequency of seed transactions because farmers are eager to experiment with new varieties.

Seed systems

Siart's (2008) thesis examined the function of local seed systems for sorghum in southern Mali from the perspective of how they could be leveraged to encourage the diffusion of improved varieties. Consistent with other research on the topic (Sperling et al. 2003; Smale et al. 2008; Coulibaly et al. 2008), Siart (2008) found that customary norms discouraged commercial purchase or monetized exchanges of seed among farmers. Customarily, seed diffusion depends very much on personal relations, and as seeds are not ascribed a monetary value, farmers do not sell seeds. After a drought year, they are more likely to accept seeds from outside of their families and village, and purchase seed. Siart (2008) did find that farmers expressed interest and a willingness to pay a higher price for quality seed of improved varieties. However, the demand was likely to be limited and too unpredictable to support private sector interest, suggesting the need to begin seed commercialization through a farmer cooperative, in conjunction with seed of other crops, or in association with grain trade. Overall, Siart (2008) concluded that the absence of a formal seed system is accepted as a "fact" by farmers in the project zones, and that there is potential for decentralized seed production to supply improved seed. A study by Delaunay et al. (2008) found that even in the cash-oriented economy of a village in the cotton-producing zone of Burkina Faso, traditional exchange systems for sorghum seed persisted. Consistent with the notion that there is potential for decentralized seed production, Diallo (2009) tested the quality of farmer-produced seed. She found that farmer-produced seed generally met the standards established by the national seed service in Mali.

Jones (2014) studied seed systems and strategies for disseminating seed in sites of Mali, Burkina Faso, and Niger, funded by the McKnight Foundation and HOPE project. These included agro-dealer sales of mini-packets, sales by farmer unions, and farmer-to-farmer exchange or sales by farmer testers. Formal, market-based systems and informal, exchange-based seed systems are often treated as a dichotomy, but the framework proposed by Jones integrates them.

Her thesis research confirmed that emerging local markets for seed (as represented by the seed sales strategies included in the project) continue to be socially embedded. In this context, the promotion of a narrow value chain approach, or any approach that is confined to formal seed systems, will exclude many farmers. In designing more inclusive programs, it is important to recognize that there are important differences in seed access choices not only according to rainfall and the physical development of market infrastructure, but also between men and women farmers, farmers who are members of unions and those who are not, and farmers with and without with access to social infrastructure.

Jones (2014) found that many farmers appreciate the reliability that comes with certified seeds, as well as with standardized market transactions, and have begun to move toward integration into a formal seed system. However, the sale of mini-packets and the production of improved variety seeds by local seed producers has also provided points of integration between a new, formal seed system and local, traditional seed systems. For example, points of integration occur when seed is sold directly from a seed producer's field, or when seed that hasn't been certified by the national certification agency is exchanged based on trust and incorporated into the local, socially-based seed system. Similarly, exchanges of measures of grain for measures of second-generation, improved seed allow the genetic resource initially accessed through the purchase of mini-packets in the formal seed system to enter the local seed system. Given the history of farmer-breeder collaboration in the project sites, many farmers are already familiar with the traits of the new varieties and are able to incorporate them into their local seed systems through exchanging, giving, and saving.

Women's use of sorghum seed

Researchers funded by ICRISAT's program have begun to recognize the evolving role of women in sorghum production in Mali and the potential for women's involvement in testing, seed production and diffusion. Van den Broek (2007) found few women engaged in exchange of seed. Women usually received sorghum seed from their husbands or their parents, which could serve as a means of introducing a new variety into a village. Noting the importance of sorghum in household food security, Siart (2008) expected to find that women expressed a demand for early-maturing varieties. Instead, they were interested in appropriate varieties and preferred an independent source of seed outside the decision-making structure of their production units. All women interviewed by Ehret (2010) in the three villages cultivated sorghum in 2004 and 2010, and most grew the same variety as the men in the household. Some (2011) found that women tended to grow groundnut in association with sorghum on their small individual plots, tended to planted only one sorghum variety at a time, and depended for access to farm equipment on the decisions of the head of the production unit.

Van den Broek's (2009) thesis explored the potential for the sorghum program's strategies to improve the agricultural conditions of women in the project zone. Traditionally, in the sorghum-based systems of southern Mali, men are responsible for grain production and food security from the crop harvested on family fields. Married women contribute their labor on the family fields and also cultivate individual plots on which they grow crops that provide the legumes, groundnuts, and vegetables to complement the staple food and provide a source of cash to pay for school fees and other needs of their children. In contrast with this stereotype, Van den Broek (2009) found that all women she interviewed grew sorghum in their individual plots. Women explained that due to droughts and soil degradation, harvests on the collective fields were often insufficient to feed the extended family. Except when contributing to the family stocks in times of shortage, however, women decide what they grow and control the harvest from their plots. Their harvests provide them with income to buy the ingredients for their food (spices, salt, sugar and oil), clothes for themselves and their children, gifts, and items for their daughter's dowry.

In her thesis, Donovan (2010) sought to inform sorghum breeders about how to better engage women farmers in participatory plant breeding. After surveying over one hundred women in five villages, Donovan (2010) found that most women cultivate at least a small amount of sorghum, typically receiving their first sorghum seed from men in the household, but often save their seed from year to year. Most women surveyed had heard of the testing program, but had not been part of the breeding program or received any improved seed, even if they had husbands or male family members involved in the program. Most women belonged to at least one cooperative, but factors such as wealth and age seemed to have an effect on membership. Clearly, engaging women independent of their production units, as managers of their individual plots, is fundamental for ensuring their participation.

Methodology

Farm survey

The farm survey conducted for this study was used to measure rates of adoption of sorghum ecotypes and seed use. The survey represents a baseline census of all farm households in 58 villages located in the principal sites where IER/ICRISAT has conducted its pilot-testing activities from 2009 to 2013.

Initially, 60 villages were identified where (a) computerized records indicated that the IER/ICRISAT program had conducted research and extension activities through partnerships with farmers' associations from 2009, and (b) population sizes were under 1000 persons (assumed to be equivalent to roughly 100 households). Of these, 2 were eliminated when field visits revealed that farmers in these villages had not participated directly in activities led by farmers' associations.

The villages are located in the Cercles of Kati, Dioila, and Koutiala, which constitute three of nine Cercles that compose the sorghum belt of Mali. Kati and Dioila are located in the region of Koulikoro, and Koutiala is found in the region of Sikasso. Koutiala is the most populated Cercle with a density of more than 90 persons per sq km due to the well-developed export value chain for cotton. Rainfall in this zone varies on an average between 700 mm to 900 mm. Major cereal crops grown are maize, sorghum and pearl millet; cotton, sesame, groundnuts and vegetables are cash crops. While soils in the higher reaches of the toposequence tend to be degraded and deficient in plant available phosphorus, degraded soils in the lower reaches used for cotton and maize cultivation, tend be regularly fertilized, and soil conservation practices are more widely applied here than in the other two regions. Pearl millet production can also benefit from residual effects of fertilizers applied to cotton and maize. The Cercle of Dioila is moderately populated, with population densities that reach 65 persons per sq km. Rainfall ranges from 700 to 1000 mm. Cereal crops grown are sorghum, maize and pearl millet. Cotton, ground nut and cowpea are also produced. Soils are suitable for sorghum production. In the Mandé zone of the Cercle of Kati, soils are clay to silt, and rainfall varies between 750 to 1000 mm. The population density is also relatively high due to vicinity with Bamako. Major cereal crops are sorghum, millet and maize. High value crops include vegetables and mango, and women focus heavily on groundnut production for the peri-urban market.

Teams composed of an "animateur" (village agent) and enumerators then implemented the survey instrument included in Annex A in each household, totaling 2,430 family farm enterprises (exploitations agricoles familiales, or EAFs). The instrument includes (a) a list of all household members with socio-demographic information, (b) a list of all plots by crop planted, with information on size and soil type, (c) a list of all sorghum varieties grown from 2009 to 2013, with information on seed source, mode of acquisition, changes in area planted over the past five years, and stated reasons for changes.

