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

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Cassava is regarded as the crop of last resort for millions of marginal farmers and their domestic animals in tropical regions. The Cassava Biotechnology Network (CBN) is addressing the major socioeconomic and agronomic challenges of this orphan crop by bundling the scarce resources available and uniting the major stakeholders involved in cassava breeding, production, marketing, and consumption worldwide. 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 in addressing them. The author concludes that the CBN represents an innovative, demand-oriented and multistakeholder-driven crop research network that is able to effectively address the challenges in cassava agriculture that were perceived to be most important in the survey. Its innovations could be of particular benefit to Central Africa—a region that is highly vulnerable to starvation and malnutrition and relies mostly on cassava as the main staple food. However, in order to make it happen, some major institutional bottlenecks need to be addressed in the international agricultural research system.

Key words: agricultural research, cassava, Central Africa, crop network, innovation.

Introduction

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; more than 500 million people consume 100 Kcal per day (Kawano, 2003). Even though cassava faces serious challenges as a vegetatively propagated crop that is prone to genetic erosion as well as pest and virus infestation, it generally responds well to irrigation or favorable rainfall conditions, and the use of fertilizers. 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 need,[1] make it the crop of last resort for farmer families and their domestic animals in the tropics (Hillocks, Tresh, & Bellotti, 2001).

The importance of cassava as a food crop in Africa becomes obvious when its annual per-capita consumption is compared to the rest of the world. Whereas the world average of annual cassava consumption was around 17 kg/capita in 2001 (according to FAOSTAT data obtained in 2003), 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 more than 40 kg/capita in the early 1970s to slightly more than 20 kg/capita in 2002.

Figure 1 shows the development and distribution of cassava consumption per 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 over the past 40 years. In Western Africa, per-capita production and consumption experienced a strong upward trend at the beginning of the 1990s but then remained stagnant; in Eastern Africa, per-capita production and consumption declined slightly from 1991 to 1995, then subsequently returned to previous levels. 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.

1. *Cassava has no definite maturation point—the root tubers start bulking after about eight months 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 crop to manage food security in subsistence farming.*

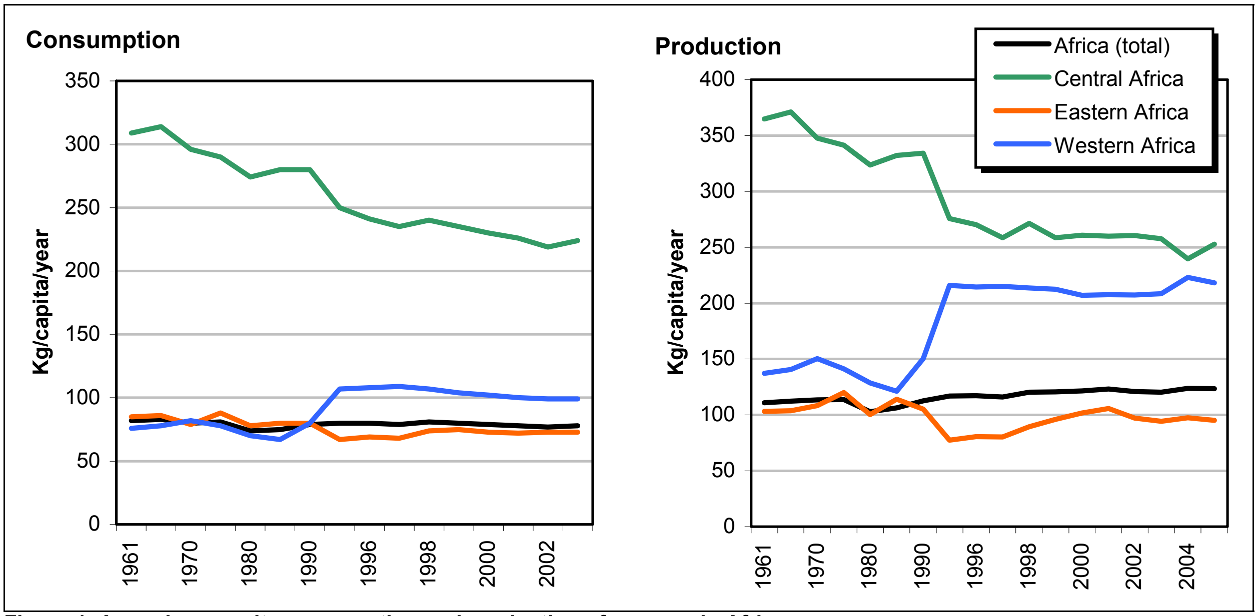

Figure 1. Annual per-capita consumption and production of cassava in Africa.

Note. Data from Food & Agriculture Organization of the United Nations (FAOSTAT, 2006). 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, and Mauritania. Central Africa comprises Central African Republic, Equatorial Guinea, Democratic Republic of Congo, Angola, Cameroon, Chad, Sao Tome y Principe, and Gabon. Eastern Africa comprises Kenya, Somalia, Djibouti, Ethiopia, Eritrea, Burundi, Rwanda, Uganda, Tanzania, Madagascar, Seychelles, Comoros, Mauritius, Mozambique, Malawi, Zambia, and Zimbabwe.

The decrease in consumption of cassava in Central Africa would be a good sign if it indicated that people's daily meals have become less dependent on cassava and substituted by more protein-rich crops. (Cassava provides mostly carbohydrates in form of starch.) However, there is no indication that this is the case. FAOSTAT indicated in 2004 that all the major food crops (root & tubers, maize, potato, millet, sorghum, sweet potato, yam) are in decline in Central Africa (with the exception of rice, which still provides a very low share of the daily intake of calories).

