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**Mobilizing Science and Technology for Development: The
Case of the Cassava Biotechnology Network (CBN)**

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Abstract

Cassava is regarded as the crop of last resort for millions of marginal farmers and their domestic animals in tropical regions. Yet, cassava consumption and production in Central Africa, the region where cassava is the most important staple food, is strongly declining and not substituted by any other important food crop. This alarming indication of hunger and malnutrition in this region and its dependence on cassava is rarely covered in the mass media. The Cassava Biotechnology Network (CBN) is counteracting this trend by bundling the scarce resources and uniting the important stakeholders involved in cassava breeding, production, marketing and consumption in and outside Africa with the aim to overcome the basic constraints of cassava as a food and a cash crop. Based on a small expert survey, this article investigates the importance of the problems in cassava agriculture and the approaches considered to be most effective to address them. The paper concludes that CBN represents a successful example of an emerging unbureaucratic, demand-oriented and multi-stakeholder-driven international research network that provides a global public good that is of particular benefit to the poorest regions in the World.

The importance of cassava in Africa

Cassava is produced mostly by smallholders on marginal and submarginal lands in the humid and subhumid tropics. It is efficient in carbohydrate production, adapted to a wide range of environments and tolerant to drought and acidic soils. An estimated 70 million people obtain more than 500 Kcal per day from Cassava and more than 500 million people consume 100 Kcal per day (Kawano 2003). Its ability to grow on poor soils and under difficult climatic conditions as well as the advantage of flexible root harvesting

whenever there is a need¹, make it the ‘crop of last resort’ for farmer families and their domestic animals in the tropics (Hillocks et al. 2001). The importance of cassava as a food crop in Africa becomes obvious when its annual consumption per capita is compared to the rest of the world: While the World average of annual cassava consumption lies around 17 kg/capita in 2001, Africa’s annual consumption is still above 80 kg/capita. Latin America’s consumption has decreased by half over the past 30 years from a peak of above 40 kg/capita in the early 1970s to slightly above 20 kg/capita in 2002.

Figure 1 shows the development and distribution of cassava consumption/capita within Africa: whereas production and consumption of cassava per capita in Africa as a whole slightly increased or at least remained stable, Central Africa experienced a steep decline in consumption and production of cassava for the last 40 years. In Western Africa production and consumption/capita experienced a strong upward trend at the beginning of the 1990s but then remained stagnant; whereas in Eastern Africa, a slight decline in production and consumption/capita can be observed from 1991-1995 which, subsequently reached the previous levels again. The strong decline in Central Africa might be related to plant diseases and pests as well as a breakdown of local cassava trade due to the ongoing civil wars. In spite of this decline Central Africa continues to be by far the biggest consumer and producer of Cassava in Africa.

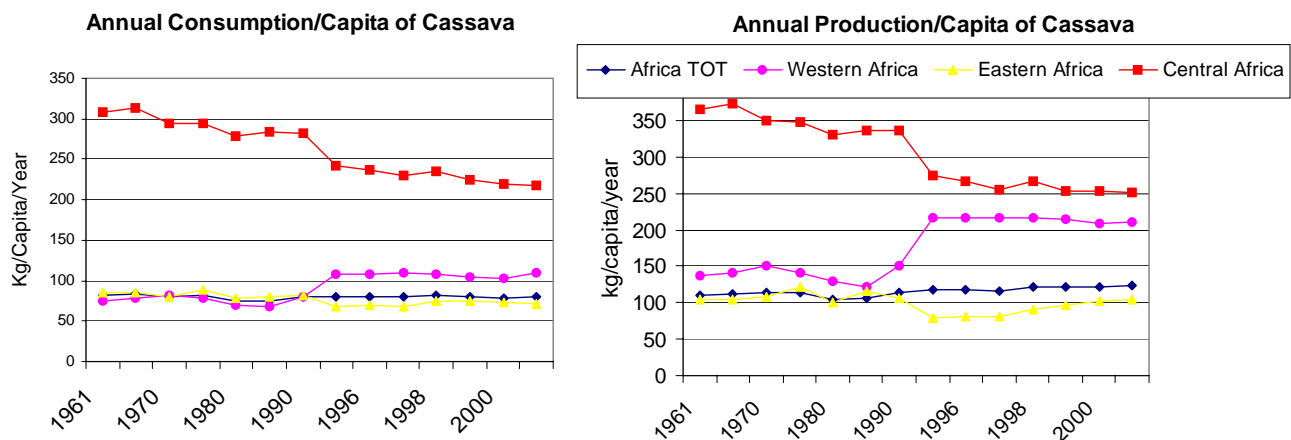


Figure 1: Annual Consumption and Production of Cassava per Capita in Africa²

The decrease in consumption of cassava may be a good sign if it would indicate that people’s daily meals have become less dependent on cassava and more protein-rich

¹ Cassava has no definite maturation point: the root tubers start bulking after about 8 month and can then be stored in the soil for several months. Cassava is therefore the ideal famine reserve (for humans and their domestic animals) and thus an essential food security crop in subsistence farming

² Western Africa comprises: *Nigeria, Niger, Togo, Benin, Ghana, Guinea, Guinea-Bissau, Gambia, Ivory Coast, Liberia, Sierra Leone, Senegal, Burkina Faso, Cape Verde, St. Helena, Mali, Mauritania.*

Central Africa comprises: *Central African Republic, Equatorial Guinea, Dem. Rep. of Congo, Angola, Cameroon, Chad, Sao Tome y Principe, Gabon.*

Eastern Africa: *Kenya, Somalia, Djibouti, Ethiopia, Eritrea, Burundi, Rwanda, Uganda, Tanzania, Madagascar, Seychelles, Comoros, Mauritius, Mozambique, Malawi, Zambia, Zimbabwe*

(cassava provides mostly carbohydrates in form of starch). It is however a matter of growing concern if there are indications that cassava consumption is declining, but not substituted by other food crops. This is likely to be the case in regions such as Central Africa: Figure 2 shows that almost all major food crops are in decline in Central Africa (with the exception of rice, which still provides a very low share of the daily intake of calories).

