Feasibility Study on Striga Control in Sorghum

AFRICAN AGRICULTURAL TECHNOLOGY FOUNDATION
FONDATION AFRICAINE POUR LES TECHNOLOGIES AGRICOLES

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This report was written by JM Mbwika, H Odame and EK Ngugi, Finance and Business Economic Consultants, Nairobi, Kenya and George Marechera of AATF

Contents

List of Tables

List of Figures

Abbreviations and acronyms

AATF	African Agricultural Technology Foundation
ABU	Ahmed Bello University
ADP	Agricultural Development Programme
AGRA	Alliance for Green Revolution in Africa
ALS	Acetolactate Synthase
CIMMYT	International Maize and Wheat Improvement Centre
CNEV	Comité National des Espèces et Variétés/ National Species and Varieties Committee
CRS	Catholic Relief Services
CVRC	Crop Variety Registration and Release Committee
EIAR	Ethiopian Institute of Agricultural Research
ESE	Ethiopian Seed Enterprise
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of United Nations Statistics
FBSPMS	Farmer Based Seed Production and Marketing Scheme
FFS	Farmer Field School
FIBEC	Finance and Business Economic Consultants
GMOs	Genetically Modified Organisms
HR	Herbicide Resistant
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IAR	Institute of Agricultural Research
IARCs	International Agricultural Research Centres
IER	Institut D'economie Rurale
INTSORMIL	International Sorghum and Millet Collaborative Research Support Program
IPM	Integrated Pest Management
IR Maize	Imidazolinone Resistant Maize
MAS	Marker Assisted Selection
MoARD	Ministry of Agriculture and Rural Development
MET	Metsulfuron methyl
NADS	National Agro-Dealer Support
NARIs	National Agricultural Research Institutes
NARS	National Agriculture Research Systems
ORIAM	Réseau des Opérateurs d'Intrants Agricoles du Mali/ Malian Network of Agri-Input Dealers
PASS	Programme on African Seed Systems
PPPs	Public and Private Partnerships
PROMISO	Project Millet and Sorghum
QTL	Quantitative Trait Loci

RBA	Regional Bureaus of Agriculture – Ethiopia
SSA	Sub-Saharan Africa
SSN/NSS	Service Semencier National/ National Seed Services
SSR	Simple Sequence Repeat
WASA	West Africa Seed Alliance
USAID	United States Agency for International Development
USDA	United States Department of Agriculture

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J Mbwika, H Odame and K Ngugi

Executive summary

Sorghum remains an important food security crop in Sub-Saharan Africa (SSA) and especially in the marginal areas where other crops do not do well. Sorghum production in SSA is estimated at 26 million MT with Nigeria being the leading sorghum producer in Africa and the second in the world after USA. Mali ranks second in Africa and sixth in the world with Ethiopia rankingthird in Africa and eighth in the world. Sorghum is primarily a smallholder crop grown primarily for household food security. Commercialisation of the crop is rather limited and its value chain is under developed. However, the crop is gaining commercial significance especially in the malting and brewing industry, with Nigeria malting and brewing industries consuming about 152,000 MT per annum. Similar efforts are being replicated in Ghana, Uganda and Kenya where the brewing industries are contracting sorghum farmers to grow sorghum on agreed prices.

Striga remains a major constraint not only to sorghum production but also to other cereals and other crops (including sugarcane). In Ethiopia, for instance, *Striga* affects all cereal crops and unlike other countries like Kenya it is also found in the highlands where the soils are fertile. Annual sorghum losses attributed to *Striga* in SSA are estimated at 22–27% and specifically at 25% in Ethiopia, 35% in Nigeria and 40% in Mali. In terms of monetary value, the annual cereal losses due to *Striga* are estimated at US$ 7 billion in SSA. In Ethiopia, Mali and Nigeria, the annual losses are estimated at, US$ 75 million, US$ 87 million and US$ 1.2 billion, respectively.

Various methods have been recommended for the control of *Striga* in sorghum including: cultural practices such as hand weeding and planting of trap crops, planting of *Striga* tolerant or resistant varieties and chemical or herbicide treatments. Despite these efforts, there has been limited success in elimination of *Striga* in sorghum. Some countries in Africa, have identified or even developed *Striga* resistant or tolerant varieties. However, in most cases these varieties do not meet certain criteria for wide adoption by sorghum farmers. This feasibility study was therefore commissioned to generate information on the viability of developing, testing and deploying herbicide resistant (HR) sorghumvarieties for *Striga* control in selected countries in SSA. The HR sorghum, if successfully deployed will contribute in reducing the current losses in sorghum attributed to *Striga* in SSA. Field evaluation of HR sorghum, currently underway in West Africa has shown promising results. Acetolactate Synthase (ALS) resistant sorghum has the potential to control the spread of *Striga* and also produces high grain yields. Experience with IR maize by CIMMYT, in the past has demonstrated that seed dressing with the herbicide is economically feasible and smallscale farmers will adopt it when convinced of the benefits.

This study demonstrates that there are potential benefits in terms of yield gains and farmer incomes from use of HR sorghum varieties. The anticipated yield increases are between a minimum of 17.5% in Ethiopia and a maximum of 36% in Mali, depending on the level of protection achieved. The income gains range from US$ 10.96 million to US$ 83.3 million per annum in the three study countries under different scenarios. Adopting the HR technology will also contribute to improved food security. The economic viability of the technology is dependent on yield gains. Successful deployment of the HR sorghum has potential to contribute to improved seed systems. The expected capacity building accompanying the deployment of the HR sorghum will also contribute to farmers' agronomic and post-harvest handling of sorghum. The technical viability of the HR sorghum hinges on the level of protection it will confer to sorghum against *Striga*, level of increased yields realised, strengthening of seed delivery systems, and capacity building of seed companies, agro-dealers and producers in handling the HR sorghum. Farmer perceptions are also critical in terms of the technical viability of the technology. This means that the HR sorghum should not only lead to increased yields, but also have other attributes critical to sorghum farmers such as biomass and food quality attributes of the sorghum. This is of importance considering sorghum is grown mainly for food security reasons by poor farmer households in some of the most fragile environments. The technology therefore has the potential to significantly contribute to producer and consumer welfare through increased incomes to producers and reduced cost of food to consumers. The technology also has the potential to contribute to the commercialisation of smallholder agriculture and improved trade relations.

The HR sorghum seed will come with challenges as most farmers traditionally use retained grain as 'seed' and the formal seed systems in SSA are not well developed for the supply of improved seed to farmers. The delivery of the HR sorghum will require strong and efficient seed systems. In Ethiopia, the seed delivery system is still under state control, which is largely inefficient. The capacities of most seed companies are limited in terms of scale, capitalisation, technical expertise and organisation. Linkages between the seed companies and farmers are also weak. The problem is also compounded by the fact that sorghum is open pollinated, which makes private investment in sorghum seed unattractive. The Alliance for Green Revolution in Africa (AGRA) through its Programme on African Seed Systems (PASS) is working with seed dealers in Mali and Nigeria to build their capacities for efficient seed delivery to farmers. Some of the dealers are already delivering quality sorghum seed to farmers. However, the quantities still remain small and none of the companies has invested in seed dressing technology.

In SSA, there is need to develop the capacity of the National Agriculture Research Systems (NARS) in terms of infrastructure and human resources, to ensure that that the HR sorghum is successfully deployed. The sorghum value chains across SSA are still very weak considering that the crop is mostly used for domestic consumption. In Nigeria, there has been an increase in commercial use of sorghum in the brewing industry. The study found out that the value chains for sorghum should be developed to link producers with agro-processing facilities so that they can diversify it into processed products. This will lead to improvement of the marketing aspects of sorghum resulting in an increased adoption rate for the HR sorghum.

Concerns for safe delivery of the herbicide treated seed on humans and the environment were raised by a number of key informants in the research, seed and processing sector where this study was done. They were concerned about possible effects of the herbicide to other crops, considering that sorghum is often intercropped, and the farmers also handle other crops during planting. Respondents were also concerned about possible chemical residues of the herbicide in the harvested grain of the herbicide-treated seed varieties. It can be recommended that the development and testing work on HR sorghum should proceed, but include testing on farmer preferred varieties and those with potential for industrial application especially in the malting and brewing industry. AATF should develop a strong stewardship and communication strategy to support the testing and deployment of the HR sorghum among producers, seed companies and consumers.

Strong partnerships with NARS, National Seed Systems and authorities responsible for registration of agro-chemicals must be built to support the deployment of the HR sorghum.

Background

Striga weed thrives well in poor soils and depletion of soil fertility is one of the major causes of the spread of the weed (*Ransom, 1996 cited in Esilaba AO, KARI, 2006*). It is a ferocious weed that affects most cereals and even sugarcane in Africa. Although it thrives well in lowlands and in areas with poor soils; in Ethiopia it has been observed in the highland areas.

The weed is responsible for about 26% loss of sorghum and millet in Africa thus compounding the food insecurity problem faced in particular African countries (*Gressel et al, 2004*). Research work on the control of *Striga* in sorghum and maize has been undertaken for several years. The methods used for control of *Striga* in sorghum range from cultural ones such as soil and water management (*Esilabi and Ransom, 1997; Esilabi et al, 1997a, cited in Esilabi KARI 2006*), intercropping, use of cover crops, use of trap crops (*Ekere et al, September 2002*), and recently use of herbicide treatments. Post-emergence chemical control methods have also been used. Research on *Striga* resistant or tolerant varieties has also been conducted with some degree of success as reported in countries such as Kenya and Ethiopia. The need for further work to develop technologies to address the elusive weed has therefore been a subject of research by a number of institutions. DuPont, Purdue and Kansas State Universities have developed the herbicide technology that has gone beyond the proof of concept and are testing it using a hybrid herbicide resistant sorghum variety. This technology is being evaluated in a number of countries in West Africa. The initial evaluation of the technology is showing promising results in terms of *Striga* control and yield improvement.

Although significant progress has been made in controlling *Striga*, the weed continues to devastate sorghum farming communities across SSA. It is estimated that the continent loses about US$ 7 billion worth of sorghum per annum (*Ejeta, 2007*; *de Groote, 2007*) with Ethiopia, Mali and Nigeria accounting for a combined loss of US$ 2.83 billion per annum.

The purpose of the study

The purpose of this feasibility study on *Striga* control in sorghum using herbicide resistant sorghum varieties was to generate information on the viability of developing, testing and deploying herbicide resistant sorghum varieties for *Striga* control. Sorghum is a major food crop in dry areas of SSA. This feasibility study sought to do the following.

1. Identify countries in SSA where sorghum is a major staple crop.
2. Assess data and information on sorghum production, marketing, distribution and consumption in the identified countries.
3. Assess and recommend on the value chain analysis for sorghum production.
4. Evaluate the technical and economic feasibility on development, testing and deployment of sorghum varieties which are resistant to *Striga* in SSA, taking into account infrastructure, human resource, product capability and policy requirements.
5. Conduct cost–benefit and break-even analyses to enable documentation of economic benefits and market demand associated with deployment of the sorghum varieties resistant to *Striga* in SSA.

6. Evaluate the expected impact of the project in the target countries in terms of sorghum yields, income, welfare, trade and smallholder agriculture.
7. Determine prospects for raising necessary financial resources critical for the deployment of sorghum varieties which are resistant to *Striga* in sorghum producing regions of SSA.
8. Conduct an analysis of the seed delivery systems in the countries and recommend an effective seed system for the project.
9. Assess socio-cultural factors likely to influence development and uptake of sorghum varieties which are resistant to *Striga*, including consumer preferences and acceptability.
10. Critically evaluate and demonstrate whether the proposed project on development, testing and deployment of sorghum varieties, which are resistant to *Striga*, is capable of being implemented and deployed safely with none or minimum adverse effects to human health, agriculture and the environment.

Methodology

The study involved literature review, key informant interviews and field visits. Several documents were reviewed from websites as well as National Agriculture Research Systems (NARS) and ICRISAT. The case studies focused on Ethiopia, Mali and Nigeria. Key informant interviews were conducted with AATF technical staff, ICRISAT scientists in Nairobi and in Bamako, CIMMYT scientists in Nairobi and Addis Ababa, and IFPRI scientists in Addis Ababa. Interviews with NARS scientists were conducted at the Ethiopian Institute of Agricultural Research (EIAR) headquarters and at Melkessa Research Institute in Ethiopia; Institut D'economie Rurale (EIR) in Mali; and at Ahmed Bello University and Agricultural Research Institute (AIR) in Nigeria. Interviews were also conducted with Ministries of Agriculture; and policy, extension and marketing staff in Ethiopia, Mali and Nigeria. In Nigeria the interviews also involved staff of the Agricultural Development Programme (ADP) of Kaduna State. A total of five seed companies were interviewed (a state controlled seed company in Ethiopia, two private seed companies and a seed cooperative in Mali, and a private seed company in Nigeria). In addition, there was an interview with one of the leading sorghum malting company in Nigeria which provided invaluable information on sorghum malting and processing business in Nigeria, and challenges of the sorghum value chain. The information collected was analysed and formed the basis of this report.

To calculate the cost–benefit analysis, various assumptions were made regarding the expected yield gains from the use of the HR sorghum because the technology is still under development. Additional benefits are associated with labour savings from weeding and use of other conventional methods of *Striga* weed control. The costs assumed are those related to development, seed dressing and deployment of the technology. Since the cost of dressing the seed is not yet determined, the current cost of dressing IR maize which is US$ 0.25 per kilogramme was used. Cost – benefit analysis is used to determine the economic viability of the technology, while assessment of sorghum research programmes and capacities; seed delivery systems, capacities and policies; and farmer perceptions are used to assess the viability of the technology.

Sorghum production in Sub-Saharan Africa

Sorghum (*Sorghum bicolor (L.) Moench)* is a viable food grain for many of the world's most food insecure people who live in marginal areas with poor and erratic rains and often poor soils. Worldwide, it is the fifth major cereal crop in terms of production, after maize (*Zea mays L. ssp. mays*), wheat (*Triticum aestivum L.*), rice (*Oryza sativa L.*), and barley (*Hordeum vulgare L.*) (FAO 1998). Sorghum is a staple food crop for millions of people in Africa, South Asia and Central America. In terms of tonnage, sorghum is Africa's second most important cereal. In Africa, production has increased steadily over the past 40 years from nearly 10 million metric tonnes to 26 million metric tonnes on approximately 25 million hectares (FAO 1998). Sorghum production is however, negatively influenced by abiotic (heat, drought and low fertility) and biotic stresses (diseases, insects and weeds). Much of the African continent is characterised by semi-arid and sub-tropical climatic conditions and not suited to other important food security cereals such as maize, wheat and rice which require higher and reliable levels of rainfall. Sorghum originated from Africa and it is uniquely adapted to Africa's climate, being both drought resistant and able to withstand periods of water-logging.

In West Africa, sorghum is one of the most important food crops in the drier regions, accounting for 37% of the total food grain grown in the region, with smallholder farmers responsible for all the production (In Mali, sorghum is the third most important cereal crop after rice and millet. In Nigeria, sorghum is one of the most important cereal crops for food security and for use in the malting and brewery industry. This is more so after Nigeria banned the importation of barley in 1986. In Ethiopia, sorghum is the fourth most important food crop after maize, wheat and teff and it is the most important in the drier parts of the country. The crop is produced by smallholders as a subsistence crop.

Sorghum production trends in Sub-Saharan Africa

In Africa, Nigeria is the leading producer of sorghum with Sudan, Ethiopia, Burkina Faso and Niger occupying number 2, 3, 4 and 5 positions, respectively (Table 1).

Table 1: Country sorghum production as a percentage of total Africa sorghum production

Country	2000	2001	2002	2003	2004	2005	2006	2007	Rank
Nigeria	41.89	33.91	37.95	34.62	40.78	36.5	36.95	34.75	1
Sudan	13.52	21.05	14.23	22.4	12.85	19.89	21.7	22.41	2
Ethiopia	6.45	7.42	7.79	7.71	8.17	8.75	8.66	8.34	3
B. Faso	5.52	6.57	6.92	6.95	6.65	6.18	5.68	6.21	4
Niger	2.01	3.14	3.2	3.27	2.85	3.75	3.48	3.74	5
Mali	3.07	2.48	3.23	3.15	3.16	2.5	2.88	3.46	6
Tanzania	3.25	3.31	3.2	0.86	3.08	2.9	2.67	3.45	7
Egypt	5.11	4.13	4.54	4.14	4.11	3.39	3.32	3.24	8
Chad	2.13	2.38	2.42	2.44	2.14	2.32	2.6	2.21	9
Cameroon	2.28	2.42	2.73	2.48	2.89	2.08	1.69	1.92	10
Uganda	1.96	2.03	2.15	1.82	1.9	1.79	1.65	1.75	11
Ghana	1.52	1.34	1.59	1.46	1.36	1.21	1.18	1.34	12

Country	2000	2001	2002	2003	2004	2005	2006	2007	Rank
South Africa	2.57	0.99	1.3	1.12	1.77	1.03	0.36	0.68	13
Mozambique	1.05	1.5	1.58	1.36	1.6	1.22	0.77	0.65	14
Eritrea	0.34	0.38	0.14	0.28	0.21	0.45	0.56	0.5	15
Others	7.32	6.96	7.02	5.95	6.48	6.03	5.86	5.36	
	100	100	100	100	100	100	100	100	

Source: FAOSTAT (calculated from FAOSTAT Africa sorghum production data)
Note: The leading five major producers are highlighted.

Sorghum production in Ethiopia and Nigeria grew by more than 5% between 1961 and 1979 before falling to about 2% between 1980 and 1986. Since 1986, sorghum production in both Ethiopia and Nigeria has recorded a tremendous growth rate of more than 6%, with Ethiopia recording a growth rate of over 12% between 2000 and 2007. In Mali, however, the sorghum production growth rate was in the negative between 1961 and 1986, before recording a positive growth rate of about 1% between 1987 and 1999. Sorghum production in Mali in the last decade grew by 2% (Figure 1).

