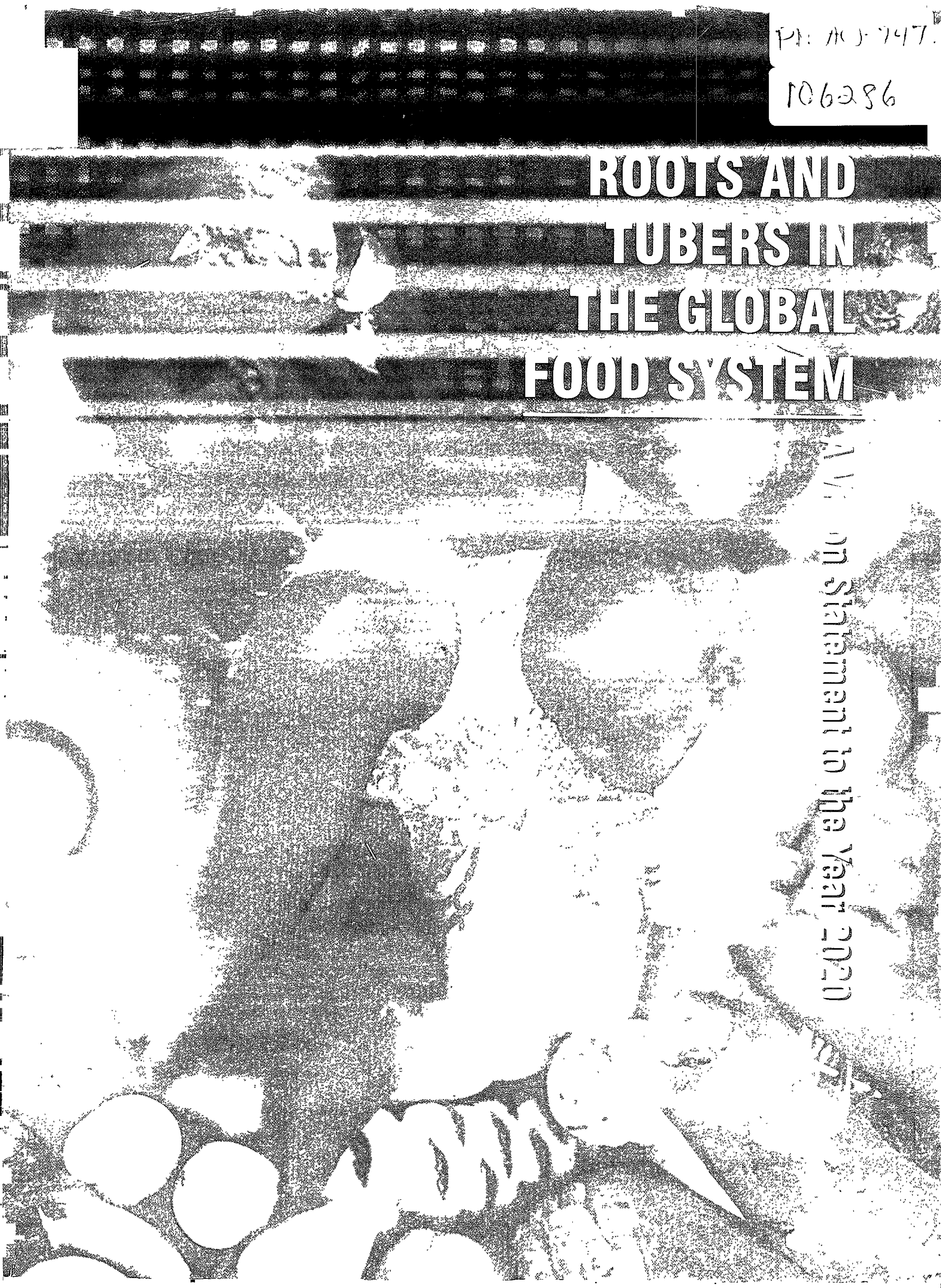
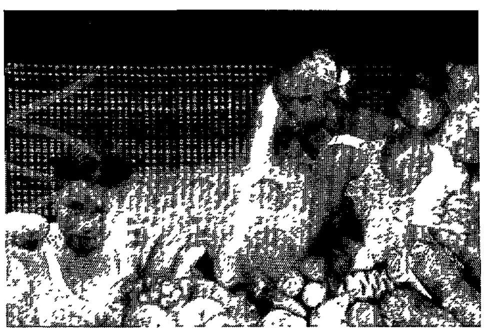
ROOTS AND TUBERS IN THE GLOBAL FOOD SYSTEM

A Vision Statement to the Year 2020





Root and tuber crops have complex roles to play in feeding the developing world in the coming decades. By 2020, more than two billion people in Asia, Africa, and Latin America will depend on these crops for food, feed, and income. Many of them will be among the poorest of the poor Current decisions about research investment on root and tuber crops in the CGIAR—and the strategy chosen for this research—will have profound implications for people around the world now and for decades to come.

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ROOTS AND TUBERS IN THE GLOBAL FOOD SYSTEM

A Vision Statement to the Year 2020

Report to the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) by the Committee on Inter-Centre Root and Tuber Crops Research (CICRTCR)

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Roots and tubers in the global food system:
A vision statement to the year 2020
Lima, Peru.

ISBN: 92-9060-203-1
Press run: 3400 copies
July 2000

Correct citation:

Scott, G.J., R. Best, M. Rosegrant, and M. Bokanga. 2000. *Roots and tubers in the global food system: A vision statement to the year 2020* (including Annex). A co-publication of the International Potato Center (CIP), Centro Internacional de Agricultura Tropical (CIAT), International Food Policy Research Institute (IFPRI), International Institute of Tropical Agriculture (IITA), and International Plant Genetic Resources Institute (IPGRI). Printed in Lima, Peru: International Potato Center.

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Acknowledgments

We are grateful to the numerous individuals both in and outside of the CGIAR who have commented on some or all of the earlier versions of this document. In particular, the authors would like to thank Malachy Akoroda (U. of Ibadan), Robert Asiedu (IITA), Lukas Brader (IITA), James Cock (Cenicaña, Colombia), Pablo Eyzaguirre (IPGRI), Shaun Ferris (IITA), Francesco Goletti (IFPRI), Maria Veronica Gottret (CIAT), Anton Haverkort (AB-DLO), Guy Henry (CIRAD), Clair Hershey (consultant to CIAT), Reinhardt Howeler (CIAT), Masa Iwanaga (IPGRI), John Lynam (The Rockefeller Foundation, Kenya), Rebecca Nelson (CIP), Felix Nweke (Visiting Scholar, Department of Agricultural Economics, Michigan State University), Inno Onwueme (University of Technology, Lae, Papua New Guinea), Douglas Pachico (CIAT), Judith Thompson (IPGRI), Imke Thormann (IPGRI), Tom Walker (CIP), Andrew Westby (NRI), Jenny Woolfe (MAFF), Mahesh Upadhya (CIP), Christopher Wheatley (CIAT), and Dapeng Zhang (CIP). We specifically acknowledge C.M. Sourang (IFAD) for his permission to cite the "Global development strategy for cassava" report (Plucknett, Phillips, and Kagbo, 1998) and the "Global cassava market study" (dTp Studies, Inc., 1998); the reader's attention is drawn to the fact that these are both works in progress.

The authors would also like to thank Anna Coccia and Concha Calpe of FAO's Commodities and Trade Division for their sharing of information and documentation on root and tuber crops. Greg Scott would also like to express his gratitude to Nikos Alexandratos and Jelle Bruinsma of FAO's Global Perspectives Studies Unit for their providing the opportunity for interaction on the trends and projections for root and tuber crops through FAO's program for cooperation with academic and research institutions.

A special acknowledgment is due to Fred Powledge for his work editing the final version of the document, to Jo Sears for her copy editing, to Luis Maldonado and Victor Suarez for their support in data analysis, and to John Stares for his support in getting the manuscript to press.

Executive Summary

In 1995, TAC commissioned an Inter-Centre Review of Root and Tuber Crops Research in the CGIAR, and that group's final report was submitted in April 1996. Among its findings, the review recommended that the Centers working on these crops prepare, in consultation with non-CGIAR members, "a comprehensive, documented text that sets out a vision for root and tuber research employing Inter-Centre collaborations and institutional partnerships...." (TAC, 1997). At International Centers' Week 1996, representatives of CIAT, CIP, IFPRI, IPGRI, and IITA met, formed an informal committee, and established a task force to prepare such a report, with CIP and CIAT representatives acting as co-convenors. This document synthesizes the principal findings of the subsequent work.

Roots and tuber crops have myriad and complex roles to play in feeding the world in the coming decades. Far from being one sort of crop that serves one specific purpose, they will be many things to many—*very* many—people. By 2020, roots and tubers will be integrated into emerging markets through the efficient and environmentally sound production of a diversified range of high-quality, competitive products for food, feed, and industry. These crops' adaptation to marginal environments, their contribution to household food security, and their great flexibility in mixed farming systems make them an important component of a targeted strategy that seeks to improve the welfare of the rural poor and to link smallholder farmers with these emerging growth markets. We estimate that by 2020 well over two billion people in Asia, Africa, and Latin America will use roots and tubers for food, feed, and income. Many of these people will be among the poorest of the poor. The CGIAR Centers, with their partners, will contribute to achieving this vision through the application of science; dissemination of information, tools, and methodologies; policy support; and, strengthening of national research and development systems.

Roots and tubers deserve particular attention because many of the developing world's poorest and most food insecure households look to these crops as a contributing, if not the principal, source of food, nutrition, and cash income. Among other things, farm households see the value of roots and tubers in their ability to produce more edible energy per hectare per day than other commodities and in their capacity to generate yields under conditions where other crops may fail. In 1995-97, farmers in developing countries harvested 439 million metric tons of the major roots and tubers—cassava, potato, sweetpotato and yam—with an estimated annual value of more than US$41 billion, nearly one-fourth the value of the major cereals.

While the versatility of all the root and tuber crops in terms of why they are grown and how they are used will remain an enduring attraction for producers and consumers alike, we envision an overall trend toward greater specialization in end use, in the location of production, and in the types of production systems in which these crops are cultivated. From a global perspective, potato and yam will be used largely as food and primarily in fresh form. The rise in consumption of potato, though, will involve more processed products, made possible largely by more environmentally friendly varieties with the appropriate processing characteristics. Cassava, sweetpotato, and other roots and tubers will be increasingly used in processed form for food, or feed and starch-derived products. Non-food, non-feed uses will grow in volume as a result of research that enhances varietal characteristics (as through biotechnology) and lowers their cost as a source of raw material.

Our collaborative work on projections for roots and tubers to 2020 indicates continued positive growth rates in output, but noticeably higher for some crops than others. Cassava, potato, sweetpotato and yam production will increase 1.74, 2.02, 0.8, and 2.7 percent annually, respectively, between 1993 and 2020, according to simulations based on more conservative estimates of key parameters. A second set of simulations gives greater emphasis to recent trends in production and use for roots and tubers. They show that production growth rates will be particularly strong for potato (2.7 percent per year) and yam (2.9 percent per year). Growth for cassava as well as sweetpotato will expand at a more modest pace—1.95 and 1.0 percent per year respectively—although in Sub-Saharan Africa their growth rates in production will be comparable to those for potato and yam. Moreover, the projected growth rates for cassava, potato, and yam in developing countries exceed those projected for the major cereal crops such as rice and wheat. While these growth rates may appear high, they actually represent a considerable slowdown in the recent rates of expansion for these roots and tubers and from that historical perspective are quite reasonable.

Our projections also indicate increased regional and/or continental concentration of production. By 2020, over 60 percent of global cassava production will be in Sub-Saharan Africa. Potato production in West, South, and East Asia will account for nearly 80 percent of developing country totals. Sweetpotato will be heavily skewed toward China with over 82 percent, with the bulk of the remainder in Central, East, and Southern Africa. Yam will be even more highly concentrated, over 90 percent in West Africa.

To add to this complex portrait of diversity is a dichotomous set of supply-side versus demand-side constraints. Each of the commodities faces constraints from both sides and the CGIAR contributions are best considered in a systems framework covering production through to utilization and policy. But, potato and yam are more vulnerable to supply-side problems, while broadly speaking cassava, sweetpotato, and other roots and tubers face more demand-side limitations.

Research, of the sort at which the CGIAR system excels, can cope with both kinds of constraints. Research and development can remove or reduce barriers to increased output, and such techniques as germplasm improvement to lower raw material costs and enhance quality can deal with demand-side constraints. Strengthening grower-processor linkages and small- to medium-scale enterprises, as well as improved policies, can also remove constraints.

Our projections of the economic value of these commodities indicate that these commodities are likely to sustain their importance in the decades ahead. It is noteworthy that these calculations take into consideration the production of nearly all the major food commodities in the global food system: cereals, roots and tubers, soybean, and meat. Our set of more conservative calculations estimates roots and tubers' share of the total value of these products is projected to drop from 10.5 percent in 1993 to 8.8 percent in 2020. Our simulations grounded more in recent trends project roots and tubers' share will remain at 10.5 percent of that total, identical to the estimated value in the base period 1993.

The three principal Centers working on roots and tubers account for over 95 percent of the total CGIAR budget for these commodities. CIAT, with headquarters in Colombia, works on cassava for Latin America and Asia; CIP, in Peru, has the global mandate on potato, sweetpotato, and Andean roots and tubers; and, IITA, in Nigeria, works primarily in Sub-Saharan Africa on cassava and yam. Additional, complementary work on food policy research is done by IFPRI, with headquarters in the United States. IFPRI's mandate is not specific to roots and tubers, but it places those crops in the wider context of production, utilization, and trade. IPGRI, in Italy, focuses on genetic resources. In 1998, these activities were carried out in some 35 projects at a cost of about US$44 million. This figure represented 14 percent of the total CGIAR budget, a percentage that has remained fairly constant since 1972. A series of impact studies has found that investments in research on roots and tubers have paid very high rates of return.

Given the projected increases in supply and demand, the importance of roots and tubers in developing countries is unlikely to diminish by 2020 or long afterward. In order to attain the objectives of improving food security and eradicating poverty, it is fit, proper, and necessary for the CGIAR as well as other national, bilateral, and multinational organizations to retain these crops as an integral part of a global strategy to increase food production and utilization in Asia, Africa, and Latin America in the decades ahead.