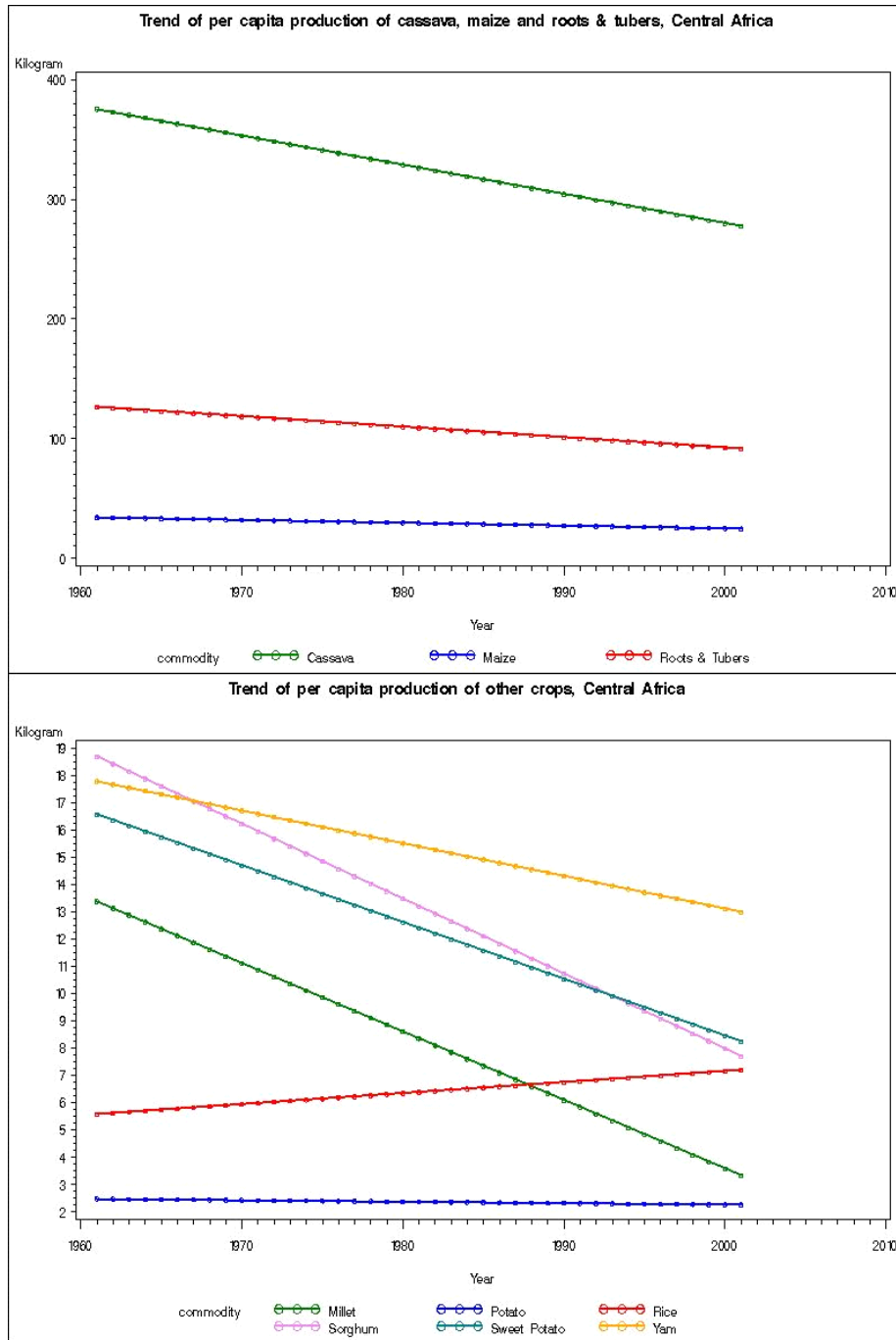


Figure 2: *Production/capita of major food crops. Summary graphs of regression lines of the various crops in Central Africa*³

This is an alarming sign because the decline of cassava cannot just be explained by food crop substitution or diversification. The recent FAO report on Food Insecurity in the World (FAO 2003) also points out that the numbers of undernourished people decreased in Asia and Latin America but increased in Africa, where Central Africa again shows the strongest increase. This tragedy has a lot to do with political instability and the general neglect of Central Africa by foreign donors and investors; in Congo, 1000 times more people die every year than in Palestine, but annual foreign aid designed for Congo amounts to just half of what Palestine receives (Economist 2003). But it is also related to the genetic erosion of traditional crops, poor soils, pests and plant diseases, and lack of access to fertilizer. Cassava continues to be the most important food crop in Central Africa and is strongly affected by genetic erosion, pest infestation and plant disease because it is a vegetatively propagated crop. Cassava generally responds well to irrigation or higher rainfall conditions, and to the use of fertilizers. However, the gap between the yield of cassava harvested under optimal experimental conditions (over 80 tons/he) and the average yield harvested by African farmers of around 8-12 tons/he indicate the numerous limiting factors in Cassava subsistence agriculture (Taylor and Fauquet 1997).

Constraints in cassava subsistence agriculture

Subsistence farmers with poor access to fertile soil, credit, markets and technology are likely to practice low input cassava agriculture. They are particularly exposed to numerous biotic stresses such as pest and disease infestation for they lack the resources to effectively control them. Plant diseases that particularly hit cassava agriculture in Central Africa are the different strains of Africa Cassava Mosaic Virus Disease (ACMV) and the Cassava Brown Streak Virus (CBSV). The most important cassava pests are the mealybug, the hornworm, white flies (which are also an important virus transmitter), and soil-born pests (Phytophthora).

As the crop of last resort it is grown on rather infertile and highly erosive soils and has itself a very poor retention capacity, which is further contributing to the very low yields achieved in the farmer's field, especially in Africa⁴.

Cassava is a perennial food crop that produces roots harvested on average between 8 to 12 months after planting. According to the COSCA study (1996), the late bulking of cassava is perceived to be one of the most important food security problem for subsistence farmers who sometimes need to harvest earlier (in case of crop failure elsewhere). The other complementary food source derived from cassava are its leaves which are rich in protein content. Yet, usually the leaves fall off at an early stage of development and, consequently, are not used as a complementary food dish to the roots. Moreover, the high cyanogenic (HCN) content of 'bitter' cassava, grown in many regions of tropical Africa, render its fresh products (leaves and roots) highly toxic for human

³ Trends for cassava, maize, and roots and tubers was separated from the rest of the major crops because of their relatively large per capita production values. It would therefore be difficult to recognize some important trends if all the crops were combined in one graph.

⁴ Personal communication with Prof. Dr. Emmanuel Frossard, soil scientist at ETH Zurich.

consumption, especially for malnourished people that lack essential sulfur rich amino acids that allow for cyanid detoxification in the body. The result is a neural disease called Konzo that slowly cripples the human body. The fact that bitter cassava is often cheaper and more resistant to pests and diseases makes it increasingly popular with poor cassava growers. This is not a problem if bitter cassava goes through a proper traditional fermentation process that ensures proper detoxification (cooking itself is not sufficient) and increases its storage life. But the increasing demand for cheap cassava in the growing African cities induce cassava producers to shorten the time of the traditional fermentation process from four to two days. Since this leaves detoxification of cassava incomplete it heightens the risk for urban consumers to be affected by Konzo (NZZ 1999).

Considering the importance of cassava as the crop of last resort, the late bulking, its poor nutritional value and toxicity is a matter of great concern and needs to be addressed by encouraging plant geneticists and breeders to develop cassava varieties that have a low cyanogenic content but still maintain their resistance to pests and diseases. Moreover, farmers must be encouraged to adopt and store more protein-rich food sources, and if that is not possible, to seek ways to increase the nutritional value of cassava roots themselves. The lack of nutritional value of cassava roots is a matter of particular concern in drought periods when no other crops are available for immediate consumption.