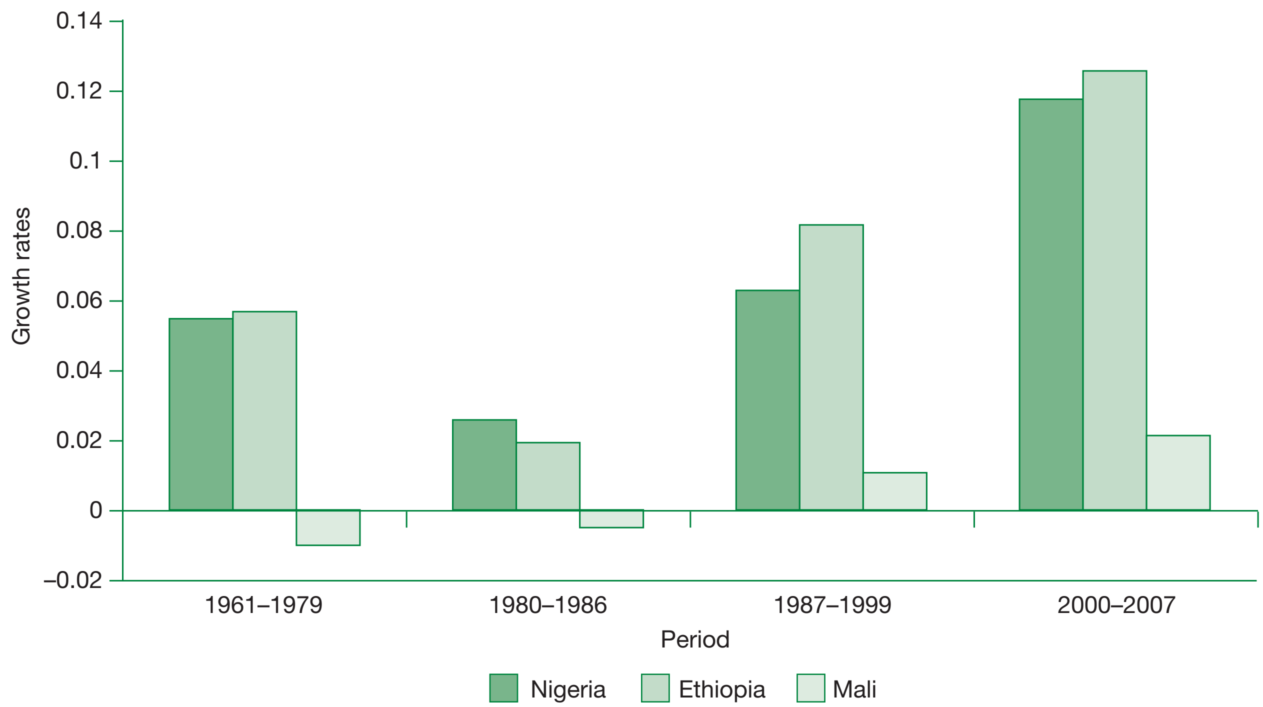


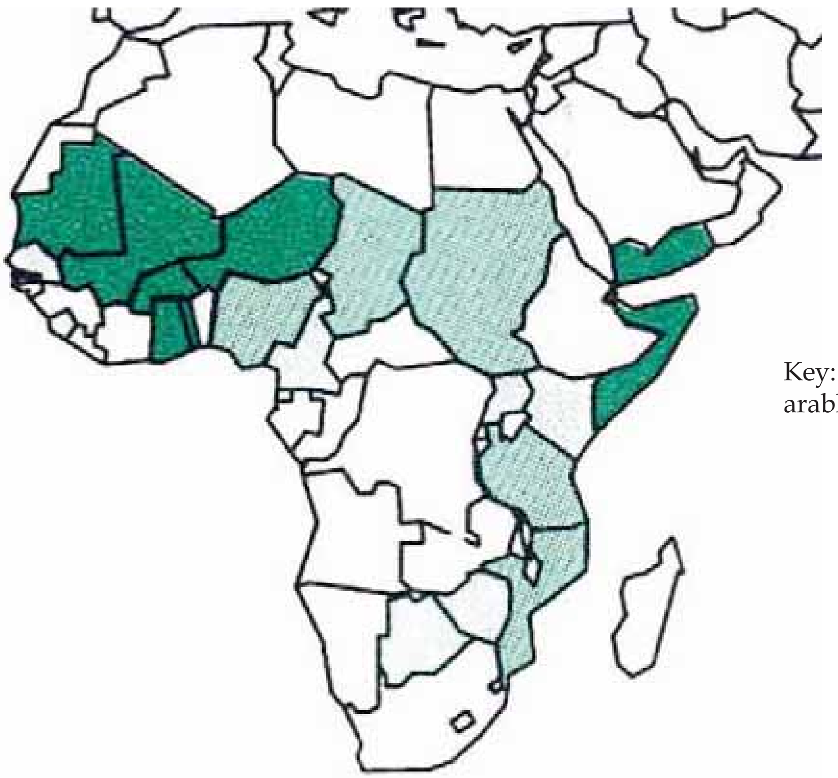
***Figure 1**. Sorghum production growth rates (1961–2008)*

The high positive growth of sorghum production in Nigeria after 1986 could be attributed to increased industrial demand from the malting and brewing companies following a Government policy to ban importation of barley in the country.

In Mali, sorghum production increased from 711,645MT in 1995 to 907,966MT in 2007. Sorghum production in Mali occupies more than 25% of the arable land as shown in Figure 2. The main sorghum producing regions in the country based on the 2007 production data were: Sikasso (45.31%), Kayes (18.53%), Koulikoro (16.66%) and S□gou (15.11%). Sikasso's share of national production has increased from 29.49% in 1995 to 45.31% recorded in 2007. The other regions have recorded a decline in their share of production of sorghumSorghum production in Mali is based on the three agro-climatic zones: Guinea, Sudan and Sahel. There are different varieties that are produced in each of the three agro-climatic zones.

Between 2006 and 2008, Ethiopia produced an average of 2.5 million MT of sorghum per annum up from 700,000MT produced in the early 1990s, representing 357% growth in production. This growth has been more from the area under cultivation than increase in yields. The yields increased from an average of 1.12MT/ha in the early 1990s to an average of 1.5MT/ha for the period 2003/04–2007/08. an increase of 33.9%. At the same time the area under sorghum cultivation in Ethiopia increased from an average of 858,000ha in the early 1990s (1992/93–1995/96) to 1,168,640ha cultivated between 2003/04 and 2007/08 an increase of 36.2%. The main sorghum producing regions in order of importance in Ethiopia are Oromia, Amhara, Tigray, SNNPR and Benishangul-Gumuz.

Sorghum production in Nigeria increased from 7.7 million MT in 2000 to 9.1 million MT recorded in 2007 (FAOSTAT, 2009). The five leading sorghum producing states inNigeria based on the 1999–2006 production average are Borno, Kaduna, Niger, Zamfara and Kano in that order (*Federal Ministry of Agriculture and Rural Development, Projects Coordination Unit, 2004*). Sorghum in Nigeria occupies between 10% and 25% of the national arable land as shown in Figure 2.



Key: sorghum area as % of national arable land
>25%
10–25%
5–10%
<5%

Figure 2: Area under sorghum as a percentage of national arable land in Africa.
Source: Taylor 2009, JRN

Sorghum yields in SSA remain low compared to potential yields because of a number of factors such as poor agronomic practices, lack of commercialisation of the crop which has resulted in low usage of productivity enhancing technologies, and the *Striga* problem which affects almost all parts of the sorghum growing areas of SSA.

In Egypt and South Africa where sorghum production is highly commercialised, the yields are very high compared to the average SSA yields. In Egypt, for example, the yields are 430% higher than the Africa average while in South Africa they are 214.7% higher than the African average as illustrated by Table 2.

Table 2: Sorghum yields in leading Africa sorghum producing countries

Yield (MT/ha)	2000	2001	2002	2003	2004	2005	2006	2007	Average 2000-2007
Burkina Faso	0.83	0.93	0.93	0.96	0.97	1.09	1.14	1.01	0.98
Cameroon	1.20	1.20	1.41	1.34	1.27	0.99	0.85	0.91	1.15
Chad	0.60	0.63	0.69	0.71	0.69	0.74	0.75	0.64	0.68
Egypt	5.79	5.80	5.78	5.74	5.67	5.61	5.69	5.68	5.72
Eritrea	0.42	0.47	0.16	0.32	0.21	0.51	0.57	0.57	0.41
Ethiopia	1.17	1.14	1.37	1.34	1.31	1.46	1.58	1.48	1.36
Ghana	0.97	0.85	0.94	0.98	0.96	1.00	0.98	1.03	0.96
Mali	0.84	0.74	0.70	0.89	0.66	0.85	0.84	0.83	0.79
Mozambique	0.58	0.75	0.63	0.61	0.64	0.63	0.50	0.57	0.61
Niger	0.17	0.25	0.28	0.33	0.27	0.38	0.35	0.34	0.30
Nigeria	1.12	1.10	1.10	1.16	1.22	1.26	1.35	1.16	1.18
South Africa	3.32	2.34	3.43	2.72	2.87	3.01	2.58	2.55	2.85
Sudan	0.59	0.77	0.56	0.73	0.71	0.55	0.59	0.65	0.64
Tanzania	0.81	1.00	0.97	0.44	0.93	0.99	0.80	1.00	0.87
Uganda	1.29	1.50	1.50	1.45	1.40	1.53	1.43	1.45	1.44
Average	1.31	1.30	1.36	1.31	1.32	1.37	1.33	1.32	1.33

Source: FAOSTAT, © FAO Statistics Division 2009, 16 December 2009 calculated statistics

The yield levels recorded in Mali are between 750 and 900kg/ha compared to the potential of 2500MT/ha. The main factors responsible for below optimal yields include: *Striga* infestation, poor soil fertility, use of poor seed and varieties, and poor crop husbandry practices.

An assessment of the sorghum value chains

The sorghum value chains in the three countries are not well developed because of poor development of sorghum marketing and limited commercial use of the crop. The players along the value chains include: research institutes which produce basic seed; national seed systems that are responsible for foundation seed; poorly capitalised and low capacity seed producers; smallholders responsible for sorghum production; local traders and brokers that bulk and trade in sorghum; wholesalers and retailers of sorghum grain; processors; and consumers (Figures 3 and 4). The brewing industry is the largest single consumer of sorghum in Nigeria as illustrated in Figure 4. The weakest link along the chain is between producers and markets.

In Ethiopia and Mali where sorghum is informally traded, the analysis of the sorghum chain will focus on evaluating the role of bulking agencies and small traders (wholesale and retail) in main urban centres. It will also focus on understanding the quantities utilised in various food production enterprises, where most of the traded sorghum is utilised. In Ethiopia, there is also the traditional brewing industry which utilises sorghum as a raw material but the quantities used are not documented. This chain will also be explored. The potential for use of sorghum in the brewing industry in Ethiopia as in other emerging countries will also be explored. In Mali, the value chain analysis will primarily focus on the food chain, building on the work funded by USAID and implemented by IER in collaboration with INTSORMIL and University of Purdue.

In Nigeria, the sorghum supply chain to malting and brewing industry cannot be overlooked in any development work involving commercialisation of sorghum in the country. This chain needs to be studied to understand how it can be linked to the HR sorghum project. This study shows that the brewing and malting value chains hold great potential but are not without challenges, especially in terms of quality and consistency of sorghum.

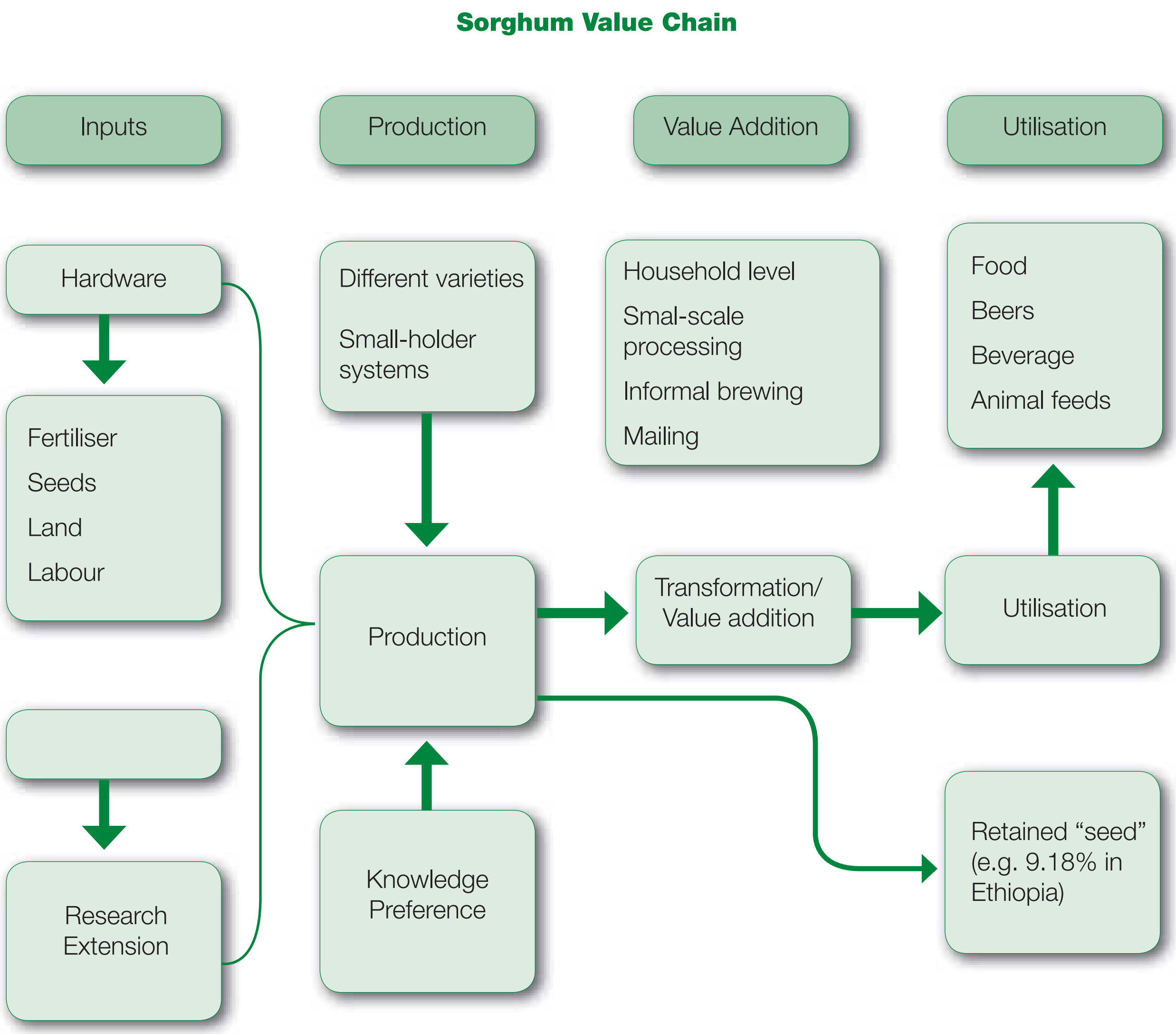


Figure 3. Sorghum supply chain in Ethiopia and Mali

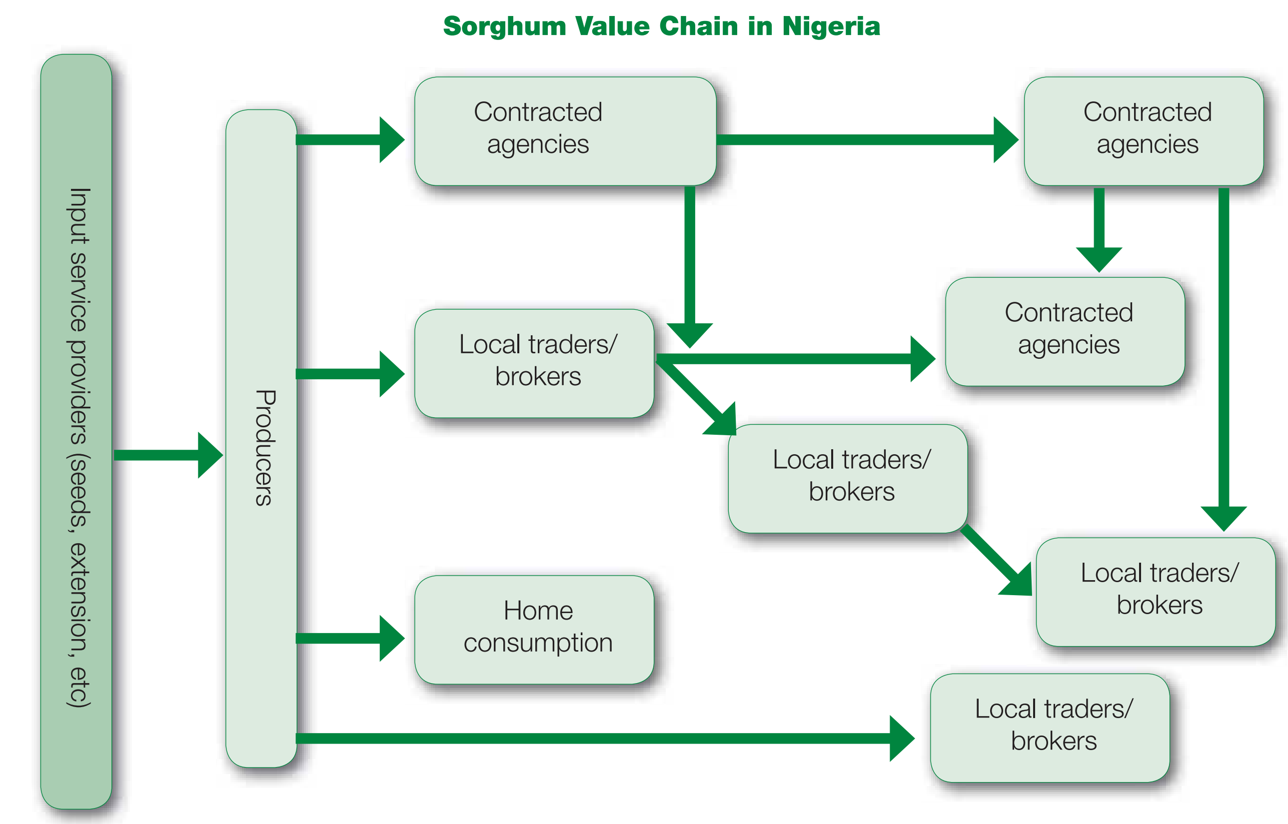


Figure 4: Sorghum Supply chain in Nigeria

Input supplies and production systems

Use of commercial inputs in sorghum production as in many subsistence agriculture production systems is limited. The main inputs used in the production process include seed, labour, land and to some limited extent fertiliser. The seed are mainly sourced from retained grain, and only in limited cases, are improved seed used. Family labour is the main source of labour used in sorghum production and harvesting. The production is carried out under smallholder systems in which family or communal land is used.

Marketing

The marketing system for sorghum in SSA is poorly developed, and has limited industrial use. In some countries such as Nigeria, the malting and brewing industry has provided market leadership in the commodity. In Ethiopia, only 11.47% of the crop is sold with 74.23% being consumed at the household level, 9.18% is retained as seed and the rest is used in other ways such as payment of wages in kind (1.17%), and animal feed (0.94%) (*Ethiopia, Central Agricultural Census Commission, 2003*).[1] In Mali, a survey by ICRISAT and IER with support from AOPP, indicated low levels of sorghum marketing, with the sample households reporting marketed share of only 25%. Even in Nigeria, where the crop is more commercialised because of industrial use, only a small fraction of the estimated 8 million tonnes a year production is marketed.

1 Ethiopian Agricultural Sample Enumeration, 2001/02.

The sorghum marketing problem in Mali is however being addressed in a project[2] implemented by INTSORMIL in collaboration with the University of Nebraska. The project promotes advances in agriculture by moving sorghum and millet production technologies onto farmer fields, linking farmer organisations to food and feed processors and by commercialising processing technologies so as to enhance markets. The project also promotes improved nutrition and thus contributes to the betterment of human health (*Project Quarterly Report, January – March 2009*).

In Ethiopia, sorghum marketing involves rural assemblers or brokers who either transport to main urban centres or sell to traders cum transporters in the rural market centres. Once the grains reach the wholesale markets which also double as retail outlets, they are sold to retailers through a brokerage system. The sorghum grains are segregated by colour and size, with very little mixture of the grains. They are sold to consumers using weighing scale at prices based on colour and size of the grains. The traders and brokers are usually small business people with low capital and often deal in multiple cereals. The traders usually have an advantage over the producers because they have better information on market conditions.

In Nigeria, sorghum production and marketing is better organised as a result of the 1986 Government ban on importation of barley for malting purposes forcing local industries to turn to sorghum as a raw material for malt. The sorghum producers in Nigeria are linked to malting and brewing companies[3] through agents who may also be seed companies or purely traders in cereals. A study on the organisation of the staple food grain marketing systems in Northern Nigeria focusing on sorghum and millet found the marketing organisation to be competitive in terms of structure and price formation, with reasonable marketing margins. However, investigations of spatial price differentials among 15 selected markets in four Northern States indicated weak inter-relationships among markets with price differentials exceeding transfer costs in many cases. The study suggested improvement of access roads to more remote areas, collection and better dissemination of market price information, introduction of standard grain measure, and improved input distribution system. The actual quantity of sorghum that goes through formal marketing in Nigeria is however not documented. Previous studies on sorghum profitability in Kaduna State of Nigeria, found sorghum farming to be profitable with gross margins of 0.45 Naira for every Naira invested (Baiyegunhi LJS and Fraser GCG, 2009). Interviews with industry players in Nigeria indicated there is still much that needs to be done to make the linkages more efficient. Farmers still need to be well organised and provided with adequate support to produce industry grade grains.