This is an alarming sign, because the decline of cassava cannot just be explained by food crop substitution or diversification. The Food and Agriculture Organization of the United Nations (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 the foreign donors and investors; in Congo, 1,000 times more people die every year than in Palestine, but annual foreign aid designed for Congo amounts to just half of what Palestine receives ("A United Nations Appeal," 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. In other regions of the world, these problems were addressed during the Green Revolution, but Central Africa and its traditional food crops did not experience such a Revolution (de Vries and Toenniessen, 2001). The gap between the yield of cassava harvested under optimal experimental conditions (over 80 tons/ha) and the average yield harvested by African farmers of around 8–12 tons/ha indicate the numerous limiting factors in cassava subsistence agriculture (Taylor & 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 mealybug, hornworm, whiteflies (also a vector for virus transmission), and soil-born pests (*Phytophtora*).

As a perennial food crop, cassava produces roots that can be harvested on average only 8–12 months after planting. According to the COSCA study (Collaborative Study of Cassava in Africa, 1996), the late bulking of cassava is perceived to be one of the most important food security problems for subsistence farmers who sometimes need to harvest earlier (in case of crop failure elsewhere). The lack of nutritional value of the starchy cassava roots is also a matter of particular concern in drought periods when no other crops are available for immediate consumption. Cassava leaves would be the ideal complementary food source because they are rich in protein content. However, the leaves usually fall off at an early stage of development and consequently are not used as a complementary food dish to the roots.

An additional problem is the high cyanogenic (HCN) content of "bitter" cassava, grown in many regions of tropical Africa, which render its fresh products (leaves and roots) highly toxic for human 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 increasing demand for cheap cassava in the growing African cities induces many cassava producers to shorten the time of the traditional fermentation process from four to two days. This leaves detoxification of cassava incomplete and heightens the risk for urban consumers to be affected by Konzo (Feldmeier, 1999).

Moreover, cassava farmers in marginal areas often lack adequate postharvest facilities and essential infrastructure such as roads, means of communication, and input supply systems. These postharvest 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 manure (Alfred Dixon, International Institute of Tropical Agriculture, personal communication, November 2003). Considering the importance of cassava as the crop of last resort, these problems are highly relevant in the fight against poverty and malnutrition and need to be addressed in research, policy, and farm management.

Cassava as a Cash Crop

By 2005, global cassava trade is projected to increase by 1.6% up to an annual production of 5.8 million tons, reflecting a moderate growth in import demand for cassava feed (used for chicken, pigs, cattle, and fish), other novel cassava food products (cassava instant meals, cassava snacks, and cassava ingredients for sweeteners and prepared foods), and nonfood products such as starches and flours for sizing textiles and papers (FAO, 2003; FAO/International Fund for Agricultural Development [IFAD], 2001).

The market potential of cassava remains largely underexploited in the tropics. The rapid postharvest deterioration of fresh cassava, as well as labor- and time- intensive processing, are the major constraints that put cassava at a disadvantage to other cash 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 (Figure 2).

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, as 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.

Why Promote Cassava?

Considering all the physiological, nutritional, agronomic, postharvest, environmental, and marketing constraints of cassava, would it not be better to abandon the crop entirely and encourage farmers to grow corn or more protein-rich soybean instead? The problem is that cassava has unique characteristics that help subsistence farmers to deal with extremely high economic, political, and environmental uncertainty.

Cassava is less drought-prone than corn. In addition, cassava has also a big potential to be a profitable cash crop in Africa. The case of Thailand proved that cassava can become a profitable export crop if successful international breeding partnerships, 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 other countries where the commercialization of cassava has reached an advanced stage (such as Costa Rica and Brazil), technologies have been developed in recent years that make planting, harvesting, and posthar-

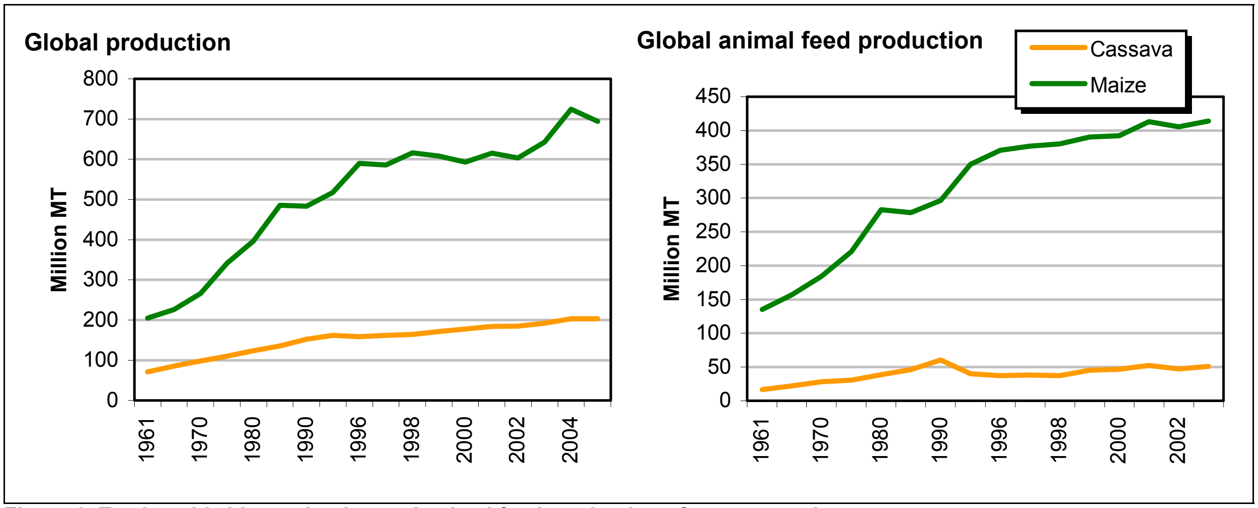

Figure 2. Total worldwide production and animal feed production of cassava and corn.
Note. Data from FAOSTAT (2006).

vest 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 (Figure 3).