Once the roots are harvested they need to be processed and consumed within a couple of days for post-harvest deterioration advances quickly (the same applies to the stakes, or stem cuttings, that need to be planted within a few weeks after harvesting). Moreover, cassava-producing areas often lack reliable post-harvest facilities, and infrastructure such as roads, means of communication and input supply systems. These post-harvest and market constraints hamper the development of cassava trade in the tropics significantly and often lead to the situation that any surplus beyond the immediate home consumption becomes waste or manure⁵.

Cassava as a cash crop

By 2005, global cassava trade is projected to increase annually by 1.6% up to 5.8 million tons, reflecting a moderate growth in import demand for cassava feed (used for chicken, pigs, cattle and fish) and other novel cassava food products (cassava instant meals, cassava snacks, and cassava ingredients for sweeteners and prepared foods) and non-food products (starches and flours for sizing textiles and papers⁶ (FAO/IFAD 2001).

The market potential of most of these products remains largely underexploited in the tropics. The rapid post-harvest deterioration of fresh cassava and the labor- and time-intensive processing of dried cassava and cassava starch represent major constraints that put cassava at a disadvantage to other crops designed for starch and animal feed production such as corn. A comparison of cassava and corn in total production and production designed for the animal feed market clearly shows where investments have gone for the past three decades (see Figure 3).

The advantages of cassava as a supplier of high-quality and inexpensive industrial starch and animal feed seemed not to be heeded by the private sector throughout the 1990s since

⁵ Personal communication with Dr. Alfred Dixon, Plant Breeder at the International Institute of Tropical Agriculture (IITA) in Nigeria in November 2003.

⁶ Other cassava products derived from its extraction of alcohol and oil as well as its starch use for biodegradable products are of negligible quantity.

corn has continuously outperformed in these global markets (one exception is Thailand, where cassava has become a competitive export product). Latin American and Asian countries that saw the most conspicuous substitution of cassava by corn in animal feed are particularly concerned because of the growing dependence on US corn imports.

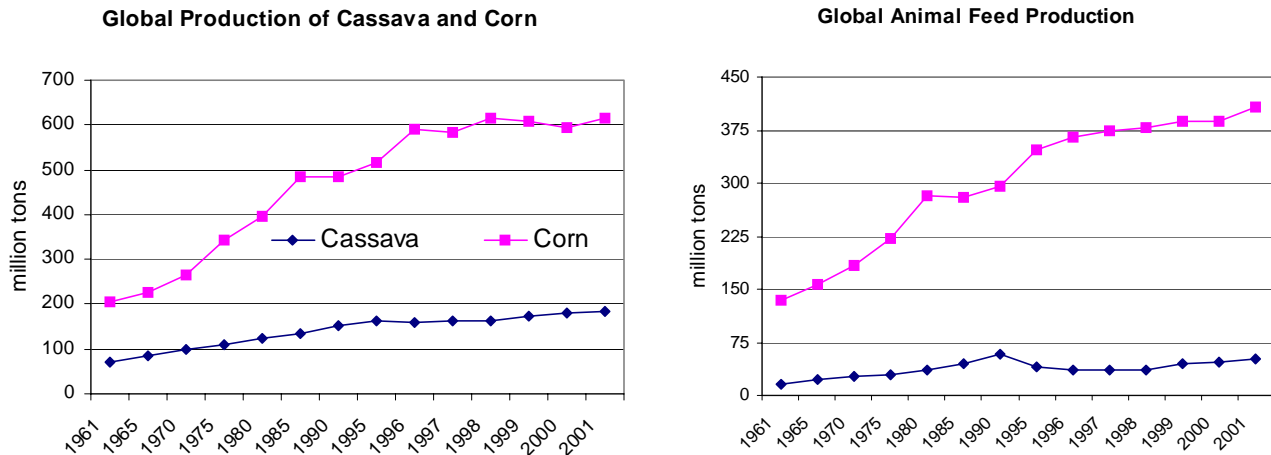


Figure 3: Total production and animal feed production of cassava and corn worldwide

Why promoting cassava

Considering all the physiological, nutritional, agronomic, post-harvest, environmental and marketing constraints of cassava, would it not be better to abandon the crop entirely and encourage farmers instead to substitute cassava for corn or more protein-rich soybean? The problem is that cassava has unique characteristics that help subsistence farmers to deal with extremely high economic, political and environmental uncertainty. Corn may have gained in importance in Sub-Saharan Africa but this is largely a spill-over effect of the large advances in corn breeding and corn market development in the 20th century that was achieved by large public and private investments in the corn business. Cassava has only received a fraction of that attention and thus remained an orphan crop. It is therefore all the more astonishing that its importance has nevertheless grown steadily over the past 50 years. Poor farmers who grow cassava in the tropics have very few incentives to produce more than what is needed to feed themselves and their dependents, because cassava faces too many post-harvest and marketing challenges. So any surplus is basically used as manure. The levels of underutilized cassava in Africa, Asia and Latin America continue to be very high. In Latin America waste even exceeds the amount of cassava used for food consumption (FAO/IFAD 2001).

Cassava would have nevertheless the potential to be a profitable cash crop but the lack of investment in the improvement of its quality and its industrial processing, as well as inadequate post-harvest facilities, market infrastructure development and marketing may make it less competitive.

The case of Thailand proved that cassava can become a profitable cash crop if successful international breeding partnerships for the generation of basic breeding material and a national commitment to applied breeding (distribution and selection of improved

materials) and marketing are combined. Fresh root yield was improved by 100% and root dry matter content by more than 20% (Kawano 2003).

In countries where the commercialization of cassava has reached an advanced stage such as in Thailand, Costa Rica and Brazil, technologies have been developed in recent years that make planting, harvesting and post-harvest processing more efficient and less time-consuming. The efforts to make cassava production more cost-effective may explain the revival of global cassava production designed for animal feed over the last decade, following a remarkable slump at the beginning of the 1990s (see Figure 4