Assessment of investment rate of return

Following Yapi et al. (2000), we apply an economic surplus model (Alston et al. 1995; Masters and Ly 1995) to derive summary measures of the expost benefits of investing in sorghum improvement in Mali.

In any economic surplus model, the key parameters that influence the magnitude of the economic benefits are, (1) the adoption rate in terms of area under new genetic materials; (2) average yield gains (or avoided losses) following adoption; (3) pre-investment (seed cost) levels of production and prices; (4) time lags from initial investment to adoption; and (5) the time value of money, or discount rate. Price elasticities of supply and demand are also needed to generate estimates.

Table 4. Parameter values used to estimate investment rate of return

Parameter	Value
Productivity change due to investment (%)	30 (hybrid), 20 (improved) 21% area-weighted average
Change in sorghum production cost per ton harvested (%)	5
Maximum adoption level (%)	33
Gestation lag (years until start of adoption)	8
Adoption lag (years until maximum adoption)	19
Price elasticity of supply	0.5
Price elasticity of demand	−0.4
Discount rate (%)	5
Total investment (US$ million nominal)	3.5
Time path of benefits	2005/6–2024/25
Time path of costs	1997/98–2011/12

Source: Authors.

Table 4 presents the parameters used to project the economic impacts in this study. The maximum adoption rate (33%) is based on results of the village census (reported below), which is also consistent with expert opinion for the nation as a whole (Ndjeunga et al. 2012). Key informant interviews with farmers in study villages provided representative budgets with associated yield advantages and per unit cost changes (Annex B). Most applicable for better-off farmers in relatively good growing conditions, these estimates are likely to overstate yield advantages attained over a broad range of farmers and farming conditions. Rattunde et al. (2013) reported yield advantages of individual hybrids of 17% to 47% over the local check, with the top three hybrids averaging 30%. For hybrids, we utilize a yield advantage of 30%, and for improved varieties, 20%. Expert opinion suggests up to 50% yield advantages with improved varieties, but only under better conditions. With respect to changes in production costs, which are also affected by yield advantages, we apply an average of 5% due to seed and higher harvest labor requirements. While application of manure, compost, and chemical fertilizer is recommended, along with herbicides and weeding practices (as shown in representative budgets, Annex B), many farmers are unable to follow recommendations.

Price series for sorghum during the analytical period (1997-98 through 2013-14) were obtained from Observatoire du Marché Agricole (OMA). Current prices (most frequently US$ 250/ton) were collected during key informant interviews. Area and production data were provided by the Cellule de Planification Statististique du Secteur du Développement Rural (CPS-SDR). Series are shown in Annex B.

A search of both published and unpublished literature did not reveal estimations for price elasticities of demand and supply in Mali, or elsewhere in the region (Burkina Faso, Niger). Yapi et al. (2000) assumed a price elasticity of sorghum supply to be 0.4 given that sorghum is a staple food and the objective of many of Mali's smallholder farmers is to meet subsistence needs of family members (a value < 1 implies inelastic supply). A recent study by Munyati et al. (2013) used farm-level data to estimate a supply response in terms of acreage response on commercial as well as subsistence-oriented farmers in Zimbabwe. The authors estimated a long-run price elasticity of supply of 0.51, including both types of farmers. For the purpose of this study, we apply 0.5. As did Yapi et al. (2000), we applied a price elasticity of demand of (- 0.75). Again, this reflects the fact that demand is fairly inelastic (< 1).

Research investment costs were borne by IER and ICRISAT. Over the time period studied, improved sorghum varieties were diffused primarily by government extension services (regional offices), and farmers unions (AOPP, AMEED, ULCP). Data on the annual costs of research on sorghum incurred by IER for the period 1997-2012 were obtained from a discussion with the chief of "Programme Sorgho de l'IER." Cost series include salaries of scientists and technicians, as well as expenditures on tests and demonstrations. ICRISAT annual costs were provided by ICRISAT-Mali. Total project cost was used to derive annual cost depending on research intensity. The estimated cost of sorghum research investment in Mali by ICRISAT is estimated at US$ 226,133 a year, as compared to US$ 50,000 for IER. Discussions with the regional extension directors led to an estimated annual costs of diffusion at US$ 40,000 a year. Extension costs associated with government extension services reflect the investment flow in research and extension; at an early stage, investment is small in magnitude. Amounts invested each year peak and then decline for a given set of varieties or hybrids. Costs series are shown in Annex B.

Formulae for deriving benefits are drawn from Alston et al. (1995), assuming a closed economy (as compared to an export commodity traded in an open economy). Yield changes lead to a downward shift in the supply curve, equivalent to a reduction in cost of production. Annual supply shifts were projected for the period from 2005 to 2024 for research starting in 1997.

Benefits were calculated from 2004 through 2024 and costs were calculated from 1997 through 2011. Benefits and costs were discounted at a real, social discount rate (r) of 5% per annum to derive the net present values (NPV) in 1997 terms over the years considered (*t*). The aggregate NPV, including three target zones (*i*) for sorghum production, was thus derived as:

$$NPV = \sum_{t=2005}^{2024} \sum_{i=1}^{3} \left(\frac{\Delta ES_{i,t}}{(1+r)^t} \right) - \sum_{t=1997}^{2011} \left(\frac{C_t}{(1+r)^t} \right)$$

The change in economic surplus (ΔES) is equal to $[P_0 Q_0 K_t (1+0.5 Z_t \eta)]$, where K_t is the outward supply shift representing the product of cost reduction per ton of output as a proportion of product price (K) and technology adoption at time *t* (A_t); P_0 represents pre-research price; Q_0 is pre-research level of production; η is the price elasticity of demand; and Z_t is the relative reduction in price at time *t*, which is calculated as $Z_t = K_t \varepsilon/(\varepsilon+\eta)$, where ε is the price elasticity of supply.

ΔES was calculated over the benefit period beginning in 2005/2006 (following an adoption lag of eight years from the initial investment in 1997, to account for development and testing of improved varieties) and ending in the 2024/25 season, when the maximum adoption rate of 33% is attained. Costs begin in 1997/1998, but end for the set of varieties considered in 2011/2012. Costs and benefits are discounted at the social discount rate (*r*) of 5% per annum. *NPV* is understood in terms of 2009 values.

The aggregate internal rate of return (*IRR*) was calculated as the discount rate that equates the aggregate net present value (NPV) to zero. The aggregate benefit–cost ratio (B/C) was calculated as the ratio of the present values of aggregate benefits to the present values of research and extension costs:

$$B/C = \frac{NPV}{\sum_{t=1997}^{2024} \left(\frac{C_t}{(1+r)^t} \right)}$$

In addition to these parameters, the impact of the sorghum improvement program on rural poverty reduction in Mali was estimated, as shown below. First, the marginal impact on poverty reduction of an increase in the value of agricultural production was calculated using poverty reduction elasticities associated with growth in agricultural productivity, following Alene and Coulibaly (2009) and Thirtle et al. (2003). In a meta-analysis undertaken with data from a number of countries in Africa, south of the Sahara, Thirtle et al. (2003) found that a 1% growth in agricultural productivity reduces the total number of rural poor by 0.72%.

Under the assumption of constant returns to scale, a 1% growth in total factor productivity leads to a 1% growth in agricultural production. In the second component of the equation, the reduction in the total number of poor was calculated by considering the estimated economic benefits as the additional increase

$$\Delta N_p = \underbrace{\underbrace{\underbrace{\left(\frac{\Delta ES}{\text{Agric.value added}}\times 100\%\right)}_{\text{Gains from R\&E as \% of agricultural production}} \times \underbrace{\frac{\partial \ln\left(\frac{N_p}{N}\right)}{\partial \ln(Y)}}_{\text{Poverty elasticity=0.72\%}}}_{\text{Poverty reduction as \% of the poor}} \times N_p}_{\text{Number of poor escaping poverty}}$$

in agricultural production value. For the zones in Mali, the number of poor people lifted above the US$1 a day poverty line was thus derived as:

where ΔN_p is the number of poor lifted above the poverty line, N_p is the total number of poor, N is the total population, Y is agricultural productivity, and ΔES is as defined above. The poverty elasticity of 0.72% is interpreted as the marginal impact of a 1% increase in agricultural productivity in terms of the decline in the number of poor people as a percentage of the total number of poor people (N_p), rather than as a percentage of the total population.