One of the engines of innovation in cassava research and development that contributed substantially to the success stories of cassava in Thailand and other parts of Asia and Latin America is the Columbia-based Centro Internacional de Agricultura Tropical (CIAT). Apart from being involved in many of the current global initiatives related to yield and nutritional improvements of orphan crops, CIAT is also the driving force behind the Cassava Biotechnology Network (CBN), an emerging type of crop research network that is essentially changing the structure of international agricultural research. CIAT would like to use the CBN as a vehicle to bring cassava innovations that were developed at CIAT (in collaboration with institutes in Asia and Latin America) to Africa. However, it still faces some institutional obstacles within the existing international agricultural research system to make it happen. In this article, we present cassava expert and farmer views on the major problems and the best approaches to solve these problems in cassava cash and food crop agriculture. Subsequently, we illustrate how the members of CBN effectively address these problems and show how their approach differs from the one pursued by traditional research institutions and NGOs. Finally, the article makes some recommendations on how to overcome the institutional obstacles that still hamper the adoption and sustainable management of cassava innovations in Africa.

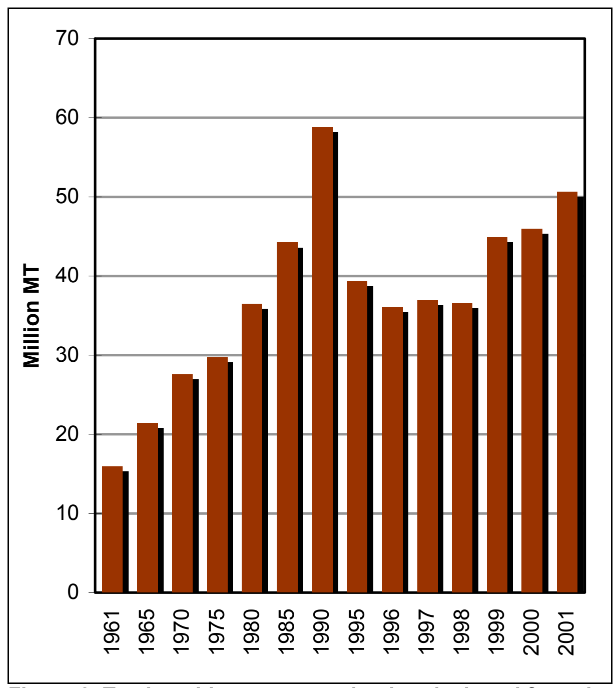

Figure 3. Total world cassava production designed for animal feed.
Note. Data from FAOSTAT (2006).

A Small Survey on Cassava Problems and Solutions

A small survey was conducted in November 2003 with cassava experts at ETH Zurich (Switzerland), the International Institute of Tropical Agriculture (IITA, Nigeria), the Donald Danforth Plant Science Center (DDPSC, 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. The project was sponsored by the Swiss Center for International Agriculture (ZIL). Altogether, 27 respondents completed a small questionnaire on the problems in cassava subsistence and cash crop agriculture and the different approaches to solve the respective problems. The descriptive analysis derived from the survey data mainly serves illustrative purposes. In addition to the survey, in-depth 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) in the first column. Their importance had to be rated in a scale from 1 (*not important*) to 5 (*very important*). In the subsequent seven columns, the different approaches for solving each of these problems (rows) had to be assessed using the same scale (1 being *not useful* and 5 being *very useful*). The different approaches to address the problems of subsistence agriculture were *biocontrol*, *integrated management*, *conventional breeding*, *marker-assisted breeding*, *tissue culture*, *genetic engineering*, and *genomics*.

In the second part of the questionnaire, a similar table was designed to rate the problems and solutions in cassava commercial agriculture (mostly problems of demand and supply, as well as infrastructure and policy problems). This list of possible solutions included *market reform*, *awareness campaign (marketing)*, *improved accountability*, *global incentives*, *investment in technology*, and *investment in dialogue*.

Tables 1 and 2 show the problems of subsistence and cash crop agriculture as they were listed in the questionnaire tables and the number of respondents that assessed these problem categories and corresponding potential solutions. Table 3 shows the number of respondents in five different countries.

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 to the list after experts suggested it in a very early stage of the survey.) The problems are presented in five major catego-

Table 1. Problems of cassava subsistence agriculture.

	# of respondents
Diseases (Cassava Mosaic Virus Disease; Cassava Bacterial Blight; Cassava Brown Streak Virus [CBSV]; fungi & nematode diseases)	18.5
Pests (Lepidoptera [e.g., hornborers]; mites; mealybugs; whiteflies)	18.3
Yield (low yield [gap between potential and real yield]; late bulking; leaf senescence)	17.3
Root quality (cyanogenic glucosides [HCN]; low starch content; low storage life; low protein content)	19.3
Abiotic stresses (soil nutrient uptake; drought; flood)	16.7
Soil erosion	15
Clean planting material	13

Table 2. Cassava cash crop problems.