Having considered a variety of alternative organizational arrangements for root and tuber research in the CGIAR, the task force identified the following three future scenarios: 1) continued informal collaboration, 2) a global collaborative root and tuber program, and 3) a root and tuber Center. At their annual meeting in Washington during International Centers' Week 1999, Center representatives reviewed these options and recommended the System-wide Root and Tuber Crop Program for further consideration. This recommendation is now being considered by the Centers and their respective governing bodies.

The Annex to this document consists of supporting information, commodity statistics, a synthesis of numerous reports, and organizational schema intended to provide a substantive justification for this vision. It includes a detailed review of constraints and opportunities for these crops as well as a synthesis of current research in and with the CGIAR on roots and tubers.

Preface

This document and associated ones evolved from a series of discussions and papers dating to International Centers' Week (ICW) 1993, when the Consultative Group on International Agricultural Research (CGIAR) requested its Technical Advisory Committee (TAC) to conduct a "critical examination of CGIAR programs in the context of a long-term vision, taking into account current and future trends with options for structural change within the system." Subsequently, at the CGIAR's mid-term meeting in 1994, TAC presented the paper, *The CGIAR in the 21st Century: Options for Structural Change*. In that paper, TAC noted the urgent need to define a strategy "for roots and tubers research in the medium-term and to explore alternative mechanisms..." (TAC, 1994).

In 1995, TAC commissioned an Inter-Centre Review of Root and Tuber Crops Research in the CGIAR, and that group's final report was submitted in April 1996 (TAC, 1997). While the review noted the wide variety of previous and ongoing collaborative activities involving the different Centers engaged in research on roots and tubers, it considered that there were still gains to be captured through a slightly more formalized, comprehensive, and forward looking approach. Among its recommendations was the formation of an Inter-Centre Consultative Committee on Root and Tuber Crops Research (ICRTCR) that would advise on system-wide planning, coordination, and operation. The review further recommended that a task force, including consultation with non-CGIAR members, be convened to prepare "a comprehensive, documented text that sets out a vision for root and tuber research employing Inter-Centre collaborations and institutional partnerships..." (TAC, 1997).

In response to the recommendations of the Inter-Centre review, the International Potato Center proposed a meeting of CIAT, CIP, IFPRI, IPGRI, and IITA representatives at ICW 1996 for the purpose of formalizing the ICRTCR.* That meeting took place and the task force was established, with CIP and CIAT representatives acting as co-convenors, with the following terms of reference: (a) to provide a vision of the potential for root and tuber crops and how they can make a fuller contribution to the food, feed and industrial requirements of developing countries in the 21st century; (b) to identify the factors that constrain the development of root and tuber crops and that limit the realization of their full social and economic potential; and, (c) to formulate a set of recommendations for the development of a coherent research and development strategy for root and tuber crops. At ICW 1997, a preliminary set of projections for root and tuber crops was presented by the task force to the ICRTCR. At ICW 1998, the ICRTCR was re-christened the Committee on Inter-Centre Root and Tuber Crops Research (CICRTCR) and a complete draft of the vision statement was circulated for internal review and subsequently sent out to a group of non-CGIAR scientists for their inputs. These comments served as the basis for a series of revisions. This statement synthesizes the principal findings of the subsequent work.

For additional information on trends and projections for roots and tubers, see Scott, Rosegrant, and Ringler (2000, 2000a).

* ISNAR was also invited to attend, but declined to participate.

Roots and tubers in the global food system: A vision statement to the year 2020

Roots and tubers have myriad and complex parts to play in feeding the world in the coming decades. Far from being one sort of crop that serves one specific purpose, they will be many things to many—very many—people. In some cases, they will mean the difference between subsistence and achieving a leg up on the economic ladder; in others, they will mean the difference between survival and starvation. In all instances, their potential to help improve food security and eradicate poverty will be important. We propose, therefore, a vision for the contribution that these crops will make to the global food system by the year 2020. This vision can be summarized as follows:

> *By 2020, roots and tubers will be integrated into emerging markets through the efficient and environmentally sound production of a diversified range of high-quality, competitive products for food, feed, and industry. These crops' adaptation to marginal environments, their contribution to household food security, and their great flexibility in mixed farming systems make them an important component of a targeted strategy that seeks to improve the welfare of the rural poor and to link smallholder farmers with these emerging growth markets.*
>
> *The CGIAR Centers, with their partners, will contribute to achieving this vision through the application of science; dissemination of information, tools, and methodologies; policy support; and, strengthening of national research and development systems.*

Mission of the CGIAR

The mission of the Consultative Group on International Agricultural Research (CGIAR) is worthy and far-reaching—with profound implications for humanity's most basic necessities now and for generations to come. The CGIAR seeks "To contribute to food security and poverty eradication in developing countries through research, partnership, capacity-building, and policy support, promoting sustainable agricultural development based on the environmentally sound management of natural resources" (CGIAR, 1998: viii).

A vision of the future

"Vision" comes from the Latin "to see." A modern dictionary demonstrates the term's several meanings: It can be something that is seen to "convey a revelation." Alternatively it can be "the act or power of imagination." Or—and this is the sense in which we look ahead and try to glimpse the future of an important component of the foods that keep people alive—it can mean an "unusual discernment or foresight." Here that foresight is based on the accumulated knowledge of hundreds of scientists and policymakers at CGIAR and allied organizations.

The questions addressed in this statement concern an extremely important element in that battle for food security and poverty elimination: How can the CGIAR best ensure that the different species of roots and tubers—cassava, potato, sweetpotato, yam, as well as the aroids and Andean roots and tubers—each make the greatest contribution to its overall mission, and, in so doing, to the global food system?* And how will these crops' roles evolve by the year 2020, when the world will be quite a different place, filled with many more people, all of them needing to be fed?

These questions deserve particular attention because many of the developing world's poorest and most food insecure households look to roots and tubers as a contributing, if not the principal, source of food, nutrition, and cash income (Alexandratos, 1995). Among other things, farm households see the value of roots and tubers "in their ability to produce large quantities of dietary energy and in their stability of production under conditions where other crops may fail" (Alexandratos, 1995:189). In 1995–97, farmers in developing countries produced 439 million metric tons (mt) of the major roots and tubers—cassava, potato, sweetpotato and yam—with an estimated annual value of more than US$41 billion, nearly one-fourth the value of the major cereals (Table 1).

* The different species are cassava (*Manihot esculenta*), potatoes (*Solanum* spp.), sweetpotato (*Ipomoea batatas*), and yams (*Dioscorea* spp.). Other roots and tubers includes aroids such as taro (*Colocasia esculenta*) and Andean roots and tubers such as ulluco (*Ullucus tuberosus*), arracacha (*Arracacia xanthorrhiza*), maca (*Lepidium meyenii*), and oca (*Oxalis tuberosa*).

The answers are complex, covering a diversity of areas, activities, and actors, each of which is in constant flux and each of which affects the others. They include population growth; nutrition; protection of the environment; the evolution of farming systems; traditional and emerging research technologies; tastes that change as income rises and people throng to urban areas; and the opportunities as well as sometimes traumatic alterations brought about by falling trade barriers and the increasing globalization of economic activity.

Perhaps the most influential of these trends for root and tuber crops are those noted by Pinstrup-Andersen, Pandya-Lorch, and Rosegrant (1999) in their recent assessment of the world food situation to 2020:

- The increase in global population from 5.7 to 7.5 billion people (United Nations, 1999), more than 95 percent of which will take place in developing countries. Hence, the proportion of the world's population living in developing countries will increase from nearly 80 percent to 84 percent.
- The growing urbanization of the developing world; the developing world's urban population is expected to double to 3.4 billion (United Nations, 1996).
- The differentiated growth rates in income in particular with higher per capita incomes in Asia and considerably lower levels in Sub-Saharan Africa.

As a result, tremendous pressure will be placed on the global food system to produce more food and to provide

Table 1. Production, edible energy and protein, and value of major roots, tubers, and cereals in developing countries, 1995–97.

Commodity	Price (US$/mt)	Production (million mt)	Edible energy (trillion kilocalories)	Edible protein (million mt)	Value (US$ billion)
Cassava	53	165.3	142	0.7	8.8
Potato	157	105.3	65	1.8	16.5
Sweetpotato	88	137.0	127	1.9	12.1
Yam	130	31.5	28	0.5	4.1
Major roots/ tubers		**439.1**	**362**	**4.9**	**41.4**
Wheat	146	272.2	687	27.4	39.7
Maize	126	257.6	786	20.1	32.5
Milled rice[a]	284	350.0	851	15.7	99.4
Major cereals		**879.8**	**2,324**	**63.2**	**171.6**

Source: Scott, Rosegrant, and Ringler (2000)
Note: Production data based on FAO (1998 June, accessed July); coefficients for calculating edible energy and protein are based on Horton (1988), prices are based on estimates for 1993 and 2020 baseline scenario interpolated for 1995–97, see Table A9, totals may not sum due to rounding.
[a] Milled rice is more readily comparable to the other commodities for the purposes of calculating utilization, hence the production figures are presented here in comparable units

Food security—and insecurity

What is "food security" and its opposite, "food insecurity"? Here are some recent definitions, gathered from the literature on international agricultural research:

- People suffer from food insecurity when they do not get enough food to lead healthy, active lives. "Healthy, active lives" is a component of virtually all definitions of the term. Insecurity often applies to the majority of people in a region, but it also can refer to individuals who live in an otherwise affluent area.
- When food security is lacking, people have a reduced capacity to cope with unexpected setbacks in their economic or natural environments.
- "Food security...exist[s] when all people at all times have physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life. Food insecurity exists when the availability of nutritionally adequate and safe foods, or the ability to acquire acceptable foods in socially acceptable ways, is limited or uncertain." (United States of America General Accounting Office, 1999:1-2).
- "Food security means access by all people at all times to the food needed for a healthy life. Sustainable food security aims to achieve this goal without compromising the productive capacity of natural resources, the integrity of biological systems, or environmental quality." (FAO and UNDP, 1994.)

increasing percentages of that output to urban as well as rural areas. Furthermore, agriculture and food systems will remain the principal means for income generation among the rural poor in Asia, Africa, and Latin America in the decades ahead.

The decisions and research investments that the CGIAR and its partners make today will strongly affect the role of roots and tubers in the global food system over the next fifteen or twenty years and as a result the potential of these crops to help improve food security and eradicate poverty. Our underlying hypothesis is that the developing countries' benefits from root and tuber crops in 2020 will be strongly related to the strength of the support the CGIAR provides at the beginning of the new century—right now. We further believe that these commodities, often underestimated in accountings of "the crops that feed the world," are vital elements in carrying out the CGIAR's mission. Over two billion people in the tropics and subtropics depend on roots and tubers for their sustenance and livelihood.

Multipurpose commodities

More than is the case with most of the commodities in the CGIAR's repertoire, roots and tubers mean different things to different people in different regions of the world, and at different levels of economic well-being. Far from being simply bulky, perishable starchy staples produced for on-farm consumption, the crops fulfill a number of basic roles in the global food system, all of which have fundamental implications for meeting food requirements, increasing food security, and reducing poverty. Demographic changes and the evolution of per capita incomes will continue to differentiate those roles by commodity and region. Thus, we estimate that by 2020 well over two billion people in Asia, Africa, and Latin America will use roots and tubers for food, feed, or sources of income. Many of these people will be among the poorest of the poor. Here are some examples:

- In **Sub-Saharan Africa**, where economic growth will be slow but population growth fast, cassava will be a favored source of cheap carbohydrates in the countryside and also continue to serve as a food security crop (Scott, Rosegrant, and Ringler, 2000a). Furthermore, as urbanization continues in the region, more people in cities and towns will purchase their food, rather than grow it themselves. That will continue to give small farmers a source of cash income from cassava; some of it will reach the market in processed form (Nweke, 1992). The resulting gains in poverty eradication and greater food security will depend in part on an integrated set of research outputs that include higher-yielding, pest-resistant varieties; improved crop management as well as processing equipment and procedures; better linkages among producers, processors, and consumers through capacity-building in market analysis and enterprise development; and improved policies that facilitate the development and adoption of these innovations.

- In **West Africa**, yam will be a preferred local vegetable (in some locations a staple) and will be increasingly important as a source of cash income; in parts of **Central**, **Eastern**, and **Southern Africa**, sweetpotato will play a supplementary role to cassava and maize as a seasonal source of food, food security, and cash. Both sweetpotato and yam can help eliminate poverty and improve food security in their respective areas of greatest concentration. Research is needed to develop pest-resistant varieties, improve the availability of planting material, and exploit the growing demand for inexpensive nutritious foods and processed products.

- In **Asia**, generally, faster economic growth and slower population expansion will shape the future of roots and tubers. Higher incomes will bring less dependence on cereals and greater demand for potatoes in fresh and processed form (FAO, 1995). Potato will be the most important vegetable in Asia, with increased production providing more food, income, and employment. The crop's expansion will be speeded by development and adoption of yield-increasing technology and policies aimed at continuous improvement of storage and marketing.

- In **China**, higher incomes and increased urbanization will stimulate further increases in the demand for meat and prepared foods. This will translate into greater use of sweetpotato as a source of starch for processed food and other starch-derived products and as an inexpensive source of animal feed—particularly in poorer, more isolated areas—and hence into higher incomes for less well-off households engaged in sweetpotato processing. Again, research will help produce the most useful type of roots, commercially viable procedures and products as well as policies to induce adoption of improved production and postharvest technologies.

- In **Southeast Asia**, there will be demand for cassava, also, for use as processed food and feed, and for specialized starch products (dTp Studies, Inc., 1998). The competitiveness of these products, and the resulting benefits to low-income households, will be assured by the continued reduction of production costs through the diffusion of higher-yielding varieties with higher dry matter content so as to maximize conversion rates from raw material to processed product, the adoption of fertility and erosion management practices, and the incorporation of improved processes and management practices by agro-enterprises.

- In parts of **Oceania**, yam and other roots and tubers such as taro will continue to be utilized in more localized production and consumption systems.

- In **Latin America**, production of cassava and potato will remain important in quantitative terms but will become less and less important from a global perspective. Private sector investment will make an increasing contribution to research and development of cassava for use as processed food and feed. Sweetpotato, yam, and Andean roots and tubers such as achira (or canna), ulluco, and arracacha will continue to be important to poor households in much more specific locations. Once the properties of these roots and tubers are better understood by science, they too may become candidates for specialized markets.