Sorghum Farm Gate Prices

Although sorghum export trade is controlled in Nigeria and Ethiopia, its internal marketing is liberalised and there is no state interference in price formation. Price information to farmers

2 Transfer of Sorghum, Millet Production, Processing and Marketing Technologies Project in Mali (USAID/EGAT/AG/ATGO/Mali Cooperative Agreement # 688-A-00-007-00043-00)

3 The brewing and malting companies provide market leadership in the sorghum value chain which is lacking in most of the sorghum producing countries in SSA including Ethiopia and Mali.

is however lacking and this puts producers at a disadvantage in negotiating for better prices. The traders usually have an upper hand as they have information on market prices.

The farm gate prices for sorghum in Wollo region (North Eastern Ethiopia) were estimated at 6birr/1.25kg for Jigurtie variety, 8.5birr/1.25kg for Degalit variety and 5.5birr/1.25kg for the rest, depending on variety (distinguished by colour and size of grain). At Nazareth Wholesale Market, the prices ranged between 4.5birr and 8birr per kilogram depending on type which is determined by colour and size of grain. White sorghum with large grain was selling at a premium price, while red sorghum attracted the lowest price.

Processing and utilisation

In Africa, sorghum is processed into a variety of traditional foods, such as semi-leavened bread, couscous, dumplings, and fermented and non-fermented porridge. It is also the grain of choice for brewing traditional African beers. In the competitive environment of multinational enterprises, sorghum has been proven to be the best alternative to barley for lager beer brewing.

In Nigeria, Ghana, Uganda and more recently in Kenya (*Kitavi Mutua, East African, 10 April 2009*), commercial use of sorghum in the brewing industry is gaining momentum. In Uganda, a local variety developed at Serere, known as *Epuripur,* is being promoted for commercial beer brewing. Farmers growing this variety under a contract from Nile Breweries were earning a guaranteed price of US$ 150/MT. In Ethiopia, sorghum and millet are used in making local brew called *Tela*, which is popular in North and Central Ethiopia.

In Mali, sorghum is processed into a number of products such as bread, biscuits, confectioneries, sorghum crunch and composite flours. The Directorate of Chercheur Transformatrice Cereales at IER is charged with promotion of value addition of cereals including sorghum. IER in collaboration with INTSORMIL and the University of Purdue is implementing a sorghum project funded by USAID-Mali and the Bill and Melinda Gates Foundation that focuses on technology transfer. The project was started in 2008 and is being implemented over three years. The project components include:

- value addition and marketing
- improvement of grain quality
- cleaning of grain before processing.

The project works with individual processors, but in one location it works with women groups. The main products processed under the project are flour and composite flours. The processed products are sold locally and also exported to France and the USA. The quantities processed are low compared to the national sorghum production. Commercialisation of sorghum production in Mali will therefore need identification of a large scale processor who can be linked with producers to guarantee a reliable market outlet.

In Nigeria, sorghum is widely used as a raw material in malting for beer and other non-alcoholic drinks such as “Malta” and hot drinks such as “Milo”. It is also used directly in manufacturing opaque beers such as Guinness. The by-products are used in manufacturing animal feeds. There are four sorghum malting companies, with a combined capacity of 78,000MT/annum. The companies are listed below.

I. LifeCare Ventures Limited established in 1991 with a capacity of 12,000MT.
II. Derivatives Industries Limited with a 24,000MT capacity and established in the mid 1990s by former managers of LifeCare Aba Malting Company located in Eastern Nigeria and owned by Nigerian Breweries, with a capacity of 30,000MT. This plant started operations in 2009 and had processed about 21,000MT of sorghum malt by the time of this study.
III. Taiobod Ventures established in 2002 with a capacity of 12,000MT.

LifeCare Ventures Limited specialises in manufacturing malt for local beverage and food manufacturing companies. It has a contract to supply Nigeria Breweries and Nestle Company with sorghum malt. In 2008, the company supplied 10,500MT of malt to the contracted companies with Nigeria Breweries consuming 7,500MT, Nestle 2,000MT and Guinness Nigeria 1,000MT. It is also important to note that Guinness uses another 60,000MT of sorghum grain in the manufacture of Guinness beer brand.

At the time of visit by the study team, LifeCare Ventures was undergoing an ambitious expansion programme signifying the confidence in the sorghum malting business in Nigeria. The Managing Director informed the mission that sorghum processing has been growing at 10% per annum in the last five years. In 2009, the intake of malting sorghum in Nigeria was as follows: Nigeria Breweries 64,000MT, Guinness Nigeria 70,000MT (60,000MT of sorghum and 10,000 of sorghum malt) and Nestle 3,600MT (data provided by LifeCare Ventures Limited). Cadbury also uses sorghum malt in the manufacture of Bournivita. This means a total of 152,000MT[4] of sorghum was used in the malting and brewing industry in Nigeria in 2009. Earlier reports showed that of the 8 million metric tonnes of sorghum produced in Nigeria; only an estimated 120,000 metric tonnes are utilised by the industries (Murty et al, 1996). According to the Managing Director of LifeCare Ventures Limited (personal communication), 80% of the grain is recovered as malt.

Grain consistency, moisture content, aflatoxin and weevils are the main quality concerns facing the brewing and malting industry in Nigeria which leads to rejection of about 12% of delivered grain. The varieties used in malting for brewing in Nigeria are SK5912 and ICSV400 which contain necessary enzymes for malting purposes (Ogbonna, University of Uyo). Cross pollination in the field also brings about challenges in terms of getting quality grain for processing. These concerns stem from poor organisation and extension services to farmers to ensure good agronomic practices.

The Nigerian model of linking farmers with processing companies through seed companies is promising in terms of commercialisation of the crop as it ensures farmers get quality

4 This includes 60,000mt of sorghum grain used by Guinness and 73,600mt of malt converted into sorghum grain assuming each metric tonne of grain translates into 800kg of malt, based on information provided by LifeCare Ventures.

seed and a guaranteed market outlet. This arrangement needs to be strengthened through capacity building of the seed companies to ensure they are well capitalised, have qualified personnel and seed processing equipment. Additional support should focus on enabling the seed companies to expand their distribution networks to ensure more farmers have access to quality seed.

The demand for sorghum in the brewing industry should not be viewed as the only avenue for commercialisation of sorghum, since the industry also has limited capacity as witnessed in Uganda in 2007, when Nile Breweries scaled down purchase of sorghum due to an oversupply of the commodity. It is prudent also to support product diversification such as production of blended flours.

Policy issues around sorghum production and marketing

Nigeria has specified sorghum as one of the key priority crops for promotion within its National Food Security Programme. The main focus is to improve productivity. On the seed policy, the Government commits to strengthening of the National Seed Service to ensure delivery of quality seed to farmers. The policy also states that State Governments will subsidise the supply of certified seed to farmers. Under the strategy, the Government also commits to improve commodity marketing systems through the establishment of market and distribution centres, re-engineering of the Abuja Commodity Exchange to support full trading of agricultural products as well as warehousing receipts (Federal Republic of Nigeria, National Food Security Programme, 2008-2011).

In Mali, the government has a policy to exempt new companies in the agricultural sector from taxation for a period of three years. Within that period they can also import equipment duty free. IER in Mali is also in the process of protecting local varieties. Thus, genetic transformation for commercial use of such varieties will require negotiations with the Institute.

In Ethiopia, the Government has prioritised agricultural research in order to improve the food security situation. To this end, the government has increased its budgetary allocation to agricultural research to 95% of the total research budget. The Government has also banned export of all the major cereal crops.

Socio-cultural factors likely to influence uptake of HR sorghum

Variety choice

Food quality, biomass (viz feed, fuel and construction) and industrial use determine variety choice. Sorghum is a grain of choice for industrial processing into products such as instant soft porridge and malt extracts. Multinational corporations are also increasingly using sorghum as the best alternative to barley for lager beer brewing. Other uses include feed, silage, building material, fuel and molasses.

Varieties of choice for food and biomass

The factors affecting demand and preference for sorghum depend on whether it is for human consumption, commercial use or a combination of the two and other factors such as use of the by-products (such as the biomass). In the case of human consumption, the preference is for big, white grain with low tannin, palatability and digestibility. In Ethiopia's Nazareth Market these preferences were manifested through price differentiation. It was observed that traders charged different prices for different qualities[5] of sorghum. The large white grains attracted the highest price, while the brown grains attracted the lowest price.

In most SSA countries, sorghum is grown as a subsistence crop where there are many locally selected and adapted varieties. Traditional types have been selected for the following.

- Strong early root development to compensate for irregular early rains.
- Good tillering to compensate for erratic rains during the growing season.
- Long growing cycle to make the best use of infertile soils.
- Resistance to insect and moulds.
- Tolerance to bird pests and *Striga* (parasitic plant).
- Suitable quality for local food preparations.

In Ethiopia, modern sorghum varieties despite their early maturity, are not resilient in the face of drought-related production shocks;, on the other hand local sorghum crop genetic diversity is an important means of coping with these shocks (Cavatassi et al, 2006). The same situation applies to the two ex-Purdue sorghum varieties, Gubiye and Abishir that are resistant or tolerant to *Striga* (see Table 3).

These varieties were released in 2000 but have only reached 10,000 farmers. The low adoption rate of these varieties is attributed to several factors: Availability, Accessibility, Affordability and Appropriateness. For instance, even if a variety that farmers desire is available, its accessibility may be limited due to poor distribution networks, high prices relative to returns and lack of credit. Also, weak agricultural extension service is a major barrier to adoption

5 In this market the qualities were defined by size and colour of grain.

of MVs, particularly in more marginal production areas. Sorghum producers in the review countries also consider other factors such as quality of the sorghum plant for animal feed, fuel wood and construction. The leaves and grains are used as animal feed and the stalks in thatching houses, fencing and as firewood (Baiyegunhi LJS and Fraser GC.G, 2009).

Table 3: Introduced exotic sorghum varieties released or registered in Ethiopia

Variety	Original name	Year of release or registration	Source	Specific character
Meko	M36121	2000	ICRISAT	Good food making quality
Teshale	3443-OP	2002	ICRISAT	Good food making quality
Gubiye	P9401	2000	Purdue University	*Striga* resistant
Abishir	P9403	2000	Purdue University	*Striga* resistant

Source: Adapted from Adugna A

Varieties of choice for industrial use

Apart from food and biomass uses, sorghum is also malted commercially on a large scale in Nigeria for the production of lager beer and stout, and for non-alcoholic malt-based beverages. In African countries where sorghum is malted commercially, the respective agricultural departments and commercial breeders, breed sorghum cultivars with good malting quality for brewing. The primary quality criterion is their potential to produce malt with high diastatic capacity (that is enzymatic conversion of starch into sugar).

Suitable sorghum cultivars, such as the white Farafara for beer brewing and yellow Short Kowrie for malt beverages have been selected in Nigeria and are cultivated on large scale. In Nigeria, the most widely used varieties as raw material for lager beer brewing are: SK5912, KSV8 and ICSV400 (see Table 4). The malting and brewing properties of these varieties compare well with barley malt (Ogbonna AC, 2008)

Table 4: Sorghum varieties in Nigeria

Variety	Adaptation Region	Maturity	Yields (t/ha)	Seed colour	Use
SAMSORG-24 (KSV3-SK5912)	Southern Guinea Ecology	Long season (165-175 days)	2.5–3.5 t/ha	Yellow	Malting, brewing and confectionary
SAMSORG-14 (KSV8)	Northern Guinea Savanna Ecology	Medium season (130–140 days)	2.5 –3.0 t/ha	White	Malting and brewing
SAMSORG-40 (ICSV400)	Sudan Savanna Ecology	Short season (95-100 days)	2.5–3.5 t/ha	Cream	Malting and brewing

Source: Adapted from Ogbonna AC 2008

In the case of industrial use, the consideration in Nigeria is for malting quality of the grain. Other factors that influence the demand are mainly to do with post-harvest handling such moisture levels, foreign matter, weevil infestation and grain purity. The capacity of the brewing and malting companies is another factor determining sorghum demand. Price of barley is also a determinant of demand for sorghum in the brewing industry.

Economic factors of HR sorghum

Economic benefits: Small-scale farmers in SSA will adopt HR sorghum when convinced of the benefits. It has to be demonstrated to farmers that there are potential benefits in terms of yield gains and farm incomes from use of HR sorghum varieties.

Cost of seed: The HR seed should be reasonably priced to ensure that farmers are able to afford and see economic benefits. Most important is that, due to high transaction costs and limited information, there is no well functioning market for seed varieties in many SSA countries.

Income sources to households: Although farming provides food for most households, some of these food crops such as sorghum and millet are sold for cash; thus important in terms of income generation to households. HR sorghum will contribute a large proportion of the total income to households especially in northern Nigeria.

Levels of education: The level of education of heads of households (and members in general) is an essential attribute for adoption of technologies. Higher education has been associated with higher possibilities of adopting new technologies. This is also important in terms of interpreting the guidelines that often accompany the new technologies such as HR sorghum.

Human and social capital: The labour endowments of households is important for adoption of new technologies more so where they require more labour input. Members in farming communities often rely on each other for moral and material support. It is also easier to access new technologies and services as organised groups. The other important parameter with regard to capital is access and use of extension service provided by both government and NGOs.

Perceptions of farming community

Sorghum in a subsistence system: Intercropping is a dominant sorghum cropping system, which is highly associated with farm risk minimisation. Here local sorghum is the most popular variety. Modern sorghum varieties are also grown but on a limited scale. Use of inorganic fertilisers on sorghum is also limited. Further, seed rates of local sorghum, which are recycled, are higher than the recommended rates for improved seed. This caution is because of the fear of pests and diseases as well as the urge to get higher harvests, but it may discourage the use of costly HR sorghum seed.

Cultural control methods: Farmers perceived *Striga* infestation as the major constraint in sorghum production, but they continued to use the less effective cultural control methods of uprooting, burning and manuring. The level of awareness and appropriate use of the alternative modern technologies though still very low, is gaining momentum. This calls for more extension service to promote HR sorghum technology during its deployment.

Extension service: Extension agents will likely be the weakest link despite being important sources of technology and information in HR sorghum. Other related factors that will influence the uptake of HR sorghum include: inadequate supply of seed and financial constraints to buy seed and other inputs. Equally important is farmer perceptions on the safe use of HR sorghum. There will be need for farmers to be introduced to various HR sorghum technology application guidelines to allay this fear and avoid the negative effect of sorghum seed coated herbicide on other uncoated seeds.

Productivity and farm management: Farmer perceptions on productivity of various sorghum varieties and farm management will be influenced by the following varietal attributes: *Striga* reduction, soil fertility enhancement, ability to withstand biotic and abiotic stresses, earliness in maturity, yield performance, vegetative vigour, technical simplicity and low management cost. Other farmer feelings on HR sorghum may be whether it would bring high labour requirement hence reduce time to socialise as well as lead to unequal distribution of seed and inputs.

In summary, the important factors that may influence the possibility of adopting HR sorghum include: the HR sorghum yield compared to other varieties traditionally grown by farmers, the level of extension support farmers receive, the management cost compared to expected returns, and the variety's ability to reduce *Striga* population. The most influential factor will be the farmer perceptions on the presence of various government and NGO activities in support of the HR sorghum project.

The *Striga* problem in sorghum and control methods

Striga problem in sorghum

Striga is a major constraint affecting sorghum, other cereal crops and sugarcane production in SSA. Smallholder farmers are the most affected by the *Striga* problem because they have limited ways and means of controlling it. There are two *Striga* species that attack sorghum, *Striga hermonthica* and *Striga aspera*. Of the two, *Striga_hermonthica* is the most widespread in SSA and most damaging to sorghum. The two also attack maize and sugarcane, while *S. hermonthica* also attacks rice and millet. According to Greeslet (2003), 21.9 million hectares of sorghum and millet fields in Africa are affected by *Striga* compared to an overall 26.43 million hectares of all cereal crops. This makes sorghum and millet the most affected cereals by *Striga* in Africa. The estimated loss is about 9.3 million MT of sorghum and millet per annum (see Table 5). Figure 5 shows the *Striga* distribution in Africa, with the major producers of sorghum such as Nigeria, Sudan, Ethiopia, Mali and Burkina Faso heavily affected.

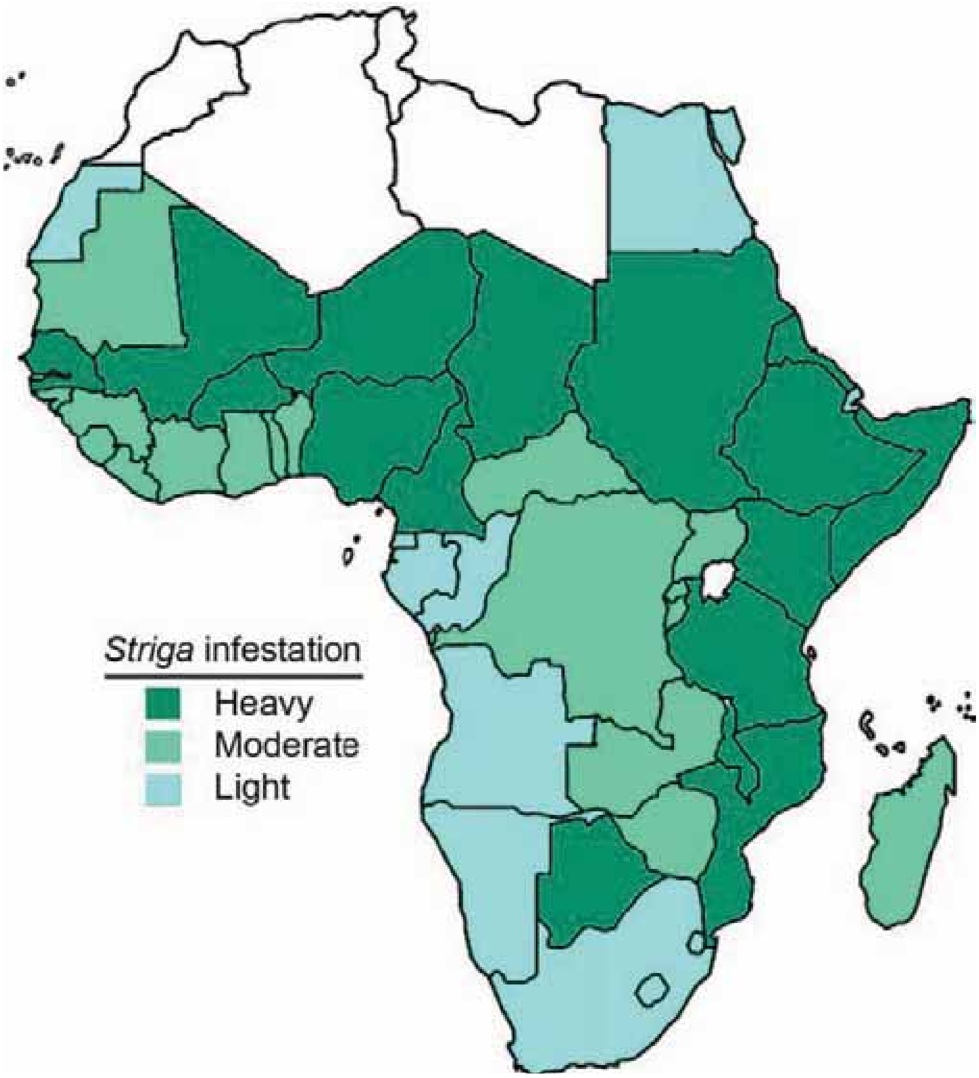


Figure 5. *Striga* ***distribution in Africa (Source: Ejeta Gebisa and Gressel, 2007)***

Table 5: Estimated area under Striga infestation in Africa (excluding maize).