	# of respondents
R&D	17
Labor	21
Capital	21
Land	21
Demand	22
Infrastructure	22
Market structure	21
Input costs	23
Storage facilities	20
Processing	21
Policy	19
Investments	19
Science collaboration	19
PP collaboration	20
Low adoption	21
Polarization	16
Starch composition	10

Table 3. National affiliation of respondents.

	# of respondents
Brazil	8
Colombia	7
Nigeria	5
USA	4
Switzerland	3
Total	27

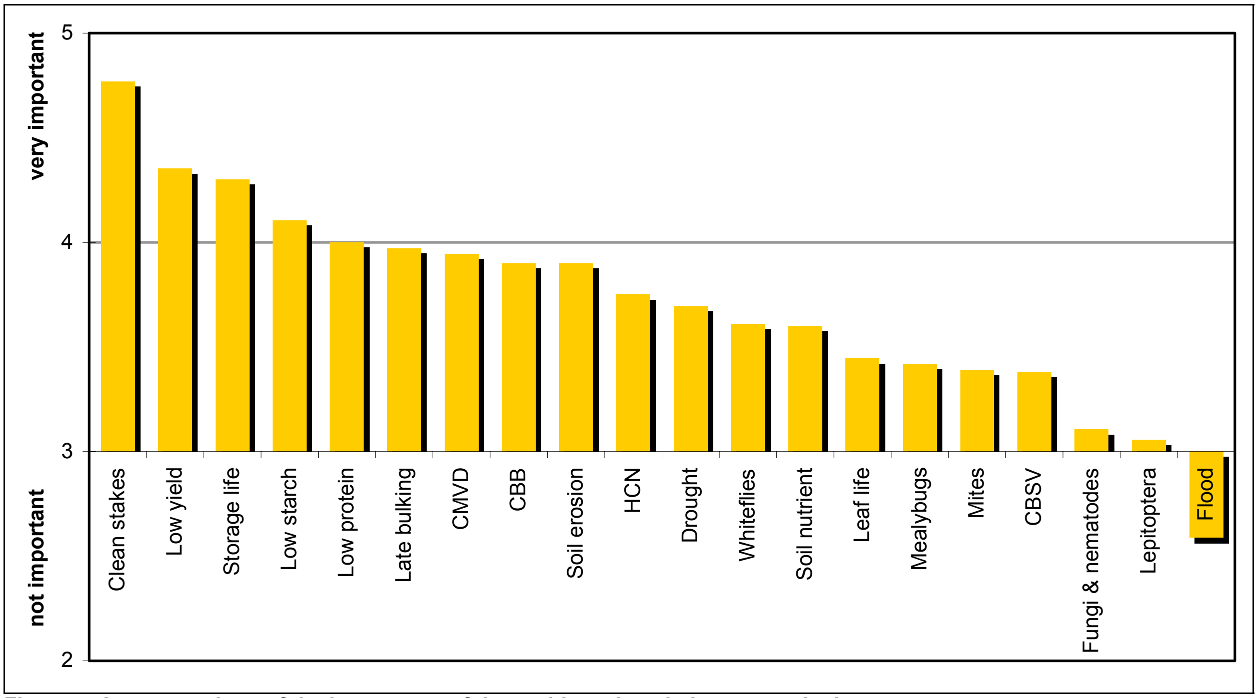

Figure 4. Average ratings of the importance of the problems in subsistence agriculture.

ries: *diseases*, *pests*, *yield*, *root quality*, and *abiotic stresses* (plus soil erosion and clean planting material).[2]

Figure 4 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 per-hectare yield 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, and high HCN content), plant diseases (e.g., ACMV or Cassava Bacterial Blight), abiotic stresses (soil erosion, drought, and soil nutrient), and pest infestation (whiteflies, mealybugs, and mites).

Cassava Brown Streak Virus (CBSV), fungi and nematodes, and Lepidoptera (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, because resistance against this particular virus has not been achieved by means of conventional breeding. The only problem that was considered to be unimportant (average rating below 3) was flood.

Whiteflies are probably a more serious problem than it would appear in the rating, because they are not only causing damage as pests but are also a major vector for ACMV virus transmission. Entomologists have difficulties to find any effective mean against them (Anthony Bellotti, CIAT, personal communication, November 2003).

Figure 5 shows how respondents assessed the potential of the different approaches (biocontrol, integrated management, conventional breeding, tissue culture, marker-assisted breeding, genetic engineering, and genomics) 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 used.

The results show that tissue culture was assessed to have the biggest potential for solving the problem of lack of clean stakes. 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.

2. *These problems are of particular relevance to subsistence farmers who must primarily ensure their own food security, have little access to input and output markets, and are unable to insure themselves properly against crop failure.*