Thus, any projections of consumption and output patterns for roots and tubers in developing countries must pay careful attention to the different ways in which the crops are used. While the versatility of all the root and tuber crops in terms of why they are grown and how they are used will remain an enduring attraction for producers and consumers alike, we envision an overall trend toward greater specialization in end use, in the location of production, and in the types of production systems in which these crops are cultivated.

From a global perspective, cassava and sweetpotato will be increasingly used in processed form for food, feed and starch-derived products, e.g. high fructose syrup, monosodium glutamate. Non-food, non-feed uses will grow in volume as a result of research that enhances varietal characteristics (as through biotechnology) and lowers their cost as a source of raw material. Potato and yam will be used largely as food and primarily in fresh form. The rise in consumption of potato, though, will involve more processed products, made possible largely by more environmentally friendly varieties with the appropriate processing characteristics. Research on the quality characteristics of yam starch may identify additional market segments beyond those for fresh roots (Berthaud, Bricas, and Marchand, 1998).

Our collaborative work on projections for roots and tubers to 2020, using IFPRI's IMPACT model (see box, p. 17), indicate continued positive growth rates in output (Table 2), but noticeably higher for some crops than others. They will be particularly strong for potato (2.7 percent per year) and yam (2.9 percent per year). Growth for cassava as well as sweetpotato will expand at a more modest pace—1.95 and 1.0 percent per year respectively—although in Sub-Saharan Africa the growth rates in production for cassava and sweetpotato will be

IFPRI's IMPACT model

Global projections of root and tuber supply and demand were based on an updated version of IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). IMPACT covers 37 countries and regions and 18 commodities, including all cereals, soybean, roots and tubers, meats, and dairy products (accounting for virtually all of the world's food and feed production and consumption). The model is specified as a set of country-level demand and supply equations linked to the rest of the world through trade (see Rosegrant, Agcaoili-Sombilla, and Perez, 1995).

The results presented here are from a revised and updated version of IMPACT. These projections attempt to go beyond past estimates of future root and tuber supply and demand in a number of important respects, including disaggregating roots and tubers in a multi-commodity model (see Scott, Rosegrant and Ringler, 2000, 2000a for details).

Table 2. Production of roots and tubers in 1993, and projections and growth rates to 2020.

	Cassava[a]			**Potato**			**Sweetpotato and yam**[b]		
	Production		**Growth rate**	**Production**		**Growth rate**	**Production**		**Growth rate**
Country/region	**1993**	**2020**	**1993–2020**	**1993**	**2020**	**1993–2020**	**1993**	**2020**	**1993–2020**
	(million mt)		(percent/yr)	(million mt)		(percent/yr)	(million mt)		(percent/yr)
China	4.8	6.6	1.21	42.5	87.8	2.72	108.5	136.0	0.84
Other East Asia	na	na	na	2.4	3.3	1.18	0.8	1.1	1.36
India	5.8	7.1	0.76	16.3	43.3	3.67	1.2	1.3	0.44
Other South Asia	0.8	1.3	1.61	3.5	7.7	2.98	0.5	0.7	1.27
Southeast Asia	42.0	48.2	0.51	1.3	2.3	2.08	5.3	8.0	1.49
Latin America	30.3	42.0	1.22	12.6	20.2	1.76	2.6	3.7	1.41
W. Asia/N. Africa (WANA)	0.1[c]	0.2[c]	1.61	13.0	23.4	2.21	0.1	0.2	1.55
Sub-Saharan Africa	87.8	183.8	2.77	2.6	6.0	3.06	36.0	78.0	2.90
Developing	172.4	290.3	1.95	94.3	194.0	2.71	155.9	230.2	1.45
Developed	0.4	0.4	0.67	191.0	209.5	0.34	2.1	2.3	0.36
World	172.7	290.8	1.95	285.3	403.5	1.29	158.0	232.5	1.44

Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000).

Note: 1993 signifies the three-year moving average for 1992–94; na signifies not applicable; totals may not sum due to rounding. Other East Asia covers Hong Kong, Macau, Mongolia, North Korea, and South Korea. Other South Asia covers Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka. Southeast Asia covers Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. Latin America covers Central and South America plus Mexico. West Asia/North Africa (WANA) covers Algeria, Bahrain, Cyprus, Egypt, Gaza Strip, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, Western Sahara, and Yemen. Sub-Saharan Africa covers Central, West, Eastern, Northern, and Southern Sub-Saharan Africa.

[a] These figures are for cassava and other roots and tubers such as taro. For developing countries, cassava alone accounts for over 97 percent of the total.

[b] Estimates for Sub-Saharan Africa are largely for yam, given the 80/20 distribution of production in the region of the two crops according to FAO (1998 June); in Asia and WANA for sweetpotato only as FAO (1999 April) indicates only the Philippines produces yam and less than 30,000 mt on 5900 ha; and, in Latin America 68/32 for sweetpotato versus yam.

[c] FAO indicates very high yields in Egypt for a small area.

comparable to those for potato and yam. Moreover, the projected growth rates for cassava, potato, and yam in developing countries exceed those projected for the major cereal crops such as rice and wheat (Figure 1).

While these growth rates may appear high for potato and yam as well as cassava in Sub-Saharan Africa, they actually represent a considerable slowdown in the recent rates of expansion and from that historical perspective are quite reasonable. According to FAO (1999 April), growth rates for potato, yam and cassava (in Sub-Saharan Africa) production in developing countries over the last decade have been 4.7 percent, 8.7 percent, and 3.5 percent. Farmers worldwide are increasingly aware of the capacity of roots and tubers to out-produce the cereals in terms of quantities of edible energy harvested per hectare per day (Figure 2). To cite but one of a series of recent examples, according to FAO (1999 April) India now produces over 25 million mt of potato annually—up from 16 million mt in 1992–94 (Table 2). IFPRI's IMPACT model shows that production rising to 43 million mt by 2020.

Our projections also indicate increased regional and/or continental concentration of production (Table 3). By 2020, over 60 percent of global cassava production will be in Sub-Saharan Africa. Potato production in West, South, and East Asia will account for nearly 80 percent of developing-country totals. Sweetpotato will be heavily skewed toward China with over 82 percent; with the bulk of the remainder in Sub-Saharan. Yam will be even more highly concentrated, over 90 percent in West Africa.

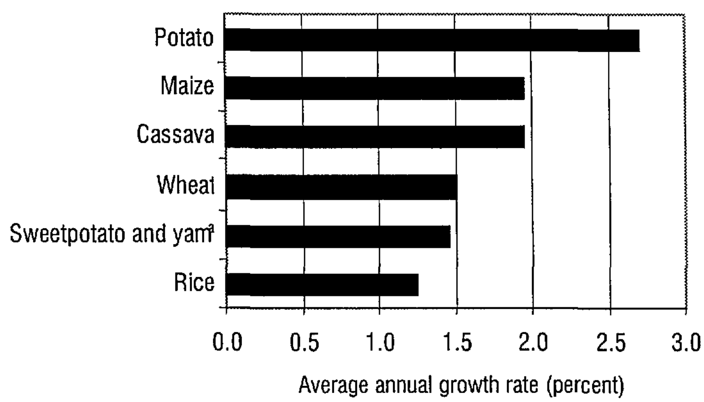
There will be strong differences, too, in the production systems in which these commodities are cultivated. Thus, while the diversity among roots and tubers means that different crops are capable of contributing to different developing-country food systems in different ecological regimes, potato will increasingly be dominant in two systems—the subtropical lowlands in Asia and North Africa, and the subtropical highlands throughout the developing world—whereas cassava and sweetpotato will increasingly achieve prominence in several other, quite distinct systems.

To add to this complex portrait of diversity is a dichotomous set of supply-side versus demand-side constraints. Each of the commodities faces constraints from both sides, but potato and yam are more vulnerable to supply-side problems, while broadly speaking cassava and sweetpotato face more demand-side limitations. Research, of the sort at which the CGIAR system excels, can cope with both kinds of constraints. Research and development can remove or reduce barriers to increased output, and such techniques as germplasm improvement to lower raw material costs and enhance quality can deal with demand-side constraints. Strengthening grower-processor linkages and small- to medium-scale enterprises, as well as improved policies, can also remove constraints.

The beneficiaries

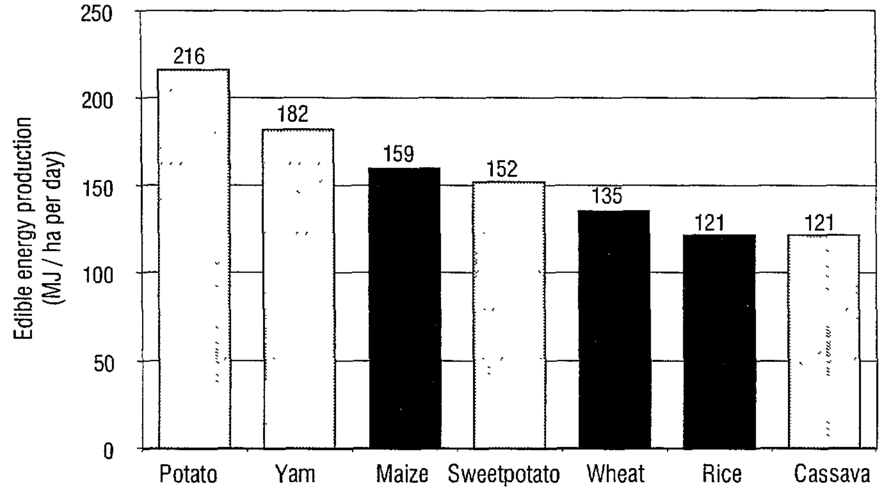
With the help of the kind of technological expertise that the CGIAR system can provide to overcome these constraints, the beneficiaries of roots and tubers in terms of poverty eradication and greater food security can cover a range as broad as the crops' uses. When research is oriented toward development, as it is in the CGIAR, by definition it has an overriding focus on people. Thus it is appropriate to consider who the intended beneficiary groups are; what their needs are for improved income and food security;

Figure 1. Projected growth rates for major food crops in developing countries, 1993–2020.



Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000).
[a] Disaggregated growth rates for sweetpotato (1.0) and yam (2.9) are estimated outside IFPRI's IMPACT, but calculated based on those simulations and historical trends.

Figure 2. Production of edible energy from roots, tubers, and major cereal crops.



Source: Horton and Fano (1985).

Table 3. Projected regional distribution of root and tuber production in 2020.

Country/region	Cassava[a] 2020 (million mt)	Cassava[a] (%)	Potato 2020 (million mt)	Potato (%)	Sweetpotato[b] 2020 (million mt)	Sweetpotato[b] (%)	Yam[b] 2020 (million mt)	Yam[b] (%)	All R&T 2020 (million mt)	All R&T (%)
China	6.6	2.3	87.8	45.3	136.0	82.2	-	-	230.4	32.2
Other East Asia	0.0	0.0	3.3	1.7	1.1	0.7	-	-	4.4	0.6
India	7.1	2.4	43.3	22.3	1.3	0.8	-	-	51.7	7.2
Other South Asia	1.3	0.4	7.7	4.0	0.7	0.4	-	-	9.7	1.4
Southeast Asia	48.2	16.6	2.3	1.2	8.0	4.8	...[c]	...	58.5	8.2
Latin America	42.0	14.5	20.2	10.4	2.5	1.5	1.2	1.9	65.9	9.2
W. Asia/N. Africa	0.2[d]	0.1	23.4	12.1	0.2[d]	0.1	...[e]	..	23.9	3.3
Sub-Saharan Africa	183.8	63.3	6.0	3.1	15.6	9.4	62.4	98.1	267.7	37.5
All Developing	290.3	100.0	194.0	100.0	165.4	100.0	63.6	100.0	714.6	100.0

Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000). See also notes c, d, and e below.

Note: R&T= roots and tubers; ellipses (...) signify negligible data; na signifies not available; totals may not sum due to rounding. For country/region definitions see note, Table 2.

[a] These figures are for cassava and other roots and tubers such as taro. For developing countries, cassava alone accounts for over 97 percent of the total.

[b] The figures for 2020 for sweetpotato and yam are estimates calculated outside IFPRI's IMPACT, but based on those simulations and historical trends See also note b Table 2.

[c] According to FAO (1999 April), only the Philippines produces yam and less than 30,000 mt on 5900 ha.

[d] FAO indicates very high yields in Egypt for a small area.

[e] According to FAO (1999 April), West Asia/North Africa (WANA) produces no yam and in 1992–94, Egypt produced some 128,000 mt of sweetpotato on 5100 ha.

how other, unintended groups might be affected; and, how these groups are linked in ways that should influence a research strategy.

There are several actors in the global food system that benefit from the sort of advances in roots and tubers that research can provide.

Producers constitute the largest group of people directly affected by research and development outputs. Their diets, health, and incomes are the principal focus of these endeavors. They are typically farmers with small holdings, on less-favored or marginal lands, and at the lower end of the economic scale, but also include farm workers and their families who help cultivate and transform these crops.

Processors, manufacturers, and traders are fewer in number, compared to producers and consumers, but they have important links to those who grow and those who use these crops. Furthermore, they manage many of the resources that can influence demand for the products farmers can offer in the marketplace. They are catalysts in the global food system, and they should be integrated into a research and development strategy.

Consumers of roots and tubers include those who make traditional use of food and feed as well as those who use products derived from processing, such as starch (Bricas and Attaie, 1998; Hermann and Heller, 1997; Nweke, 1992; Woolfe, 1987, 1992) in one way or another. The consumer market includes practically everyone, for starch from roots and tubers is used in pharmaceuticals, paper, and textiles (dTp Studies, Inc., 1998). We focus here though solely on the consumer benefits from research at the direct-use or basic processing levels.

Research and development has the potential to strongly impact the **providers of products and services** that surround the world of roots and tubers. Employment of landless labor, for example, is critical for potato production in South Asia; the starch industry in southern Brazil is a growing market for manufacturers of industrial machinery; women in Sub-Saharan Africa in particular often look to root and tuber crops as a source of food and income. Agricultural research can shape its products

Production systems for roots and tubers

Roots and tubers are found in a wide variety of production systems and do well under various levels of management, from low-input systems to high-input systems. This is a distinctive feature of roots and tubers which makes them important for improving the productivity and richness of agro-ecosystems. Some prominent examples include the following.