Country	Area ('000ha) cultivated		Present crop yields (t/ha)		*Striga* infested area (sorghum)		Est. % yield loss	Yield loss ('000 tonne)
	Sorghum	Pearl millet	Sorghum	Millet	'000 ha	% total		
(A) East and Central Africa								
Burundi	50	13	1.22	0.77	–	–	–	–
Eritrea	160	17	0.62	0.30	64	37.5	20–60	30–90
Ethiopia	1,760	250	1.27	0.95	528	30.0	25	500
Kenya	150	86	1.05	0.42	80	53.3	35–40	50–60
Rwanda	80	2	1.05	0.83	1.6	2	5	5
Somalia	500	–	0.46	–	150	30	15	30
Sudan	6,250	2,500	0.66	0.25	1,600	25.6	30	1,060
Tanzania	690	320	0.50	0.71	650	90	Upto 90	550
Uganda	270	410	1.50	1.57	27	10	10	<1
Total	**9,910**	**3598**			**3,101**	**32**	**22–38**	**2,225–2,295**
(B) Southern Africa								
Botswana	100	6	0.11	0.17	30	30	25	8
Malawi	54	34	0.68	0.60	8	15	20	40
Mozambique	376	51	0.52	0.26	150	40	35	–
Namibia	53	233	0.38	0.28	–	–	–	–
South Africa	179	212	1.94	0.18	18	10	5	20
Swaziland	1	–	0.60	–	0.2	15	10	<1
Zambia	42	64	0.66	0.77	6	15	15	5
Zimbabwe	133	252	0.5	0.26	27	20	25	20
Total	**938**	**852**			**239**	**22**	**18**	**95**
(C) West Africa								
Benin	142	38	0.78	0.66	9	5	10	10
Burkina Faso	1,398	1,239	0.89	0.64	1,319	50	35–40	710–820
Cameroon	497	54	0.75	1.01	55	10	15–20	70–90
Chad	550	591	0.71	0.48	114	10	15	100
Cote de'Ivore	50	84	0.60	0.84	7	5	5	5
Gambia	20	97	1.66	1.08	–	–	20–35	30–50
Ghana	311	202	0.91	0.83	77	15	35	170
Guinea	7	11	0.70	0.83	1	5	10	1
Mali	957	1,205	0.77	0.60	1,513	70	40	580
Niger	2,261	4,866	1.08	0.38	4,989	70	40–50	930–1,160
Nigeria	5,700	5,200	1.07	0.89	8,720	80	35	3,750
Senegal	133	895	0.87	0.61	411	40	20	120
Togo	184	130	0.77	0.52	6	2	35	70
Total	**12,210**	**14,612**			**17,221**	**64**	**24–27**	**6,555-6,926**
Total – Africa								**8,875-9,316**

Compiled by AB Obilana
[a]On sorghum only in East Central and Southern Africa. Pearl millet is not infested by *Striga* in these regions.
[b] Includes both sorghum and pearl millet combined in West Africa.

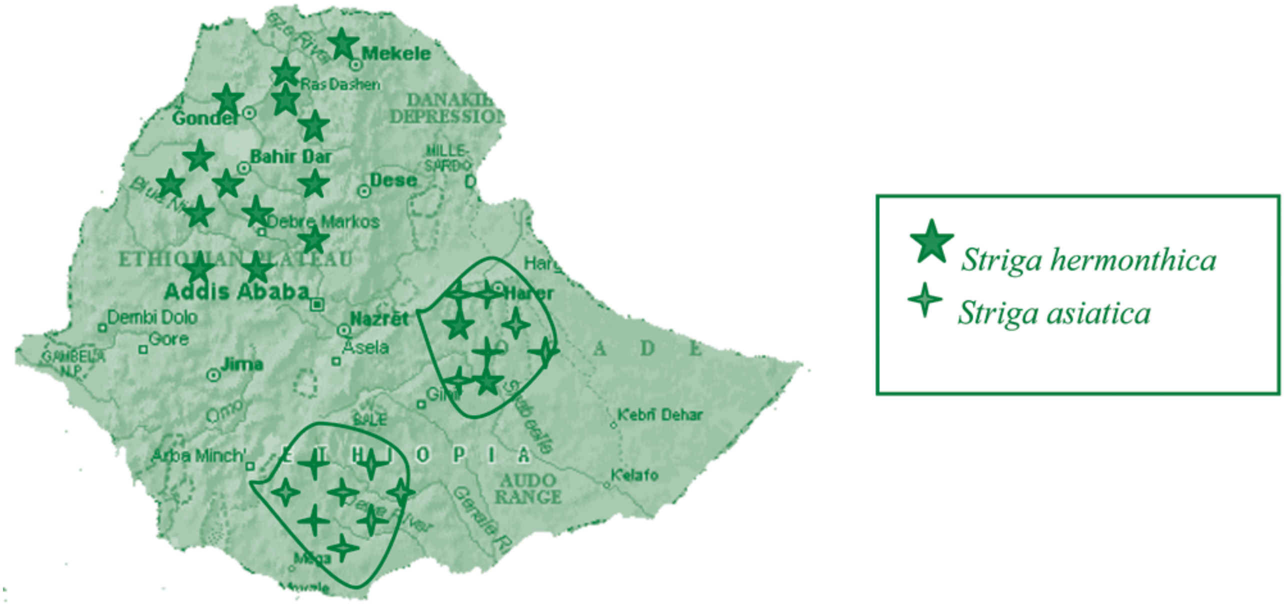


Figure 6. *Distribution of the two major Striga species in Ethiopia (Source: Fasil Reda - EIAR, Headquarters)*

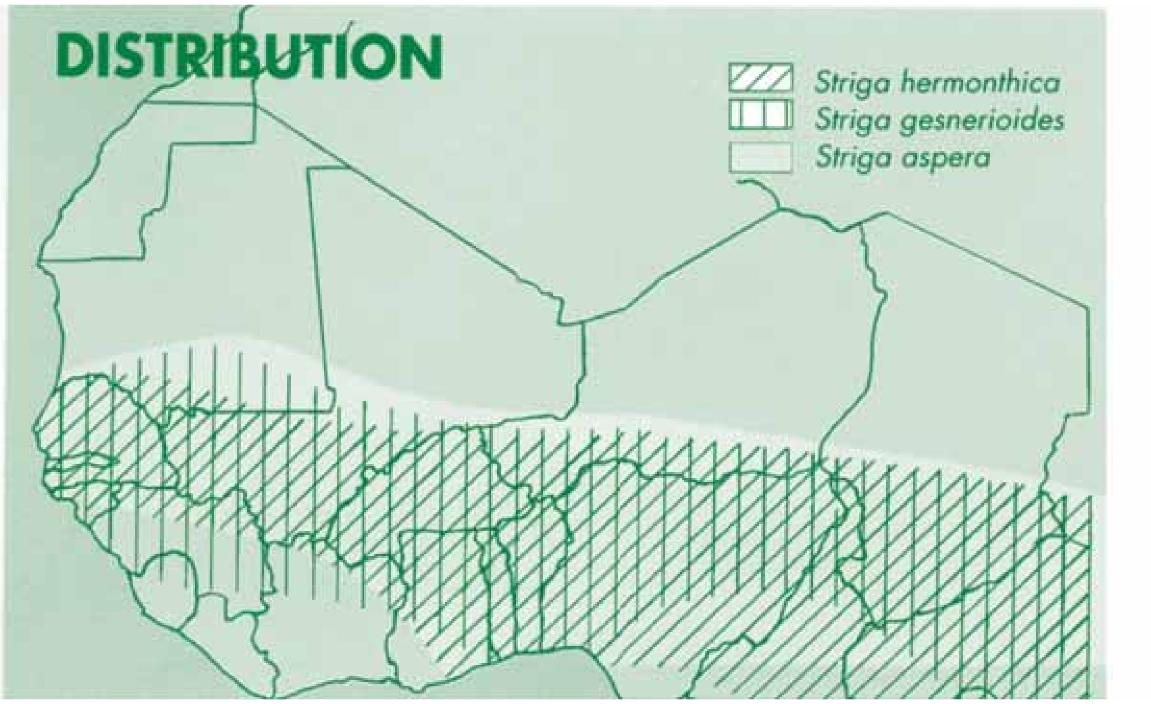


Figure 7. *Striga distribution in west Africa (Source: ICRISAT-Mali; Striga scourge of food crops in the Sahel (poster presentation)*

In Ethiopia *Striga* is a major biotic constraint and a serious threat to subsistence food production. The weed is endemic to the country and earlier records (Richard et al, 1982) documented that it was part of the farming systems in the country for over hundred years. However, severity of the parasitic weed has dramatically increased since 1980 favoured by the overall deterioration of natural resources. Although about 12 species of *Striga* are believed to occur in the country, only seven have been registered so far. These are (in order of importance): *Striga hermonthica* on sorghum, maize, finger millet and a number of small cereals, including teff; *S. asiatica* on sorghum and maize; *S. aspera* on maize; *S. latericea* on sugarcane; *S. gesnerioides* on sweet potato; and *S. forbesii* and *S. pinatifida* on wild vegetation.

Survey reports revealed that many damaging *Striga* species do occur in the country (Fasil and Parker, 1994). *Striga hermonthica,* the dominant species, is most severe in the highly degraded north, north western and eastern parts of the country vis Tigray, Wollo, Gonder, Gojam, north Shewa and Harerghe (Figure 6). Its host range includes sorghum, maize, millet, teff, barley and wheat. Infestation on the main cereal crops is such that farmers are often forced to abandon their land or resort to less important crops. *S. hermonthica* seems less affected by ecological barriers (elevation, temperature and soil type) and it has been recorded within the elevation range of 950–4,050 metres above sea level.

Scientists in Ethiopia think that *Striga* is a bigger problem in their country compared to other SSA countries because it is found everywhere, whereas in other SSA countries it tends to be isolated in certain locations, usually associated with low soil fertility and low elevations. Italso affects other crops such as teff, rice and wheat. As a result, scientists are of the view that herbicide technology is a welcome and promising technology that needs to be given necessary attention. However, in Ethiopia, they expect challenges along the way in deploying the technology largely due to the under developed seed delivery systems in the country.

In Mali, *Striga* is manifested in the sorghum and cotton growing areas (*interviews with Dr Eva Weltzien, ICRISAT Mali*). *Striga hermonthica*, *S. gesnerioides* and *S. aspera* are all found in Mali and mainly concentrated in the southern parts of the country (Figure 7). With less cotton being grown in Mali, the *Striga* problem will become worse in sorghum production. The main methods of control are integrated cultural methods which include soil fertility improvement through application of fertiliser as well as use of a cover crop which is principally a spreading cowpea variety which suppresses the growth of *Striga*. IER has also developed some *Striga* tolerant materials which they are popularising in the country.

Striga control methods and results obtained

Conventional techniques that have been applied to control *Striga* in sorghum since 1999 consist of those that reduce the number of *Striga* seed in the soil bank, those that prevent production of new seed, and those that prevent spread from infested to non-infested soils (Berner et al, 1994; Hess and Ejeta, 1992; Obilana, 1984; Obilana and Ramaiah, 1992). *Striga* damage and infestation can therefore be alleviated by adopting management practices and measures that curb its spread at the different stages of development. These measures include hand weeding, inter-cropping cereals with trap crops, soil fertility and crop rotation with trap crops. However, these management practices work well when applied in an integrated manner and not in isolation, which rarely happens in many SSA countries. Since 2001, significant progress has been made in identifying molecular markers for *Striga* resistance in sorghum under field conditions by ICRISAT. Genomic regions (quantitative trait loci, QTL) associated with stable *Striga* resistance from resistant line N13 have been identified across a range of ten field trials in Mali and Kenya. Foreground and background selection of these QTL are underway in several NARS and ICRISAT laboratories to introgress the *Striga* resistance into farmer preferred sorghum varieties. However, there are no varieties that have so far been developed and deployed to farmers in SSA using Marker Assisted Selection (MAS) and these efforts are likely to take some time before the products are available to farmers. A few NARS (Kenya, Sudan and Nigeria) have also reported sorghum varieties that show complete immunity to *Striga* through conventional breeding but they are yet to demonstrate whether these genes exist in favourable backgrounds and whether transferring these genes into farmer preferred varieties will not be bogged down by the inevitable genetic-drag effects. Research is yet to demonstrate how these varieties will be maintained.

Du Pont in collaboration with the University of Kansas has developed Herbicide Resistant (HR) sorghum which promises to be more effective in controlling the spread of *Striga* than all the other previously tested efforts. HR sorghum is based on the same concept as that of HR maize (developed by CIMMYT), which is successfully being adopted in *Striga* infested maize growing areas of Kenya, Uganda and Malawi. As noted elsewhere in this report, the evaluation of HR sorghum technology is beyond the proof of concept and is currently being tested in farmers' fields in West Africa.

Herbicide control strategies of *Striga*

The development of herbicide resistance in plants offers significant production and economic advantages; as such the use of herbicides for controlling weeds in crops has become almost a universal practice. However, application of such herbicides can also result in death or reduced growth of the desired crop, making the time and method of herbicide application critical or in some cases unfeasible. Of particular interest to farmers is the use of herbicides with greater potency, broad weed spectrum effectiveness and rapid soil degradation. Plants, plant tissues and seed with resistance to these compounds provide an attractive solution by allowing the herbicides to be used to control weed growth, with minimal risk of damage to the crop. One such class of broad-spectrum herbicides are those that inhibit the activity of the acetolactate synthase (ALS) enzyme in a plant. Acetolactate synthase is required for the production of essential amino acids such as valine, leucine and isoleucine in plants (this biochemical pathway is not present in humans or other animals). Sorghum is susceptible to many ALS inhibiting herbicides that target monocot species, making the use of these herbicides to control grassy weeds almost impossible, as they will also inhibit the growth of the crop. Imazapyr is a non-selective herbicide used for the control of a broad range of weeds including terrestrial annual and perennial grasses and broad-leaved herbs, woody species, and riparian and emergent aquatic species. Herbicide (imidazolinone) resistant maize varieties have been developed that, in combination with the herbicide, are very successful in combating *Striga* infestations in maize (Gressel et al, 2002; Kanampiu et al, 2002). The technology has been shown to have potential for application in sorghum carrying acetolactate synthetase (ALS) target site resistance to enable the application of high herbicide levels which can be localised on the crop seed coat.

The herbicide seed treatment combines low-dose Imazapyr (a systemic ALS-inhibiting herbicide) seed coating applied to Imazapyr resistant (IR) seed. Use of herbicide seed treatments for parasitic weed control was first demonstrated by Berner et al (1994) using imazaquin on cowpea [*Vigna unguiculata* (L.) Walp.] to control *Striga gesnerioides* (Willd.) Vatke. Later, Jurado-Exposito et al (1996, 1997) showed that seed treatments with other imidazolinone herbicides improved control of crenate broomrape (*Orobanche crenata* Forssk.) on broad bean (*Vicia faba* L.) and pea (*Pisum sativum* L.). According to studies done on maize by CIMMYT (Kanampiu et al, 2002), small quantities of Imazapyr as little as 30 grams coated on the maize seed prevents the attachment of *Striga* on maize seed before the emergence of the *Striga* from the soil. The herbicide, Imazapyr, that is not absorbed by the maize seedling diffuses into the surrounding soil and kills un-germinated *Striga* seed. In sorghum, Dembele et al (2005) evaluated five herbicides as seed treatments by seed priming against *Striga hermonthica* in Mali and reported that 2,4DB treated seed gave the best *Striga* control but did not result in increased sorghum yields. The mechanism by which 2,4DB reduced witchweed levels was not clear. Although the mobility of 2,4DB in sorghum has not been documented, it is likely that the herbicide has an indirect mechanism. Their study as well as that of Kanampiu et al (2001) concluded that the efficacy of the herbicide is dependent on herbicide formulation and method of application to the seed implying that higher levels of herbicide and coating would give more effective control. Obviously this has cost implications if adopted by farmers. Other studies have also demonstrated that treating sorghum seed with 2,4-D and 2,4-DB prior to planting minimises early attachment of *Striga* onto sorghum roots and subsequently reduces the number of *Striga* shoots that emerge above ground. The effect of 2,4-D and 2,4-DB and similar herbicides has been reported in several parts of the world (Babiker and Reda, 1991). In Uganda for example, seed of two sorghum varieties, 'Epuripur' and 'Seredo', when coated with 2,4-D and 2,4-DB herbicides before planting reduced *Striga* emergence by 50%–90%(JR Olupot, DSO Osiru, J Oryokot and B Gebrekidan, 2002).

Studies by Tuinstra et al (2009) evaluated the efficacy of three levels of Imazapyr (IMI) and three levels of met-sulfuron methyl (MET) in the control of *Striga* using seed of herbicide tolerant sorghum hybrid in Mali and Niger. Herbicide seed treated plants with met-sulfuron methyl, reduced *Striga* emergence, and increased sorghum yields and dry matter. Evaluation of efficacy of herbicide treated seed by National Scientists in Mali and Niger, with support from the University of Purdue, Kansas State University and Wageningen University were carried out using an acetolactate synthase (ALS) herbicide tolerant sorghum hybrid treated with two ALS-inhibiting herbicides. Treatments included three rates of Imazapyr (IMI), three rates of met-sulfuron methyl (MET), and an untreated control group. During greenhouse trials, observations at 32, 46 and 60 days after planting showed that seed treated with highest herbicide rates had the fewest *Striga* attachments and the greatest delay in attachment. All plants in the untreated group died at or before sorghum flowering, however, herbicide seed treatments, particularly met-sulfuron, reduced *Striga* emergence and significantly increased grain yield and dry matter production.

Increasing rates of imazypr showed a linear decrease of *Striga* emergence as was also the case with maize (Kanampiu et al, 2001) again implying better control will only be achieved by applying higher rates of the herbicide. Both MET and IMI treatments reduced *Striga* emergence. Most sorghum varieties are susceptible to ALS and in the case of this study there was need to make an F1 hybrid tolerant to ALS herbicides before testing. Esilaba (2006) recommends use of herbicides that persist in the soil allowing germination of *Striga* seed but killing the seedlings before attachment to the host plant. The herbicides must also be compatible with mixed cropping systems practised by sorghum farmers and be profitable to use with low capital outlay.

Coating of sorghum seed with Imazapyr and pyrithiobac could be used as part of an integrated approach to preventing damage from parasitic *Striga hermonthica*. Since sorghum is predominantly grown by resource poor households in marginal areas where access to herbicides is non-existent, and because there is the danger of *Striga* developing herbicide resistance, it is important that these potential challenges are considered in the development and deployment of herbicide resistant varieties. It is also important to consider the potential environmental effects of the herbicide to the soil and non-target crops that are inter-cropped with sorghum by farmers.

This study finds that HR sorghum offers small-scale farmers in *Striga* infested countries in SSA an opportunity to control the spread of *Striga* and therefore increase their yields. Given the experience of HR maize in eastern Africa, it is very likely that the cost of treating seed will be minimal compared to benefits accruing from the technology and smallscale farmers are likely to adopt it, especially where sorghum markets are linked to breweries. Tom Mourik of ICRISAT Mali (personal interview) believes that herbicide technology when applied to hybrid varieties is worth pursuing. In the short term, Du Pont can introduce the hybrids through the NARS or the seed companies, and conduct performance trials. The seed can then be multiplied and dressed through specifically contracted seed companies. In the long term, the project should introduce the preferred trait in HR sorghum into the farmer preferred varieties. The third option is to characterise local varieties (land races) for resistance to ALS. The delivery of the HR sorghum seed will require strengthening of the contracted seed companies, seed stockists, the NARS, and the seed inspectorate agencies.

To improve the adoption rate of the HR sorghum, the project could start with pre-financed seed supplied to contracted farmers who are linked to market end users such as breweries and malting companies in Nigeria, and food processing industries in Ethiopia and Mali. Meanwhile, the project through its stewardship strategy should invest in farmer capacity building and development of strong value chains to link farmers with markets.

Capacities for testing and safe deployment of HR sorghum

The laboratory and human resource capacities for sorghum research and development work exist in SSA but these capacities differ from country to country. This section summarises both existing and required infrastructure, procedures and human resource capacities for: (i) sorghum research, (ii) seed dressing and deployment, (iii) product capability, and (iv) policy requirement in Ethiopia, Mali and Nigeria.

Research capacity

The three surveyed countries (Ethiopia, Mali and Nigeria) have strong sorghum research for development programmes. They have invested in biotechnology laboratories although in Mali it is yet to be installed and made functional. There are also a few trained scientists in biotechnology work in each of the three countries.