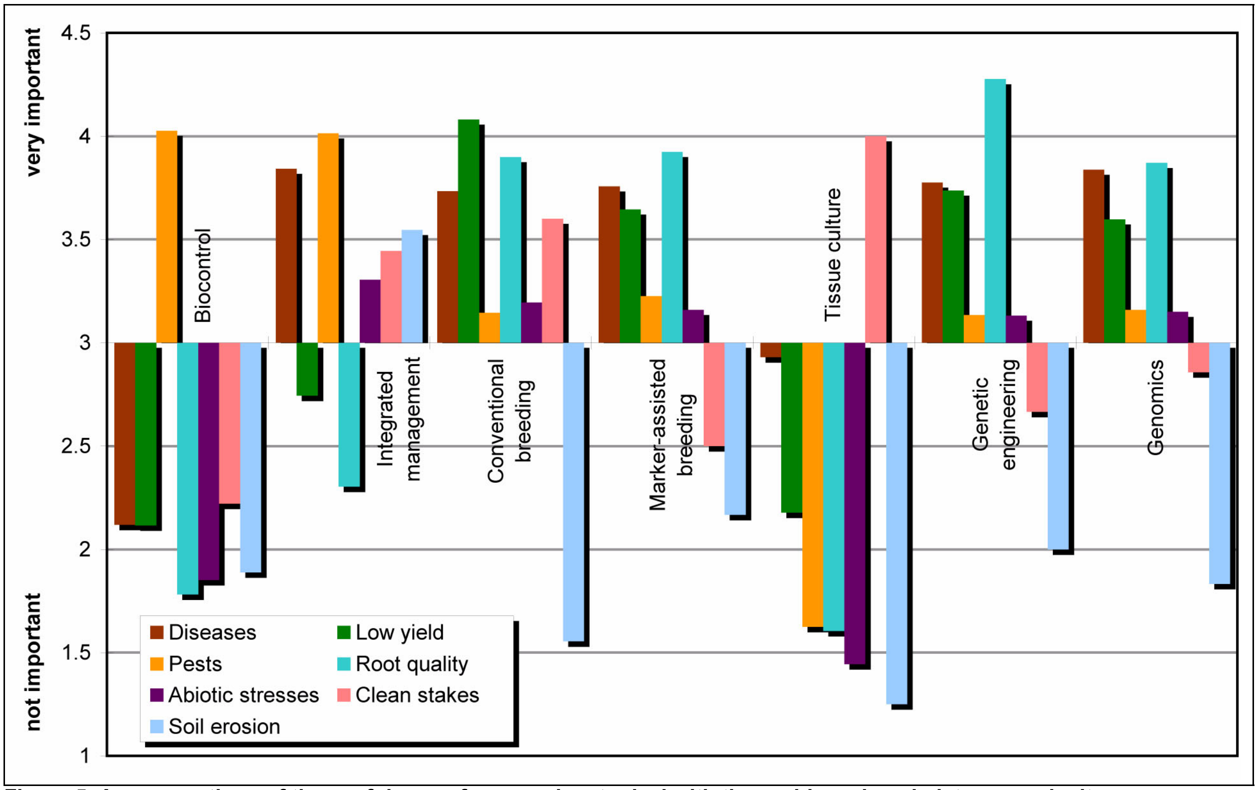

Figure 5. Average ratings of the usefulness of approaches to deal with the problems in subsistence agriculture.

Furthermore, respondents believed the potential of biocontrol to be limited to solving the problem of pest infestation. Integrated management methods are seen as a possible answer to pests, diseases, abiotic stresses, contaminated stakes, and (very important) soil erosion. Integrated Management may therefore be seen as an integral part in the general practice of crop yield improvement. 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. The highest potential of the modern tools of biotechnology, which 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. The respondents were asked to assess the usefulness of the six different approaches to solve these problems specific to commercial agriculture.

As shown in Figure 6, inadequate starch composition for industrial purposes 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 in a very early stage of the survey. There are therefore fewer respondents who rated these two problems (see Tables 1 and 2). The fact that a separate row (added by hand) was assigned to this problem 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 were 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.