- **Cassava** in Sub-Saharan Africa is often grown on marginal soils, under hot, rainfed conditions. Few purchased inputs are applied. Cassava is most often grown in association with other commodities such as maize or groundnuts. The crop takes from 8 to 12 months to mature and the roots may be left in the field for months after that as a form of in-ground storage. The roots are often processed prior to use or sale for human consumption.

- **Potato** production has expanded most rapidly in the subtropical lowlands, e.g. West Bengal in India during the cool, dry, winter months, where the crop is grown as a monoculture under irrigated conditions, utilizing hefty doses of chemical fertilizers and pesticides, and in tight crop rotations with rice. The tubers are harvested 110–130 days after planting with the bulk of the output sold fresh for cash.

- **Sweetpotato** in Asia is cultivated predominantly under lowland conditions. One common system involves a variety of different rotations with rice. In this system, the crop is irrigated and harvested at maturity after four to five months. Long grown as a food security or famine crop, sweetpotato is increasingly cultivated for cash where both vines and roots are processed into feed or starch prior to sale.

- **Taro** is locally important in many parts of the humid tropics and subtropics. Taro is often intercropped with corn, beans, sugarcane, fruit trees, and vegetables in the rainfed and irrigated uplands, or with rice in the paddy fields, or is rotated with winter crops such as garlic and broad bean.

- **Yam** is cultivated predominantly in the humid forest, forest/savanna transition, and the southern Guinea savanna (SGS) zones of West Africa with most of the current production in the SGS. It is grown as the sole crop or in various combinations with maize, vegetables, cassava, plantain, sorghum, or coffee. The crop matures in 7 to 12 months, depending on species and cultivar, and the tubers may be stored in fresh form for over six months under ambient conditions.

to explicitly influence the service sector, and that influences the relationship between this sector and producers and consumers.

It is difficult to make generalizations about the interaction between roots and tubers and **the environment**, but one common feature is the need for soil disturbance at harvest, which in some cases can encourage erosion. Cassava can be (and is) grown on low-fertility, erodible hillsides (Howeler, Oates, and Costa Allem, 1999), potato on highland slopes in fragile ecosystems. Potatoes may also (and do) need frequent applications of pesticides, with exposure to these chemicals a concern for human health (Crissman, Antle, and Capalbo, 1998). As roots and tubers are sought more as sources of starch, the risk of pollution from a high concentration of small processing plants in particular locations increases (Goletti, Rich, and Wheatley, 1999). Some root crops, most notably sweetpotato, offer the promise of environmental benefits—in this case by being planted as quick cover crops to reduce soil erosion.

All food crops are constantly evolving, not only in terms of their genetic makeup but also their social, economic, and environmental relationships with the people who grow, sell, and consume them. That truism applies even more emphatically to cassava, potato, sweetpotato, yam, and other roots and tubers. These plants play multiple, changing roles as food and industrial economies evolve in response to population growth and relocation, changes for better or worse in financial well-being, pressures on the environment, and claims for recognition from women, community groups, and farmers insisting on a role in the research process.

Roots and tubers will continue to provide basic food security (as in Africa), but they increasingly will function as sources of income (as in parts of Asia, Africa, and Latin America). As foods of the new urban majority, they will provide diversity in the diet: as a vegetable for some, a basic calorie source for those less affluent, and an additional source of essential vitamins (vitamins A and C) and minerals for many. Producers are increasingly inclined to exploit their potential as animal feed, as sources of starch and specialty foods, and as competitors for grains (Best, 1996). All this requires integration of supply and demand, as well as capitalizing on growing commercial demand for processed food, feed and intermediate products such as starch. Ensuring that food security and income benefits reach all the target groups requires a careful integration of research, and that must include the non-target groups who serve as important catalysts—the processors and traders. All these needs for multifaceted research are especially important because, with few noteworthy exceptions in the case of potato, the private sector has demonstrated a relatively low level of involvement in roots and tubers.

As a complement to the projections of future aggregate supply, Table 4 presents an overview of selected, major

An overview of cassava in Africa *by Felix Nweke.*

In 1993–1995, 84 million mt of cassava were produced per year in Sub-Saharan Africa. Of this, 75 percent was produced in four countries: Nigeria, 31 million mt; the Democratic Republic of Congo, 19 million mt; Tanzania, 7 million mt; and, Ghana, 6 million mt. In the same period, 95 percent of cassava production (after discounting for waste) was used for human consumption, according to FAO. The remaining 5 percent was used for feed; use for industrial raw material or export was minimal.

The Collaborative Study of Cassava in Africa (COSCA)* shows that cassava serves multiple roles: it is a family food staple in producing countries; it is a famine-reserve crop in countries such as Tanzania, where rainfall is uncertain; and, is a cash crop in Ghana and Nigeria, where improved processing and food preparation methods are used to prepare the cassava roots for sale in urban markets. In both Nigeria and Ghana, an average of 45 percent of total cassava fields are planted for sale, which is higher than the percentage for other staples. The remaining 55 percent of the cassava fields are planted for home consumption. Cassava production is the most important source of income in the cassava-growing areas of Nigeria and Ghana. To realize cassava's potential as an income-generating crop in Africa, opportunities now exist for diffusing the best practices for cassava processing and food preparation found in Ghana and Nigeria to other countries in order to satisfy the mushrooming demand for food in urban and rural areas.

*The COSCA study was a multinational and multi-institutional study carried out during 1989–1997 under the leadership of the International Institute of Tropical Agriculture (IITA) and funded by the Rockefeller Foundation and IITA

Table 4. Selected markets for roots and tubers in 2020 and their associated traits.

Market	Region (crop)	Factors driving growth	Priority areas for research[a]	Beneficiaries	CGIAR mission
Rural/urban starchy staple; leaves for protein[b]	Sub-Saharan Africa (cassava); West Africa (yam); West, South and East Asia (potato); Oceania (other roots and tubers)	Population growth	Stability in marginal areas; yield; processing; policy	Poor farmers and consumers	Food security; income
Urban vegetable	Metropolitan areas close to production (all crops)	Urbanization	Product quality; marketing	Farmers and consumers	Income
Competitor with grains for starch, flour, animal feed	Asia, Latin America (cassava, sweetpotato[c])	Income growth	Yield efficiency; soil management; processing; marketing; policy	Farmers; industry; non-farm labor	Income
Specialty markets (specialized starch, snack foods, leaves)	Asia, Latin America, West Africa (all crops)	Income growth	Product quality; processing; product development; marketing	Farmers; industry; non-farm labor	Income; biodiversity

Source: Compiled for this study.
Note: For country/region definitions see note, Table 2.
[a] In addition to these more market-specific research needs, there are research thrusts that go across all markets, such as integrated pest and disease management, or environmentally sound crop production practices.
[b] For cassava leaf (primarily for parts of West, Central, and Southern Africa, Brazil, and Indonesia) and sweetpotato stems, petioles, and leaves (primarily parts of West Africa and East Asia).
[c] Primarily for China and Vietnam.

markets for roots and tubers in 2020. This representation of the utilization of roots and tubers shows how their many dimensions relate to one another and to the CGIAR mission.

Our projections of the economic value of these commodities (Table 5) indicate that, based on the best available information to date, they are likely to sustain their importance in the decades ahead. It is noteworthy that these calculations take into consideration the production of nearly all the major food commodities in the global food system: cereals, roots and tubers, soybean, and meat. Roots and tubers' share of the total value of these products in 2020 is projected to remain at 10.5 percent of that total, identical to the estimated value in the base period 1993.

What the CGIAR brings to the vision

If roots and tubers are already projected to remain an important component in the global food system, it might be asked, why is the CGIAR's help needed? The answer lies in the unique set of assets and activities of the CGIAR. When the CGIAR's founders looked around the world of 30 years ago, they saw a place that faced the distinct possibility of widespread famine. They also saw looming gaps in agricultural research and development that had to be filled. Their vision to alleviate poverty and improve food security resulted in the justly celebrated assets of the CGIAR today:

- well-characterized germplasm collections
- plant varieties with value-added traits
- collections of the major pests and pathogens and the beneficial organisms that control them
- databases and other accumulated knowledge on field production and management, and on postharvest processing and market development
- innovative research facilities that range from the well-lighted laboratory to the tiniest village's community meeting hall—from the latest techniques in molecular biology to the newest methods of farmer participation in research
- a dedication to scientific excellence and fair-mindedness that have given the CGIAR and its constituent organizations reputations as honest

Table 5. Total value of selected food commodities for developing countries, 1993 and 2020.

	1993[a]				2020			
Commodity	**Price (US$/mt)**	**Production (million mt)**	**Value (million US$)**	**(%) of total**	**Price (US$/mt)**	**Production (million mt)**	**Value (million US$)**	**(%) of total**
Potato	160	94.3	15,094	4.1	145	194.0	28,131	4.9
Sweetpotato and yam	91[b]	155.9	14,185	3.9	82[b]	230.2	18,879	3.3
Yam	135[c]	31.2[c]	4,209[c]	1.1[c]	115[c]	66.9[c]	7,693[c]	1.4[c]
Cassava[d]	54[b]	172.4	9,307	2.5	48[b]	290.3	13,937	2.4
All roots and tubers		**422.6**	**38,586**	**10.5**		**714.6**	**60,946**	**10.5**
Wheat	148	249.3	36,901	10.0	133	372.7	49,575	8.6
Maize	126	231.6	29,181	7.9	123	390.1	47,977	8.3
Other grains	122[b]	105.9	12,912	3.5	106[b]	171.1	18,133	3.1
Rice[e]	286	341.4	97,628	26.5	266	475.6	126,510	21.9
All cereals		**928.1**	**176,622**	**48.0**		**1,409.5**	**242,195**	**41.9**
Soybean	**263**	**57.7**	**15,176**	**4.1**	**235**	**106.2**	**24,958**	**4.3**
Sub total			**230,384**				**328,099**	
Beef	2,023	22.1	44,583	12.1	1,771	43.9	77,805	13.4
Pork	1,366	39.3	53,624	14.6	1,212	81.3	98,594	17.0
Sheep and goat meat	2,032[b]	6.0	12,225	3.3	1,845[b]	10.7	19,815	3.4
Poultry	1,300	21.0	27,321	7.4	1,159	46.8	54,253	9.4
All meats		**88.3**	**137,752**	**37.4**		**182.8**	**250,467**	**43.3**
Total			**368,136**	**100.0**			**578,567**	**100.0**
Percent share of R&T in all commodities				**10.5**				**10.5**
Percent share of R&T in cereals + R&T + soybean				**16.7**				**18.6**

Source: IFPRI's IMPACT simulations, high demand/production growth scenario, as presented in Scott, Rosegrant, and Ringler (2000a).
Note: R&T = roots and tubers; totals may not sum due to rounding.
[a] Average for the three years; 1993 equivalent to 1992–94.
[b] Composite price.
[c] Prices, production, and growth rates for yam alone are estimated outside IFPRI's IMPACT, but based on TAC (1996, 1997a), IMPACT simulations and historical trends.
[d] These figures are for cassava and other roots and tubers such as taro. For developing countries, cassava alone accounts for over 97 ercent of the total.
[e] Production figures for rice have been multiplied by 0.65 to estimate the quantities of milled rice listed. Milled rice is more readily comparable to the other commodities for the purposes of calculating production. Similarly, these prices are for milled rice.

brokers and capacity-builders among its partner organizations

- the ability, thanks to the CGIAR system's uniquely international nature, to serve as the transfer point for information across frontiers or between developing countries and advanced laboratories in developed countries.

These assets pertain to any of the commodities with which the CGIAR organizations are associated–roots and tubers among them. Our best attempt at a vision for roots and tubers, however, clearly shows that the well-being of these crops and their contribution to future food security and poverty elimination can benefit most from the CGIAR's continued and enthusiastic involvement.

Need for a systems approach

In roots and tubers perhaps more than other commodities, these contributions are best considered in a systems framework covering production through to utilization and policy.

- The backbone of the CGIAR is the **value-added germplasm** that it conserves and maintains. It is this germplasm that can stabilize or increase yields or quality, and that leads directly to greater food security and income. The CGIAR Centers hold in trust, for the public good, the world's largest collections of cassava, potato, sweetpotato, and yam. CIP also holds collections of several other root and tuber crops. These responsibilities should continue to 2020 and beyond. Nevertheless, the collections are still incomplete, and collection and characterization —especially of the crops' wild relatives— needs to continue. Compared to cereals and some grain legumes, roots and tubers, with the possible exception of potato, lag behind in terms of our basic knowledge and exploitation of their genetic diversity. It is likely, too, that by 2020 there will be a wide range of commercially available transformed and patented genotypes. Their availability in developing countries may depend on negotiated agreements in which the CGIAR plays important parts.

- Certainly by 2020 there will be advances in molecular techniques that will make it possible to better manage pests and diseases and practice **environmentally sound production methods**. But history has shown that pests and pathogens have a near-perfect record of outwitting whatever science can throw at them. Maintaining crop competitiveness, yield sustainability, and adequate environmental protection will require continued investment in pest and disease research. The CGIAR Centers, with their sources of genetic diversity, their location in the crops' centers of origin, and their scientists who are expert in pest and disease research, are well placed to undertake such research. Important here also is the CGIAR's ability to disseminate the results of its research among national agricultural research systems.

- **Post-production research** on roots and tubers is a recent but important addition to the CGIAR agenda, albeit at relatively low levels of investment compared to production-related research. The linking of root and tuber farmers and processors to growth markets is a key to achieving our vision for these crops, particularly for cassava and sweetpotato. This is especially true in the more isolated, marginal areas of the developing world, situated far from growing urban markets. Exploiting market opportunities for cassava- and sweetpotato-based products through new product development research will be fundamental requirements of our global research strategy. There is a need for the parallel dissemination of business and management skills for root- and tuber-based enterprises. It is likely that by 2020, these opportunities will be recognized by the private sector, and research and development will enjoy private funding. Given the limited resources in this area in national agricultural research institutes, what is needed now are catalysts and champions to, as Plucknett, Phillips, and Kagbo (1998:12) indicate, "keep the needs of industry before the public and decision makers...[and]...for research and development, provision of infrastructure and investments, and changes in policies to grasp the new opportunit[ies]."