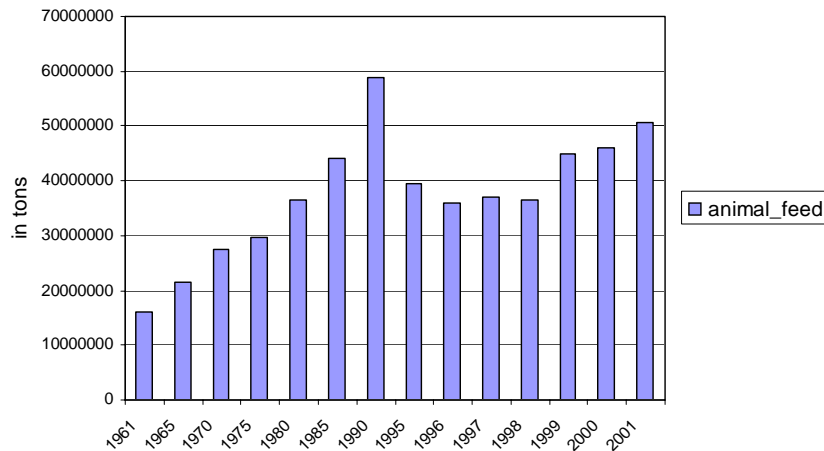


Figure 4: Total World cassava production designed for animal feed

A small survey on cassava problems and solutions

A small survey (including personal interviews) was conducted in November 2003 with cassava experts at ETH Zurich (Switzerland), the International Institute of Tropical Agriculture, IITA (Nigeria), the Donald Danforth Center for Plant Science, DDCPS (USA), the Centro Internacional de Agricultura Tropical, CIAT (Colombia), EMBRAPA (Brazil), as well as representatives from local universities, farmer organizations and multinational companies that collaborate with these institutions. Altogether 26 respondents completed a small questionnaire on the problems in cassava subsistence and cash crop agriculture and the different approaches to solve the respective problems. In addition to this survey, in-dept expert interviews were conducted with experts from different areas of research and business.

The first part of the questionnaire contained a table with a list of problems in cassava subsistence agriculture (mostly biotic and abiotic stress factors). Their importance had to be rated in a scale from one to five. Subsequently the different approaches for solving these problems had to be rated also in the same scale (1 being not useful/important and 5 being very useful/important). In the second part (or table) the rating had to be done for the problems and solutions in cassava commercial agriculture (most post-harvest and marketing problems).

As Figure 5 shows the problems of subsistence and cash crop agriculture listed in the questionnaire tables, as well as the number of respondents that assessed these problems

and the corresponding solutions to these problems. It also shows the institutional affiliation of the participants.

Problems of cassava subsistence agriculture		Cassava cash crop problems	
	<i>Nr of Respondents</i>		<i>Nr of Respondents</i>
Diseases	18.5	R&D	17
Cassava Mosaic Virus Disease		Labor	21
Cassava Bacterial Blight (CBB)		Capital	21
Cassava Brown Streak Virus (CBSV), Fungi, Nematodes Diseases		Land	21
Pests	18.3	Demand	22
Lepidoptera (e.g. Hornborers)		Infrastructure	22
Mites		Market Structure	21
Mealybugs		Input Costs	23
Whiteflies		Storage Facilities	20
Yield	17.3	Processing	21
Low Yield (gap between potential and real yield)		Policy	19
Late Bulking		Investments	19
Leaf senescence		Science Collab.	19
Root Quality	19.3	PP Collab	20
Cyanogenic Glucocides (HCN)		Low Adoption	21
Low starch content		Polarization	16
Low storage life		Starch Comp.	10
Low Protein content		Institutional Affiliation of the respondents	
Abiotic Stresses	16.7	Embrapa (Brazil)	8
Soil nutrient uptake		CIAT (Colombia)	7
drought		IITA (Nigeria)	5
flood		DDCPS (USA)	5
Soil Erosion	15	ETH (Switzerland)	4
Clean Planting Material	13		
		<i>Total</i>	<i>26</i>

Figure 5: *Participation rates in the survey*

Evaluation of the problems of cassava subsistence agriculture

Part 1 of the questionnaire consisted of a list of 20 problems related to cassava subsistence agriculture (the problem of clean planting material was added after suggestions made in the very early stage of the survey). The problems are presented in 5 categories: diseases, pests, yield, root quality and abiotic stresses (plus soil erosion and clean planting material). The importance of the problems and the usefulness of 7 different approaches (listed in the first row of the table) to address these problems were assessed in a scale from 1 to 5. The different approaches to address the problems are ‘Biocontrol, Integrated Management, Conventional Breeding, Marker-assisted Breeding, Tissue Culture, Genetic Engineering and Genomics.

This does not mean that the problems listed and its possible solutions are not applicable to cassava commercial agriculture, but they clearly are of more importance to subsistence farmers who have little access to input and output markets and are not able to insure themselves properly against crop failure.

Figure 6 portrays a ranking of the average ratings of all the problems in subsistence agriculture. The lack of clean planting material (Clean Stakes) is assessed to be by far the most important problem, followed by low yields (gap between the potential and the real yield/he of cassava). Pest-and disease-contaminated stem cuttings are also often the

primary cause of genetic erosion and low yields. These problems are followed by root quality problems (short storage life, low starch and low protein content, late bulking, HCN content), plant diseases (ACMV, CBB), abiotic stresses (soil erosion, drought, soil nutrient) and pest infestation (whiteflies, mealybugs, mites). The only problem that was considered to be unimportant was 'Flood'.

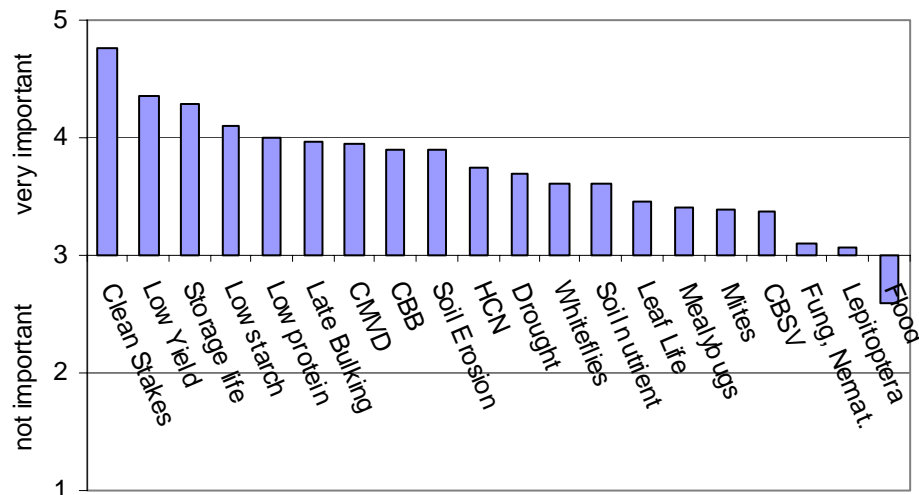


Figure 6: Average ratings of the importance of the problems in subsistence agriculture

Cassava Brown Streak Virus (CBSV), Fungi & Nematodes (Fung.Nemat.) and Lepitoptera (e.g. hornborer) may be considered less important problems because they are serious only in certain African or Latin American regions. CBSV is nevertheless considered to be one of the coming serious problems since resistance against this particular virus has not been achieved by means of conventional breeding.

Whiteflies are probably a more serious problem than it would appear because they are not only causing damage as pests but are also a major vector for ACMV virus transmission, and entomologists have difficulties to find any effective mean against them.