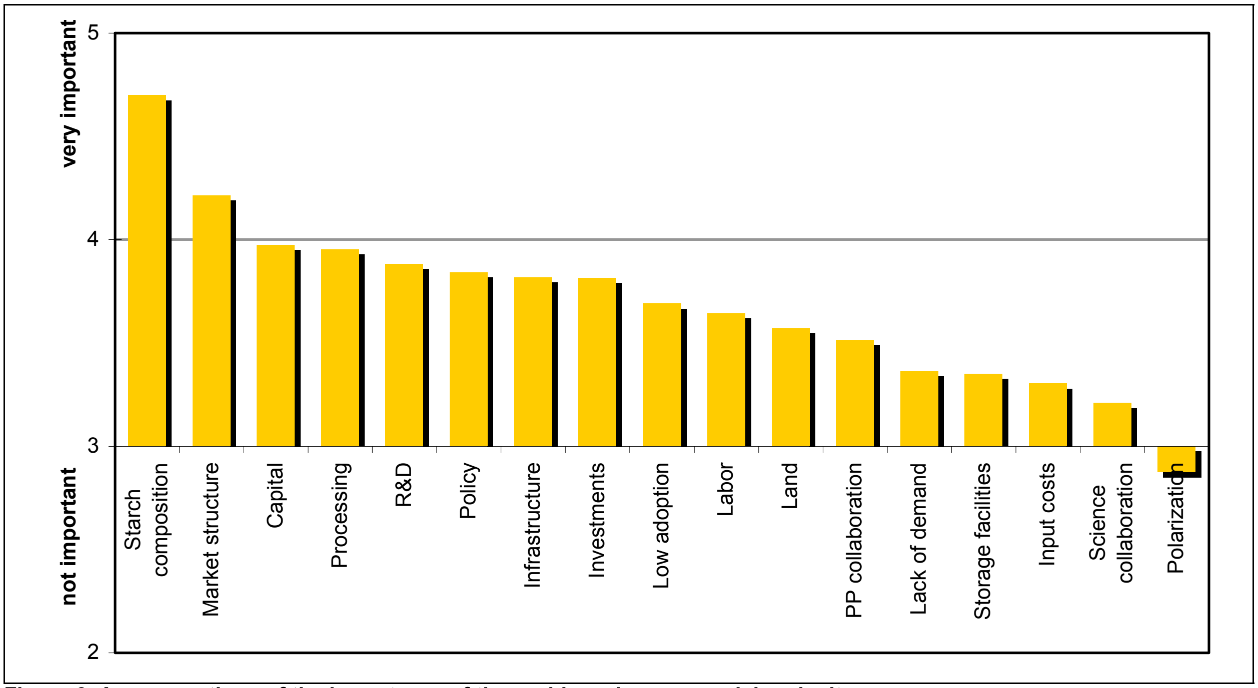

Figure 6. Average ratings of the importance of the problems in commercial agriculture.

According to many personal interviews with scientists at IITA (Alfred Dixon, Iwan Inglebrecht, Patrick Kormawa, personal communications, November 2003), the problem of labor, even though not at the top in the illustration, is one of the most important constraints in commercial agriculture in Africa. Commercial cassava production is still very labor intensive in Africa, as compared to Asia and Latin America; the opportunity costs for young local people to work in cassava commercial agriculture are very high.

Figure 7 presents the average ratings of the usefulness of the different approaches to solve these important problems. Investment in technology is considered to be the best solution for inadequate starch composition, processing, R&D, and labor; awareness campaign, which is also related to better marketing, is seen as the most important approach to improve the inefficient market structure and access to capital. The creation of global incentives is considered be an important solution for all the different problems. Investment in dialog is also perceived to be important, except for the problem of labor. Improved accountability 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.

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 the major challenges of cassava agriculture.

The 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 of mobilizing the development and application of biotechnology tools for the enhancement of the value of cassava for food security and economic development. It links advanced research institutions and widely dispersed national and regional programs with each other and with producers and consumers (Carvahlo, Thro, & Vilarinhos, 2000). The network is mainly funded by the Special Program on Biotechnology and Development Cooperation of the Directorate-General for International Cooperation (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

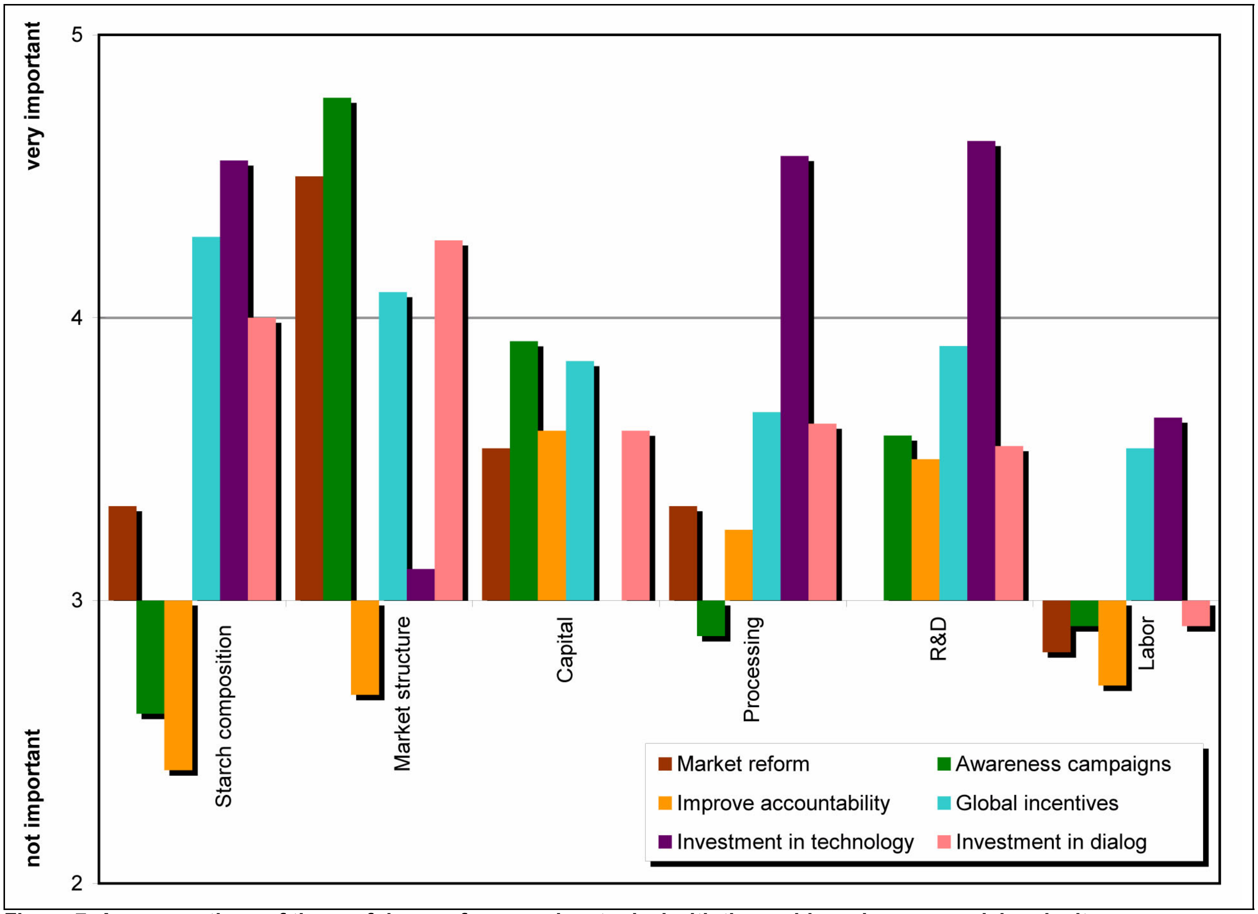

Figure 7. Average ratings of the usefulness of approaches to deal with the problems in commercial agriculture.