- The CGIAR excels at dealing with **institutions and policy** across a wide range of actors, including governmental, nongovernmental, and private sectors, and gathering those actors around a common research and development agenda. This is an asset that needs to be strengthened in the future. For example, recent research has highlighted the importance of policies in both developed and developing countries to catalyze continued increases in production and utilization of root and tuber crops in Asia, Africa, and Latin America (dTp Studies, Inc., 1998; Scott, Rosegrant, and Ringler, 2000a; Spencer and Associates, 1997). For example, developed countries should eliminate trade barriers to root and tuber imports from developing countries, who in turn should remove subsidies on substitute products in domestic markets. At a minimum, the CGIAR should be able to draw upon expertise from within and outside its own doors; develop relevant strategic research projects that seek solutions to common problems; and analyze and synthesize across cases for the development of tools that can be used by partners to design and execute successful research and development projects.

In the current configuration, five different CGIAR Centers undertake root and tuber research. The three principal root and tuber Centers account for over 95 percent of the total CGIAR budget for these commodities. They are: CIAT, with headquarters in Colombia, which works on cassava for Latin America and Asia; CIP, in Peru, which has the global mandate on potato, sweetpotato, and Andean roots and tubers; and, IITA, in Nigeria, which works primarily in Sub-Saharan Africa on cassava and yam. Additional, complementary work on food policy research is done by IFPRI, with headquarters in the United States. IFPRI's mandate is not specific to roots and tubers, but it places those crops in the wider context of production, utilization, and trade. IPGRI, in Italy, focuses on genetic resources. This includes research on Andean roots and tubers in Latin America and the Caribbean,

Table 6. CGIAR research projects on roots and tubers and their budgets, 1998.

Center, project title	**Commodity**	**Budget**[a] US$ million
CIAT		
Integrated conservation of neotropical plant genetic resources	Cassava	
Assessing and using agro-biodiversity through biotechnology	Cassava	
Genetic enhancement of cassava	Cassava	
Integrated pest and disease management in major tropical agro-ecosystems	Cassava	
Assessment of past and expected impact of agricultural research	Cassava	
Linking smallholders to growth markets for improved resource management	Cassava	
Integrating improved germplasm and resource management for enhanced crop and livestock production	Cassava	
		6.96
CIP		
Integrated control of late blight	Potato	
Integrated control of bacterial wilt	Potato	
Control of potato viruses	Potato	
Integrated management of potato pests	Potato	
Propagation of clonal potato planting materials	Potato	
Sexual potato propagation	Potato	
Global sector commodity analysis and impact assessment for potato	Potato	
Potato production in rice-wheat systems	Potato	
Conservation and characterization of potato genetic resources	Potato	
		15.9
Control of sweetpotato viruses	Sweetpotato	
Integrated management of sweetpotato pests	Sweetpotato	
Postharvest utilization of sweetpotato	Sweetpotato	
Breeding for high dry matter in sweetpotato	Sweetpotato	
Global sector commodity analysis and impact assessment for sweetpotato	Sweetpotato	
Conservation and characterization of sweetpotato genetic resources	Sweetpotato	
		5.0
Conservation and characterization of Andean roots and tubers	Andean roots and tubers	
		0.8
IITA[b]		
Cassava productivity in the lowland and mid-altitude agro-ecologies of Sub-Saharan Africa	Cassava	
Integrated management of cassava pests and diseases	Cassava	
		9.4[b]
Improvement of yam-based production systems	Yam	
		2.8[b]

Contd.

Contd.

Improving postharvest systems	Cassava and yam	
Molecular and cellular biotechnology for crop improvement	Cassava and yam	
Conservation and genetic enhancement of plant biodiversity	Cassava and yam	
Short fallow stabilization	Cassava and yam	
Agro-ecosystems development strategies	Cassava and yam	
Farming systems diversification	Cassava and yam	
IFPRI		
CGIAR micro-nutrients project	Cassava	
Starch industry development as a strategy for agro-food based rural industrialization	Cassava and sweetpotato	
Policy options for using livestock as a strategy for rural income diversification	Cassava and sweetpotato	
Policies for improved land use management in Uganda	Cassava and sweetpotato	
Ending hunger in the 21st century	All roots and tubers	
Global water resources and food security	All roots and tubers	
2020 vision for food, agriculture, and the environment	All roots and tubers	
		0.24[c]
IPGRI[d]		
Support to plant genetic resources programs and regional networks in the Americas	Andean roots and tubers, cassava and potato	
Support to plant genetic resources programs and regional networks in Europe	Potato	
Support to plant genetic resources programs and regional networks in Asia, the Pacific and Oceania	Sweetpotato, taro and yam	
Support to plant genetic resources programs and regional networks in Sub-Saharan Africa	Yam	
CGIAR genetic resources support program	Cassava, potato, sweetpotato and yam	
Ex situ conservation technologies and strategies	Cassava, potato, sweetpotato, taro and yam	
Locating and monitoring genetic diversity	Taro	
In situ conservation of crop plants and their wild relatives	Taro	
Human and policy aspects of plant genetic resources conservation and use	Taro	
Support to plant genetic resources programs and regional networks in West Asia and North Africa	Roots and tubers	
Global capacity-building and institutional support	Roots and tubers	
Promoting sustainable conservation and use of genetic resources	Roots and tubers	
Linking conservation and use	Roots and tubers	
Information management and services	Roots and tubers	
Public awareness and impact assessment	Roots and tubers	
		2.9
Total		**44.0**

Source: Compiled for this study.
[a] Based on 1998 Center budgets; includes overheads.
[b] These figures are estimates drawn from different research projects as IITA does not break down its budget by commodity.
[c] This figure is an estimate as IFPRI does not break down its budget by commodity.
[d] Some of these projects include work on aroids such as taro and Andean roots and tubers.

aroids in East Asia and the Pacific region, and sweetpotato in Asia. These activities are currently carried out in some 35 projects at a cost of about US$44 million (Table 6). This figure represented 14 percent of the total CGIAR budget in 1998, a percentage that has remained fairly constant since 1972 (Figure 3). A series of impact studies have found these investments have paid very high rates of return (Fuglie et al., 1999; Johnson, 1999; Norgaard, 1988; Walker and Crissman, 1996).

To these contributions must be added another that is distinctively fundamental to the CGIAR's modus operandi and infrequently found elsewhere: working together. CGIAR scientists do this in two ways that are central components to our vision. First, they participate in a number of research and development networks, consortia, and initiatives alongside scientists from national agricultural research institutes and collaborators from organizations in developed countries (see also Annex, Section 6).** These organizations cover a broad range of topics and geographic regions (Table 7). Prominent examples are the Cassava Biotechnology Network (CBN); the User's Perspective with Agricultural Research and Development network (UPWARD); the Eastern Africa Rootcrop Research Network (EARRNET); the System-wide Genetic Resources Programme (SGRP); and, the recently launched CGIAR initiative on Urban Agriculture.

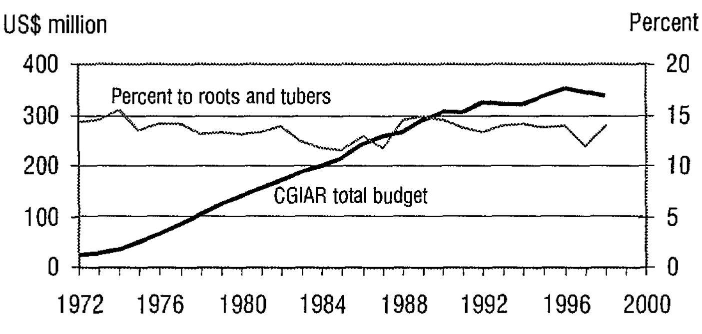
** In addition, the Centers support and participate in a number of professional societies to encourage research on roots and tubers in developing countries. Prominent examples include the International Society for Tropical Root Crops (ISTRC) with its regional branches, the African Potato Association (APA), and the Asociación Latinoamericana de la Papa (ALAP).

Second, complementarity and synergy among the CGIAR staff and the private sector is a key to bringing the best of science to the beneficiaries we seek to assist. Activities where complementarity and synergy already make the CGIAR system more effective in root and tuber research include (but certainly are not limited to) germplasm management (ranging from seed generation of vegetatively propagated crops to *in vitro* collection techniques) at IPGRI, CIAT, CIP, IITA, and their partners; genetic improvement at CIAT, CIP, IITA, and members of different biotechnology networks; studies of starch, the carbohydrates which roots and tubers produce very efficiently, at CIAT, CIP, IITA, and IFPRI; and, integrated pest management (from whitefly to soil pathogens to cassava bacterial blight) at CIAT, IITA, CIP, International Centre for Insect Physiology and Ecology (ICIPE), Asian Vegetable Research and Development Center (AVRDC), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and other Centers.

There are four major areas covering interrelated aspects of the food systems for these commodities within which the Centers' expertise, channeled through partnerships and collaborative efforts, can be particularly useful in realizing the future potential of roots and tubers.

- The vegetative propagation of the root and tuber crops presents a wide range of common problems, but also some opportunities. The problems include transmission of many pests and pathogens from one generation to another; quarantine complications; low rates of multiplication; bulkiness; and, perishability of planting material. Cryopreservation of germplasm is one common area of work with similar techniques applicable to all these crops. Collaboration on the

Figure 3. Annual total CGIAR budget and percent spent on roots and tubers, 1972–1998.



Source: CGIAR Secretariat.

Table 7. CGIAR networks, initiatives, and programs that include work on roots and tubers.[a]

Network	Commodity	Centers
Asian Cassava Research Network	Cassava	CIAT[b]
ANSWER (Asian Network on Sweet Potato Genetic Resources)	Sweetpotato	IPGRI, CIP
AHI (African Highlands Ecoregional Program)	Potato	CIP
CBN (Cassava Biotechnology Network)	Cassava	CIAT[b], IITA
CMPGR (Caribbean Committee for the Management of Plant Genetic Resources)	Roots	IPGRI[c]
CONDESAN (Consortium for the Sustainable Development of the Andean Ecoregion)	Potato and Andean roots and tubers	CIP
EARRNET (Eastern Africa Rootcrop Research Network)	Cassava	IITA
EPHTA (Ecoregional Program for the Humid and Sub-humid Tropics of Africa)	Cassava, yam and other roots	IITA[b]
FOODNET (Postharvest and Marketing Research Network for Eastern and Central Africa)	Cassava and sweetpotato	IITA[d], CIP
Global experiment on *in vitro*/slow growth of sweetpotato	Sweetpotato	IPGRI
GILB (Global Initiative on Late Blight)	Potato	CIP[b]
The Global Mountain Program	Potato and Andean roots and tubers	CIP[b]
GRENEWECA (Genetic Resources Network for West and Central Africa)	Roots and tubers	IPGRI
Manihot Genetic Resources Network	Cassava	CIAT[b]
CGIAR Micro-nutrients Project	Cassava	IFPRI[b], CIAT
Pan-American Network for Cassava Improvement	Cassava	CIAT[b]
PRAPACE (Regional Potato and Sweetpotato Improvements Program for Eastern and Central Africa)	Potato and sweetpotato	CIP[b]
PRECODEPA (Programa Regional Cooperativo de Papa)	Potato	CIP[b]
PRGA (Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation)	Roots and tubers	CIAT, CIP, IFPRI, IITA, IPGRI
RECSEA-PGR (Regional Collaboration in Southeast Asia on Plant Genetic Resources)	Roots and tubers	IPGRI
REDARFIT (Andean Network on Plant Genetic Resources)	Roots and tubers	IPGRI[c], CIP
REMERFI (Mesoamerican Network of Plant Genetic Resources)	Roots and tubers	IPGRI[c]
SARRNET (Southern Africa Rootcrop Research Network)	Cassava and sweetpotato	IITA[b], CIP

Contd.

Contd.

SGRP (System-wide Genetic Resources Programme)		IPGRI[b],
	Cassava	CIAT
	Potato, sweetpotato and Andean roots and tubers.	CIP
	Cassava and yam	IITA
SPGRC (Southern African Development Community [SADC] Plant Genetic Resources Centre)	Roots and tubers	IPGRI
UPWARD (User's Perspective with Agricultural Research and Development)	Potato and sweetpotato	CIP[b], CIAT
Urban Agriculture Initiative		CIP[b], CIAT

Source: Compiled for this study.
[a] Many of these networks, initiatives, and programs include participation by one or more CGIAR Centers than those listed here. This list is intended to indicate those Centers who participate in these activities for work specifically on root and tuber crops.
[b] Convening Center.
[c] Subregional networks on plant genetic resources in the Americas. Most of them are the result of collaboration between IPGRI, Instituto Interamericano de la Cooperacion para la Agricultura (IICA), and other partners including Centro Agronomico Tropical de Investigacion y Enseñanza (CATIE).
[d] Executing Center.

documentation associated with germplasm characterization, the movement of germplasm across international borders, and the development of effective policies to help protect the property rights of national programs while facilitating the exchange of materials merits a continued, coordinated effort.

- The root and tuber crops produce large quantities of starch (edible energy) in relatively less time than other crops, although each of them also provides other important nutrients. This starch content endows these crops with an extraordinary range of potential end uses; already it is employed in manufacturing monosodium glutamate and plywood in Thailand, and sorbitol, manitol, and noodles in China. Priority areas for coordinated future investigation include i) root and tuber processing and enterprise development involving CIAT, CIP, and IITA in Sub-Saharan Africa; ii) cassava and sweetpotato for processed food, animal feed, and starch in East and Southeast Asia involving CIAT, CIP, and IFPRI. In the former instance, over 80 percent of the total increase in supply and demand for cassava in developing countries is projected to occur in Sub-Saharan Africa (Table 2). Virtually all of the increase in yam output, a large share of the increase in sweetpotato production, and a sizeable proportion of the additional supply of other roots and tubers e.g. taro and cocoyam, are also projected to occur in this region.

  Achieving or surpassing that projection will depend certainly in part on the ability of farmers and entrepreneurs to provide more processed food products to meet growing food requirements in both the countryside and towns. East and Southeast Asia is the second largest area for cassava production in the developing world, and the largest by far for sweetpotato. Combining limited resources and comparative areas of expertise within CIAT, CIP, and IFPRI to exploit commercial opportunities for starch-based and animal feed products plus capacity-building in the area of small agro-enterprise development, and drawing in additional partners is highly complementary.