Figure 7 shows how respondents assessed the potential of different approaches to solve these problems in subsistence agriculture. Instead of listing every single problem separately, the problem categories Diseases, Low Yield, Pests, Root Quality, Abiotic Stresses, Clean Stakes and Soil Erosion were formed.

The results show that respondents believe biocontrol to have only a potential for solving pest problems, while the approach that is seen as having the biggest potential for solving the problem of 'lack of clean stakes' – by cloning clean planting material- is tissue culture. Considering that the lack of clean stakes is perceived to be the most important problem and also related to pest and disease contamination, tissue culture plays a key role in solving the major problems of cassava subsistence agriculture.

Integrated Management methods are seen as a possible answer to pests, diseases, abiotic stresses, contaminated stakes and, very important, soil erosion. Conventional breeding, marker-assisted breeding, genetic engineering and genomics show similar patterns as regards their potential to solve problems; the choice of the approach may differ from problem to problem. All approaches are regarded as possible solutions to poor root quality, abiotic stresses, diseases, low yield, and, to a lesser extent, pests.

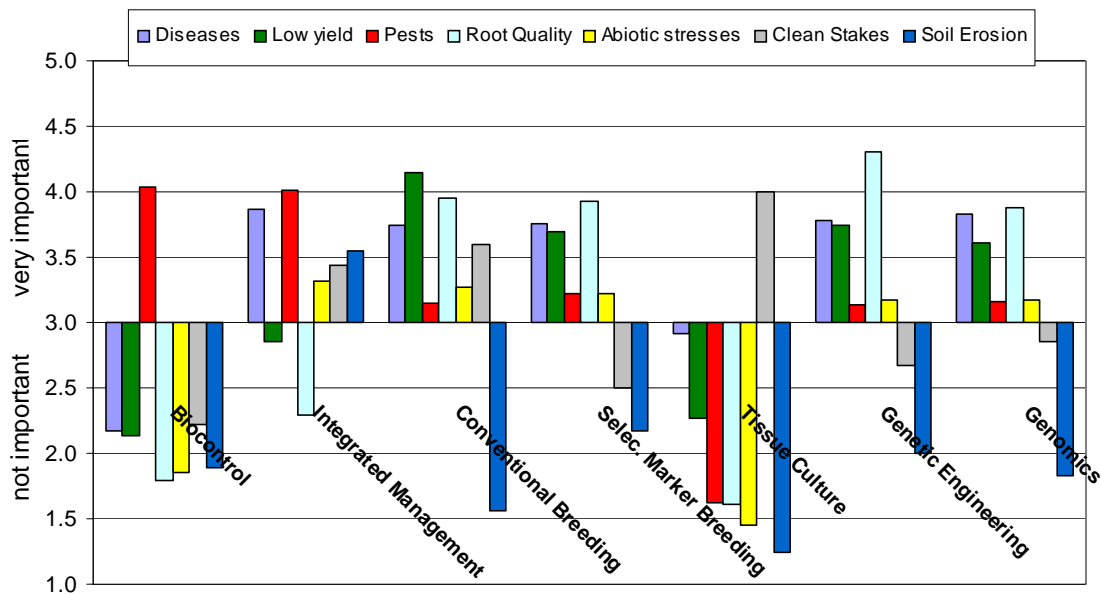


Figure 7: Average ratings of the usefulness of approaches to deal with the problems in subsistence agriculture

The highest potential of the modern tools of biotechnology, that include marker-assisted breeding, genetic engineering and genomics, is seen in the improvement of root quality.

Evaluation of the problems in Cassava commercial agriculture

In Part 2 of the questionnaire, 17 problems related to cassava commercial agriculture were listed in the first column of the table. The importance of the problems had to be assessed again in a scale from one to five and, and the respondents were asked to assess the usefulness of 6 different approaches to solve these problems specific to commercial agriculture. These approaches included market reform, awareness campaign (marketing), improved accountability, global incentives, investment in technology, and investment in dialogue.

As we see in Figure 8, inadequate starch composition for industrial purposes (Starch Comp) is perceived to be by far the most important problem in cassava commercial agriculture.

Analogous to the case of clean stakes in subsistence agriculture, starch composition was added to the list later in the survey. Therefore there are fewer respondents who rated these two problems (as is clearly visible in Figure 5) and the fact that it was given a separate row (added by hand) may have had an impact on its assessment of importance. Inefficient market structure, lack of access to capital, and expensive and time-intensive processing of cassava are also perceived to be very important problems; followed by lack of incentives to invest in R&D of cassava, discriminating crop policy, bad infrastructure and low investment in the cassava business. The only problem that was perceived to be unimportant was 'Political Polarization'. Obviously, there seemed to be a consensus about what needs to be done and how public resources must be allocated to improve cassava as a commercial crop.

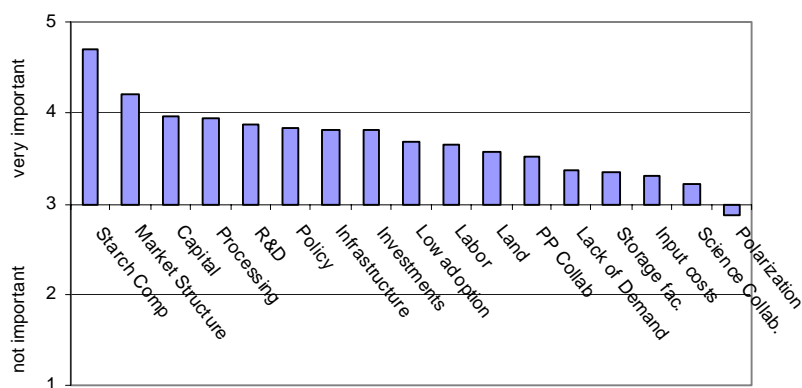


Figure 8: Average ratings of the importance of the problems in commercial agriculture

According to many personal interviews with scientists at IITA, labor, even though not at the top in the illustration, is one of the most important constraints in commercial agriculture in Africa. The commercial cassava production is still very labor-intensive in Africa, compared to Asia and Latin America; and the opportunity costs for young local people to work in cassava commercial agriculture are very high.

Figure 9 presents the average ratings of the usefulness of the different approaches to solve of the most important problems. While Investment in Technology (Invest. Tech.) is considered to be the best solution for inadequate starch composition, processing, R&D and labor, Awareness Campaign (Awareness Camp.), which is also related to better marketing, is seen as most important to improve the inefficient market structure and access to capital. The creation of global incentives (Global Incent.) is considered be an important solution for all the different problems. Investment in dialog(ue) is also perceived to be important, except for the problem of labor. Improving accountability (Improv. Accou.) is regarded important to create better access to capital, better processing facilities and more investment in R&D.

Market Reform is self-evidently seen as having the biggest potential with respect to inefficient Market Structure.