Regarding the ongoing evaluation of the herbicide technology, scientists in the three countries were of the view that the NARS need to be more engaged and that there was need for further evaluation work. Site specific evaluations were recommended by national scientists because of the nature of sorghum. For instance, scientists in Ethiopia and Mali indicated the need to be brought on board in the early stages of the project because further development work will have to be conducted using farmer preferred local sorghum material to confer herbicide resistance.

Related evaluations of herbicide resistance by the respective NARS would involve testing for potential environmental effects of the herbicide on the soils and other crops, especially because sorghum is grown by smallholder farmers who practice intercropping. There is also the need to conduct tests on potential effects on other sorghum varieties that farmers may mix with the herbicide-treated seed. Field trials on farmer fields would then need to be conducted over a period of two years. During this period, capacity building with target farmers will have to be done to ensure that appropriate agronomic practices that ensure maximum benefits from the project and adverse environmental effects are observed.

Research capacity in Ethiopia

In Ethiopia, public research is the mandate of the Ethiopian Institute of Agricultural Research (EIAR), a semi-autonomous body under the Ministry of Agriculture and Rural Development (MoARD). EIAR, with its Regional Agricultural Research Institutes (RARIs) represents the main agency responsible for the coordination of agricultural research in the country. Its functions include plant breeding, production of breeder/foundation seed, and its supply to basic seed producers.

There is a relatively strong sorghum breeding programme in Ethiopia. In particular, EIAR has had a long history of research on *Striga*. Some of the recent research work includes that of collaboration with the University of Purdue in which two *Striga* resistant/tolerant varieties (P9401 and P9403 referred to as Gubiye and Abishir, respectively, were released.

According to scientists at EIAR, these varieties have now reached about 10,000 farmers. The low adoption rate of these varieties is attributed to several factors. Among them is farmer preference for local varieties in meeting their food and biomass needs (fuelwood, animal feed and construction). Thus, scientists require capacity building in terms of infrastructure, human resources and funding in molecular assisted selection and breeding (MAS/B) to confer *Striga* resistance to farmer preferred sorghum varieties. At the same time, EIAR has an ambitious programme to test varieties twice a year using both rainfed and irrigation during the off-season. This initiative has implications for laboratory and human resource capacity in sorghum breeding which is yet to be determined.

Research capacity in Mali

In Mali, the Institute of Rural Economy (IER), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and Rural Polytechnic Institute (IPR) have worked together to develop new, stress tolerant crop varieties that are well adapted to smallholder farmer conditions. The country has a strong sorghum research programme funded by USAID and implemented in collaboration with the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL). In addition, research work on sorghum by ICRISAT (Mali) spans over the last 32 years. At the moment there are efforts to evaluate *Striga* resistant varieties that have been developed in collaboration with the Nairobi-based ICRISAT scientists. Although the public research organisations may want to increase accessibility of new varieties to the smallholder farmers, there is lack of infrastructure and human resource capacity to promote improved access and use. Mali is also one of the countries in which the herbicide resistant varieties developed by DuPont/Purdue University are being evaluated. Others countries include Nigeria and Niger. In Mali, the three sites in which this work is being conducted are Sotouba Research Centre, Cinzana and at the ICRISAT centre. The country has also had previous experience in testing herbicide treatment on sorghum (Dembele et al, 2005).

Regarding introducing *Striga* tolerant sorghum varieties, key informants were emphatic that these varieties must meet the farmer preferred sorghum attributes. The regional preferences are for tall varieties (that is the Guinean varieties; hence, the acceptance criteria include human diets, animal needs, construction and fuel). Like in Ethiopia, there will be need to equip the new biotechnology laboratory to make it functional as well as train researchers in molecular sciences to enable them do basic work of characterising sorghum varieties.

Research capacity in Nigeria

In Nigeria, sorghum research is done by the Institute of Agricultural Research (IAR) and Ahmadu Bello University (ABU). The current research thrust is towards transferring the traits of interest into farmer preferred sorghum varieties through conventional breeding. More recently, researchers at DuPont and Purdue University have taken a popular variety of sorghum (that is SK5912) from Nigeria for evaluation in the USA. This variety is a yellow variety with high glucose content and has good malting quality.

Upon completing on-station testing, the variety will be tested in 5-6 multilocations involving on-farm trials. The data from these trials will be compiled and submitted to the National

Performance Trials (NPTs). It was pointed to the study team that plant breeders believe that building resistance in farmer preferred sorghum varieties was preferred. The resistance varieties include SRM 48/41 which is red seeded. However, farmers do not like it because its heads are small. Farmers also do not like its red colour and high tannin content.

There is only one plant breeder per crop which calls for capacity building in this area. The importance of sorghum in the malting and brewery industry in Nigeria also requires more emphasis on sorghum research to respond to industry needs.

Seed dressing and deployment capacities

Capacities for seed dressing are limited and in the three countries there was no evidence of sorghum seed dressing. Their capacities for seed deployment are also limited because of low capitalisation and limited linkages with seed stockists or agro-dealers. Borrowing from experience of the IR maize in Kenya, it would be necessary to ensure that seed companies install separate seed dressing lines for HR sorghum.

In Ethiopia, the Ethiopia Seed Enterprise (ESE) has seed dressing units in all the seed producing areas of the country. ESE does not think dressing of sorghum seed with herbicide will be a major challenge to them. The main constraint that would need to be addressed is access to the chemical and also safe handling of seed issues in the dressing and deployment of the treated seed.

In Mali, the challenge of limited funding affects the formal seed systems (including seed dressing). Recently some small seed companies (such as Faso Kaba) received an AGRA grant under the Program for African Seed Systems (PASS). It is AGRA's position that seed companies should dress their seed but they do not treat seed. They often sell seed and agro-chemicals separately; the only exception is a farmer cooperative known as Semenko which dresses its seed. At the same time, the small seed companies expressed the desire to acquire seed processing equipment.

In Nigeria, like in the other two countries, sorghum seed is not dressed. Therefore, capacity building in seed dressing will require training personnel on safe handling and setting up separate lines of seed treatment, warehousing and transport facilities. Overall, capacity building on seed dressing and safe deployment will first focus on the largest sorghum-producing countries in SSA. As shown in Table 6, the target actors and components for capacity building are seed companies, seed inspectorate staff, seed stockists, extension staff, NARS of the target countries and farmers.

Table 6: Seed dressing and deployment capacity requirements

Capacity of seed companies in five countries (Ethiopia, Mali, Burkina Faso, Niger, Nigeria)	
	Seed dressing lines including installation
	Seed dressing costs 4MT of dressed seed per country per year
	Training of seed company staff in year 1 and in year2
	Basic/foundation seed production (ICRISAT/NARS)
	Seed multiplication by desiganted agencies
Capacity building of seed inspectorate staff	
	Laboratory equipment
	Staff training
	Environmental impact assessment in year 3 and in year 4
	Seed inspection (testing and certification) - 5k per country/yr
Capacity for seed stockists	
	Training
Capacity for extension staff	
	Training
Training and capacity of NARS (Ethiopia, Mali, Burkina Faso, Niger, Nigeria)	
	Short term training in seed evaluation techniques
	Seed evaluation and testing costs
	Laboratory and equipment supplies
	Short term training in seed dressing
Capacity building of farmers	
	On-farm trials (from year 3)
	Training in agronomic practices
	Cost of seed supplied to farmers in years 4-5

Product capability

Sorghum breeding programmes in SSA have targeted the *Striga* problem through the development of *Striga* resistant or tolerant varieties. The herbicide coating technology has been tried in the past (Bekele et al, 2008), but wide adoption has been limited for a number of reasons including poor seed development systems, limited knowledge on the herbicide technology by farmers, and lack of demonstrated economic benefits of the herbicide treated seed. Adoption rates of improved agricultural technologies in SSA are also low, estimated at between 5% and 10%. A study by Purdue University in Tigray Area of Ethiopia looking at farm level adoption of sorghum technologies found that access to information, soil type, and farmer perceptions of technology characteristics and rainfall risk were the factors associated with the adoption of the new sorghum cultivars (Nega Gebreselassie Wubeneh and Sanders JH, November 2006). They noted that, varieties combining the desirable characteristics of higher grain and biomass yields of the traditional cultivars with *Striga* resistance were expected to be more successfully adopted. The price of the technology and its accessibility have also been determinants of its adoption. There has been limited use of chemical control of *Striga*, mainly through post-emergency spraying in Ethiopia and Mali (*Personal interviews with Comptor in Mali and researchers at Melkesa Research Institute, Ethiopia*). In the case of HR sorghum, price and the accessibility of the technology to farmers will be critical factors.

The success of the HR sorghum hinges on developing a strong seed delivery system, ensuring the seed is affordable, and developing market linkages between producers and markets. In addition there will be need to build the capacity of seed producers, agro-dealers and farmers in handling the HR technology. The following are suggested as requirements for successful deployment of HR sorghum.

- **Product demonstration:** Build capacity for farmers to learn how to use HR sorghum varieties within their farming systems, thus promoting uptake of the technology.
- **Strengthen seed production and delivery systems:** Build the capacity of the seed industry to handle the HR sorghum, strengthen the agro-dealer network to ensure farmers have access to the technology, and ensure that the seed is produced at minimal cost to make it affordable to the farming community.
- **Information dissemination:** Information about the technology should be well packaged and disseminated. Of importance is to demonstrate the economic viability of the technology in terms of addressing the *Striga* problem and potential yield gains, and development and circulation of documents among stakeholders to create awareness and share information related to HR sorghum technology (these include baseline studies, farmer perception study reports, handouts, Q&A, pamphlets, booklets and posters).
- **Commercialisation:** Capacity in facilitation of national performance trials and distinctiveness, uniformity and stability (DUS) tests to ensure variety registration and release, so that the improved seed are available to agro-dealers and further acquisition by farmers in *Striga* infested areas. This should be followed by building capacity of sorghum value chains; the main focus being seed producers, farmers, traders and promotion of industrial use of sorghum especially in the malting, brewing and food industry.
- **Participatory monitoring and evaluation (PM&E):** Build capacity of user group to continuously assess performance of the HR sorghum technology, and farmer adherence to user instructions for optimal performance. This will be done through field workshops, training meetings for various stakeholders, including farmers, extension officers, agro-dealers and seed companies.

Policy requirement

In order to have sustainable sorghum growing in SSA, the policy environment needs to be reflective of the problems and constraints that affect the enterprise, besides advocating for innovative institutional solutions. The policy requirements areas outlined below.

- Streamlining of procedures for licensing public varieties to enhance adequate availability of foundation seed for multiplication and distribution by the private sector. This includes facilitating institutional and attitude change to encourage consultations and collaboration.
- There is need to build institutional capacity for compliance or enforcement of regulations on seed, chemicals, product standards and quality, IPRs and elite germplasm.

- Regional integration and regulatory harmonisation in seed registration (such as variety release, seed certification and chemical testing approvals) are required to overcome problems of the existing small seed markets and illegal cross-border seed movement.
- To spur demand for formal seed, there is need for government leadership and championing of agriculture such as market-friendly input subsidies, price incentives for farmers, strengthening agro-dealer network and agricultural extension.
- Output trade policies require attention especially with respect to the export ban on sorghum grain in Ethiopia and the import ban on barley (which stimulated domestic sorghum demand for malting and brewing) in Nigeria.

Seed production and delivery systems

Good seed is the foundation for farmers to increase their yields. Seed play an important role in determining the level of investment farmers make in their crops. However, smallholder farmers in SSA have limited access to high yielding and locally-adaptive varieties of their staple food crops. They instead rely on low-quality seed that has been saved and re-used over time resulting in low yields.

African farmers require a viable and sustainable seed system that provides them with higher yielding and locally adaptive varieties. This section analyses the seed systems in SSA and in particular as it relates to sorghum seed industry in Ethiopia, Mali and Nigeria. The key elements of this analysis include seed production and delivery, seed pricing and seed policy environment because it will require a viable seed industry to deliver HR sorghum varieties in SSA.

State of Africa's seed sector

There are enormous challenges, with impediments at nearly every link in Africa's seed supply chain. The formal seed system is preferred by actors such as the public sector players because of assurance of seed quality, but its effectiveness in seed supply is limited by several challenges as highlighted independently by many authors (Bay, 1998; FAO, 1998; and Scowcroft and Scowcroft, 1998). These include high seed prices, lack of information among farmers about the modern varieties, distant seed sources, unreliable seed sources, poor seed quality, narrow range of exchange mechanisms (cash only), and narrow range of crops (focus is mainly on maize hybrids and vegetable seed). Due to these constraints, many farmers are unable to access seed of improved varieties and tend to use farmer saved seed that is of poor quality resulting to low yields.

Although the informal seed system is an integral part of Africa's seed sector, it exhibits many challenges, as highlighted by Tripp (2001), Bay (1998), and van der Burg (1998). These include limited seed production because of mixed or combined seed and grain production, exchange of the harvests for income resulting in shortage of own saved seed, seed exchanges limited within a community, difficulties in accessing seed of improved varieties hence focus on local landraces, slow variety replacement, vulnerability to adverse weather conditions and crop diseases, lack of sustainability of donor supported seed initiatives, and farmers' lack of skills and capacity to effectively maintain seed purity in cross-pollinated crops and post-harvest storage.

One crucial area addressed by different authors is the need to develop a strong, private sector made of local companies producing and disseminating high quality, certified seed. As exemplified by our selective studies of sorghum seed systems in Ethiopia, Mali and Nigeria, a strong, African-based commercial seed sector devoted to serving smallholder farmers is the missing link in improving the lives of local farmers and increasing food supply across the continent.

Seed systems in Ethiopia

The seed delivery system in Ethiopia is not well developed; and it is still under state control. The capacities of the seed companies are limited in terms of scale, capitalisation, technical expertise and organisation. Linkages between the seed companies and farmers are also weak. The problem is also compounded by the fact that sorghum is open-pollinated and most farmers use retained seed. Sorghum farmers prefer their own varieties because of the high biomass which is used as feed for livestock and also as construction material and firewood. This makes private investment in sorghum seed unattractive. Key players in the seed systems include public regulatory agencies, Regional Bureaus of Agriculture (RBAs), research institutes (for example the Ethiopian Agricultural Research Institute), Regional Agricultural Research Institutes (RARIs), Higher Learning Institutes (HLIs), extension service and Non-Governmental Organisations (NGOs). There are also market actors which comprise domestic and foreign private firms, cooperative unions, trade associations, private breeders, seed companies, stockists, civil society actors, community based organisations and the farmers themselves.

The Ethiopian Seed Enterprise (ESE) , a government parastatal has virtual monopoly of the seed industry. It controls over 95% of the seed business in the country. ESE is the major player in seed production and distribution in the formal system. It has a 6,000ha seed multiplication farm and produces about 20,000MT of seed. ESE also contracts individual farmers to produce seed for them but it is only able to meet 10% of the national seed demand. About 75% of the seed produced by ESE is red wheat, while hybrid maize and other crops take 12% and 13%, respectively. ESE does not have a seed or agro-dealers distribution network, hence distribution of improved seed from ESE is done by the State Ministry of Agriculture through RBAs and farmer cooperatives. Usually the RBAs get less than 10% of what they request (see Figure 8).

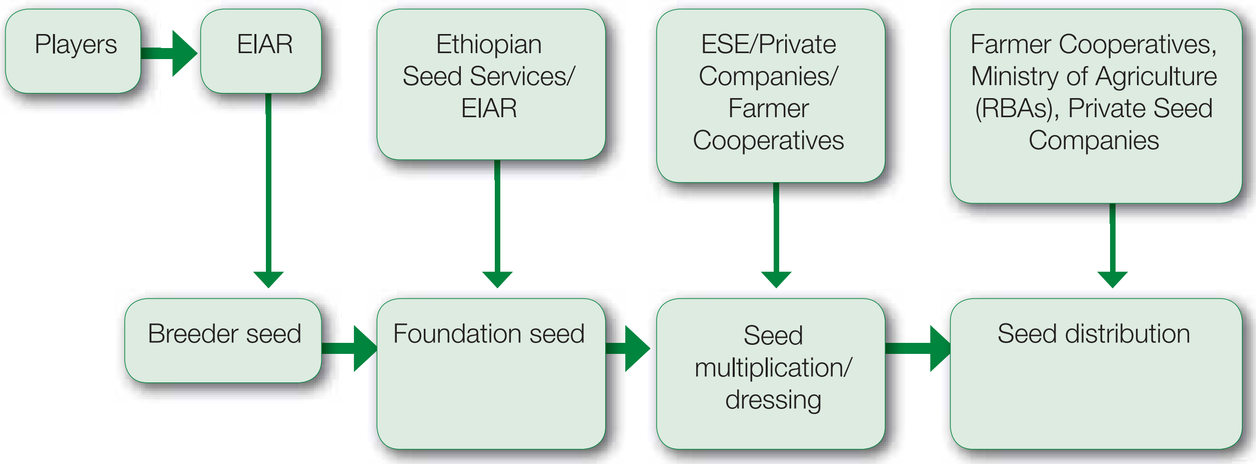


Figure 8: Ethiopia seed supply chain

(Source: Authors' compilation)

While there are 15 private seed companies in Ethiopia all dealing in maize and rice seed production, there is none dealing in sorghum. For instance, Pioneer Seed Co. supplies 28%

of the certified maize seed in Ethiopia. According to interviews with EIAR and ESE staff, it is estimated that only 30% of the maize seed demand is met. Ethiopia was estimated to produce 6,000MT of maize seed in 2009. To increase seed production, Ethiopia is expanding irrigation facilities in all its research centres. ESE and the Oromia Regional Seed Enterprises are the only companies producing certified sorghum seed in Ethiopia (Interviews with EIAR and ESE staff). The demand for sorghum seed is not documented and commercialisation of sorghum seed has been hampered by the fact that farmers retain their own grain as seed after harvest. Also, sorghum seed are open-pollinated which undermines private sector investment in the sorghum seed industry.

But the main challenge for the Ethiopian seed system lies in the area of seed multiplication. Ethiopia has a limited capacity for production of basic seed due to limitations at research centres. This affects the whole seed chain. Financial allocations to the ESE are also limited and the state control over the seed business also limits the development of the seed industry. As a result, improved seed is only available in a limited number of crops that are produced in significant quantities for distribution to smallholder farmers (Alemu D and Spielman Dr 2006) ESE has seed dressing units in all the seed producing areas of the country. Thus, dressing of sorghum seed with herbicide is not a major challenge but the constraint that would need to be addressed is access to the chemical and safety issues in the dressing and deployment of the dressed seed. The cost of the chemical could make the seed expensive to the farmers and hence encourage continued use of retained seed.

Seed pricing in Ethiopia

ESE is only allowed a 1% profit margin in its operations and this constrains its capital base for expansion. Table 7 summarises seed prices in Ethiopia.

Table 7: 2008 seed prices in Ethiopia

Crop	Price	
	birr per quintal	birr per kg
Sorghum	670	6.7
Maize	998	9.98
Wheat	910	9.1

Source: Ethiopia Seed Enterprise; US$ 1 = 12.57 birr

Seed systems in Mali

Liberalised seed production in Mali is at infancy. After many years of state control, the Government decided to transfer the seed production responsibility from the National Seed Service (NSS) to six apex cooperatives in 2006. Three of these cooperatives are producing sorghum seed. The breeder seed is acquired from IER. The National Seed Service has the responsibility of multiplying foundation seed which is then passed on to farmer cooperatives and private seed producers for multiplication. The apex cooperatives then produce seed on contract from primary cooperatives. There are 138 primary cooperatives in Mali. Figure 9 demonstrates the seed supply chain in Mali.