- Many of the tools of biotechnology are broadly applicable across species, including the aroids and Andean roots and tubers. Molecular research into tomatoes, for example, is expected to increasingly benefit their relatives in the potato fields; a similar linkage exists between research on *Hevea brasiliensis* (natural rubber) and *Manihot esculenta*. It is increasingly obvious that the sort of biotechnology research that is being done by industry in the developed countries does not see the developing world as its primary beneficiary. There is, and will continue to be, a need for researchers such as those of the CGIAR who appreciate the needs of the less-affluent world. An example is the late blight pathogen in potato. The CGIAR's approach to *Phytophthora infestans*, which emphasizes integrated pest management, is quite different from that of the multinational seed and chemical companies. By working together in genomics—a new science applicable to humans, livestock, and plants that permits sequencing and mapping of the genome (a genetic map of a living organism)—the Centers working on roots and tubers can capture economies of scale in developing the basic tools in this fast-moving and costly area of research.

- Institutional and policy issues, including those related to commodity projections, the underlying databases on which those calculations are based, as well as work in the area of market analysis and trade policy, constitute another area for synergy among the Centers, drawing upon their respective areas of expertise that each individually cannot afford. From the institutional perspective, the Global Cassava Development Strategy that International Fund for Agricultural Development (IFAD) has been leading, with the very active participation of the cassava IARCs (international agricultural research centers), is an example of trying to gather actors around a common agenda. This process of consensus building might be adopted for root and tuber crops as a whole through the work of the Committee on Inter-Centre Root and Tuber Crop Research (CICRTCR – see Preface) itself.

We believe that there are other areas that will continue to emerge in the future that will justify closer interaction between two or more Centers (see Annex, Section 7). However, we believe that the above-mentioned deserve top priority.

Conclusions

It is clear from our vision that the root and tuber crops will remain a vital component of the global food system in the world of 2020. All the trends show this. It also is clear that these commodities, the farming systems in which they are produced, and the people who produce, process, and consume them will value and depend on roots and tubers in the decades ahead. This is particularly true for many of the world's poorest and most food-insecure households.

Root and tuber crops provide a wide variety of beneficiaries with the basic needs: food, employment, and income. Continuing to meet these needs will become more of a challenge in the future as more people populate the Earth. However, as the roles of these commodities in the global food system evolve, the differences across crops (such as potato and yam for food in fresh form versus sweetpotato and cassava for processed foods, starch-based products, and feed; cassava production in Sub-Saharan Africa versus potato in Asia) will become more conspicuous. Specialization in end use, i.e. fresh versus processed, will become more pronounced by commodity.

Production of roots and tubers will increase, and they will maintain their relative economic importance versus the other major food commodities. The growth rates projected for cassava, potato, and yam actually exceed those for the major cereals such as rice and wheat. With continued population growth and partly as a result of food systems in poorer areas of Asia, Africa, and Latin America coming under increasing stress, considerations like the capability of roots and tubers to produce more carbohydrates per hectare per day than other food crops, and also to yield well even under adverse growing conditions, will loom all the more important in the decades ahead. These projections therefore engender a real sense of the value of continued support to realize that potential and to capture the projected benefits for developing countries, most notably poverty eradication and improved food security. Consequently, support from the CGIAR to enable the member Centers to help realize the associated benefits becomes all the more critical in terms of the implications for the global food system. With that continued support comes the challenge to the Centers to prioritize and exploit synergies.

Recommendations

Given the projected increases in supply and demand, the importance of roots and tubers in developing countries is unlikely to diminish by 2020 or long afterward. In order to attain food security and the eradication of poverty, it is fit, proper, and necessary for the CGIAR as well as other national, bilateral, and multinational organizations to retain these crops as an integral part of a global strategy to improve food production and utilization in Asia, Africa, and Latin America in the decades ahead.

Having considered a variety of alternative organizational arrangements for research on roots and tubers, we have identified the following three future scenarios.

- **Continued informal collaboration.** The first of our scenarios would build on the existing organization but modify it to reduce the effects of its vulnerabilities. The role of the CICRTCR would be strengthened, converting it to a permanent mechanism for incorporating the views and needs of our partners. Each Center would dedicate resources to a common fund for financing or "seeding" projects of common interest in program areas that had been assigned high priority. The collaborative projects could either be commissioned by the CICRTCR itself or generated through a competitive bidding mechanism. Under this scenario, there would be organizational adjustments within the individual Centers in terms of both inter-Center relations and the costs of projects.

- **A global collaborative root and tuber program.** A convening Center would oversee a wide range of global collaborative root and tuber research that would constitute the System-wide Root and Tuber Crop Program (SRTCP). The SRTCP would be governed by a directing committee drawn from the participating Centers and from non-CGIAR organizations and national and regional representatives with interests in root and tuber research. This committee would construct a common planning, prioritizing, and evaluating framework that would be used to develop global, high-priority research projects in those specific areas where past experience has shown that individual Centers, and organizations outside the CGIAR, lack sufficient expertise or infrastructure to undertake singlehandedly, let alone capture, the gains from such endeavors. This would include work on biotechnology, post-production research (e.g. research on starch, feed, and agro-enterprise development), and institutions and policy.

  The specific intent would be to realize efficiencies and achieve greater impact by closer collaboration between Centers in these fields, as well as between the Centers and their collaborators in developed and developing countries. The SRTCP would provide an organizational mechanism whereby the potential breakthroughs related to research on root and tuber crops could be more effectively captured, to the benefit of small farmers and low-income consumers worldwide. These projects would constitute the global program. The projects would be funded by core resources from each participating Center, and managed by the global program. In this scenario, the SRTCP would not represent the totality of root and tuber research. Individual Centers would continue to mount their own projects in those areas where collaboration provides no benefits.

- **A root and tuber Center.** This is the most ambitious of the scenarios: unifying all research on roots and tubers in the CGIAR under the mandate of a single Center. It also would be the most costly in terms of its establishment, although in the medium term the transaction costs of collaboration among the existing Centers that presently do root and tuber research would be virtually eliminated. Creation of this Center would require the naming of a board and selection of management. We envisage the adoption of a decentralized approach to research and outreach, making use of the infrastructure already in place. Once the Center's research strategy had been established, the new organization would decide on placing research projects in the most appropriate existing facilities of the CGIAR Centers that presently are conducting root and tuber research, or other CGIAR Centers, or third party organizations.

At its annual meeting in Washington during International Centers' Week (ICW), October 1999, the CICRTCR reviewed these options and recommended the System-wide Root and Tuber Crop Program. This recommendation is now being considered by the respective Centers. It is envisioned that adoption of this scenario would have profound effects, not only on the CGIAR and its constituent members, but also on roots and tubers—the potato, sweetpotato, cassava, yam, and Andean crops—and the two billion plus people in developing countries who rely on them for their staple foods, for their livelihoods, and for even their survival. These are the most vulnerable people in the global society, and the CGIAR is one of the few organizations that consistently looks out for their interests.

Annex

Section 1 – Introduction and background

Many of the developing world's poorest producers and most food insecure households are highly dependent on roots and tubers as a contributing, if not the principal, source of food, nutrition and cash income (see, e.g. Alexandratos, 1995:100–102). Certainly in part, farm households see the value of roots and tubers "in their ability to produce large quantities of dietary energy and in their stability of production under conditions where other crops may fail" (Alexandratos, 1995:189). In recent years, these issues have taken on renewed importance as programs to develop new agricultural technology in the CGIAR have added food security and eradication of rural poverty to the set of overall objectives. Hence, an improved understanding of the importance of production, utilization and future role of these crops in the global food system in the decades ahead has potentially far-reaching implications for investments in agricultural research at both the international and, perhaps even more importantly, national level as well as for achieving the goals those investments were intended to reach.

A contemporary review of research and training on roots and tubers in the CGIAR concluded that a key element in the effort to achieve their potential is a clearer vision of the future role of these commodities in the food systems in developing countries (TAC, 1997). That vision should be more accurate and more comprehensive in its projections. While different CGIAR Centers have detailed plans for their respective crops or crop-related program mandates, recent system-wide reviews of these efforts have concluded that there may well be important synergies, involving collective efforts by two or more Centers, that have yet to be fully captured (CGIAR, 1998). A new round of deliberations and calculations regarding resource allocations across commodities and Centers is also beginning. It seems timely, therefore, to take a fresh look at roots and tubers in order to get better balance on the role of research on these crops within the total effort of the CGIAR system.

The rationale for elaborating a vision document on root and tuber research in the CGIAR has several facets:

- the sense that the role and importance of these crops in the global food system can and should be better understood
- the new challenges facing the CGIAR's efforts to meet poverty eradication, food security and biodiversity goals. These include access to food for the rural landless and urban poor; generation of employment and income-earning opportunities; and, safeguarding the environment
- the generation of new knowledge about the crops
- the timeliness of the CGIAR's deliberations about new partners, the renewal of the CGIAR system itself, resource limitations, and the new round of resource allocation
- the system-wide review of root and tuber research recommendation and the CICRTCR, i.e. absence of such a vision and the related strategy for root and tuber research.

Therefore, the purpose of this Annex is to spell out in greater detail answers to the following key questions that could only briefly be summarized in the vision statement itself:

- What is our vision of future global development trends, or the context of that vision?
- What is our vision of the key characteristics, trends, and projections for production and use of roots and tubers in developing countries?
- What is our vision of the opportunities and constraints for roots and tubers in developing countries?
- What is our vision of current research on roots and tubers both within and outside the CGIAR, and of alternative future scenarios?

Section 2 – Global development trends

Any vision for root and tuber crops in the global food system must be grounded within the context of the broader environment in which these crops are produced and used, and their further potential is developed. Key factors influencing the evolution of this broader environment are:

- the growth in the size and location of future food requirements (population, urbanization)
- food security (income, employment, and food availability issues)
- trends in consumption (changing tastes and preferences)
- disasters (both natural and man-made)
- marketing and trade policies (market liberalization, and tariff and non-tariff reductions) and
- sustainability (pressure on the resource base) and the interaction between poverty and environmental protection or degradation.

A review of these global economic development trends and of the challenges and opportunities that they provide for roots and tubers in developing countries follows.

Population and urbanization

The earth's population is projected to grow to 7.5 billion by 2020, up from some 5.7 billion in 1995 (United Nations, 1999). However, the rate of population increase is falling, from a high of 2.1 percent in 1965–70 to a projected 1.0 percent by 2020 and beyond (Alexandratos, 1995, p. 75).

Population growth rates in many developing countries are still relatively high (>1.5 percent per year) and as such will account for over 97 percent of the increase in the world's population to 2020 (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant, 1999). Sub-Saharan Africa has the highest projected growth rates in population averaging over 2.4 percent (see Table A10). It is noteworthy that in this same subregion, roots and tubers play a greater role in local food systems than they do in any other area in the world.

We envision that population growth will catalyze further increases in root and tuber production and utilization in rural areas for a variety of reasons. Where population growth results in accelerated declines in farm size, many farm households will turn to roots and tubers because of their ability to produce large quantities of carbohydrates in relatively short periods of time. We see this as especially likely in, albeit not confined to, those areas where limited resources at the farm level (e.g. irrigation, chemical fertilizers) will favor more rustic crops and associated cultural practices. Continued population growth in rural areas will also generate additional demand for roots and tubers in both fresh and processed form for off-farm consumption and sales, accelerating a trend that has existed for some time (Nweke, 1992; Scott, 1994). Part of this latter trend is attributable to the growing demand for food by rural non-producers. For example, in South Asia an additional, massive block of rural consumers consists of the rural landless. These poor households already account for some 50 percent or more of the rural population in large parts of the region (Scott, 1988).

Demographic changes mean that, in addition to more people to feed in absolute terms, a greater and greater percentage will be located in towns and cities. While in Latin America typically 60–70 percent of the population already resides in urban areas, the vast majority of consumers in Africa and Asia still reside in rural areas. As a result, in many developing countries, urbanization rates are well above the rates of overall population increase. The CGIAR envisions that by 2020 over 50 percent of the population in developing countries will live in urban areas (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant, 1999).

Urbanization presents a challenge to producers of roots and tubers, namely to reduce their perishability and bulkiness to make them easier to transport and store so as to facilitate consumption far from production centers. Urbanization has certainly generated a much higher demand for processed agricultural products, be they for direct human consumption, for animal feed, or for industrial use. However, whereas some countries have seen sharp declines in per capita consumption of fresh roots and tubers that are associated with rising urbanization, not all countries have witnessed such declines—even in per capita consumption of root and tuber crops in fresh form. In Latin America, for example, both Peru and Colombia experienced rapid rural-to-urban migration over the past three decades. During the same period, per capita potato consumption fell significantly in Peru, but just the opposite occurred in Colombia (FAO, 1995). Moreover, in recent years, even per capita potato consumption in Peru has rebounded due in part to the boom in the fast food industry in Lima, the capital (Escobal, Agreda, and Reardon, 1999). In Sub-Saharan Africa, some entrepreneurial growers have simply moved production and processing of roots and tubers to urban peripheries, as for example with cassava in Nigeria (Nweke et al., 1994). In effect, the impact of urbanization on the food system for roots and tubers has been complex as alternative forms of utilization have emerged in many countries opening up new markets for these crops.

Income

In recent years we have witnessed a rebound in income growth rates in many developing countries, particularly when compared to the dismal performance of the 1980s in much of Sub-Saharan Africa and Latin America. As a consequence, projected rates of increase in GDP are generally higher for future periods, for example, 1994–2003 when compared to 1983–1994. The absolute projected growth rates we envision to 2020 vary from 3.2 percent per year for Nigeria to 5.6 percent per year for China (see Table A10). Absolute per capita income levels in the base period are considerably lower in Sub-Saharan Africa than in Asia or Latin America as well.

Assessing the potential impact of income changes on the prospects for roots and tubers is certainly more complicated than aggregate generalizations often imply. One frequently mentioned scenario is the supposed negative effect on root and tuber crops resulting from rising incomes. In other words, as consumers' purchasing power increases, they choose to consume less starchy staples in the form of roots and tubers in order to include more preferred foods in their diets. The partial evidence available suggests that the impact of income increases on the demand for roots and tubers can and does vary by commodity, form (fresh or processed), current income, and consumption levels, among other factors. For example, as per capita incomes and per capita potato consumption are both low in many parts of Asia, Africa, and Latin America, income gains often translate into a desire by consumers to diversify diets away from cereals to include more potato (Scott, 1996). Rising incomes in most developing countries have frequently led to increased potato consumption. However, rising incomes have had just the opposite effect in the case of sweetpotato consumption, at least in fresh form for direct human consumption. Yet even this scenario overlooks the possible effect of rising incomes on demand for processed sweetpotato, e.g. starch and feed (see also Scott, Rosegrant, and Ringler, 2000).