2001 as an offshoot of the erstwhile global CBN (1992–1998). The regionalization was a result of reviews of the parent CBN but also reflected 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 triennial CBN meetings (the seventh will be in 2007) bring together around 300 cassava researchers (of whom two thirds are based in developing countries), local farmer and NGO representatives, delegates from governments, big agribusiness companies, and international foundations. The aims of the participants of the CBN meetings 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. The 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 search of joint solutions to particular constraints in cassava agriculture. Members of the CBN are aware that what ultimately counts is not research itself but the demand for the products that are derived from such research. 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.

The CBN serves as a broker for emerging cassava partnership projects that involve national agricultural research and development institutions (NARDIs), international donors, local farmer organizations, and the private sector. 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 local 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:

- The Global Cassava Development Strategy and Implementation Plan (GCDS) was set up in 1996 by the Food and Agriculture Organization and the International Fund for Agricultural Development (IFAD). Its aim is to counteract the negative trends of cassava food and cash crop agriculture by using a demand-driven approach to promote and develop cassava-based industries (FAO/IFAD, 2001).
- The Consorcio Latinamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca (CLAYUCA), established in 1999, is a self-financing consortium that aims at boosting research for technology transfer and information exchange in cassava cash crop agriculture throughout Latin America. Its main partner in Africa is the Southern Africa Root Crops Research Network (SARRNET).
- The Global Cassava Partnership (GCP21) constitutes a worldwide, multi-institutional research and development consortium dedicated to employing the new tools of biotechnology to deliver improved germplasm to end users in the tropics.
- The BioCassavaPlus Project was established under the Global Health Challenges Program of the Bill and Melissa Gates Foundation. It addresses the major nutritional challenges related to cassava subsistence agriculture.
- The Double Haploid Initiative (funded by the Rockefeller Foundation) addresses the problem of inbreeding depression in cassava, as well as the costs associated with germplasm exchange and transportation of a vegetatively propagated crop (stem cuttings as opposed to botanical seed). Strong inbreeding depression is due to the strong heterozygosity of cassava. The Double Haploid Initiative aims to solve this problem through the rapid and complete achievement of homozygosity in cassava breeding (Hernán Ceballos, CIAT, personal communication, Octover 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. 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. 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 hardly involves the farmers and end users in the choice of varieties and techniques. CBN researchers responded to this problem by supporting a participatory tissue-culture project developed at CIAT's Biotechnology Research Unit (BRU), in cooperation with FIDAR (Fundación para la Investigación y Desarrollo Agrícola). 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 to be 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 the 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 farmers prevent the genetic erosion of their cassava planting material through in-vitro propagation of improved clones (Escobar et al., 2002). This experience made them aware for the first time that biotechnology is not magic practiced by inaccessible Western scientists but rather a practical tool can be used to address their 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 communities.[3] Poor farmer communities in particular benefit from such activities,

3. *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 micro-credit 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 made them more open to innovations in crop management and soil conservation, and the additional income allowed them to send their children to school and invest more time in education themselves.*

because it is cheaper for them to increase cassava yields by improving the planting material themselves rather than buying expensive planting material, pesticides, and fertilizers from agribusiness companies. This shows that technology may become a tool of empowerment rather than domination if appropriate institutions are in place.[4]

2. Fostering research linkages around high-priority topics. CBN members are fostering research linkages around 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 nutritional 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 that is still resistant to pests; a team at the University of Bath is developing cassava varieties that are more resistant to postharvest deterioration; another team at the University of Adelaide is analyzing the micronutrient content of cassava. A Brazilian researcher at Embrapa in Brazil discovered cassava varieties preserved over centuries by indigenous tribes in the Amazon region. Among these varieties was a yellow cassava that was rich in beta carotene, a variety that contained a root-specific protein rich in glutamic acid, and another one that produced sugar instead of starch (babyfood cassava). He discovered these characteristics by using the modern biotechnology toolkit to do biochemical pathway analysis (Carvahlo et al., 2000). This 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 indigenous cassava varieties with higher nutritional content discovered in the Brazilian Amazon are being introduced in Africa through IITA via the CBN (Luis Castelo Branco Carvalho, Embrapa, personal communication, November 2003; his research will also be part of the global biofortification initiative within Harvest Plus).

Transgenic cassava varieties that are resistant to ACMV disease have been developed at the Donald Danforth Plant Science Center in Missouri, USA and the Swiss Federal Institute of Technology (ETH Zurich) in Switzerland. 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. They also explore the new biotechnology tools in the area of gene silencing and genomics 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, unfavorable market conditions, and lack of investment in cassava business (capital) and public R&D. The CBN's response to these challenges is investment in technology and awareness building (marketing). The problems are effectively addressed by improving postharvest technologies and marketing through the fostering of research and business linkages (e.g., by intensifying collaboration with CLAYUCA and local business).