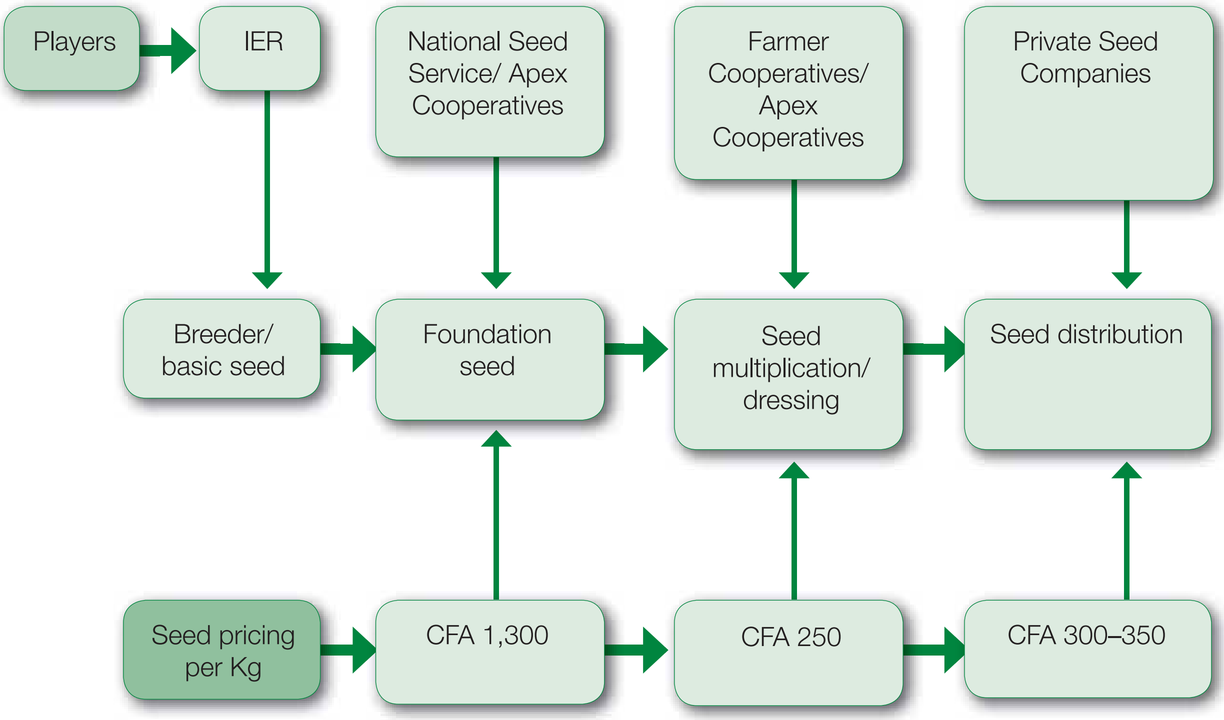


Figure 9. Seed supply chain in Mali

(Source: Authors' compilation)

Sorghum seed production represents about 10% of the total seed production as shown by Table 8. The most important crops are rice, maize and cotton. The formal seed system in Mali is evident in maize while the informal system spreads across all crops in the country.

Table 8: Seed production in Mali in 2009

Crop	Metric tonnes
Rice	2,609
Maize	950
Sorghum	117
Millet	125
Groundnut	10

Source: National Director of Agriculture

In the informal seed systems, the farmers' source their seed from their own stock, saved "seed" from the previous season's harvest and from other farmers[6]. A farmer's reputation in supplying good seed is the main reason for another farmer paying a higher price for seed than grain. NGOs and religious groups also help in distributing seed of new varieties. But most of these interventions tend to be *ad hoc*. The sorghum seed industry is weak hence there

6 An interview with scientists at IER in December 2009 revealed that farmers emphasise on availability and convenience as the main advantages of keeping their own seed. In some cases, the shortage of cash at planting time and a lack of confidence in the formal seed sources makes farmers continue using the informal seed system.

is often no clear set of procedures for obtaining seed of new varieties or even for learning of its availability. An innovative strategy by IER for overcoming some of these difficulties currently involves the provision of small packs of seed of new varieties. The strategy attempts to bridge the gap between farmer interest in seed of new varieties and the commercial potential for seed production. In 2009, some small seed companies in Mali received an AGRA grant under the Program for African Seed Systems (PASS). AGRA's initiative supports small seed companies and their networks of agro-dealers to sell small quantities of seed through local shops, extension agencies, NGOs or other local outlets as part of a seed production scale-up initiative. Faso Kaba is one of the smallscale seed dealers that received a two-year financial support of US$ 200,000 from AGRA to scale-up its seed dealership activities. Table 7 summarises seed production by the three cooperatives in Mali.

Table 9: Cooperative sorghum seed production (kg) in Mali

Cooperative	Year				
	2004/05	2005/06	2006/07	2007/08	2008/09
Samanko	1,771	3,240	784	851	1,664
Pessoba	2,631.5	4,003	857	1,400	1,898
Babougou	16,223	17,618	2,410	1,237	1,715

Source: Authors' compilation

In 2008, FASO Kaba sold 180MT of seed of which 10MT were of sorghum. The company has five agro-dealers in the farming regions of the country. Faso Kaba deals in four sorghum seed varieties: CSM 63 (Djakunbe), CSM388, Gringan and CE151-262 (IRAT204). Another seed company in Mali, Comptor, established in 1994 (specialising in agro-chemical distribution) but also dealing in seed, was of the view that any chemical that can control *Striga* will be welcome by farmers as *Striga* is a major constraint.

Seed pricing in Mali

The breeder seed is obtained from NSS or EIR at CFA 1,300/kg. After the cooperatives multiply the seed, they sell it to seed companies at CFA 250/kg who then sell to farmers at CFA 300-350/kg. Farmers complain the price of seed is too high and would prefer to pay between CFA 150 and 200/kg. The price of the grains is usually a third of that of the seed and this increases temptation to use grain instead of seed. Lack of seed dressing also makes it difficult for farmers to differentiate seed from grain.

Seed systems in Nigeria

Like in the other three countries, the cereal seed system in Nigeria is not well developed both in volumes of production and seed delivery. In particular, seed companies are not well organised. The demand for improved sorghum seed is also low.[7] This disparity compounded by lack of clear distinction between the seed and the grains encourages farmers to use retained seed. The other contributing factor for use of retained seed is the fact that the seed system

7 http://www.agr.hr/jcea/issues/jcea7-3/pdf/jcea73-15.pdf

is not well organised to promote use of improved seed. The study noted that formal seed uptake in Nigeria is about 2-5%.

The breeder seed is sourced from the research institute while the foundation seed is bought by private seed companies (such as Alheri) from the National Seed Service (NSS). The National Seed Service has the responsibility of producing foundation seed. Alheri is a smallscale seed dealer located in Zaria, Kaduna and was established in 1997. It also acts as a broker of sorghum grain for malting and brewing companies. Its sister company, All Green was started in 2005 and works on the seed value chain. Alheri supplies these companies with quality sorghum grains.

The seed companies intermediate between seed production and malting or beer brewing companies. For instance, Alheri provides technical back-up to farmers through the sister company, All Green Limited. All Green Limited supplies OPV seed to farmers from their production system on contract. In 2009, Alheri sold 30MT of seed to farmers and its target is to purchase 3,000MT of grain at the end of the cropping season.

Seed pricing in Nigeria

The price for seed is 100 naira/kg, but they supply their farmers at 80-90 naira/kg and on credit. The grain price has been as follows 43 naira/kg in 2008, and between 42-43 naira/kg between 2005 and 2007. This is a major disincentive for farmers considering the seed is not dressed. The seed price is therefore twice that of grain as illustrated by Table 10.

Table 10: Comparison of seed and grain pricing in the three study countries (US$/kg)

Country	Grain price	Seed price	Price difference (%)
Ethiopia	0.15	0.53	253
Mali	0.15	0.77	413
Nigeria	0.32	0.67	109

Source: Calculations based on price data from the field
Note: Mali's grain price is based on data from FAOSTAT. Grain price is the farm gate price of sorghum. For Ethiopia, the grain price is an average of various sorghum varieties.

There is significant difference between the grain price and the seed price for sorghum in the study countries. The Nigerian price difference is comparable to other observed seed pricing in other countries. The Mali pricing is therefore most worrying and farmers have already complained of the high seed prices.

Seed policy and regulations

Basic seed regulation: The justification of basic seed regulation in SSA is to overcome market failures because markets are not yet sufficiently developed; and some type of third-party regulation is required. However, the performance of most seed regulatory systems in SSA need improvement in terms of variety and seed quality as well as cross border trade. Variety release regulations generally require a set of trials, over several years, to ensure that a new variety is acceptable on the basis of meeting minimum standards and the requirement that it outperforms existing varieties. The rigour in the requirements has implications for the authority's capacities to understand the precise farmer priorities and conditions under which the variety will be grown.

Variety release system: In the past few years there has been a tendency for the rigour of the examination to be relaxed to "let the market decide" even in the nascent formal seed systems. But many variety release systems in SSA still face several challenges. First, there are many instances of bias although most national systems are theoretically open to varieties from other countries and from the private sector. Second, the technical competence of the regulatory procedures needs examination especially in providing adequate testing of a range of varieties, destined for a wide variety of farming environments. A third challenge is the high cost of variety testing in several years of trials in a number of locations. For orphan crops like cowpea, sorghum or millet, where perhaps only one or two new varieties will be available to test, the per-variety cost, and the lack of financial support, impedes progress towards release and dissemination.

Seed certification: With the development and diversity of small and medium seed enterprises in SSA, the challenges of seed certification are multiplied as agencies now have a wide variety of clients. In most cases the resources devoted to seed certification are inadequate, jeopardising the performance and reputation of national seed industries. Although there have been attempts to deregulate the seed industry by allocating some tasks to seed companies, extension staff or private agencies, it is difficult to consider these options until there is a clear idea of what the costs are and who will pay them. In most countries in SSA, a review of certification and quality control options is needed.

Regional harmonisation: In the past decade there has been a great deal of donor pressure for seed regulatory reform and some progress has been made. Moves toward regionally harmonised variety release procedures have been responsible for some increased agility in variety approval (Maredia et al, 2009). Similar moves to harmonise seed certification probably show less progress due to procedures that are badly managed and inadequately funded in the individual countries. This is attributed to intense conservatism of almost everyone involved from threat to positions of regulatory agencies to policymakers worrying that something will go wrong under a more relaxed regime. It will take pressure from the industry and from farmers to make significant progress. There are also several issues related to seed regulation that affect regional trade. Seed is subject to phyto-sanitary regulation, and there have been efforts at regional harmonisation, but seed is still often held up at borders for not having adequate resources for an inspection and/or the delay as an excuse for rent-seeking by customs officials. Therefore, regional seed harmonisation collaboration should be a high priority in SSA.

Towards viable seed systems for HR sorghum

In light of policy, research and implementation challenges of sorghum seed systems in SSA, a successful deployment of HR sorghum varieties will require a two-pronged approach:

one, a short term commercialisation strategy of promoting hybrid HR sorghum varieties for industrial use, and two, a medium to long term food security. The two strategies would require working with national seed systems, including regulatory and registration agencies and the extension agencies. The project should collaborate with pesticide and chemical control agencies to ensure fast tracking of approvals for use of the chemicals. In addition there will be need to build capacities of the seed companies that would multiply, dress and distribute the HR sorghum seed. The capacity of seed stockists and farmers in handling the HR sorghum to avoid contamination of other seed will also need to be addressed.

In the short term, Du Pont can introduce the HR sorghum hybrids through the NARS or the seed companies, and conduct performance trials. The seed can then be multiplied and dressed through specifically contracted seed companies. To promote adoption of the HR sorghum, the project could start by pre-financing some seed to contracted farmers linked to large sorghum consumers such as breweries, malting and food processing companies. In the long term, the project should introduce the preferred trait in HR sorghum into the farmer preferred varieties. In both cases, the project would need to invest in development of the sorghum value chain to increase commercialisation of sorghum production which is necessary for increased adoption of HR sorghum.

Safe deployment of HR sorghum

This section examines whether deployment of HR sorghum would lead to adverse effects on human health, agriculture and the environment. This examination is mainly based on risk assessments done on Imazapyr by the USA Environmental Protection Agency (Enntrix3-Report) and from evaluation done by Pless P D et al (2005) in California, USA on Imazapyr application for control of non-native, invasive Spartina in estuarine habitats in Washington State.

The mechanism of action of Imazapyr and its effects

The mechanism of action of a herbicide is the biochemical or physical method by which it causes the suppression of growth or death of specific plants. Imazapyr herbicides are systemic broad-spectrum herbicides that are applied to, and absorbed by, roots and foliage and are rapidly transported via the plant's phloem and xylem to its meristematic tissues or growing regions. Both herbicides block a specific enzyme in the synthesis of certain amino acids in plants. The ensuing disruption of protein synthesis leads to interference in cell growth resulting in chlorosis and tissue necrosis of new leaves. Imazapyr inhibits an enzyme in the biosynthesis of the three branched-chain aliphatic amino acids valine, leucine and isoleucine (BASF, 2004.) Because animals do not synthesise branched-chained aliphatic amino acids but obtain them from eating plants and other animals, the engineered mechanism for plant toxicity (that is the interruption of protein synthesis due to a deficiency of the amino acids valine, leucine and isoleucine), is not generally relevant to birds, mammals, fish or invertebrates.

Environmental fate in air, soil, water and biological tissues

The environmental fate of herbicides, adjuvants or their mixtures is determined by the physical or chemical characteristics described above and the conditions of the environmental compartments or media (air, water, soils, sediments and biota). The fate of Imazapyr after application varies with environmental conditions. The movement through the environment of the weak acid is primarily determined by the pH of the environmental compartments.

(i) Air: Because the vapour pressure and Henry's Law constant for Imazapyr are very low, the fate pathway of this herbicide through volatilisation is non-existent.

(ii) Soils: Imazapyr is relatively mobile in soils because it adsorbs to soils and sediments only weakly. Adsorption increases with decreasing pH. Above a pH of 5, Imazapyr is ionised and does not adsorb to soil. Volatilisation of Imazapyr from soil is insignificant. Aerobic degradation in soils occurs primarily by very slow microbial metabolism with quinoline as the main metabolite. Anaerobic metabolism in soils appears to be insignificant.

(iii) Water: In water, Imazapyr rapidly degrades via photolysis. A number of field studies demonstrated that Imazapyr rapidly dissipated from water within several days and no detectable residues of Imazapyr were found in either water or sediment within two months. In estuarine systems, dilution of Imazapyr with the incoming tides contributes to its rapid dissipation. This suggests that Imazapyr is not environmentally persistent in the estuarine environment and does not result in material impacts to water quality.

(iv) Biological tissues: Imazapyr has a very low propensity to bio-concentrate or bio-accumulate as indicated by its low log Kow of 0.22 and its calculated BCF of 3. Several freshwater pond studies with a variety of fish, a crustacean and a mollusc confirm these theoretical conclusions for aquatic organisms. (Entrix 10/03, p 39). In plants, Imazapyr residues decline rapidly in the first 24 hours following foliar application with the parent compound remaining as the major residue. Half-lives in plants have been determined to vary from 15 to 37 days. (Neary & Michael, 1993; Knisel et al, 1992; both in SERA 12/04).

Toxicity

There are various ways of measuring toxicity that have been developed. Results from toxicity studies are typically provided as so-called effect concentrations (EC) causing a certain percentage inhibition of a process. According to EPA ecotoxicity criteria, Imazapyr is considered practically non-toxic to mammals via oral or dermal administration based on acute and chronic studies conducted with a variety of mammalian species. For example the reported acute oral LD50 for technical Imazapyr in rats is greater than 5,000mg/kg body weight (bw). Rats were observed to rapidly excrete Imazapyr in urine and feaces with no residues detected in their liver, kidney, muscle, fat or blood. No observable effect was noted for any formulation of Imazapyr administered dermally. Chronic and sub-chronic toxicity studies with Imazapyr in dogs, mice and rats did not suggest any systemic toxic or carcinogenic effect. Based on the US EPA ecotoxicity classification for insects, Imazapyr is practically non-toxic to bees. Most toxicity testing of herbicides uses either the technical grade active ingredient or its formulations. However, toxicity to non-target organisms may change depending on the adjuvants contained in the tank mix. Many adjuvants can produce wide-ranging effects on physiological and metabolic processes and almost all of these effects can occur at low concentrations or doses. (Tu et al, 2001). The risk of Imazapyr surfactants to insects and fish were characterised as insignificant in the Enntix3 report. The overall weight of evidence from this report suggests that Imazapyr herbicides can be a safe, highly effective treatment for control and eradication of *Striga*. Based on the evaluation presented in the Spartina report, it can be concluded with reasonable certainty that the use of Imazapyr herbicide for *Striga* control may not result in any significant adverse impacts to human health, agriculture and the environment. However, it is important to realise that some plants have developed resistance to ALS-inhibitors.

Risk management

Different risks arise at different steps of the development and deployment of the HR sorghum varieties. It would be important to develop capacity for risk management with key methodologies for risk identification, assessment and management at the development, testing and deployment stages of the herbicide resistant varieties. Post-release stewardship of the herbicide resistant varieties should be a high priority once it is proved that the herbicide resistant sorghum variety does not pose any adverse effects to the environment including human health. Table 11 summarises the risk factors, their consequences and preventative actions for the HR sorghum.

Table 11: Risk analysis

Risk factor	Consequence	Preventative action
Performance risk Treatment may not give expected results.	The herbicide doesn't kill the *Striga*. No significant yields realised.	- Evaluation should be tried in several locations to ascertain effectiveness on the herbicide treated seed.
Environmental risk - Soil degradation or harmful effects on other crops and sorghum varieties grown by farmers who are also cultivating the herbicide resistant variety.	- Potential negative effects on soils and other crops grown by farmers including other sorghum varieties.	- Assess and mitigate potential effects of the herbicide on soil and other crops - Determine if there are any significant residues of the herbicide in the grain of the herbicide treated varieties.
Economic/market - Limited purchasing power of farmers and consumers. - Failure of the herbicide resistant variety to achieve a significant market share. - Failure to get market acceptance.	- Targeted smallholder farmers limited. - Lack of profitability. - Sales will be low or not occur.	- Build strong value chains in the herbicide resistant varieties. - Develop herbicide resistant varieties that are acceptable in the market. - Maintain low overheads in seed production.
Partnerships - Failure to go ahead with current venture.	- Delay in project activities. - Postponement of income or revenue.	- Identify alternative partners and distributors.

Source: Authors' compilation

To manage and minimise the risks, there will be need to work with established national and regional institutions. In West Africa, the Sahel countries have an established Pesticides Scientific Committee which approves introduction of new pesticide control technologies in the region. A 2-year testing for efficacy can be done in any of the Sahel countries. Phyto-sanitary and agro-ecological testing is also carried out by the Sahel Committee Phyto-sanitary Secretariat. The committee has two experts per country, plus three independent toxology experts from outside the Sahel. This committee would be a useful partner in the development and testing of this herbicide technology. A provisional authorisation can be obtained for a period three years after initial testing and is renewable for a further three years after a registration certificate for five years is issued. After the five years, a timeless certificate is issued. Within this period the committee monitors the efficacy of the pesticide on environment and other effects.

Based on this scenario, a six year programme for the herbicide evaluations, testing and deployment is recommended. This can be done in the following phases: on-station evaluation for a minimum of two years, multi-locational testing for a period of two years and farm level testing for two years. Within this period, capacity at different levels should also be provided (viz at research in terms of training and laboratory facilities, seed companies in terms of seed dressing technologies, and handling of the herbicide including load levels). Capacity building of target farmers should also be done.

Project stewardship

Stewardship in this regard is viewed as a process that identifies and reduces public and environmental risks at every stage of the product life cycle. It is also a way of conducting business that lessens negative impacts on the people, animals and the environment in general. Stewardship thus contributes to the sustainable use of products and demonstrates responsibility for product development and deployment.

The introduction of herbicide technologies especially in form of dressed seed may have environmental and other safety concerns. Economic, marketing and consumer preference as well as food, feed and environmental safety aspects must be actively managed early in the process of testing the herbicide treated seed to ensure safe delivery of the product to end users.

AATF will have to develop a clear strategy for promotion of the herbicide resistant varieties and work closely with NARS who produce the breeder seed, the seed companies that produce the foundation seed and the companies that multiply, clean, dress and distribute the seed. A clear monitoring strategy for the performance of the product will also need to be developed as part of the product development, testing and deployment business plan.

The proposed stewardship programme for AATF and its partners builds on their experience of implementing IR maize in Kenya and will involve the following five steps: 1) partnership arrangements and IPR issues, 2) HR sorghum technology development, 3) creation of awareness and demonstrations, 4) HR sorghum seed production and distribution, and 5) monitoring and evaluation.