The link between changes in incomes and consumption of roots and tubers also merits mentioning in two other respects. The drive for higher incomes as part of the process of economic development also has its rural dimension, namely that agriculture in developing countries is increasingly becoming a source of income as well as sustenance. This also applies in the case of roots and tubers. Although they are frequently described in the literature as "subsistence" crops, empirical evidence points decisively to the increasing importance attached to cash sales of these commodities—even by small farmers (Nweke, 1992; Scott 1996; Scott and Maldonado, 1999). The commercialization of root and tuber production systems has important implications for strategies aimed at maximizing their potential in the years ahead.

The linkages among agriculture production, income generation, and poverty eradication present another dimension to the potential contribution of root and tuber crops to the global food system. These crops are often produced by farm households situated in the poorer countries; or, within countries in the poorer, more isolated production zones, e.g. the highest altitudes of the Andean region (potato), the marginal farming areas in the north coast of Colombia (cassava), and the poorer, rainfed land in southwest China (sweetpotato). Given the structure of the economy in these areas, local efforts to generate additional income are highly dependent on agriculture. More specifically, they depend greatly on the ability to increase productivity for these same root and tuber crops that so dominate the local farming systems. From that perspective, the link between improving incomes to reduce poverty and efforts aimed at improving production, utilization, and marketing of root and tuber crops becomes clearer.

Finally, the link between expanded production and usage of root and tuber crops and poverty eradication also involves non-producers in both rural and urban areas. For the rural landless in South Asia, for example, employment generation as a result of greater potato production, storage, and processing means increasing the availability of food to non-producers in the lean season, when poverty in the form of hunger is likely to be more acute, and providing access to important vitamins, minerals and amino acids (e.g. vitamin C, lysine) that are deficient in the local, cereal-based diets (see Scott 1988; Woolfe 1987). Small-scale entrepreneurs engaged in cassava-processing in or adjacent to metropolitan areas of Sub-Saharan Africa provide another example.

Diets

Diets are changing rapidly in Asia, Africa, and Latin America. The overall trend in developing countries is towards consumption of more processed food products. This is partly the consequence of urbanization and income changes as alluded to earlier and to some extent a result of the advertising and cultural factors associated with this rural-to-urban migration; to be "modern" is to eat a "modern diet". Among other reasons, the impact of the eating habits of foreign tourists on local consumption patterns, greater female participation in the formal workforce, changes in office hours to shorter more hurried "Western" lunch breaks, advertising, and tastes acquired while traveling and studying abroad have all contributed to the increased consumption of processed food products, or more preferred foods (Scott, 1994; Zhang et al., 1999).

Expansion of transportation and communication networks (especially television) into previously remote rural areas has also altered dietary patterns in these heretofore isolated locations through the increased availability of a variety of new foods. This has also provided an incentive for local farmers and processors to engage in production of fresh and processed products for both urban consumption centers and rural markets which are now more closely linked. The growth in containerized shipping capacity has had a similar effect on the volume and diversity of food and feed products traded internationally.

As mentioned, diets are also changing because of improved incomes in recent years (particularly in Asia), as consumers have opted to eat more meat and dairy products in addition to consuming more of the preferred foods. This shift has raised the demand for feed for all varieties of livestock and placed tremendous pressure on local, small-scale livestock production systems to increase both output and efficiency. At the macro level, countries that have historically been major feed importers are eagerly exploring options to increase feed self-sufficiency and to reduce imports of meat and dairy products.

The rapid growth of the fast-food industry and the associated sale of french fries—particularly in Asia and Latin America—is perhaps the most blatant example of the potential effect of changing human diets on root and tuber crops, and their role in developing country food systems (Scott, Basay, and Maldonado, 1997; Zhang et al., 1999). Less conspicuous, but also extremely important, has been the expansion in cassava processing in Sub-Saharan Africa (Natural Resources Institute, 1992; Ugwu and Ay, 1992). The shift in sweetpotato utilization in China from human consumption to pig feed provides another example (Woolfe, 1992).

It might be thought that trends in improved processing and marketing of root and tuber crops would have direct effects on the maintenance or resurrection of traditional foods. However, recent field research has generated mixed results. For example, the modest resurgence in consumption of sweetpotato in Japan in the form of sweetpotato leaves has been documented. But the findings in other cases, such as the Andean roots and tubers in South America, have been preliminary or not conducive to widespread generalizations.

Disasters

Climatic change, political instability, civil wars, and regional conflicts have all contributed to a persistent and increasingly pervasive outbreak of disasters in parts of the developing world. Sub-Saharan Africa has been particularly hard hit by famines in recent years. With this pattern of acute food scarcity has come a concern about the global food system's capacity to respond more effectively to such circumstances. This concern has only been heightened by the devastating effects of "El Niño" and Hurricane Mitch as well as the theory, rapidly gathering greater credence, that the world is entering a new phase of increasing climatological instability.

Under these circumstances, roots and tubers have attracted increasing attention because of their remarkable ability to produce tremendous amounts of food, at a modest cost, in a short period of time. Moreover, the social history of many of these commodities is replete with instances where the local, if not national, population was saved from starvation by root and tuber production (see, e.g. Scott, 1988a: 71; Woolfe, 1992:487; Zhang, 1999). Recent experience in Kivu province, Democratic Republic of the Congo, provides the latest example of how rapid expansion of production of root and tuber crops was part of the relief effort to assist refugees fleeing ethnic hostilities in neighboring Rwanda (Tanganik et al., 1999).

Trade and market liberalization

One major component of the uncertainty regarding the future for roots and tubers in any of the above-mentioned forms is related to the major drive worldwide to reduce tariffs and non-tariff trade barriers for agricultural products of all types. This process is already under way as many developing countries are now part of regional trading blocs (e.g. MERCOSUR, CACOM, SAFTA) or have signed new, bilateral trade agreements. This development alone has reduced tariffs on a host of agricultural commodities and jump-started trade in the process. For example, with the inauguration of MERCOSUR, Argentina exported more than 160,000 mt of fresh potatoes to Brazil in 1994 (FAO, 1999).

A further dimension of the trend toward globalization and tariff reductions has been new agreements between developed and developing countries. Two prominent examples already concluded are the North American Free Trade Agreement (NAFTA), involving Mexico, the USA, and Canada, and the renegotiation of the trade agreement regarding cassava pellets entering the European Union (EU) from Southeast Asia. The implications of these kinds of agreements for root and tuber crops are far-reaching. In the case of NAFTA, Mexico's external tariff on fresh potatoes imported from the USA or Canada is scheduled to fall from nearly 300 percent in 1994 to zero in 2003. Exports of cassava pellets from Thailand to the EU have contracted considerably (Henry, 1998). These agreements have also served as a catalyst to diversify root and tuber utilization and in the more aggressive search to develop new markets. The drive by Thailand to export cassava starch is the most prominent example (Titapiwatanakun, 1998); growing interest in the potential for exports of exotic roots and tubers from the Andean region to developed countries represents another (Fano et al., 1998).

The signing of the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) and membership of the World Trade Organization (WTO) represents a third dimension of globalization. This involves all countries—developed and developing alike—and commitments them to lower tariffs to agreed levels in the future. Here in many instances the effect of lower tariffs has yet to materialize as countries have frequently opted for tariff reduction schedules that put off the sharpest declines until well into the future, for example 2010 or 2015. Nevertheless, these standing commitments do mean that root and tuber producers and processors are obliged to face future levels of competition that in most instances they have not yet had to contemplate.

One immediate side effect of this trend has been that countries are rapidly engaging in further negotiations with their neighbors to lower tariffs still further—or to maximize protection of whatever products they can before they become isolated and overwhelmed by the rising tide of globalization as, for example, the negotiations currently under way between the Andean pact countries (Bolivia, Colombia, Ecuador, Peru, and Venezuela) and MERCOSUR (Argentina, Brazil, Paraguay, and Uruguay). However at a very minimum it can be said that, with a few noteworthy exceptions, the mass of participants in the root and tuber sector are rarely fully aware of the possible implications for their respective commodities.

Frequently lost amid the foreign trade implications of globalization is any consideration of the massive changes in domestic marketing in recent decades. The expansion in marketing infrastructure including storage facilities, roads, wholesale markets, and telecommunication systems has contributed to a tremendous surge in domestic food marketing in developing countries that, in turn, has fed back to production systems (see, e.g. Scott, Basay, and Maldonado, 1997). In the case of roots and tubers, there are a number of examples—both positive and negative—of how this has impacted particular crops in particular countries. The massive growth in refrigerated storage in South Asia—currently with a capacity of over 8 million mt—has helped catalyze the sharp rise in potato production (FAO, 1995). Road building in Bolivia and Peru has facilitated the influx of cheap cereals to previously isolated rural, highland enclaves, cutting demand for traditional roots and tubers. Future internal marketing developments are most likely to have similar, highly variable effects on roots and tubers.

The environment

Concern over the future sustainability of food production and transformation in light of adverse effects on the environment and human health has spread to also include roots and tubers (Howeler, Oates, and Costa Allem, 1999; Scott, 1988a; Scott, Rosegrant, and Ringler, 2000). Potatoes are often noted for their heavy dependence on fertilizers and pesticides (Bardhan Roy et al., 1999). The environmental consequences of a potato monoculture has raised concerns not only for the environment but also for human health (Crissman, Antle, and Capalbo, 1998). Likewise, the lucrative returns of potato production or the pressure to produce more food for a rapidly growing rural population have been cited among other factors as contributing to the expansion of area planted on vulnerable hillsides (Howeler, 1994; Howeler, Oates, and Costa Allem, 1999), in forest zones or national parks (Duffy, 1999), or in areas with rapidly declining fallow (Spencer and Associates, 1997).

However, this would not currently apply to all root crops—even all potato production—everywhere in the developing world. Mid- to higher-elevation potato production in parts of Asia often takes place in paddy fields that have been terraced for rice cultivation. Other root crops, for example sweetpotato, have been noted for their environmentally friendly attributes such as serving as a quick cover crop to reduce erosion, or their ability to provide decent yields even without heavy doses of fertilizers and pesticides. A related concern is the impact of root crop processing (Howeler, Oates, and Costa Allem, 1999) on water supplies. Just one example would be the discharge into the local water supply of starch waste from small-scale processing plants (Goletti, Rich, and Wheatley, 1999).

The interest by researchers, donors, and policymakers in minor Andean roots and tubers is partly driven by concern for issues of biodiversity. In that regard, reconciling the exigencies of the marketplace to allow continued, remunerative cultivation of these crops by peasant producers, presents a major challenge for the future.

Last, the advent of genetically modified plants not only offers tremendous promise: It also raises an array of new issues ranging from unanticipated effects on the environment, to quantifying the risks associated with the development and diffusion of such technologies, to schemes to monitor and enforce their most appropriate use, to the distribution of benefits from such advances (Scott, Rosegrant, and Ringler, 2000). The response to this challenge will require a combination of new technologies, policies, and institutional strengthening, with a critical role for the IARCs (international agricultural research centers).

Summary

Future prospects for the role of roots and tubers in the global food system will be greatly influenced by various demographic, economic, political, and environmental trends. Foremost among these factors that both affect and are affected by roots and tubers are population growth and rates of urbanization as well as income levels and rates of increase/decline in consumers' purchasing power. Changing diets, recurrent disasters, trade and market liberalization, and pressures on as well as protection of the natural resource base will also influence future supply and demand for roots and tubers. Our analysis suggests that many of these trends will stimulate growers and consumers to produce and consume more roots and tubers, in new ways, for new uses, and using new technology. However, the precise response will no doubt vary by crop, region, and type of producer and consumer. Hence, these crops merit a more careful, commodity-by-commodity analysis of both their particular characteristics as well as past trends and future projections for production and use.

Section 3 – Characteristics, trends, and projections for roots and tubers

Roots and tubers constitute a large and remarkably diverse set of commodities. In the first part of this section, we present a brief review of their origins as well as their agronomic, postharvest and nutritional characteristics, highlighting similarities and dissimilarities as appropriate. The remainder of this section presents a synthesis of recent research on historical trends and future projections for root and tuber crops to the year 2020 (Scott, Rosegrant, and Ringler, 2000, 2000a). Results of this assessment are essential building blocks for a vision for these commodities in the decades ahead as well as for a system-wide research strategy to achieve that potential.

The crops, their origins, and characteristics

Root and tuber crops include a wide variety of edible plants (Table A1). Foremost among them in terms of aggregate output and estimated value of production are cassava (*Manihot esculenta*), potatoes (*Solanum* spp.), sweetpotato (*Ipomoea batatas*), and yams (*Dioscorea* spp.). Other roots and tubers include the Andean roots and tubers —grown in the Andean region, as well as in other parts of South America (e.g. Brazil) and East Asia (e.g. China, Vietnam)— and the aroids such as taro. These other roots and tubers are of minor global importance. Nevertheless, for particular countries, regions or agro-ecologies, one or more of these other roots and tubers can and do play an important role in existing food systems (Horton, 1988).

This report focuses primarily on the major root and tuber crops—cassava, potato, sweetpotato, and yam— with some information also on other roots and tubers such as taro and tannia. Limited time, resources, and readily available data prevented a more extensive analysis. Still, we hope this study will serve as the basis for more detailed reviews of other root and tuber crops either globally or for particular regions, such as Sub-Saharan Africa where their importance is already more widely recognized.

Potato, cassava, and sweetpotato all originated in Latin America (Horton, 1988). Yam is a multi-species crop with some species *(D. rotundolo)* moving from Africa to America, and others (*D. alata* and *D. esculenta*) from Asia to Africa (Hahn et al., 1987). Taro is of Asian origin but widely distributed throughout the tropical regions of the Old and New World. Tannia was first domesticated in tropical America and is now distributed throughout the tropics and is a very important subsistence crop in West Africa and the Pacific regions.

In spite of their bulkiness and perishability, most roots and tubers have proven remarkably mobile over millennia. Cultivation of these crops continues to spread worldwide.