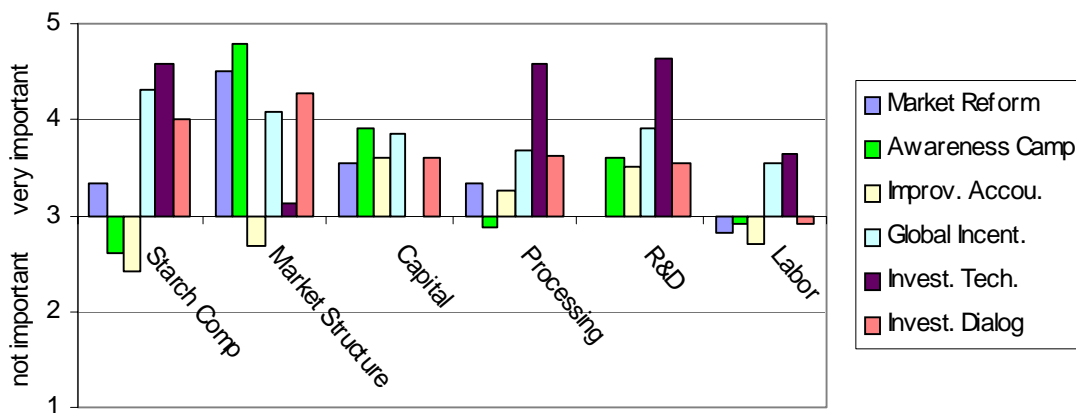


Figure 9: *Average ratings of the usefulness of approaches to deal with the problems in commercial agriculture*

The Cassava Biotechnology Network

The small survey shows that there are many challenges in cassava subsistence and cash crop agriculture that need to be addressed with the most effective approaches available. The Cassava Biotechnology Network (CBN) proved to be key in bringing researchers from all over the world together to join forces with local researchers and farmers to address these challenges in cassava agriculture.

CBN was established in 1988 and is based at the Centro Internacional de Agricultura Tropical (CIAT) in Colombia. It started as a global initiative to pool the resources for cassava researchers and end users united by the goal to mobilize the development and application of biotechnology tools for the enhancement of the value of cassava for food security and economic development in the poorest rural areas in developing countries. It links advanced research institutions and widely dispersed national and regional programs with each other and with producers and consumers. The network is supported by funds provided mainly by the Special Program on Biotechnology and Development Co-operation (DGIS/BIOTECH) of the government of the Netherlands and the Canadian International Development Research Co-operation (IDRC). The current regional CBN-LAC (CBN for Latin America and the Caribbean) started activities in 2001 as an offshoot of the erstwhile global CBN (1992-1998). The regionalization was a result of reviews of the parent CBN, but also reflecting the growing public controversy on the use of biotechnology in agriculture in Europe.

Despite its regionalization, CBN(-LAC's) activities continue to be global. The bi-annual CBN conferences (the seventh will be in 2006) bring together around 300 cassava researchers (of whom 2/3 are based in developing countries), local NGO and farmer representatives as well as delegates from governments, big agribusiness companies and international foundations. CBN provides the essential link between researchers from inside and outside Africa. Its main partner in Africa is the International Institute of Tropical Agriculture (IITA) in Nigeria, which also has the regional mandate of cassava in Africa, whereas CIAT has the global mandate. The aims of the CBN conference participants are to share knowledge on cassava, identify new challenges in research, improve farmer adoption and marketing of cassava and set up new research collaborations that are focused not primarily on research but on the development of new products for cassava farmers.

These meetings are interdisciplinary in nature. CBN has managed to develop a hands-on spirit in which soil scientists, entomologists, molecular biologists and social scientists from research programs all over the world collaborate productively in the search of joint solutions to particular constraints in cassava agriculture. Members of CBN are aware that ultimately it is not research itself but the demand for the products that eventually come out of it, that count. This also makes it necessary for CBN members to learn from farmers and the local private sector to find out what might be profitable for end-users and therefore sustainable.

Besides scientific meetings, CBN also stimulates research on cassava by encouraging and providing assistance in project proposals on priority topics. Furthermore, it serves as broker in the coalition-building between national agricultural research and development institutions (NARDIs) and donors. It also supports the formulation of research proposals

through its Small Grants Program, which has funds of about US\$100,000 per year. These small grants are designed for research, training and participatory projects related to the genetic improvement of cassava. They also encourage crop researchers in developing countries to become more entrepreneurial and come up with proposals that address relevant cassava problems with innovative research approaches.

CBN members were and are crucially involved in various other international cassava-related initiatives, such as:

- The Global Cassava Development Strategy and Implementation Plan (GCDS) initiated by the Food and Agriculture Organization (FAO) and the International Fund for Agricultural Development (IFAD) set up in 1996. Its aim is to counteract the negative trends of cassava in food and cash crop agriculture by using a demand-driven approach to promote and develop cassava-based industries with the assistance of a coalition of groups and individuals interested in developing the cassava industry (FAO/IFAD 2001).
- The Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca (CLAYUCA) set up by representatives from private and public institutions in Bolivia, Colombia, Cuba, Ecuador, and Venezuela in 1999. CLAYUCA is a self-financing consortium that aims at boosting research for cassava development throughout Latin America. Its main partner in Africa is the Southern Africa Root Crops Research Network (SARRNET).
- The GCP21 was initially set up by CBN members from CIAT, the Donald Danforth Center for Plant Science (DDCPS), EMBRAPA and IITA to constitute a worldwide, multi-institutional research and development consortium dedicated to employing the power of biotechnology to deliver improved germplasm to end users in the tropics. The following problems were identified as the major obstacles to improve quality and quantity of cassava production in Africa: African Cassava Mosaic Virus Disease (ACMD), Cassava Bacterial Blight (CBB), post harvest deterioration and low nutritional protein content (Fauquet and Thome 2002)
- CBN members are also running the Cassava Alliance within the Harvest Plus Initiative. HarvestPlus is a global alliance of research institutions and implementing agencies that have come together to breed and disseminate crops for better nutrition. The initiative is jointly financed by The Bill and Melissa Gates Foundation, the Danish International Development Assistance (DANIDA), the Swedish International Development Assistance (SIDA), the U.S. Agency for International Development (USAID), and the World Bank.
- CBN members are committed to improved breeding conditions that make cassava a viable alternative to corn in the animal feed and starch business. Cassava is a vegetatively propagated and highly heterozygous crop that makes the dissemination of the crop cumbersome and risky (transportation and phytosanitary problems) and its a typical breeding program time-intensive because of inbreeding depression. The double haploid initiative (funded by the Rockefeller Foundation) and run by CIAT members aims at the rapid and complete achievement of homozygosity. This implies a reduction of costs and time for the genetic improvement of Cassava (by reducing the time involved in the production of inbred lines). It may also enable germplasm exchange based on botanical seed, which is much easier compared to stem cuttings (reduced risk of disease transmission through transboundary movements) and

allow for cleaning planting stocks from viral and other pathogens without the need of meristem culture and many other tricks to improve breeding (Zaida Lentini and Hernan Ceballos 2003).