Step 1: Partnership arrangements and IPR issues

- The success of HR sorghum will require well networked shareholders (including DuPont, Universities of Purdue and Kansas State, ICRISAT, NARS and local seed companies and their agro-dealer networks) for effective technology development and deployment in terms of roles and resource matching.
- Making HR sorghum seed to be widely affordable and managing farmers' relationship with seed companies and multinational corporations.
- A negotiated IPRs-process involving DuPont, ICRISAT and the NARS for incorporating the desired traits into farmer preferred varieties.
- Encouraging farmers to join farmer organisations to explore economies of scale in acquisition of inputs and advisory services as well as marketing of farm produce.

Step 2: HR sorghum technology development

- Research is required on HR sorghum technology.
- NARS to incorporate farmer knowledge, habits and practices.
- NARS to improve capacity for *Striga* characterisation, HR sorghum seed supply, and monitoring and evaluation of technology delivery systems.
- HR sorghum seed will be treated with fungicide and insecticide like all other commercial sorghum seed. However, unlike such seed treatments, dressing of HR sorghum requires separate lines. It also requires capacity training in seed dressing, safe storage and distribution.

Step 3: Creation of awareness and demonstrations

- Facilitating on-farm demonstration and awareness programme among some farmers.
- HR sorghum seed can be planted along with the already known *Striga* suppressive legumes, such as soybean, cowpea and groundnuts which together reduce the impact of *Striga*.
- Coating seed with herbicides poses a threat to farmers if not handled carefully because farmers can destroy their own seed simply by not washing their hands properly after coming into contact with HR sorghum seed.
- Translating the user guidelines in local languages in order to reach out to more farmers and hence, enhance learning and knowledge sharing.

Step 4: HR sorghum seed production and distribution

- Facilitating production of certified HR sorghum seed.
- Distribution of HR sorghum seed to stockists and farmers.
- Training stockists on separate storage and safe handling of HR coated seed to avoid threat to or of contaminating other seed.
- Facilitating farmer adoption of this technology and their incorporation into smallholder production practice and ensure the entire technology package is adhered to.
- This information should also be communicated to extension officers for greater diffusion.
- Need to facilitate privately owned companies and local small-scale entrepreneurs to engage in HR sorghum seed distribution.

Step 5: Monitoring and evaluation

- Assessing compliance among farmers and stockists.
- Facilitating training workshops for farmers and stockists and obtaining feedback from farmers using the new technology.
- Providing support for responsible deployment of HR sorghum technology which includes meeting certain requirements to qualify as a seed producer or distributor of HR sorghum seed varieties.
- *Striga* can develop resistance to the herbicide hence the need to consider HR sorghum technology as a short term strategy which requires farmers to integrate the technology with other existing methods for effective *Striga* control.
- The herbicide is a poison, and its widespread use may have health and environmental impacts that cannot be ignored.
- Other environmental risks include contamination of ground water and killing other non-target species the chemical comes into contact with.

In summary, the deployment stage of HR sorghum varieties will involve building the capacity of the seed companies, farmers and seed inspectorate departments in the target countries. The extension services to farmers will also have to be strengthened to ensure that farmers adhere to recommended agronomic practices. Public awareness in the *Striga* affected areas about the benefits of the herbicide resistant varieties accompanied by a strong seed delivery system will have to be made. Awareness creation will take a number of forms including field demonstrations, strengthening of the private and public sector extension systems, development of a strong communication strategy for delivery of the technology, and value chain development. The value chain, linking breeders, seed companies, seed inspectorate, farmers, and markets will also have to be strengthened if the full benefits of the technology will be realised. Extension packages will also be developed with clear messages on appropriate agronomic practices and safe handling of the herbicide treated seed.

Cost-benefit analysis of deployment of herbicide resistant sorghum

Cost-benefit analysis is a powerful tool for estimating project benefits by comparing the stream of costs and cash returns (revenues) over the project period. It is useful in assessing when the project will start to accrue positive benefits. To undertake a cost-benefit analysis, one would need to get a good estimate of the project costs (fixed and variable) over the project period. The returns are the cash flows emanating from the sale of the project products.

In this particular project, the costs are for development, testing and deployment of the herbicide resistant sorghum seed. To estimate these costs the following cost items have been considered: capacity building costs of seed companies, seed stockists, farmers, NARS, seed inspectorate, extension staff; stewardship costs; and technical backstopping costs. The costs are for year one to six of the project period. In addition, costs of seed production and dressing in three selected countries over a period of six years have been included. Seed dressing and deployment starts in year four of the project. The six-year project is estimated to cost US$ 7.6 million. In addition, costs of the seed production, dressing and deployment are included. In calculating the project benefits, it would also be important to consider the current losses of sorghum associated with *Striga* in order to appreciate the benefits that would accrue from the application of the HR technology. The current sorghum losses in Ethiopia, Mali and Nigeria are estimated at 25%, 40% and 35% respectively (see Table 6; Gressel et al 2004). This translates into annual losses of 500MT for Ethiopia, 580MT for Mali and 3,750MT for Nigeria. Given farm gate prices of US$ 0.15/kg, US$ 0.15/kg and US$ 0.32/kg for Ethiopia, Mali and Nigeria respectively, which are FAO producer prices eight year average[8], the annual loss translates to US$ 75 million in Ethiopia, US$ 87 million in Mali and US$ 1.2 billion in Nigeria.

The project benefits are calculated as stream of value of sorghum arising from yield gains from use of herbicide treated seed in the three countries. Additional benefits accrue from savings on labour cost previously used in *Striga* weed control. Two scenarios of herbicide treated seed production and deployment in each country illustrated in Table 12 are assumed in making these calculations. Under scenario I, the seed quantities are based on current improved seed production levels in each country, and the level of commercialisation of sorghum that is likely to drive the demand for improved seed. The other consideration is that the herbicide will only be used in treating selected varieties that prove to be herbicide resistant and have public demand.

Under scenario II, it is assumed that the herbicide seed adoption will be double that of scenario I, through higher investment in promotion of the herbicide treated varieties.

8 The Nigerian price is consistent with that paid by Al Heri Seed Company in 2007 for farm-gate price of grain at equivalent of US$ **0.3/kg**, while that of Ethiopia is half the price reported in Wollo Region in 2009 (equivalent of US$ 0.4/kg – average farm price of the various types of sorghum).

Table 12: Herbicide seed deployed per year (MT)

Country	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Scenario I						
Ethiopia	140	200	250	300	400	500
Mali	140	200	250	300	400	500
Nigeria	1,000	2,000	4,000	5,000	6,000	7,000
Scenario II						
Ethiopia	280	400	500	600	800	1,000
Mali	280	400	500	600	800	1,000
Nigeria	2,000	4,000	8,000	10,000	12,000	14,000

Source: Authors' compilation

Assuming a seed application rate of 12kg per hectare, Table 13 shows the number of hectares that can be planted with the HR seed per country under the two scenarios. Under scenario I, the area under the herbicide seed as a percentage of area under sorghum in each country will be 0.8% in Ethiopia, 1.2% in Mali and 1.1% in Nigeria in the first year of seed adoption. This increases to 2.8% in Ethiopia, 4.1% in Mali and 7.5% in Nigeria in the sixth year of seed adoption. Under scenario II, the area will be double that under scenario I.

Table 13: Number of hectares to be planted with herbicide seed per year

Country	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Scenario I						
Ethiopia	11,667	16,667	20,833	25,000	33,333	41,667
Mali	11,667	16,667	20,833	25,000	33,333	41,667
Nigeria	83,333	166,667	333,333	416,667	500,000	583,333
Scenario II						
Ethiopia	23,333	33,333	41,666	50,000	66,667	83,333
Mali	23,333	33,333	41,666	50,000	66,667	83,333
Nigeria	166,667	333,333	666,667	833,333	1,000,000	1,166,667

Source: Authors' compilation

The application of the herbicide resistant seed is expected to increase yields of sorghum depending on the level of protection the herbicide is likely to have. In the following analysis, three levels of protection (that is 90%, 80% and 70%) from the herbicide treated seed is assumed. This allows for the calculation of the different yield gains likely to be achieved by adopting the herbicide treated seed. To restate the situation, the current losses due to *Striga* are estimated at **25%**, **40%** and **35%** in Ethiopia, Mali and Nigeria respectively. Given this level of losses, if 90% protection is achieved by using the herbicide treated seed, then the losses would decline to 2.5%, 4% and 3.5% in Ethiopia, Mali and Nigeria respectively (Table 14).

Table 14: Sorghum yield losses under different levels of herbicide protection

Country	Current loss (%)	Loss with		
		90% protection (%)	80% protection (%)	70% protection (%)
Ethiopia	25	2.5	5.0	7.5
Mali	40	4.0	8.0	12.0
Nigeria	35	3.5	7.0	10.5

Source: Authors' compilation

The percentage yield gains from use of herbicide treated seed are calculated for different levels of effective *Striga* control and presented in Table 15. In this case, if the herbicide treated seed is able to provide 90% effective control of *Striga*, the resulting yield gain would be 22.5% in Ethiopia, 36% in Mali and 31.5% in Nigeria.

Table 15: Percentage yield gains from different levels of herbicide protection

		Gains		
Country	Current loss (%)	90% protection (%)	80% protection (%)	70% protection (%)
Ethiopia	25	22.5	20	17.5
Mali	40	36	32	28.0
Nigeria	35	31.5	28	24.5

Source: Authors' compilation

To compute the new yields achieved by using the herbicide treated seed, in MT/hectare, the percentage yield gains to current yields per country is applied as reported in Table 2 (Ethiopia 1.335MT/ha; Mali 0.7912MT/ha; and Nigeria 1.183MT/ha). The new yield levels for different levels of protection are presented in Table 16. In this case assuming a 90% level of protection, the new yield for Ethiopia would be 1.635MT/hectare up from the current yield of 1.335MT/hectare, representing a yield gain of 0.3MT/hectare. The actual yield gains in kilograms per hectare are reported in Table 17.

Table 16: Achieved yields using herbicide treated seed ***(tonnes)***

	Yield with herbicide treated seed		
Country	90% protection	80% protection	70% protection
Ethiopia	1.635	1.600	1.569
Mali	1.076	1.044	1.013
Nigeria	1.556	1.514	1.473

Source: Authors' compilation

Table 17: Yield gains in kilograms per hectare

	Actual yield gains per hectare (kg)		
Country	**90% protection**	**80% protection**	**70% protection**
Ethiopia	300	265	234
Mali	285	253	222
Nigeria	373	331	290

Source: Authors' compilation

Using the farm-gate orproducer prices reported for each country (US$ 0.15/kg for Ethiopia and Mali and US$ 0.32 for Nigeria), the yield per hectare gains are then translated into monetary values and reported in Table 18 for different protection levels.

Table 18: Value in US$ of yield gains per hectare under different protection levels

	Value in US$ of yield gains per hectare		
	90% protection	80% protection	70% protection
Ethiopia	45.00	39.75	35.10
Mali	42.75	37.95	33.30
Nigeria	119.36	105.92	92.80

Source: Authors' compilation

The value of yield gains per hectare are then used to calculate the income gains over the six-year period based on different levels of hectares planted with the herbicide resistant seed, and assuming 90% level of protection as illustrated in Tables 19 and 20. The income gain for the three countries under scenario I are estimated at US$ 10.96 million in the first year of seed deployment, or fourth year of the project period. This increases to US$ 73.273 million in year nine of the project or the sixth year of adoption of the herbicide resistant seed.

Under scenario II, the income gains are estimated at US$ 21.951 million in the first year of technology adoption and US$ 83.299 million in the sixth year. Under both scenarios, the income gains far outweigh the project cost in year four, which is estimated at US$ 7.588 million.

Table 19: Scenario I: Income gains assuming 90% protection and different levels of hectares under herbicide treated seed

	Ethiopia			Mali			Nigeria		
	000ha	US$/ha	000US$	000ha	US$/ha	000US$	000ha	US$/ha	000US$
Year 4	12	45	540	12	42.75	513	83	119.36	9,907
Year 5	17	45	765	17	42.75	727	167	119.36	19,933
Year 6	21	45	945	21	42.75	898	333	119.36	39,747
Year 7	25	45	1,125	25	42.75	1,069	417	119.36	49,773
Year 8	33	45	1,485	33	42.75	1,411	500	119.36	59,680
Year 9	42	45	1890	42	42.75	1,796	583	119.36	69,587

Source: Authors' compilation

Table 20: Scenario II: Income gains assuming 90% protection and higher levels of hectares under herbicide treated seed

	Ethiopia			Mali			Nigeria		
	000ha	US$/ha	000US$	000ha	US$/ha	000US$	000ha	US$/ha	000US$
Year 4	23	45	1,035	23	42.75	983	167	119.36	19,933
Year 5	33	45	1,485	33	42.75	1,411	333	119.36	39,747
Year 6	42	45	1,890	42	42.75	1,796	667	119.36	79,613
Year 7	50	45	2,250	50	42.75	2,138	833	119.36	99,427
Year 8	67	45	3,015	67	42.75	2,864	1000	119.36	119,360
Year 9	83	45	3,735	83	42.75	3,548	1,167	119.36	139,293

Source: Authors' compilation

Using the income gains achieved under scenario II, with 90% protection over the project period, the cost-benefit analysis is conducted resulting in a break-even on the first year of adoption with an Internal Rate of Return (IRR) of 160%. Similar results are achieved under scenario I with an IRR of 53% in the first year of technology adoption. It would appear then, this is a project with high economic potential. However, investment in the seed systems, and value chains to improve commercialisation must be studiously pursued. The viability of the technology will also depend on its level of protection against *Striga* and the potential yield gains achieved.

Sorghum provides a major opportunity for farmers in dry areas where there are limited options for cash crops to make income and improve their living standards. In Nigeria where sorghum is widely used in the brewing and malting industry, thousands of farmers are benefiting from incomes from the crop. Based on field data collected during this mission about 152,000MT of sorghum are used in the malting and brewing industry. At 48 naira/kg farm-gate price, this translates to 7.1 billion naira (US$ 47.04 million) in incomes. The use of HR sorghum is also expected to contribute to improved food security and general producer and consumer welfare as a result of high yields. The HR technology would result in increased production at relatively lower costs. This will have the effect of increasing producer surplus and lowering prices for the consumer. Thus, improved food security should result from the adoption of the HR technology. By assuming that profit is an overall welfare indicator, the improved incomes for the sorghum producers and other players along the value chain will translate into improved welfare. The use of the HR sorghum will also reduce the demand for weeding labour in areas where *Striga* control involves weeding at early or late stages of its germination. The labour saved could be used in other productive activities in the farm.

The deployment of the HR sorghum is expected to contribute to transformation of the smallholder agricultural production of sorghum from the traditional subsistence nature to a more commercial undertaking as farmers demand commercial inputs such as HR seed. The smallholder farmer will also benefit from improved linkages along the sorghum value chain, which will result into better trade relations. The share of traded sorghum is expected to increase from successful implementation of the HR sorghum. However, cross border trade in

Ethiopia and Nigeria will remain restricted as long as the ban on export of cereals imposed by the two countries remains in place. To address this potential problem which could negatively affect project implementation, the project would need to enter into dialogue with relevant government institutions to review the policy.

The benefits accruing will depend on how much herbicide resistant seed will be produced and actually adopted by the farmers. This will be influenced by whether the variety which resists the herbicide meets farmer and consumer preferences. The cost of the seed will also play a major factor in determining its adoption. Efforts must be made to keep the cost of the seed to the farmer affordable. The seed system must also be able to support the deployment of the seed. This means the seed industry has the capacity to dress the seed and a good agro-dealer network exists to support the deployment. The three study countries did not have well developed seed systems. For example, in Ethiopia the government still has a strong hold on the seed industry. In Mali, the seed industry is going through liberalisation and there is little private sector interest except in the more lucrative rice and maize. Nigeria has the highest potential for HR sorghum seed because of increased commercial utilisation of sorghum grain in the malting and brewing industry. However, there is need to build the general capacity of producing, distributing and using certified sorghum seed.

Possibilities for fundraising

In many SSA countries, lack of adequate, timely and sustained financial support to the agricultural research and innovation processes have been important reasons for the shortfalls in achieving crucial development goals in terms of productivity, food security, poverty eradication and environmental protection. This problem has been increasingly recognised and a consensus is emerging between SSA governments, multilateral and bilateral donors, and sub-regional and international organisations facilitating agricultural R&D, of the need to urgently address this issue. As a result, new funding opportunities are emerging for supporting the development and deployment of orphan crops such as sorghum and millet. This section tries to review the current status of agricultural research financing for sorghum in SSA with specific focus on Ethiopia, Mali and Nigeria. This information is summarised in Table 21.

Table 21: Sorghum projects funding

Project name/ Coordinator	Key element(s)	Target countries	Funding sources, level (US$) and duration	Project partners
International Sorghum and Millet Collaborative Research Support Program-(INTSORMIL)	- Education. - Mentoring and collaborative research. - Developing new technologies to improve sorghum and pearl millet.	Africa, Central l America, Eurasia and USA	USAID	-
Developing sustainable seed systems to support commercialisation of smallscale agriculture in Sub-Saharan Africa (ICRISAT)	- Promoting sorghum and millet production technologies. - Linking farmer organisations to food and feed processors. - Commercialising processing technologies.	West African region	USAID	-
AGRA's Program for Africa's Seed Systems (PASS)	- Improved crop varieties. - Training of African agricultural scientists. - Better inputs and practices. - Development of stronger off-farm systems and markets.	Africa	Melinda and Bill Gates Foundation (BMGF)	NEPAD/CAADP, NARS, CGIAR, universities, African financial institutions, seed companies, ADB, UN & multilateral organisations
Harnessing Opportunities for Productivity Enhancement (HOPE) of sorghum and millet (ICRISAT)	- Development and delivery of improved crop varieties. - Training in crop management practices. - Development of markets.	Government of India and the CGIAR	Bill & Melinda Gates Foundation (BMGF)	Ten countries of Sub-Saharan Africa and four of South Asia (India)

Source: Field interviews

In Ethiopia, the federal government is providing 95% of the total funding, leaving only 5% for project funding from development partners. The government insists that funding has to come through the national system. In particular, any new funding has to be in line with the national strategies and objectives. Project funding should contribute towards institutional capacity building with respect to human development and infrastructure development.

Thus, the Ethiopian Institute of Agricultural Research (EIAR) receives project funding for capacity building from several collaborative projects. These include the following.

- INTSORMIL: Integrated management in *Striga* control, capacity building and scaling up.
- ASARECA: R&D investment in dry land.
- USAID: Funding sorghum breeding programme and capacity building.
- The New Melinda and Bill Gates Foundation/AGRA: agro-processing and the market side in collaboration with Tanzania and Sudan.

In Mali and Nigeria, the INTSORMIL programme is helping the countries to move from tall Guinean varieties of sorghum to the medium height varieties. Related to INTSORMIL programme is an ICRISAT-coordinated project titled "Developing Sustainable Seed Systems to Support Commercialization of Small-Scale Agriculture in Sub-Saharan Africa". The project promotes advances in agriculture by moving sorghum and millet production technologies onto farmer fields, linking farmer organisations to food and feed processors, and by commercialising processing technologies so as to enhance markets. To achieve this, it improves the supply chain from the farm level to the consumer. The project also promotes improved nutrition and thus contributes to the betterment of human health in one of the most impoverished areas of the earth (Project Quarterly Report January – March 2009). The project works with individual processors, but in one location they are working with women associations. The main products processed are flour and composite flours. The project received additional funding from the Bill & Melinda Gates Foundation that is being used to provide small processing equipment.

The Alliance for Green Revolution in Africa (AGRA) is another initiative working with seed dealers in Mali and Nigeria, among other SSA countries, to build their capacities for efficient seed delivery to farmers. Some of the dealers are already delivering quality sorghum seed to farmers through the support from AGRA's Programme on African Seed Systems (PASS). However, the quantities still remain small and none of the companies has invested in seed dressing technology.