Results

Survey findings

Findings from the village census survey are summarized in this subsection. Since the survey represents a census within villages rather than a sample, the only errors in the data are measurement (as compared to sampling) errors, and statistical tests are not relevant. Variety names were verified and classified according to race, improvement status, maturity and storability by ICRISAT-Mali.

Of the 2,430 households listed and interviewed in 58 villages, 2,014 (83%) grew sorghum in the 2013 main growing season. Considering all plots listed for this season, 24% were planted with sorghum, 21% with groundnut, 16% with maize, 9% with millet, and 10% with cotton. As expected, the share of sorghum plots was higher in Dioila (27%) than in the other sites, the share of groundnut plots was considerably higher in Kati (36%), and the share of cotton plots was highest in Koutiala (14%). Gender-related changes are worth noting: the team found that 13% of sorghum plots were managed by women (87% by men), and that women managed 51% of groundnut plots (men, particularly the younger generation managed 49%). Women tend to be more heavily represented among groundnut plot managers and less among sorghum plot managers. Almost all vegetable plots, including okra, and a third of the rice plots, but surprisingly few cowpea plots, appear to be managed by women.

About 25% households had grown varieties classified as improved (including hybrids) at least once during the past five years (2009-2013). However, adoption of improved materials is “clustered” by household. That is, when one member of a household grows a new variety, other members are also likely to do so, on the plots they manage. Table 5 reports the characteristics of all sorghum varieties grown by farmers over the 2009-2013 period, analyzed by plot. Farmers reported a total of 136 named varieties. Not all attributes are known for all varieties reported, since many are local varieties.

Newly released hybrids were grown on 3.5% of all sorghum plots planted from 2009 to 2013. Including these, 28.5% (25+3.5) of all sorghum plots were planted with improved materials. Use-rates of hybrid seeds by plot were 4.9% over the period for sorghum plots in Koutiala, as compared to 2.8% in Kati and 2.9% in Dioila. On the other hand, use of improved varieties in Kati was 43% in sorghum plots, as compared to 23% in Dioila and only 10% in Koutiala.

In terms of race, the indigenous Guinea-race was dominant among the improved varieties and hybrids grown by farmers (96%). About 61% of sorghum plots were planted with varieties that are of medium maturity (74%), while 23% were of extra-early maturing and 16% of late maturing varieties. This attests to farmer preferences for diversity in cycle length. Most types store relatively well (96%) and are tall-statured (97%).

Over the five-year period, the percentage of sorghum area planted to hybrid seed, grew from 1.75 to 2.53, fluctuating slightly among years (Table 6). All improved varieties and hybrids represented 32% of sorghum area by 2013. This adoption rate is very close to that reported by Ndjeunga et al. (2012) for Mali as a whole (33%), which was based on expert opinion.

Average areas of plots planted to each type of sorghum variety are shown in Table 7, for each year from 2009 to 2013. Mean areas planted to hybrids and improved varieties rise more rapidly than the overall average.

This pattern is confirmed by the data shown in Table 8. More than half the farmers who planted hybrids reported that the area allocated to this variety type increased over the 5-year period. By comparison, about 50% farmers reported that areas planted to local sorghum varieties remained constant. Just over one-third of the farmers increased the area they planted with improved sorghum varieties over the period (35%), compared to only 30% reporting increases in area with local varieties.

Table 5. Characteristics of sorghum varieties grown by farmers, by plot, from 2009 to 2013.

Category	Freq.	Percent
Race		
Guinea	3,088	95.49
Intermed	124	3.83
Durra	22	0.68
	3,234	100
Improvement Status		
Local	2,329	72.02
Improved variety	791	24.46
Hybrid	114	3.53
	3,234	100
Maturity		
extra early	387	22.91
Medium	1,036	61.34
Late	266	15.75
	1,689	100
Storage quality		
Good	3,119	96.44
not so good	115	3.56
	3,234	100
Plant height		
Tall	3,108	97.4
Short	83	2.6
	3,191	**100**

Source: Authors. Names identified and characterized by ICRISAT-Mali.

Table 6. Percentage of total sorghum area planted by variety type, 2009-2013

	2009	2010	2011	2012	2013
Hybrid	1.75	1.67	1.96	1.84	2.53
Improved variety	23.66	23.79	24.70	25.33	29.10
All improved	25.41	25.46	26.66	27.17	31.63
Local varieties	74.59	74.54	73.34	72.83	68.37
All varieties (%)	100	100	100	100	100
All varieties (ha)	6,179.69	6,244.58	6,689.73	6,843.17	7,307.46

Source: Authors. n=3500

Use rates for improved varieties and hybrids do not differ meaningfully between men and women plot managers. However, women represent only about 10% of sorghum plot managers, and women's plots are on average less than half the size of men's (Table 9).

In the initial year of use, 24% of seed lot (referring to the seed of a specific variety planted in a plot) were acquired through cash purchases as mini-packs or in other ways, and overall, about two-thirds of hybrid seed was purchased for cash (Table 10). According to farmers, about a third of the seed of improved varieties was originally obtained through cash purchase. This finding is significant, given that previous research has underscored the dominant social norm of 'gifts' or saved seed as primary means of acquiring seed. Gifts and exchange represented over 80% of the acquisitions of local sorghum seed. It is noteworthy that organized visits (by outsiders, such as ICRISAT scientist) were not important routes of acquisition. However, it is important to recognize that differentiating the origin of seed from the physical location of a seed source is sometimes difficult during interviews, and that these data should be interpreted with caution.

Table 7. Change in mean plot areas (ha) planted to different types of sorghum varieties

	2009	2010	2011	2012	2013
Local	1.99	2.01	2.10	2.17	2.23
improved variety	1.39	1.40	1.56	1.61	1.89
hybrid	0.63	0.59	0.79	0.75	1.19
Overall average	1.80	1.81	1.92	1.98	2.11

Source: Authors. n= 3500 (annually).

Table 8. Changes in area planted to sorghum variety types by farmers, 2009-2012

	Increase	Decrease	Constant	Total
Local	688	463	1,175	2,326
	29.58	19.91	50.52	100
Improved variety	277	175	336	788
	35.15	22.21	42.64	100
Hybrid	60	14	38	112
	53.57	12.5	33.93	100
Total	1,025	652	1,549	3,226
	31.77	20.21	48.02	100

Source: Authors. n=3500 plots

Table 9. Sex of sorghum plot manager, by variety type

		local	Improved	hybrid	Total
Men	N	2,073	717	108	2,898
	%	71.53	24.74	3.73	100
Mean plot size(ha) 2009-2013		2.22	1.66	0.82	2.04
Women	N	250	72	6	328
	%	76.22	21.95	1.83	100
Mean plot size(ha) 2009-2013		0.98	0.68	0.29	0.90
Total	N	2,323	789	114	3,226
	%	72.01	24.46	3.53	100

Source: Authors. n=3500

Table 10. Mode of sorghum seed acquisition, initial use, by improvement status

Improvement status	Initial mode of acquisition					
	Mini pack purchase	Other purchase	Gift	Exchange	During an organized visit	Total
Local (N)	62	353	1,415	492	2	2,324
(%)	2.67	15.19	60.89	21.17	0.09	100
Improved variety (N)	60	238	353	138	1	790
(%)	7.59	30.13	44.68	17.47	0.13	100
Hybrid (N)	9	64	38	0	0	111
(%)	8.11	57.66	34.23	0	0	100
Total (N)	131	655	1,806	630	3	3,225
(%)	4.06	20.31	56.00	19.53	0.09	100

Source: Authors. n=3500

Farmer seed-producers represented 11% and 7% of seed sources for improved and hybrid seed, but other farmers in the same village (either family or non-family) were the dominant sources of sorghum seed for all types, including improved germplasm. Combined with the data presented in Table 8, this suggests that farmers are also acquiring seed through cash payments to other farmers. Farmers' unions, merchants, input dealers, seed fairs and extension services each represent relatively minor sources of sorghum seed relative to other farmers (Table 11).