The results of the survey also showed that each problem may require a different mix of approaches. Cassava pest and disease problems are addressed by combining knowledge gathered from entomology, integrated pest management, conventional breeding, 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 a leading expert in the field, conventional biocontrol was so far unable to reduce the use of pesticides in any significant quantity in developing countries (Anthony Bellotti, CIAT, personal communication, November 2003). A reason for that is the migratory nature of pests that often makes it impossible to deploy parasitoids effectively. Furthermore, it is still not possible to break the life cycle of pests, which return year after year. It is expected that more unconventional biocontrol methods may result from more collaboration between biotech researchers and entomologists. It is the joint commitment of CBN members to find the best mix of approaches to solve a particular problem.

3. Promoting exchange of information and genetic materials. The exchange of information and open access to genetic materials among CBN members provides the main incentive for successful research collaboration,

4. *In this context, the CBN also contributes to institutional capacity-building by offering local services such as training in the use of tissue culture or assistance to local schools and universities in their efforts to conduct biotechnology training courses.*

especially between research institutes inside and outside Africa. It has resulted in many achievements:

- CIAT maintains in trust for FAO a collection of more than 6,000 cassava accessions. CBN members at CIAT developed alternative storage methods for cassava such as cyropreservation (storing germplasm in liquid nitrogen) and other ex-situ techniques to make the maintenance of the collection less costly.
- 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 already revealed regions of the cassava genome that account for much of the phenotypic variance for key traits. Molecular tagging of genes controlling key traits may eventually improve the breeding process significantly.
- Swiss researchers affiliated with the CBN developed the first protocol for regeneration and transformation of cassava (Li, Sautter, Potrykus, & Puonti-Kaerlas, 1996); together with many other advanced research institutes, they are continuously advancing the CBN's knowledge base of transgenic cassava research.

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 set up by the Consultative Group of International Agricultural Research (CGIAR) can no longer rely on a continuous flow of financial support from 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 end-user-focused networks of collaboration matter more than centralized institutions (de Vries & Toenniessen, 2001).

The CGIAR system's increased interest in strengthening its collaboration with 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 rapidly falling costs of information and communication technologies over the past 15 years, various global and regional networks were set up to improve the quality and quantity of major tropical food crops. 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. However, many of these crop networks are still in an early stage of development, are primarily focused on breeding problems, and do not yet have the global impact of the CBN.

These emerging crop networks are now mostly driven by stakeholders from developing countries. They also reflect the increasing trend toward more south-south collaboration in international research and development (Dickson, 2003; Margolis, 2005) and 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 (Aart van Schoonhoven, CIAT, personal communication, November 2003).

CBN Initiatives in Response to Changing Donor Priorities in the 1990s

The new, more developing country-driven initiatives (such as CBN) were not the planned result of a new policy paradigm among Western donor agencies but rather the response to the emerging constraints that were caused by a shift in paradigm in development cooperation: foreign aid—especially support for international agricultural research—decreased significantly in almost all developed countries, while investment in private-sector agricultural research skyrocketed (Pollack, 2001). This may largely be explained with the loss of geostrategic importance of the formerly nonaligned developing countries after the Cold War era (Anderson, Levy, & Morisson, 1991). In addition, many Western policy makers and activists in development co-operation tended to regard science and technology as inappropriate to address the problems of the poor in developing countries (Aerni & Bernauer, 2006). 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 (European Commission, 2005a, 2005b). These new constraints and the additional competition for funding from an increasing number of development-oriented NGOs forced the CGIAR system to adapt to the new circumstances. As a result, some CGIAR centers (such as CIAT) took advantage of the new opportunities of research collaboration offered by the IT revolution and contributed to the establishment of new international crop networks. These crop networks combine 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, services, and markets for the local people in marginal regions. An international crop network (such as the CBN) facilitates better horizontal and vertical collaboration across continents, CGIAR centers, and research disciplines, as well as between international researchers, local researchers, the private sector, and local farmers. However, the CIGAR centers continue to be focused on their specific crop mandates that were assigned to them during the Cold War period. These mandates are often overlapping and therefore create frictions in cross-continental collaborations. One such friction manifests itself between CIAT (which has the global mandate for cassava) and IITA (which has the regional mandate for cassava in Africa). Insistence on regional sovereignty over certain crops may turn out to be a serious obstacle when it comes to disseminating useful innovations in cassava R&D across different continents.

At any rate, collaborative crop research networks may become the new way of doing international agricultural research, if these networks can count on the leadership and commitment of a strong innovation-driven institution (such as CIAT) and are strongly embedded in local farming, research, and business activities (as it is the case with the CBN). The strong involvement of local people in such collaborative networks often results in the emergence of "local champions" who eventually become successful entrepreneurs in their respective regions. These entrepreneurs manage to combine the new knowledge gained from the international collaboration with their knowledge about the complex local economic, cultural, and political circumstances. As such, they do not just enrich themselves but contribute to genuine endogenous development. 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 in politics, and assume more responsibility in their respective community (UN Millennium Development Project Task Force on Science, Technology and Innovation, 2005).

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 reason to 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 challenges to improve cassava production and markets in Central Africa are huge, but the global resources to address them 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. Effective research and positive results in the field have enabled cassava researchers to tap different funding sources that enable them to embark on joint projects that address high-priority problems. The triennial meetings of the Cassava Biotechnology Network have become key in bringing the different cassava researchers together and get started on joint initiatives. The CBN also encourages local entrepreneurship in developing countries through competitive grants for cassava-related projects in the field, the promotion of farmer-managed low-cost tissue culture laboratories, and partnerships with the local private sector.

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

Even though the CBN became 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 around 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, and social scientists). The CBN is dominated by stakeholders from developing countries; 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 and services 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 to sustainable 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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