The International Crops Research Institute for Semi-Arid Tropics (ICRISAT), one of the 15 Consultative Group on International Agricultural Research (CGIAR) centers with a mandate for the semi-arid tropics, is implementing a new project entitled "Harnessing Opportunities for Productivity Enhancement (HOPE) of Sorghum and Millets in Sub-Saharan Africa and South Asia". HOPE Project is a five-year project (June 2009 to May 2013) with funding of US$ 18m from the Melinda and Bill Gates Foundation (MBGF). The project aims to increase sorghum, pearl millet and finger millet yields in SSA and SA by 35-40% in the first four years of the project through adoption of improved cultivars. It will enhance complementary management practices in an environment that is enabled and motivated through development of markets for the benefit of 200,000 households. Given the stresses and variability of the rainfed agriculture, HOPE takes an adaptive approach that links market "pull" to technology driven production.

In summary, it is important to point out that the debate on climate change is driving an R&D agenda on developing drought resistant crop varieties. Sorghum is one of such crops. For instance, there is potential for pyramiding (or combining) drought and *Striga* resistance in the development of sorghum varieties as well as increasing collection of germplasm. This is critical work because with climate change, the genetic resources are rapidly disappearing from East Africa which is the centre of sorghum origin, thus there is need to collect, evaluate and characterise germplasm.

This summary of the current status of funding for sorghum research and development in SSA and other areas demonstrates that there are opportunities for AATF to explore options for building linkages in the development and deployment of HR sorghum seed varieties in the target countries.

Summary and recommendations

There is overwhelming evidence that despite advances in the methods of control of *Striga* in sorghum, the weed continues to contribute to high levels of production loss in the crop reversing efforts to fight food insecurity and poverty among millions of the rural poor in SSA. In SSA, the loss associated with *Striga* in cereals has been estimated at US$ 7 billion, while in Ethiopia, Mali and Nigeria the combined loss has been estimated at US$ 1.362 billion per annum based on the FAO 2007 production data.

Previous attempts with herbicide treatment of sorghum have had mixed outcomes, but there is room for further work by drawing lessons from these experiments. One of the observed shortcomings is failure to lead to significant grain yields. The Du Pont herbicide has shown indications of overcoming this shortcoming in its proof of concept. Further work will however need to be done to arrive at optimal herbicide treatment that gives the maximum benefits. Application of the technology on the farmer preferred varieties will improve its adoption. The investment to develop alternative methods of control such as herbicide treatment for *Striga* resistance is therefore a welcome relief to stakeholders in the sorghum value chain. However, this should take cognisance of previous efforts including lessons learned in herbicide treatment for *Striga* control in maize and sorghum. The *Striga* resistant herbicide has already gone through proof of concept, but appropriate levels of application are still to be determined. Field experiments should determine the appropriate herbicide load levels to ensure sufficient quantities to control the *Striga* and low enough not to kill the seed or crop. The other issue is that the herbicide is being tested on a hybrid variety. The recommendation is that this work progresses as planned but with tests being carried out on local preferred varieties. Due to the nature of sorghum varieties, specific trials need to be carried out. Further, this work should be extended to Eastern Africa, especially Ethiopia where sorghum is an important food security crop. Given an earlier partnership between Purdue and EIAR, this should not be a problem. The Management of EIAR welcomed the initiative during the mission to Ethiopia.

The feasibility analysis using different scenarios shows that this technology has economic potential, with cost-benefit analysis showing break-even in the first year of technology deployment with an Internal Rate of Return (IRR) of 160% assuming high levels of seed deployment and IRR of 53% in the first year of technology adoption under lower level of seed deployment. The income gains have been estimated at US$ 10.96 million in the first year of seed deployment or fourth year of the project period in the three countries. This increases to US$ 73.273 million in year nine of the project or the sixth year of adoption of the herbicide resistant seed. The technical viability of the technology is dependent on strengthening the seed supply systems, and the sorghum supply chains through development of reliable market outlets. The HR sorghum should also meet other farmer preferences such as grain food quality and biomass for animal feeds, firewood and construction.

It has been demonstrated that the seed systems in SSA are under developed, poorly capitalised and without outreach networks. This is more so when it comes to open pollinated crops such as sorghum. The delivery of this technology will therefore have to deal with this shortcoming by supporting the development and growth of the seed systems. This is a tall order and it will be prudent to have a well focused results-oriented approach to the development of the seed system to ensure the technology can reach the target farmers. Appropriate stewardship measures will have to be developed to ensure the technology is safely deployed without adverse effects to other crops, human and animal health, and the environment.

The demand for the seed hinges on whether farmers find the treated varieties and indeed sorghum attractive enough to invest in purchased seed instead of the traditional practise of using retained grain. Efforts should therefore be made to address sorghum marketing challenges in each of the target countries. Enhancing the function of the value chain will enable farmers to offload surplus production in the market at a profit. It would be important to build on the on-going initiatives such as the USAID-funded activities in West Africa, and strengthen linkages between malting and brewing companies with sorghum farmers in Nigeria. The emerging demand for sorghum in the brewing and malting industry in Africa should be of particular interest to this project, because it provides a window of opportunity for the commercialisation of the crop. Food security concerns should however, not be relegated to the periphery but should be part of the technology delivery strategy.

From the IR maize experience there will be need to support the seed industry in the participating countries by building their technical, capital and organisational capacity for dressing the seed and associated stewardship for safe delivery and use. Establishing a separate seed treatment line would cost between US$ 30,000 and US$ 50,000.

Given the high cost of the sorghum seed in the surveyed countries, it is recommended that a mechanism to bring down the seed cost be worked out during the project period. Ideally this should involve issues of scale, efficiency in production, cleaning and distribution to minimise on the costs. The cost of the herbicide treatment should also not be prohibitive.

Due to safety concerns and a need to ensure the right amounts of herbicide are applied in dressing the seed, the chemicals will be supplied to seed companies for treatment. DuPont will work out a mechanism through which the chemical can be availed to the local seed industry with appropriate technical information on seed dressing. It is recommended that DuPont and its partners train selected seed companies on the dressing of the seed in the earlier days of technology delivery to ensure effectiveness and safety. Alternatively technical staff could be attached to some of the seed companies for a short period to provide in-house training.

The seed system must also be able to support the deployment of the seed. This means the seed industry has the capacity and finds it profitable to deal in the herbicide resistant seed. The inefficient sorghum value chains will need to be developed to ensure that farmers can offload surplus production at a profit. This is important given the HR technology will require farmers to purchase seed each season. The project should build on the emerging industrial demand in the brewing industry to encourage commercialisation of the crop. Alliances with other commercialisation efforts such as those by USAID in west Africa are recommended.

Table 22: Project budget

			Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9
			('000 US$)								
Capacity of seed companies in five countries											
	Seed dressing lines including installation (in five countries)					275					
	Seed dressing costs (0.25 US$/kg); each country (5) dress 4MT per year					5	5	5			
	Training of seed company staff (US$ 30k/country) in year 1, and 15 in year 2					150	75				
	Basic or foundation seed production (ICRISAT/NARS)					50	50	20			
	Seed multiplication					100	50	50			
Capacity building of seed inspectorate staff											
	Laboratory equipment					300					
	Staff training				100	100					
	Environmental impact assessment (50k per country in year 3 and 40k in year 4)				250	200					
	Seed inspection (testing and certification) - 5k per country/yr					25	25	25			
Capacity for seed stockists											
	Training					25	25				
Capacity for extension staff											
	Training					25	25				
Training and capacity of NARS (Ethiopia, Mali, Burkina Faso, Niger, Nigeria)											
	Short term training in seed evaluation techniques		50	50							
	Sseed evaluation and testing costs		150	150	150						
	Laboratory and equipment supplies		25	10	10						
	Short term training in seed dressing			50							
Capacity building of farmers											
	On-farm trials (from year 3)				375	375					
	Training in agronomic practices				250	250	250	250			
	Cost of seed supplied to farmers in years 4--5						200	200			
AATF	Stewardship costs										
		Advocacy workshops	50	120	200	200	200				
		Monitoring	50	50	50	50	50				
		Technical backstopping									
		Building value chains or market development		150	150	150	150				
		Negotiations and certification by Chemical Control Boards			50	50	50				
Purdue											
	Technical backstopping		50	50	50	50	50				
DuPont/ Kansas											
		Total	375	630	1,635	2,380	1,205	550			
		12% contigency	45	76	196	286	145	66			
		Total project cost (annual)	420	706	1,831	2,666	1,350	616			
Total project cost over six-year period			7,588								

Table 23: Cost-benefit analysis

	(000)US$								
	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9
Project costs	420	706	1831	2666	1350	615			
Private costs of dressed seed (Ethiopia, Mali, Nigeria)				2,344	4,400	8,260	10,280	12,480	37,764
Total project cost (annual)	420	706	1,831	5,010	5,750	8,260	10,280	12,480	37,764
Benefits based on Ethiopia, Mali and Nigeria Investments SCII 90% protection (Table 17)				21,951	42,643	83,299	103,814	125,239	146,576
Benefits based on Ethiopia, Mali and Nigeria Investments SCI9 0% protection (Table 16)				10,960	21,425	41,590	51,967	62,576	73,272
Net cash flows: Scenario II; 90% protection	(420)	(706)	(1,831)	16,941	36,893	75,039	93,534	112,759	108,812
IRR: Scenario II; 90% protection				160%	227%	252%	259%	261%	260%
Net cash flows: Scenario I; 90% protection	(420)	(706)	(1,831)	5,950	15,675	33,330	41,687	50,096	35,508
IRR: Scenario I; 90% protection				53.00%	128%	160%	170%	174%	175%

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List of people interviewed

Dr Adefris Teklewold
Director, Crop Research Process
EIAR
PO Box 2005
Addis Ababa
Tel : 251-11-6454416/ 251-91-111 3190
Email: adechere@yahoo.co.uk/ crops@eiar.gov.et

Dr Fasil Reda
Coordinator
Pastoral, Agro-Pastoral and Developing Regions Research Process and Capacity Building
EIAR (HQ)
PO Box 2005
Addis Ababa
Tel: 09911683917
Email: fasilreda@gmail.com

Mr Abrham Bokan
EIAR (HQ)
Tel: 0911865811

Dr Erinso Degu
Melkassa Research Station
Oromia Region
Nazareth
Tel: 0911627721

Dr Tafesse Gebru
General Manager
Ethiopian Seed Enterprise
PO Box 2453
Tel: 251-11-662 5298/ 251-91 151 1553
Addis Ababa
Email: tafesseg002@yahoo.com/ ese@telecom.net.et

Mr Taye Tadesse
National Sorghum Research Coordinator
Melkassa Agricultural Research Centre
PO Box 436
Melkassa
Tel: +251 221 12 7023
Cell: +251 911 62 77 21

Ms Samayit Yetreberk
Food Technologist
Melkassa Agric. Research Centre
PO Box 436
Melkassa
Email: syetreberk@yahoo.com

Dr Girma Tesfahun Kassie
Agricultural Economist
CIMMYT
Addis Ababa
Tel: +251 911 71 87 89
Email: g.tesfahun@cgiar.org

Dr Bourema Dembele
Weed Scientist
Scientific Director
Institut D'economie Rurale (IER)
PO Box 258
Bamako
Tel: +223 20 22 26 06/ 20 23 1905
Email: bourema.dembele@ier.ml/ dbourema55@yahoo.fr

Dr Tom Van Mourik
Associate Professional Officer
Striga Agronomy in Cereals
ICRISAT Mali
BP 320
Bamako
Tel: + 223 222 33 75
Email: tom.vanmourik@icrisatml.org

Mme Coulibaly Ma□mouna Sidibe
Promotrice/ Directrice
FASO KABA
Si□ge Social; Yirimadio Route de S□gou
Tel: 223 20 20 06 79/ 76282476/ 66715342
Email: fasokaba@yahoo.fr

Mr Abdramane Sidibe
Chef de la Division Legislation et Contrôle Phytosanitaire
Direction Nationale de L'Agriculture
BP 1098, Bamako, Mali
Tel : 223 76 33 52 68
Email: abdramanesidibe@hotmail.com

Dr Mamourou Diourte
Phytopatologiste et Chef Programme Sorgho
Institut D'Economie Rurale
CRR Sotuba
BP 262
Sotuba, Bamako
Mali
Tel: +223 224 60 08/ 224 26 42
Cell: + 223 645 0321
Email: kabarasso@yahoo.fr; mamourou@ier.ml

Mme Yara Koressi
Chercheur Transformtroce Cereales
Institut D'Economie Rurale
CRR Sotuba
BP 262
Sotuba, Bamako
Mali
Tel: 233 66 85 82 91
Email: ykoressi@hotmail.com

Dr Eva Weltzien Rattunde
Principal Scientist
(Sorghum Breeding and Genetic Resources)
ICRISAT
BP 320
Bamako – Mali West Africa
Tel: +223 222 33 75
Fax: +223 222 86 83
Email: e.weltzien@icrisatml.org or e.weltzien@cgiar.org

Abdoulaye Sissoko
Office de Protection des Vegetaux (OPV)
Ingenieur Agro – Formateur
Specialiste de Champ Ecole
Chef Section Lutte Integree
Bamako Rep. Du Mali
Tel Bur: (223) 22 24 04
Mobile: (223) 633 26 22/677 60 87
Email: abdoulayesissoko@yahoo.fr

Diarra Salif
Ministere del'Agriculture
Office de Protection des Vegetaux
Chief Division Etudes – Experimentation
Ingenieur d' Agriculture
Tel: (223) 222 24 04
Cell: 920 04 11
BP: E/281
Bamako, Rep. du Mali
Email: salifdiarrax@yahoo.fr

Direction Nationale de L'agriculture
Ministere del'Agriculture
Division Legislation et Contrôle Phytosanitaire
BP 1098, Bamako Mali
Tel: (223) 220 22 28 77
Cell: (223) 76 33 522 68
Fax: (223) 20 22 400 36
Email: abdramanesatilibe@hotmail.com

Muhammed Jibril
HOD AGRIC
Local Government
Tel: 0803 884 8737 or 0802 778 6300

ALHERI
Engr SD Yakubu Atar
Managing Director/CEO
Head office:
5, Sokoto Road (G.R.A.)
PO Box 472, Zaria
Factory Site
KADP Processing Plant
Tudun Saibu Maigana
Tel: 08037016371/08057746362 Or 08028433820
Email: yakubuatar@yahoo.com

AD Isiaka
Special Project Manager
Da – allgreen Seeds Limited
No. 1 MTD Road
(Opposite MTD Police Barracks Off-G.R.A.) Zaria
Tel: 08023548634
Email: adamuisiaka@yahoo.com

Engr SD Yakubu Atar
Vice Chairman/CEO
Da – allgreen Seeds Limited
No. 1 MTD Road
(Opposite MTD Police Barracks off-G.R.A)
Zaria

Tel: 08037016371/08057746362/
08028433820
Email: yakubuatar@yahoo.com

Monzon Sangare
Reseau Semencier African/ASN
Bureau National du Mali
Ingenieur d'Agriculture et du Gennie Rural
Representant du Reseau Semencier African/ASN-Mali
Bamako – Mali
Tel: (223) 76 45 72 47
Email: sangaremonzon@yahoo.fr

Mme Coulibaly
Maimouna Sidibe
Promotrice/Directrice
Societe Privee de Production et Distribution
De Semences Certifiees de Cultures Vivrieres
Siege Social: Yirimadio Route de Segou
Tel: (223) 20 20 06 79/76 28 24 76
66 71 53 42
Email: fasokaba@yahoo.fr

Mr Diarra Lassana Sylvestre
Chief division Dsai
Entomologiste Expert
Agree en Agr
Ministere del' Agriculture
BP: E/281
Bamako Rep.du Mali
Tel: (223) 222 24 04
Cell: 75142914
Email: lassidiarra@yahoo.fr

Dr Bourema Dembele
Weed Scientist
Scientific Director
INSTITUT D'ECIBINUE RYRAKE
BP: 258
Bamako – Mali
Tel: (223) 20 22 26 06/20 23 19 05
Fax: (223) 20 22 37 75
Email: bourema.dembele@ier.ml
Dbourema55@yahoo.fr

Mr Ali Abdou Gado Toure
Agronome
Directeur General Adjoint
Ministere de l'Agriculture
Office de Protection des Vegetaux
BPE: 281
Bamako du Mali
Tel: (223) 222 24 04 – 222 80 24
Cell: (223) 617 10 60 – 676 45 42
Fax: (223) 222 48 12
Email: aligado59@yahoo.fr

Yala Koreissi
Mph/International Health and Development
Nutrition Specialist
Institut of Rural Economics
Regional Center of Agronomical Research, Sotuba
Laboratory of Food Technology
BP: 262 Sotuba
Tel: (223) 66 85 82 91
Email: ykoreissi1@hotmail.com
ykoreissi@ier.ml

Mr Lanre Ogunbanjo
Life Care Ventures Limited
Managing Director
Corporate Headquarters
Lynson Chemicals Avenue
KM 2 Idi-Iroko Road, Tomori Estate
Sango-Ota, Ogun State
Tel: +234 802 778 3456, +234 177 37 692
Email: o.ogunbanjo@lcvltd.com
info@lcvltd.com
Web: www.lcvltd.com

Dr S Mu'azu
Regional Head
North West
National Food Reserve Agency
Federal Ministry of Agriculture & Rural Development
Kuduna Regional Office
U/Rimi, U/Munchi off Kinshasa Rd.
Kuduna
Tel: 062 – 215357, 238204
Cell: 0803 589 0494, 0805 961 1935
Email: pcurokad@yahoo.co.uk

Mr EI Adole
Regional Coordinator – M&E
National Food Reserve Agency
Nigeria Federal Dept of Agriculture
Plot 2 Road A
Off Kinshasa Road,
U/Rimi
PMB 2277,
Kuduna
Tel: 0803 7882481
Email: inadole2007@yahoo.com

Mrs Tabitha Tummai Buba
Director, Planning Monitoring & Evaluation
Kuduna State Agricultural Development Project
11 Race Course Road
PMB 2269
Kuduna
Tel: (062) 248212, (062) 212117

Aliyu Lubairu
Dir. Adm. Pers. & Training
Kuduna State Agricultural Development Project
No. 11 Race Course Road
Opp. Murtala Square
Kuduna
Tel: 062 – 248212, 062 – 314330
Cell: 0803 4519525

Dr Ahmed Kemoko Diallo
Entomologiste Medical
Professeur d'Enseignement Superieur
Chef Bureau Documentation Information Communication
BPE: 281
Bamako Rep. du Mali
Tel: (223) 222 24 04
Cell: (223) 7 903 23 13
Email: akediall@yahoo.fr

Dr Soualika Boire
Chercheur Entomologiste
Chef Cellule Suivi Environnemental
BPE. 281
Bamako Rep. du Mali
Tel: (223) 222 24 04
Cell: (223) 636 64 87
Email: sboire07@yahoo.fr

Moulaye Mariko
Ingenieur d'Agriculture
Et du Genie Rural
President
Bamako Rep.du Mali
Tel: 76 39 59 75

Abdoulaye Samake
President du Reseau Des Operateurs d'Intants Agricoles du Mali (Oriam)
Societe Malienne Pour I Equipement Agricole
BP: 724 Bamako – Mali
(Afrique de I'Ouest)
Tel: (+223) 66 74 36 49
(+223) 79 14 49 56

Issa Mory Dembele
Directeur
President de I'Association Semenciere du Mali
Comptoir 2000
BP: 2336 Imm.Moctar KONE
N'Golonina
Bamako, Republique du Mali
Tel/Fax: (223) 20 21 36 43
Cell: (223) 66 75 29 73
Email: comptoir2000@datatech.toolnet.org

AFRICAN AGRICULTURAL TECHNOLOGY FOUNDATION
FONDATION AFRICAINE POUR LES TECHNOLOGIES AGRICOLES

P.O. Box 30709–00100, Nairobi, Kenya
Tel: 254-(0)20-422 3700
Fax: 254-(0)20-422 3701
Email: aatf@aatf-africa.org
www.aatf-africa.org