Again, these data must be interpreted with caution given the difficulty of differentiating origin from seed sources during farmer interviews. An example is the classification of source as "inheritance," which is an origin, strictly speaking. In addition, improved varieties or hybrids are not likely to be "inherited," but are likely to be transferred within households among family members, such as from male household heads or work team leaders to women or younger men.

Investment rate of return

Considering the period spanning 1997-2013, and assuming the parameter values shown in Table 4, we estimate a net present value of US$ 16 million from investing in sorghum improvement in Mali (Table 12). The internal rate of return is estimated at 36% per year with a benefit–cost ratio of 6:1. This indicates that each dollar invested in the pilot project to develop improved sorghum varieties and hybrids generates an average of 6 dollars in terms of net benefits. This contribution to growth in agricultural productivity was sufficient to lift an estimated 20,000 Malians out of US$ 1 a day poverty, given assumptions described in the methods section. The total number of persons raising above poverty from 2004 to 2024 (the benefit period) is estimated to be 536,887, representing 5% of the poor population of Mali in 2014.

Our baseline assumptions are relatively conservative. Recognizing that the supply shift parameter—a function of yield gains and price elasticity of supply—is the major determinant of research benefits, the model was estimated under alternative scenarios related to proportional yield gains. Table 12 also presents results of a sensitivity analysis to explore how findings change with variation in key parameter values. Although the adoption rate has a major effect on indicators of investment returns, we believe that long-term adoption ceilings, as a proportion of total area planted to sorghum in Mali, may not exceed 30 to 40%. This adoption rate has been borne out by Yapi et al. (2000), the village census undertaken as part of this study (which covered a 5-year period in 58 villages), and expert opinion (Ndjeunga et al. 2012), and may reflect underlying soils, agro-ecological and economic constraints that affect farmer decision-making.

Thus, we varied other parameters in our sensitivity analysis. Alternative scenarios included, relative to baseline parameters: (1) yield gains increase by 10%; (2) production cost per ton further reduced by 10%; (3) sorghum price increase of US$ 50 per ton; (4) discount rate increased from 5% to 10%; (5) discount rate increased from 5% to 25%.

Table 11. Seed source, first year planting, by improvement status				
Source	Local	Improved variety	Hybrid	Total
Inheritance (N)	375	49	4	428
(%)	16.14	6.2	3.6	13.27
Farmer seed-producers (N)	18	89	8	115
(%)	0.77	11.27	7.21	3.57
Another farmer in same village, not family (N)	1,154	245	24	1,423
(%)	49.66	31.01	21.62	44.12
Another farmer in another village, not family (N)	102	26	0	128
(%)	4.39	3.29	0	3.97
Another farmer, family, same village (N)	484	119	3	606
(%)	20.83	15.06	2.7	18.79
Another farmer, family, another village (N)	82	27	1	110
(%)	3.53	3.42	0.9	3.41
Extension service (N)	40	152	58	250
(%)	1.72	19.24	52.25	7.75
Farmers' union (N)	32	72	12	116
(%)	1.38	9.11	10.81	3.6
Agro-dealers (N)	4	4	0	8
(%)	0.17	0.51	0	0.25
Input store (N)	4	1	0	5
(%)	0.17	0.13	0	0.16
Merchant (N)	21	4	0	25
(%)	0.9	0.51	0	0.78
Seed fair (N)	0	2	0	2
(%)	0	0.25	0	0.06
Other (N)	8	0	1	9
(%)	0.34	0	0.9	0.28
Total (N)	2,324	790	111	3,225
(%)	100	100	100	100

Source: Authors. n=3500

Table 12. Returns to investing in improved sorghum varieties and hybrids in Mali, 1997-2024				
Scenarios	Net Present Value (million US$)	Rate of Return	B-C Ratio	Poverty Reduction ('000) per year of benefit
Baseline	16	36	6	20
Scenario relative to baseline parameters (Table 4)				
Increase in average yield advantage from baseline of 10%	161	59	63	200
Production cost per ton increased to 10%	4	11	2	6
Sorghum price increase of US$ 50 per ton	19	27	8	24
Discount rate increase from 5% to 10%	7	-	4	-
Discount rate increased from 10% to 25%	1	-	1	-

An increase in the yield advantage, such as those predicted for newly released hybrids, has a dramatic impact on all summary measures of financial returns, other assumptions held constant. Net present value, benefit-cost ratios and poverty reduction rates increase by multiples of ten, and the internal rate of return more than doubles.

Higher production costs, however, would dramatically reduce net present value, internal rate of return, benefit-cost ratios, and poverty impacts. Thus, cost effects associated with greater yield advantages would partially offset the overall benefits of productivity growth. Rising sorghum prices, such as those that have occurred since the global food price crisis, would also augment benefit streams. Overall price effects are relatively minor given that sorghum is a staple and both demand and supply are relatively inelastic. Higher discount rates to reflect risk and the financial perspectives of private as compared to public investments, have no effect on the internal rate of return or poverty reduction, but have sizeable effects on the net present value and benefit-cost ratios.

Clearly, the base model estimates based on the initial assumptions and targets of the pilot project are well within the range of possible benefits implied by alternative assumptions. The sensitivity analysis thus lends credence to the stability of benefits and returns under the baseline scenario.

A reference point for returns to sorghum and millet research is a meta-analysis of 22 studies conducted by Dalton and Zereyesus (2013). The authors found a global average rate of return of about 60% per year, with a wide dispersion. Higher estimates were explained by such factors as ex ante as compared to ex post analysis (ex post analyses generate lower, more realistic estimates), self- as compared to independent evaluation, and the assumption of a pivotal as compared to a parallel shift in the supply curve due to adoption.

As a global reference point for these preliminary estimates, in a comprehensive meta-analysis of rates of return to agricultural research and development reported in 292 studies, Alston et al. (2000) reported a median rate of return of 48% per year for research, 62.9% for extension studies, 37% for studies that estimated both the returns to research and extension, and 44.3% over all studies combined.

In the USA, the Economic Research Service of the US Department of Agriculture analyzed findings from 26 studies that assessed the rate of return to public agricultural research in the United States over various periods in the 20th century. Estimated rates of return varied depending on study methodology and coverage, but most ranged from 20 to 60%.

Conclusions

Alongside millet, sorghum is one of the two main dryland cereals produced in Mali, and is both a food staple and ready source of cash for the majority of the country’s predominantly rural population. Raising sorghum productivity through development of higher-yielding varieties has been a policy priority for the Government of Mali and for ICRISAT since the Sahelian droughts of the 1970s-1980s. ICRISAT’s involvement in sorghum improvement in the Sahel dates to 1975.

Few studies have been published on the adoption and impacts of introducing improved sorghum varieties in Mali. Matlon (1990) estimated an adoption rate of only 5% for improved seed in the West African Sahel, referring to both exotic germplasm and the weakness of national research and extension systems as constraints. Yapi et al. (2000) documented farmers’ preferences for selected, “purified” landraces as compared to crosses and selections from exotic germplasm. Yapi et al. (2000) estimated overall adoption rates of 30% in Segou, Mopti, and Koulikoro. Their findings laid part of the foundation for a directional change in Mali’s sorghum improvement program. Since then, researchers at IER and ICRISAT have continued to work with exotic germplasm, but have also produced a range of improved materials, including sorghum hybrids, using local Guinea-race materials that are photo-period sensitive and have desirable grain and storage quality as well as better insect and Striga resistance. In addition, seed supply constraints related to the state-managed, formal system have led to other approaches to diffusing improved seed. The approach encouraged through ICRISAT's program in Mali is based on a decentralized, participatory approach to testing new materials and diffusing them among farmers.