CBN Priorities in line with problem assessment

CBN activities follow three major objectives that are in line with the expert assessments obtained in the small survey:

- 1) integrating the needs of cassava farmers, processors, and consumers into biotechnology research priorities
- 2) fostering research linkages around the high priority topics
- 3) exchange of information and genetic materials.

1) The integration of the needs of the local cassava stakeholders into biotechnology research priorities may be the most important answer to the problem of contaminated planting material. The lack of clean stakes was assessed to be the most serious problem in cassava subsistence agriculture in the small survey. Pest and disease infested cassava stakes are also seen as largely responsible for low yields (the second most important problem) in cassava cultivation in many developing countries. CIAT and national research programs may be able distribute clean stakes in marginal areas of cassava agriculture but the centralized production of clean stakes and the logistical challenge of distributing them is expensive and does hardly involve the farmers and end users in the choice of varieties and techniques. CBN responded to this problem by supporting a participatory tissue-culture project developed at CIAT's Biotechnology Research Unit (BRU). It is a project that encourages farmers to use low cost cassava in-vitro rapid multiplication techniques to clone the local cassava planting material they found most successful in the field. Small tissue culture laboratories, cold chambers and greenhouses were built with local materials in collaboration with local farming communities. This inexpensive equipment costs six times less than the conventional commercial equipment (Escobar et al. 2002). It enables local farmer communities to modify their precarious farming conditions by learning how to use tools of modern biotechnology to address their particular needs in cassava agriculture. In spite of some initial difficulties these participatory projects in Brazil and Colombia succeeded in helping the farmers to prevent the genetic erosion of their cassava planting material through in-vitro propagation of improved clones (Escobar et al. 2002). In an interview conducted in November 2003 with farmers that were involved in these projects, it turned out that these local men and women felt empowered through this experience. They became aware for the first time that biotechnology is not magic practiced by inaccessible Western scientists but a practical tool they can use to address their own particular constraints in agriculture. The gained self-confidence also resulted in increased local entrepreneurial activities, curiosity, and a willingness to share knowledge and information on cassava with other farmer communities⁷. Resource-poor farmer communities benefit from such activities in

⁷ Interviews with farmers and FIDAR representatives in Cali-Palmira in November 2003 confirmed this newly gained pride and enthusiasm for the new approach. Many entrepreneurial women in the farmer communities started to apply for microcredit with government institutions to start a small local business by offering clean planting material to other farmers in the region. The newly gained self-confidence also makes them more open to innovations in crop management and soil conservation and the additional income allows them to send their children to school and invest more time in education themselves.

particular because it is cheaper for them to increase cassava yields by means of their own efforts to improve planting material than by buying expensive planting material, pesticides and fertilizers from agribusiness companies. CIAT and IITA may take a combined effort to make such low-cost technologies widely available in Central Africa, where it may have the largest impact on improved food security.

2) CBN members are fostering research linkages around the high priority topics in cassava subsistence and commercial agriculture. Major problems in cassava subsistence agriculture that were identified as high priority in the short survey were short storage life, late bulking, low protein content and viral diseases. CBN members are using the modern tools of biotechnology to address these problems: researchers at Ohio State University are developing cyanogen-free transgenic cassava, a team at the University of Bath is developing cassava varieties that are more resistant to post-harvest deterioration, and another team at the University of Adelaide is analyzing the micronutrient content of cassava. Transgenic cassava varieties that are resistant to ACMV disease have been developed at the Danforth Center for Plant Science in Missouri, USA and the Swiss Federal Institute of Technology in Zurich Switzerland (ETH Zurich). The team at ETH Zurich has also developed transgenic cassava varieties with delayed leaf senescence and higher protein-content in cassava roots. These advanced research institutes have all strong research linkages to CIAT and IITA and jointly explore also the new biotechnology tools that don't require the transfer of genes such as gene-silencing, genomic research and marker-assisted breeding to address the most urgent problems related to biotic and abiotic stresses in cassava cultivation.

In cassava cash crop agriculture, the problems perceived to be most important were inadequate starch composition (starch comp), unfavorable market conditions (market structure) and lack of investment in cassava business (capital) and public R&D. CBN's response to these challenges is investment in technology and awareness building (marketing); the two important non-political approaches for the problems in cassava commercial agriculture. The problems are effectively addressed by improving post-harvest technologies and marketing through the fostering research and business linkages. The various initiatives in which CBN members are involved (e.g. GCDS, CLAYUCA, Double Haploid Initiative and many other regional networks in Asia and Latin America) must be seen in this context.

The results of the survey also showed that each problem may require a different mix of approaches to solve it. Cassava pest and disease problems are addressed by combining knowledge gathered from entomology, integrated pest management and biotechnology. CBN members are committed to science and therefore managed to resist the increasing pressure to take sides in the global debate on the risks and benefits of agricultural biotechnology. They have realized that research linkages must not just be fostered between different biotech labs but also between different scientific disciplines. Even research fields such as entomology may have to make more use of the new methods of genomics to make biological pest management more effective. According to Anthony Bellotti⁸, an entomologist at CIAT, conventional biocontrol has not been able to reduce the use of pesticides in any significant quantity in developing countries. He argues that the migratory nature of pests often makes it impossible to deploy parasitoids effectively.

⁸ Personal Communication with Dr. Anthony Bellotti, Entomologist, CIAT, Colombia in November 2003.

Moreover, it is still not possible to break the life-cycle of pests, which return year after year. He believes that more unconventional biocontrol methods may result from more collaboration between genome researchers and entomologists. It is the joint commitment of CBN members to find the best mix of approaches to solve a particular problem and to develop a useful cassava products and markets that are quickly embraced in marginal areas that may ultimately make a difference in Central Africa.

3) The exchange of information and open access to genetic materials among CBN members provides the main incentive for successful research collaboration, especially between research institutes inside and outside Africa. It has resulted in many achievements such as:

- Cassava ex-situ conservation: CIAT maintains in trust for FAO a collection of more than 6000 cassava accessions. The *'in vitro'* storage is however costly and time-intensive, because individual plantlets can only be maintained for 8 to 22 months before they have to be recycled. CBN members at CIAT developed alternative storage methods for cassava such as cryopreservation (that stores germplasm in liquid nitrogen) and other techniques.
- CBN members have developed a molecular genetic map of cassava, the first such map ever to be generated for a major food crop outside the industrialized world. An analysis of the Qualitative Trait Loci (QTL) has revealed regions of the cassava genome that account for much of the phenotypic variance for key traits that may be responsible for important constraints such as postharvest deterioration of roots, increased dry matter content, and resistance to cassava bacterial blight. Molecular tagging of genes controlling key traits may eventually improve the breeding process significantly.
- Swiss researchers affiliated with CBN developed the first protocol for regeneration and transformation of cassava (Li et al. 1996) and together with many other advanced research institutes they are continuously advancing the CBN knowledge base of transgenic cassava research. In the meantime, new transgenic cassava varieties resistant to Africa Cassava Mosaic Virus (ACMV) and Hornworm infestation were stably expressed *in vitro* and *in vivo* and are now ready for field testing.
- With the support of CBN, a Brazilian researcher⁹ discovered numerous new products derived from cassava with useful traits that were used by different indigenous tribes in the Amazon. He found a 'yellow cassava' that is enriched with beta-carotene, a 'baby food' cassava that produces sugar instead of starch, a cassava variety that produces waxy starch, and a Cassava root-specific protein rich in glutamic acid. The small survey revealed that poor root quality is perceived to be the greatest problem in subsistence agriculture (apart from poor planting material) and unfavorable starch composition (low wax content) was seen as the major handicap for making cassava more competitive as a commercial crop. His research also shows that biotechnology can be used in two complementary ways, either from the protein to the DNA (e.g. analysis of the biochemical pathway) or from the DNA to the protein (genetic engineering). This leads to various new insights that serve all cassava breeders. The

⁹ Personal communication with Dr. Luis Castelo Branco Carvalho, Geneticist, Embrapa, Brasilia in November 2003. His research will also be part of the global biofortification initiative.

indigenous cassava varieties with higher nutritional content were also introduced in Africa through IITA, via CBN.

The state of international agricultural research

The geopolitical and ideological climate has changed significantly since the end of the Cold War. Today, international agricultural research centers can no more rely on a continuous flow of financial support of Western donor agencies; instead they are partnering more intensively with local stakeholders in developing countries and are seeking more collaboration with multinational companies and advanced research institutes in developed countries to conduct relevant research. A major insight is that international agricultural research has shifted from a supply-driven to a demand-driven concept of rural development, in which networks matter more than centralized institutions.

The CGIAR's increased interest in the private sector and advanced research institutes in the 1990s was also related to the rapid development of new tools in biotechnology that helped overcome constraints faced by conventional breeding methods and integrated pest management. These tools accelerated the genetic improvement and adaptation of crops for different ecological and socioeconomic environments.

Partly in response to the slumping costs of information and communication over the past fifteen years various global networks were set up to improve the quality and quantity of major tropical food crops such as cassava. These initiatives consist of large and flexible stakeholder networks (universities, CGIARs, NGOs, companies, foundations, farmer organizations etc) that decided to pool resources for the stronger integration of biotechnology research, breeding, product development and marketing. The majority of the stakeholders in these new global networks are now from developing countries. This also confirms the increasing trend toward more south-south collaboration in international agricultural research. The increased participation of stakeholders from the developing world may also explain the emerging new paradigm that a new technology or a new product derived from international agricultural research is only sustainable if it is at least partly home-grown and profitable for the local farmers.

The new, more developing country-driven initiatives, such as CBN, were not the result of a new policy paradigm but rather the response to the emerging constraints that resulted from such a shift in paradigm in development cooperation: foreign aid, and especially support for international agricultural research decreased significantly in almost all developed countries while investment in private sector agricultural research skyrocketed (New York Times 2001). This may largely be explained with the loss of geo-strategic importance of non-aligned developing countries in the Cold War era (Anderson et al. 1991). In addition, many Western policy makers and activists in development cooperation tended to regard science and technology as inappropriate to address the problems of the poor in developing countries (Aerni 2001). These changes in perception had the effect that science and technology tended to be seen as a problem of sustainable development in many Western countries rather than an essential contribution to it. These new constraints and the additional competition for funding from an increasing number of development-oriented NGOs forced the CGIARs to adapt to the new circumstances. As a result CGIARs contributed to the establishment of new international crop networks that combined the flexible, unbureaucratic and farmer-oriented approach of NGO networks

with cutting-edge science and innovative business strategies in order to generate useful products, technologies and markets for the local people in marginal regions. These crop networks, such as CBN, facilitate better collaboration across continents and among CGIARs with overlapping crop mandates. The involvement of local people in these collaborative networks may also result in the emergence of 'local champions' that eventually become successful entrepreneurs in the rural areas of developing countries because they manage to combine the new knowledge gained from the international collaboration with their knowledge about the complex local economic, cultural and political circumstances.

Endogenous economic development through local entrepreneurship increases the self-confidence of local people, creates more business opportunities and gives the bright local people more incentives to stay, articulate their own interests and assume more responsibility in their respective community.

Discussion

Central Africa is by far the biggest consumer of cassava in the world but, at the same time, faces a decline in production and consumption not just of cassava but all important food crops except rice. The problems in agriculture in this region are not just related to political instability but also the lack of resources to control for biotic and abiotic stresses in crop cultivation as well as the lack of markets and infrastructure to increase revenues through domestic and international agricultural trade. The consequences are hunger, malnutrition and an increasing marginalization of rural areas. The heavy reliance on cassava as the most important food crop in Central Africa is a cause of concern but also a call for action. The quantity and quality of cassava in Central Africa needs to be improved and markets need to be developed to help farmers sell their surplus in the urban areas that continue to show a high demand for cassava consumption. Once farmers are able to generate more revenues they may also consider a diversification of their crops and the adoption of improved pest management practices.

The challenge to improve cassava production and markets in Central Africa is huge and the global resources to address it are scarce. This is the most important reason why cassava research needs to be organized in form of an international network that brings together the important stakeholders in the different areas of cassava breeding, production, consumption and marketing and raises the funds necessary to enable them to embark on joint projects that address the high priority problems. The Cassava Biotechnology Network (CBN) is not only a facilitator of research collaboration in high priority areas but also encourages local entrepreneurship in developing countries by offering grants to cassava-related projects in the field.

The small expert survey presented in this paper has shown that the problems that were perceived to be most important in cassava subsistence and commercial agriculture, were also the problems identified as high-priority by CBN. Each of these high-priority problems is addressed with a different mix of technology and development strategy. The focus is always on meeting the end-user demand in the fastest and most cost-effective way.

Even though CBN has become CBN-LAC (Cassava Biotechnology Network for Latin America and the Caribbean) in 2001, it continues to be a successful example of a new

global crop research network that facilitates not just collaboration between leading cassava biotech labs across the World but also effective stakeholder collaboration (e.g. between farmers, NGOs, companies and research institutes) and collaboration across research disciplines (e.g. between entomologists, soil scientists, molecular biologists, social scientists). CBN is dominated by stakeholders from developing countries and this may explain why it succeeded in putting ideological and world view differences aside in order to combine all available resources and technologies to deliver products that are likely to maximize the benefits and minimize the risks of poor farmers in developing countries. As such it provides evidence that the mobilization of science and technology for development is highly compatible with a bottom-up and end-user-oriented approach in development. Central Africa needs more of these international networks that are based on learning and combine all the resources inside and outside Africa to address the region's most urgent problems in subsistence and commercial agriculture.

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