The objective of this analysis has been to update the study by Yapi et al. (2000). We have synthesized earlier research on adoption and sorghum seed use in Mali. As part of this study, we have implemented a census of farmers in 58 villages in the Cercles of Dioila, Kati, and Koutiala, where new sorghum materials have been tested in farmers' fields through farmers' unions. We have also conducted an ex post assessment of returns to research investment.

Overall, the use rates reported here are similar to those reported by Yapi et al. (2000). However, the materials used by farmers are different today than at the time of their study. Yapi et al. (2000) analyzed use rates for purified landraces and exotic sorghum germplasm, while the current study includes all materials bred by the national program and ICRISAT, including the first Guinea-race hybrids. Thus, the fact that the percentage of sorghum area in new materials does not appear to have changed appreciably over the past few decades does not imply that advances have not been made in the use of improved seed. Changes in the composition of seed types (toward nationally-bred, Guinea-race materials), seed acquisition practices (toward cash purchases), and women's roles in sorghum production appear to be substantial.

The assumptions we have invoked in our baseline estimates of returns to research investment are conservative. Assuming only a 21% yield advantage and a ceiling adoption rate of 33%, the rate of return to investment in sorghum improvement in Mali since 1997 is estimated at 36%, with six dollars earned for every dollar invested. Each year, on average, 20,000 persons are estimated to have crossed the 1 US$ poverty line as a result of higher sorghum productivity. Increasing the yield advantage to 31%, with no change in other parameters, generates an internal rate of return of nearly 60% and benefit cost ratio of 63:1. Across a broad range of management conditions on farmers' fields, the estimated average yield advantage associated with newly released sorghum hybrids is 30%. These estimates compare favorably with the more conservative estimates generated in other global studies, and should be understood as a lower bound on our overall estimates of gains from Mali's sorghum improvement program.

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Annex A. Survey instrument

SECTION 1: MEMBRES DE l'UPA — IDM |__|__|__|__|

Enqueteur: Posez Je voudrais vous poser des questions sur la composition de votre UPA aujourd'hui.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Id. No	Nom	Prenom	Quel est le sexe de […]? 1=H 2=F	Quel est le lien de parenté de […] avec le chef du ménage? (Liste A)	Quel âge […] a-t-il(elle)?	Quel est le statut matrimonial de […]? 1=marie(e) 2=divorce(3) 3=veuf(ve) 4=celibataire	L'hivernage derniere, d'un hivernage a l'autre, […] a ete absent pendant combien de **jours**?	Quelle est la langue principale de la mere de […]? 1=bambara 2=peulh 3=miyanka 4=senoufo 5=Autre à préciser :	Quelle est la langue principale du pere de […]? 1=bambara 2=peulh 3=miyanka 4=senoufo 5=Autre à préciser :	Quelle est la langue principale de […]? 1=bambara 2=peulh 3=miyanka 4=senoufo 5=Autre à préciser :	Cette personne participe-t-elle dans ces activites semencieres dans ce village? 1=tests de varietes 2=production de semences 3=ni l'un ni l'autre	Presentement, cette personne a-t-elle des responsabilites dans le village ? 1 = Oui 2 = Non >> Q19	Si oui, indiquez toutes celles qui lui sont appropriés (Liste D)	Auparavant, avez-vous eu des responsabilites dans le village ?1 = Oui 2 = Non	Si oui, indiquez toutes celles qui lui sont appropriés (Liste D)
1													[__][__][__]	[__][__][__]	
2													[__][__][__]	[__][__][__]	[__][__][__]
3													[__][__][__]	[__][__][__]	[__][__][__]
4													[__][__][__]	[__][__][__]	[__][__][__]
5													[__][__][__]	[__][__][__]	[__][__][__]
6													[__][__][__]	[__][__][__]	[__][__][__]
7													[__][__][__]	[__][__][__]	[__][__][__]
8													[__][__][__]	[__][__][__]	[__][__][__]
9													[__][__][__]	[__][__][__]	[__][__][__]
10													[__][__][__]	[__][__][__]	[__][__][__]
11													[__][__][__]	[__][__][__]	[__][__][__]
12													[__][__][__]	[__][__][__]	[__][__][__]
13													[__][__][__]	[__][__][__]	[__][__][__]
14													[__][__][__]	[__][__][__]	[__][__][__]

Liste A: Lien de Parenté par rapport au chef d'UPA

1=Chef d'UPA	11=Fils
2=Première épouse	12=Belle fille
3=Deuxième épouse	13=Fille
4=Troisième épouse	14=Petit fils
5=Quatrième épouse	15=Petite fille
6=Mère	16=Autre à spécifier
7=Frère	A:_______________
8=Soeur	B:_______________
9=Cousin	

Liste B: Responsabilites

1=conseille au chef du village

2=leader d'une cooperative ou association de producteurs

3=conseille municipale

4=responsabilites coutumieres

5=autres (a specifier): A

SECTION 2: PARCELLES DE L'UPA

IDM [__|__|__|__|__|__|__]

Enquêteur: Demandez des informations sur chaque parcelle au responsable de la parcelle. S'il vous plaît enregistrez toutes les parcelles qui ont été cultivées ou détenus par les membres du ménage: Dites: Maintenant, je voudrais vous poser quelques questions sur les parcelles appartenant aux membres de l'UPA qui sont utilisées par les membres de l'UPA. Il s'agit non seulement de vos parcelles, mais aussi celles des autres membres de l'UPA ainsi que les parcelles louées par les membres de l'UPA.

	Quel est le membre de l'UPA qui gere cette parcelle?			4	5	6	7	8	9	10	11	12
ID de la parcelle	*1.PID*	*2.Nom*	*3. Prenom*	*Quel est le nom de la parcelle ou autre point de repere? (par example, bas-fonds, colline…sa situation)*	La parcelle a-t-elle été cultivée au cours du dernier hivernage?	Quelle est la taille de la parcelle? Taille *(hectare)*	Quelle est la source d'eau pour cette parcelle? (Liste A)	Quelle est la culture principale cultivée sur cette parcelle pendant l'hivernage? (Liste B)	Quelle est la culture principale cultivée sur cette parcelle pendant la contre-saison?	Quelle est la première culture associée sur cette parcelle? (Liste B)	Quelle est la deuxième culture associée sur cette parcelle? (Liste B)	Quel est le type de sol qui domine cette parcelle? (Liste C)
1					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
2					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
3					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
4					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
5					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
6					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
7					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
8					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
9					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
10					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
11					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
12					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
13					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
14					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
15					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
16					[__]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]

Liste A	
1=Sorgho	9=Courges
2=Mil	10=Calebasses
3=Mais	11=autres (specifier)
4=Riz	A. __________
5=Arachides	B.__________
6=Niebe	C. _________
7=Patates	
8=Ignames	

Liste B
1=Pluie
2=Puits
3=Forage
4=Irrigation à motopompe
5=Canal

Liste C	
1=Sableux	7=sab/grav
2=Limoneux	8=lim/arg
3=Argileux	9=lim/grav
4=Gravilloneux	10=arg/grav
5=sab/lim	
6=sab/arg	

SECTION 3: SEMENCES SORGHO

IDM [__|__|__|__|__|__|__]

Enquêteur: Demandez des informations au chef de travaux sur chaque ecotype ou variete de sorgho qui a ete introduit dans cette UPA dans les 5 dernieres annees.

1.	Quel membre de l'UPA a introduit cette variete?			5	6	Indiquez la superficie semee					La supercie semee de [……], a-t-elle accrue ou diminuee depuis l'introduction?		Sur quelles parcelles a-t-elle ete semee? (voir feuille 3)	
liste de toutes ecotypes ou varietes de sorgho semees de 2009-2013 (a decrire)	2.PID	3.Nom	4.Prenom	Achat, don ou echange la premiere fois semee? 1=achat minipack 2=autre achat 3=don 4=echange 5=lors d'une visite d'echange organisee	Source de semences (liens sociaux, Liste A)	7. 2013	8. 2012	9. 2011	10. 2010	11.2009	12. 1=accrue 2=diminuee	13. Pourquoi le changement	14. ID	15. Nom ou point de repere

Liste A

1=producteurs de semences
2=autre producteur, non-parente, meme village
3=autre producteur, non-parente, autre village
4=autre producteur, parente, meme village
5=autre producteur, parente, autre village
6=services de vulgarisation
7=union de producteurs
8=agro-dealers
9=boutique d'intrants
10=commercants
11=foires de semences
12=autres (a preciser) ____________________

Annex B. Data used in economic surplus model

Traditional sorghum variety farm budget

Items	Unit	Quantity	Unit cost	Value
Variable costs				
Labor				
- Field preparation	Man days	4	1,500	6,000
- Plowing	Man days	2	1,500	3,000
- Manure application	Man days	1	1,500	1,500
- Sowing	Man days	3	1,500	4,500
- Weeding1	Man days	6	1,500	9,000
- Weeding2	Man days	6	1,500	9,000
- Harvesting	Man days	8	1,500	12,000
- Threshing	Man days	5	1,500	7,500
- Hauling	Man days	3	1,500	4,500
Seeds	kg	10	100	1,000
Farm yard manure	ton	3	10,000	30,000
Insecticide	liter	0	600	0
Fertilizer	kg	0	250	0
Equipment rental	days	4	5,000	20,000
Total variable cost	CFA/ha			1,18,000
Output per Ha	Kg/ha			950
Unit variable cost	CFA/kg			125
Unit variable cost reduction	CFA/kg			-

Improved sorghum variety farm budget				
Items	Unit	Quantity	Unit cost	Value
Variable costs				
Labor				
Field preparation	Man days	4	1,500	6,000
Plowing	Man days	2	1,500	3,000
Manure application	Man days	1	1,500	1,500
Sowing	Man days	3	1,500	4,500
Weeding1	Man days	6	1,500	9,000
Weeding2	Man days	6	1,500	9,000
Harvesting	Man days	8	1,500	12,000
Threshing	Man days	5	1,500	7,500
Hauling	Man days	3	1,500	4,500
Seeds	kg	8	400	3,200
Farm yard manure	ton	3	10,000	30,000
Insecticide	liter	2	600	1,200
Fertilizer	kg	150	250	37,500
Equipment rental	days	4	5,000	20,000
Total variable cost	CFA/ha			1,58,900
Output per Ha	Kg/ha			1,500
Unit variable cost	CFA/kg			105
Unit variable cost reduction	CFA/kg	-	-	20

Hybrid sorghum farm budget				
Items	Unit	Quantity	Unit cost	Value
Variable costs				
Labor				
- Field preparation	Man days	4	1,500	6,000
- Plowing	Man days	2	1,500	3,000
- Manure application	Man days	1	1,500	1,500
- Sowing	Man days	3	1,500	4,500
- Weeding1	Man days	6	1,500	9,000
- Weeding2	Man days	6	1,500	9,000
- Harvesting	Man days	8	1,500	12,000
- Threshing	Man days	5	1,500	7,500
- Hauling	Man days	3	1,500	4,500
Seeds	kg	8 4-5	800	6,400
Farm yard manure	ton	3	10,000	30,000
Insecticide, possibly herbici herbicide, but there is no insecticide use in sorghum cultivation	liter	2 none	600	1,200
Fertilizer	kg	150	250	37,500
Equipment rental	days	4	5,000	20,000
Total variable cost	CFA/ha			1,62,100
Output per Ha	Kg/ha			2,500
Unit variable cost	CFA/kg			65
Unit variable cost reduction	CFA/kg			60

Area, production and prices of sorghum in Mali

Year	Area (000'ha)	Production (000't)	Price (CFA)
2000/2001	674.768	564.662	59
2001/2002	702	517.748	93
2002/2003	923	641.848	134
2003/2004	822	727.632	94
2004/2005	577	664	63
2005/2006	744	629	121
2006/2007	917	769.681	91
2007/2008	1,090	900.791	83
2008/2009	990.995	1,027	100
2009/2010	1,091	1,465.620	118
2010/2011	1,225.928	1,256.806	111
2011/2012	1,685	1,191	124
2012/2013	1,245.569	1,212	188
2013/2014	1,295	1,260.937	129
2014/2015	1,347	1,311	133

Source: CPS-SDR, OMA

Research and extension cost (in US$) for sorghum improvement in Mali

Year	IER	ICRISAT	Extension	Total
2000/2001	35,000	0	0	35,000
2001/2002	35,000	0	20,000	55,000
2002/2003	40,000	10,5000	20,000	1,65,000
2003/2004	40,000	10,7000	20,000	1,67,000
2004/2005	40,000	10,9000	30,000	1,79,000
2005/2006	50,000	1,11,000	30,000	1,91,000
2006/2007	50,000	1,50,000	30,000	2,30,000
2007/2008	50,000	2,00,000	35,000	2,85,000
2008/2009	50,000	2,26,133	35,000	3,11,133
2009/2010	50,000	2,26,133	40,000	3,16,133
2010/2011	40,000	2,26,133	40,000	3,06,133
2011/2012	30,000	2,26,133	40,000	2,96,133
2012/2013	20,000	2,26,133	40,000	2,86,133
2013/2014	0	1,50,000	30,000	1,80,000
2014/2015	0	1,00,000	25,000	1,25,000
2015/2016	0	0	20,000	20,000
2016/2017	0	0	10,000	10,000
2017/2018	0	0	0	0
2018/2019	0	0	0	0
2019/2020	0	0	0	0

Source: IER, ICRISAT

Annex C. List of sorghum varieties and traits, extracted from the Catalogue Officiel des Especes et Varietes (DNA, 2013).

Common name	Scientific name	Origin	Botanical classification	Release year	V=OPV H=Hybrid, R=Restorer	Rainfall isohyet (mm)	Yield (t/ha)	Cycle length to 50% flowering (days)	Cycle length to maturity (days)
CSM 415		Mali	Guinea	1987		600-800	2	55	115
DABITINNEN	MALISOR 84-7	Mali	Durra	1987		600-800	1.7	80	115
GADIABA		Mali	Race Durra	1987		600-800	2-2.5	80-90	110-120
JAKUMBE (CSM 63E)	CSM 63 E	Mali	Guineense gambicum	1987	V, R	400-700	2	55-60	100
JIGISEME (CSM 338)	CSM 388	Mali	Guineense gambicum	1987	V, R	700-1,000	2.5	85-95	125
MALISOR 84-4		Mali	Durra	1987		600-800	1.2	75	90-110
MALISOR 84-5		Mali	Durra	1987		400-600	2.5	65	100
N'TOKO	CSM 219E	Mali	Guinea gambicum	1987		400-800	2	65	105
SOFILA SIGI	MALISOR 84-I	ICRISAT INDE	Durra	1987		400-800	2	75	110
SUVITA 2/ GOROM-GOROM		Burkina Faso		1987		400-600	0.8-3	47-50	70-75
TIEMARIFING		Mali	Guinea	1987	V	700-1,000	2	85-95	125-130
	15-316	Mali (IRAT)		1987		400-800	3	45-50	60-70
	TVX 32-36	Burkina Faso		1987		400-800	0.9-1	47	70
IPS 0001		Mali (IPR)	Guinea	1991		750+	2		130-140
SANGATIGUI				1992	V	500-600			
ICSV 401		ICRISAT		1994		400-600	2.5	55-60	100-105
TIEMATIETELI	CSM 417	Mali (Sorgho Program)	Guinea	1994		600-1,000	1.5	55	115
SEGUIFA	MALISOR 92-I	Mali	Durra	1995	V	500-600	3	56	100
DJAKELE	MIGSOR 86 30-03	Mali	Guinea gambicum	1998		<700	2.0-2.5		
DJEMAN	MIDSOR 88-10-02	Mali	Guinea margaritiferum	1998		750-900	2.5-3.5		
DJEMANIN	MIDSOR 88-10-04	Mali	Guinea margaritiferum	1998		500-700	2.0-3.0		
DUSU SUMA	89-SK-F 4-53-2 PL	Mali	Caudatum	1998		800	2.0-70		117
FAMBE	MIKSOR 86 30-41	Mali	Guinea--Caudatum	1998		400-1,000	2.5-3		
FOULATIEBA		Mali	Guinea	1998		1,000-1,200	2.5		130
GNOGOME	MIPSOR 90 30-23	Mali	Guinea gambicum	1998		900-1,000	2.5-4		
GNOUMANI	MIDSOR 88-10-06	Mali	Guinea margaritiferum	1998		500-700	2.5-3.0		
KASSAROKA		Burkina Faso	Guinea	1998			2.2		120-130
N'TENIMISSA		Mali	Guinea	1998	V	800-900	2		125-130
SADJE	MIPSOR 90 30-75	Mali	Guinea gambicum	1998		450-600	2.5-3.0		
SARIASO		Burkina Faso	Guinea	1998			2		125-130
SOBLE	MIKSOR 86 25-11	Mali	Guinea gambicum	1998		500-750	2.0-2.5	60-65	

SOFIN	MIKSOR 86-25-13	Mali	Guinea gambicum	1998		500-800	2.5-3.0		
TIEDJAN	MIDSOR 88 10-01	Mali	Guinea margaritiferum	1998		750-950	2.5-3.0		
SOUMALEMBA	IS 15401	Cameroon	Guinea--Gaudatum	1999	V	1,000-1,200	2	110	
SOUMBA				1999	V	600-800			
TIEBLE (CSM 335)	CSM 335	Local ecotype issued from Malian collection	Guinea gambicum	1999	V	800-1,000	2.5	85	
ANSONA	CMI 06	Mali	Guinea gambicum	2001		750-900	2.7-3.8		
KOLOBAKARI	MIPSOR 90-25-88	Mali	Guinea gambicum	2001		900-1,000	2.5-3.5		
KOLODJAN	MIPSOR 90-30-61	Mali	Guinea gambicum	2001		900-1,000	3--4		
KOLOSINA	MIPSOR 90-25-95	Mali	Guinea gambicum	2001		900-1,000	2.5-3.5		
N'GNO-DENI	MIPSOR 90-25-93	Mali	Guinea gambicum	2001		900-1,000	2.5-3.5		
TASSOUMA	MIKSOR 86-30-42	Mali	Guinea gambicum	2001		750-900	2.5-3.0		
DARRELLKEN				2002	V	700-900			
GRINKAN				2002	V, R	700-900			
KENIKEDJE	97-SB-F-5DT-64	Mali (Sorgho Program)	Guinea	2002		600-800	2		110
KOSSA	CSM 485	Local ecotype issued from Malian collection	Guinea gambicum	2002		900-1,000	2.5	95	
MARAKANIO	CGM 19/9-1-1	Descendant of CGM 19/9-1-1 issued by CIRAD/ICRISAT	Guinea gambicum	2002	V	700-900	2.8	80	
N'GOLOFING (CSM 660)	CSM 660	Local ecotype issued from Malian collection	Guinea gambicum	2002	V	700-900	2	80	
NAZONGOLA ANTHOCYANE		Local ecotype, Burkina Faso	Guinea gambicum	2002		600-800	2	70	
NIATCHITIAMA				2002	V	800-1,000			
SAKOYKABA				2002	V	800-1,000			
SEGUETANA-CZ		Mali (Sorgho Program)	Guinea	2002	V	600-800	1.5-2		120
SOUMBA	CIRAD 406	Mali	Caudatum--Guinea	2002		600-900	2.8	70	
TIANDOUGOU				2002	V,R	800-1,000			
YAKARE	ICSV 1079	Cross between Framida x E-35-1 selected by ICRISAT/ INERA	Caudatum	2002		600-800	2	70	
ZARRA	96-CZ-F4p-99	Mali (Sorgho Program)	Guinea	2002	V	1,000-1,200	2.5		125-130
	96-CZ-F4p-98	Mali (Sorgho Program)	Guinea	2002		1,000-1,200	2.5		125-130

	98-SB-F2-78	Mali (Sorgho Program)	Guinea	2002		800-1,000	2.5-3		120
BOBOJE				2005	V	800-1,200			
TOROBA				2005	V	700-1,000			
WASSA	97-SB-F-5DT-63	Mali (Sorgho Program)	Guinea	2007	V	500-600	2		105
FADDA				2008	H	800-1,000			
SEWA				2008	H	800-1,000			
SIGUI-KOUMBE				2008	H	800-1,000			
LATA				2009	V,R	800-1,000			
DOUAJE				2010	V	800-1,200			
GRINKAN YEREWOLO				2010	H	800-1,000			
NIELENI				2011	V	600-800			
NIELENI				2011	H	700-900			
TIANDOUGOU-COURA				2011	V, R	800-1,000			
CAUFA				2012	H	800-1,000			
DIEMA				2012	V,R	800-1,100			
HOUDÔ				2012	H	800-1,000			
NIAKAFA				2012	H	800-1,000			
OMBA				2012	H	800-1,000			
PABLO				2012	H	700-1,000			
YAMASSA				2012	H	800-1,000			
SOUROUMANI	MIPSOR 90-30-34	Mali	Guinea gambicum	no date		650-750	2.0-3.0		

Common name	Plant height (m)	Panicle form	Panicle compactness	Grain color	Grain size	Grain vitreousness	Shelled yield	Tannin presence	Tô color
CSM 415	2	Drooping	Loose	Creamy white	Large	Vitreous	>60%	Absent	Light grey
DABITINNEN	1.3-1.5	Erect	Semi compact	White	Large	Medium	70-80%	Present	Beautiful
GADIABA	2.5	Crossee	Compact	White with white spots	Large 5 mm in length 2 mm in width	0.1	88%	Absent	Acceptable
JAKUMBE (CSM 63E)	3	Drooping	Loose, long hulls	White	Medium, 1.31mm in length	3	83%	Absent	Pale yellow
JIGISEME (CSM 338)	3.7	Cylindrical, drooping when mature	Loose	White	Medium, 1.24mm in length	2.5	88%	Absent	Light grey, pale olive
MALISOR 84-4	1.2-2	Erect	Semi compact	Cream	Large		70%	Present	
MALISOR 84-5	11.5-2	Erect	Semi compact	Cream	Large		70%	Present	
N'TOKO	2.3	Drooping	Loose	White	Medium	Medium	80%	Absent	Light grey, pale olive
SOFILA SIGI	2	Erect	Semi compact	Cream	Large	Medium	81%	Present	Good
SUVITA 2/ GOROM-GOROM				Light brown	Medium				

TIEMARIFING	4.5	Cylindrical, inclined to be drooping and black	Loose	Chalky white, variable depending on pericarp thickness	Medium, 4.6mm in length 3.6mm wide	2 to 3	70-80%	Absent	Good
				Violet	Medium				
				Red/white	Small to medium				
IPS 0001	4--5	Drooping	Loose	White	Medium	2.4		Absent	Beautiful
SANGATIGUI	3								
ICSV 401	2	Spindle	Semi compact	White	Large	Good	70%	Present	Clear
TIEMATIETELI	2.5	Drooping	Loose		Thick	Vitreous	>70%	Absent	Light grey
SEGUIFA	2	Spindle	Semi-compact	White	Large	Vitreous	81%	Present	Pale light grey
DJAKELE	1.6		Loose	Translucent		Medium			Red
DJEMAN	3.5-4.0	Drooping when mature	Semi loose	White		2			Whitish
DJEMANIN	3.5	Drooping when mature	Semi loose	White		2			White
DUSU SUMA	1.83		Semi compact	White		Medium	83%		White
FAMBE	3.5-4	Loose		Translucent		2			Reddish
FOULATIEBA	4.2	Loose				Vitreous			
GNOGOME	4.5-5.0	Drooping when mature	Loose	White		2			Yellowish white
GNOUMANI	3.5	Drooping when mature	Semi loose	Translucent		2			Dirty white
KASSAROKA	4.1								
N'TENIMISSA	3.5	Loose		White		Semi vitreous	83%		Good
SADJE	3.5-4.0	Drooping when mature	Loose	White		2			Brownish
SARIASO	3.4			White		Semi vitreous	83%		
SOBLE	2.5	Drooping when mature	semi loose	Translucent		2			Reddish
SOFIN	2.5-2.5	Loose		White		2			Reddish
TIEDJAN	4-4.5	Drooping when mature	Loose	Translucent		2			Yellowish white
SOUMALEMBA	4.5		Semi-compact	White		2			
SOUMBA	2.4								
TIEBLE (CSM 335)	3.6	Loose		Translucent		1			
ANSONA	3.5-4	Loose		White		2			White
KOLOBAKARI	4.5-5.0	Loose		Translucent		2			Brownish
KOLODJAN	4.5-5.0	Drooping when mature	loose	Translucent		2			Brownish
KOLOSINA	5.0-5.5	Loose		White		2			Whitish
N'GNO-DENI	5.5-6.0	Loose		White		2			Reddish
TASSOUMA	3.5-4.0	Loose		Translucent		2			Reddish
DARRELLKEN	3.5								
GRINKAN	2								

KENIKEDJE	3.5	Loose		White		Semi vitreous	75%		Good
KOSSA	1	Loose		Translucent		1			
MARAKANIO	2.5	Loose		White		1			
N'GOLOFING (CSM 660)	4	Drooping when mature	Loose	Translucent					
NAZONGOLA ANTHOCYANE	1	Loose		Translucent white		2			
NIATCHITIAMA	2								
SAKOYKABA	4								
SEGUETANA-CZ	3.5	Loose		White		Semi vitreous	70-80%		Good
SOUMBA	2.5	Semi compact at base and loose at top		Yellowish		3			
TIANDOUGOU	1.8								
YAKARE	1--2	Compact		White		3			
ZARRA	4	Loose		White		Semi vitreous	80%		Good
	4	Loose		White		Vitreous	85%		Good
	1.75	Semi loose		White		Passable	56%		Good
BOBOJE	3.8								
TOROBA	4								
WASSA	3.5	Loose		White		Vitreous	81%		Good
FADDA	3								
SEWA	2.5								
SIGUI-KOUMBE	2.5								
LATA	3								
DOUAJE	3.5								
GRINKAN YEREWOLO	2								
NIELENI	3								
NIELENI	3								
TIANDOUGOU-COURA	1.8								
CAUFA	4								
DIEMA	4								
HOUDÔ	2								
NIAKAFA	4								
OMBA	4								
PABLO	4								
YAMASSA	5								
SOUROUMANI	2.0-2.5	Loose		White		2			White
Common name	Photosensitivity	Vigor	Insect and disease resistance	Yield stability	Striga sensitivity				
CSM 415	Low	Good	Resistant to anthrax rot, tolerant to grain mold	Good					

DABITINNEN	Non sensitive	Good	Resistant to anthrax rot, tolerant to grain mold	Good	Tolerant				
GADIABA	High		Rot tolerant, mold sensitive		Tolerant				
JAKUMBE (CSM 63E)	Low	Good	Rot tolerant, mold tolerant, tolerant of leaf disease	Good	Sensitive				
JIGISEME (CSM 338)	Sensitive		Resistant to anthrax rot, tolerant to grain mold, tolerant of leaf diseases	Good	Tolerant				
MALISOR 84-4	Non sensitive	Good	Resistant to anthrax rot, resistant to mold	Good					
MALISOR 84-5	Non sensitive	Good	Resistant to anthrax rot, tolerant to grain mold	Good					
N'TOKO	Low	Good	Resistant to anthrax rot, tolerant to grain mold, tolerant of leaf diseases	Good	Sensitive				
SOFILA SIGI	Non sensitive	Good	Resistant to anthrax rot, tolerant to grain mold		Tolerant				
SUVITA 2/ GOROM-GOROM	Low		Sensitive to yellow mosaic and golden mosaic, drought tolerant, tolerant of bacterial chancre, rot tolerant, sensitive to weevils		Resistant				
TIEMARIFING	Sensitive	Good	Rot tolerant, mold resistant		Sensitive				
	Non sensitive		Disease tolerant, parasite tolerant						
	Non sensitive		Virus sensitive, thrips sensitive		Sensitive				
IPS 0001	Sensitive	Very good	Resistant to anthrax rot, sensitive to grain mold						
SANGATIGUI									
ICSV 401	Non sensitive	Good	Resistant to anthrax rot, tolerant to grain mold in it's zone	Good					
TIEMATIETELI	Sensitive	Good	Resistant to anthrax rot, tolerant to grain mold	Good	Tolerant				
SEGUIFA	Low	Good	Rot resistant, mold tolerant		Tolerant				

DJAKELE	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease						
DJEMAN	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to grain mold						
DJEMANIN	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistante to grain mold						
DUSU SUMA	Non sensitive	Good	Rot tolerant						
FAMBE	Sensitive				Good adaptation				
FOULATIEBA	Sensitive		Disease tolerant, insect tolerant						
GNOGOME	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to grain mold						
GNOUMANI	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, tolerant to grain mold						
KASSAROKA			Disease tolerant, insect tolerant						
N'TENIMISSA	Low		Insect tolerant, disease tolerant		Tolerant				
SADJE	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to grain mold						
SARIASO			Insect tolerant						
SOBLE	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to grain mold						
SOFIN	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, tolerant to grain mold						
TIEDJAN	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to grain mold						

SOUMALEMBA	Very sensitive		Very resistant to midges		Good				
SOUMBA									
TIEBLE (CSM 335)			Tolerant to water stagnation						
ANSONA	Sensitive		Resistant to helminthosporiose and Ramulespora leaf diseases, resistant to grain mold						
KOLOBAKARI	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease						
KOLODJAN	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to mold						
KOLOSINA	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to mold						
N'GNO-DENI	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, tolerant to grain mold						
TASSOUMA	Sensitive		Tolerant to helminthosporiose and Ramulespora leaf disease, resistant to mold						
DARRELLKEN									
GRINKAN									
KENIKEDJE	Low		Insect tolerant, disease tolerant		Tolerant				
KOSSA	Sensitive		Drought tolerant, resistant to midges						
MARAKANIO			Sensitive to leaf anthracnose, resistant to leaf disease		Sensitive				
N'GOLOFING (CSM 660)			Drought resistant		Sensitive				
NAZONGOLA ANTHOCYANE	Sensitive		Tolerant to weeds						
NIATCHITIAMA									
SAKOYKABA									
SEGUETANA-CZ	Low		Insect tolerant, disease tolerant		Tolerant				
SOUMBA	Low		Resistant to leaf diseases						

TIANDOUGOU									
YAKARE	Non sensitive		Resistant to leaf diseases						
ZARRA	Low		Insect tolerant, disease tolerant		Tolerant				
	Sensitive		Insect tolerant, disease tolerant		Tolerant				
	Low		Tolerant to disease, tolerant to insect		Tolerant				
BOBOJE									
TOROBA									
WASSA	Low		Insect tolerant, disease tolerant		Tolerant				
FADDA									
SEWA									
SIGUI-KOUMBE									
LATA									
DOUAJE									
GRINKAN YEREWOLO									
NIELENI									
NIELENI									
TIANDOUGOU-COURA									
CAUFA									
DIEMA									
HOUDÔ									
NIAKAFA									
OMBA									
PABLO									
YAMASSA									
SOUROUMANI	Sensitive		Sensitive to rot						

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