Root and tuber crops are frequently grouped together because they are bulky, perishable, and vegetatively propagated. Overemphasis on these similarities obscures a series of important differences among these commodities and overlooks a number of their more redeeming attributes. We will briefly outline now the agronomic, raw material, and nutritional traits of these commodities, while readily acknowledging that more detailed treatments can be found in the literature on these crops (see, in particular, Cock, 1984; Hermann and Heller 1997; Horton, 1988; TAC, 1997; Woolfe, 1987, 1992).

Potato has a shorter growth period vegetative cycle than most other root and tuber crops (Table A2)— particularly when grown under the irrigated conditions of Asia and North Africa. For optimal commercial yields, potato needs relatively high levels of chemical fertilizer and organic matter, and the plant will not form tubers well if temperatures are above 20°C. Optimal rainfall is lower than for other roots and tubers, but potato yields best when adequate water is available at key stages in plant development. These traits contrast with the other roots and tubers. Whereas potato and yam are annual crops, cassava and sweetpotato are perennials. Moreover, both cassava and sweetpotato are drought tolerant crops with low nutrient requirements. These latter two traits have favored the expansion of cassava production in Sub-Saharan Africa (Spencer and Associates, 1997).

Table A1. Common and scientific names of edible roots and tubers.[a]

Common name	Some other names	Scientific name	Part of plant used as food
Achira or Queensland arrowroot	A taa lut, ganyong, kenyong, tikas	*Canna edulis*	Rhizome
Ahipa	Frijol chuncho, huitoto	*Pachyrhizus ahipa*	Root
Air potato	Aerial yam, man khamin, ubi atas, ubi buah, utong-utongan	*Dioscorea bulbifera*	Tuber, bulbils
Arracacha	Peruvian carrot, zanahoria blanca	*Arracacia xanthorrhiza*	Root, young stems
Arrowroot	Araru, garut, saakhuu, ubi garut	*Maranta arundinacea*	Rhizome
Cassava	Kahoi, kamoteng, mandioca, manioc, man sampalang, ubi kayu, yuca	*Manihot esculenta*	Root, leaves
Chufa	Earth almond, zulu nuts	*Cyperus esculentus*	Root
Jerusalem artichoke	Topinambur	*Helianthus tuberosus*	Tuber
Lotus	Bua luang, seroja, teratai	*Nelumbo nucifera*	Rhizome, seeds, leaves, leafstalks
Maca	—	*Lepidium meyenii*	Hypocotyl, root
Mashua	Cubios, isano, mishwa	*Tropaeolum tuberosum*	Tuber
Mauka	Miso, tazo, yuca inca	*Mirabilis expansa*	Root
Oca	Apilla, ciuba, ibia, miquichi, oqa	*Oxalis tuberosa*	Tuber
Potato	Man farang, kentang, papa, ubi kentang	*Solanum* spp.	Tuber
Sweetpotato	Camote, kamote, man thet, ubi jalar, ubi keladi	*Ipomoea batatas*	Root, young stems, leaves
Tannia	Blue taro, cocoyam, keladi hitam, kimpul, kradaat dam, tania, yautia	*Xanthosoma sagittifolium*	Corm, leaves, petioles
Taro	Cocoyam, dasheen, gabi, keladi, phueak, talas	*Colocasia esculenta*	Corm, leaves
Ulluco	Melloco, papalisa	*Ullucus tuberosus*	Tuber
Water chestnut	Apulid, haeo song krayhiam, tekı	*Eleocharis dulcis*	Tuber
Winged bean	—	*Psophocarpus tetragonolobus*	Tuber
Yacon	Jíquima	*Smallanthus sonchifolius*	Root
Yam			
Buck	Man khan khaao, ubi sakai, ubi sawut	*Dioscorea pentaphylla*	Tuber
Cush-cush		*Disocorea trifida*	Tuber

Contd

Contd.

Elephant	Buk, pungapung, suweg, telinga potato, ubi kekek	*Amorphophallus campanulatus*	Corm
Greater	Man sao, ubi, water yam, white yam, winged yam	*Dioscorea alata*	Tuber
Lesser	Chinese yam, gembili, kembili, man mue suea, tugi	*Dioscorea esculenta*	Tuber
Trifoliate	African bitter yam, bitter yam	*Dioscorea dumentorum*	Tuber
White	Negro yam, white Guinea yam	*Dioscorea rotundata*	Tuber
Wild	Asiatic bitter yam, gadung, kloi, nami, white yam	*Dioscorea hispida*	Tuber
Yellow	Yellow Guinea yam	*Dioscorea cayenensis*	Tuber
Yam bean	Bengkuang, jicama, kacang bengkuang, man kaeo, sinkamas, wayaka, yaka	*Pachyrhizus erosus*	Root

Source: CONDESAN (1997); Hedrick (1972); Hermann and Heller (1997); Huaman, de la Puente, and Arbizu (1995); IBPGR (1981); National Academy of Science (1975); Willis (1973). Additional comments provided by Carlos Arbizu (CIP).

[a] There are important root crops, e.g., beet, carrot, ginger, and radish, which for statistical purposes are classified by FAO as "roots, bulbs, and tuberous vegetables" and, therefore, are not listed here. For further information, see www.fao.org/WAICENT/FAOINFO/ECONOMIC/faodef/FDEF02E.HTM#2.05, Definition and classification of commodities, 2. Roots, tubers and derived products.

Cassava can produce more dry matter per hectare than the other root and tuber crops (Table A3). Still, the potato's shorter vegetative cycle and intense use of inputs enables it to produce more energy and protein per hectare per day than not only the other root crops but also many of the cereals as well. These attributes have helped propel the expansion in potato production over the past three decades in parts of Asia that are well endowed with natural resources. The crop's high yields in short cropping cycles have favored its spread in the region's intensive production systems.

Whereas cassava can be stored in the ground for up to 36 months after maturity, potato has a relatively short in-ground storage period. Postharvest storage life for cassava roots is extremely short, i.e. 2–3 days, but that for potato can reach up to 12 months provided the tubers are free of pests and diseases, and low temperatures and high humidity are maintained.

Cassava generally has higher dry matter and starch contents than the other roots and tubers (Table A4). It also has a higher starch extraction rate, higher maximum viscosity, and lower gelatinization temperature. These postharvest traits for cassava, and similar attributes for sweetpotato, have induced greater processing of these crops in recent years.

As Horton (1988) points out, "Root crops are often thought of as 'starchy staples' that provide low-cost energy but little else to the human diet." He goes on to note that this generalization is misleading. Quantities of protein, essential vitamins, and minerals vary considerably across roots and tubers (Table A5). On average, cooked potatoes and yams have about 2 percent protein, or twice that found in cassava. Cassava, potatoes, and sweetpotatoes all provide ascorbic acid (vitamin C), whereas cereal-based foods have none. Potatoes and sweetpotatoes also contain the important amino acid lysine; commodities such as rice are deficient in lysine (Woolfe, 1987, 1992). In addition to the roots, cassava and sweetpotato leaves provide an important source of vitamin A in particular in West, Central, and Southern Africa, Brazil and Indonesia (cassava leaves) and in parts of West Africa and East Asia (sweetpotato leaves, stems, and petioles).

Some varieties of taro and tannia also produce leaves which are consumed as a vegetable. Aroids produce large leaves, tender stalks, and roots which develop a large corm at the base or cormels, rhizomes at the side roots. Depending on the species and the variety, the corm, cormels, or side roots are used as edible starch. In the case of taro, all parts of the plant—corm, cormels, rhizome, stalk, leaves, and the flowers—are edible and

Table A2. Main agronomic characteristics of the principal roots and tubers.

Characteristics	Cassava	Cocoyam (tannia)	Potato	Sweetpotato	Taro	Yam
Growth period (months)	9–24	9–12	3–7	3–8	6–18	8–11
Annual or perennial plant	Perennial	Perennial	Annual	Perennial	Perennial	Annual
Optimal rainfall (cm)	100–150	140–200	50–75	75–100	250	115
Optimal temperature (°C)	25–29	13–29	15–18	>24	21–27	30
Drought resistant	Yes	No	No	Yes	No	Yes
Optimal pH	5–6	5.5–6.5	5.5–6.0	5.6–6.6	5.5–6.5	na
Fertility requirement	Low	High	High	Low	High	High
Organic matter requirement	Low	High	High	Low	High	High
Growable on swampy, waterlogged soil	No	No	No	No	Yes	No
Planting material	Stem	Corms/ cormels	Tubers, cuttings[a]	Vine cuttings	Corms/ cormels	Tubers
Storage time in ground	Long	Long	Short	Long	Moderate	Long
Postharvest storage life	Short	Long	Long	Short	Variable	Long

Sources: Derived from Kay (1973), as presented in Horton (1988).
Note: na signifies not available.
[a]Whole tubers, cut tubers, or botanical seed.

prized in various food cultures. Many of these nutritional attributes have helped to induce greater production and consumption of roots and tubers in recent decades, i.e. potato in Asia, cassava and yam in Sub-Saharan Africa.

Production trends

Analyses of trends in root and tuber crop production over the past several decades point to three separate sets of results concerning: i) the locus and relative importance of these crops in developing countries; ii) the tremendous variability in the direction and rate of change of these trends across commodities, regions and time periods; and, iii) factors on and off the farm that drive these developments.

Over 70 percent of global root and tuber production is produced in developing countries—up from 47 percent in 1961–63. This includes 36 percent of global potato output (versus 11 percent in 1961–63), 87 percent of sweetpotato, 99 percent of yam, and 100 percent of cassava. China harvests over 80 percent of global sweetpotato production. Nigeria, Ghana, and Ivory Coast account for some 95 percent of global yam production (Lev and Shriver, 1998). From a food security perspective, these crops are also disproportionately concentrated in low-income countries where poverty reduction is a major concern of policymakers and is tied to improvements in productivity, processing, and marketing of these commodities (Alexandratos, 1995:102).

Growth rates* in production for roots and tubers have in general been strong, but highly variable (Table A6). Average annual growth rates for production in developing countries of yam (8.0 percent) and potato (4.1 percent) have soared in recent years (1983–96), far exceeding those for cassava (1.8 percent) and sweetpotato (now

Table A3. Top ranking food crops in developing countries in terms of dry matter production/ha and edible energy and protein production/ha/day.

Dry matter production		Energy production		Protein production	
Crop	mt/ha	Crop	MJ/ha/day	Crop	kg/ha/day
Cassava	3.0	Potato	216	Cabbages	2.0
Yams	2.4	Yam	182	Dry broad beans	1.6
Potato	2.2	Carrots	162	Potato	1.4
Sweetpotato	2.1	Maize	159	Dry peas	1.4
Rice	1.9	Cabbages	156	Eggplants	1.4
Carrots	1.7	Sweetpotato	152	Wheat	1.3
Cabbages	1.6	Rice	151	Lentils	1.3
Bananas	1.5	Wheat	135	Tomatoes	1.2
Wheat	1.3	Cassava	121	Chickpeas	1.1
Maize	1.3	Eggplants	120	Carrots	1.0

Source: Horton and Fano (1985).

Table A4. Raw material characteristics of roots and tubers[a].

	Cassava	Potato	Sweetpotato	Yam	Aroids
Dry matter (%FW)	30–40	20	19–35	21–40[b]	22–27
Starch (%FW)	27–36	13–16	18–28	18–25	19–21
Total sugars (%FW)	0.5–2.5	0–2.0	1.5–5.0	0.5–1.0	2.0
Protein (%FW)	0.5–2.0	2.0	1.0–2.5	2.5	1.5–3.0
Fiber (%FW)	1.0	0.5	1.0	0.6	0.5–3.0
Lipids (%FW)	0.5	0.1	0.5–6.5	0.2	0–1.5
Vitamin A (mg/100g FW)	17	Trace	900	117	0–42
Vitamin C (mg/100g FW)	50	31	35	24	9
Ash (%FW)	0.5–1.5	1.0–1.5	1.0	0.5–1.0	0.5–1.5
Energy (kJ/100g)	607	318	490	439	390
Anti-nutritional factors	Cyanogens	Solanine	Trypsin inhibitors	Alkaloids, tannis	Oxalate crystals
Starch extraction rate (% FW)	22–25	8–12	10–15	na	na
Starch grain size (micron)	5–50	15–100	2–42	1–70	1–12
Amylose (% total starch)	15–29	22–25	8–32	10–30	3–45
Max. viscosity (BU)	700–1100	na	na	100–200	na
Gelatinization temp. (°C)	49–73	63–66	58–85	69–88	68–75

Source: Bradbury and Holloway (1988); Wheatley et al. (1995).
Note: na signifies not available.
[a] The percentages and quantities reported in Tables A4 and A5 may vary because of the different species of the particular root or tuber analyzed, whether the material was raw or cooked, or whether they refer to one or a group of roots and tubers, e.g. taro versus aroids, among other things.
[b] M Bokanga (IITA) reports this range of dry matter is found in different species of yam.

approaching 0.1 percent). Growth rates for particular crops have also varied considerably across regions. In the case of cassava, for example, recent growth rates have ranged from 3.6 per annum in Sub-Saharan Africa to – 0.53 percent in China (Scott, Rosegrant, and Ringler, 2000). Area expansion has generally driven the growth in cassava production across developing regions in recent years, except for Latin America (Scott, Rosegrant, and Ringler, 2000). Yields have been as or more important for potato, except in South Asia, and sweetpotato, except in Sub-Saharan Africa. Growth rates for production and area planted have been particularly strong for cassava and yam in Sub-Saharan Africa as well as for potato in China and South Asia, further accentuating a continental—or country—concentration of production for cassava (Africa), potato (Asia), sweetpotato (China), and yam (West Africa).

* All growth rates cited are based on FAOSTAT as presented in Scott, Rosegrant, and Ringler (2000). The figures are based on three-year moving averages, i.e. 1983 refers to 1982–84.

Table A5. Nutritional composition of a 100g edible portion of various foods.[a]

	Water	Protein	Food energy	Protein/ calorie ratio	Fats	Ash	Ca	P	Fe	Na	K	Thia-mine	Ribo-flavin	Niacin	Ascorbic acid
Food[b]	**(percent)**	**(g)**	**(kcal)**	**(g/1000kcal)**	**(g)**	**(mg)**									
Maize (grits)	87	1.2	51	24	0.1	0.6	1	10	0.1	205	11	0.02	0.01	0.2	0
Potatoes	80	2.1	76	27	0.1	0.9	7	53	0.6	3	407	0.09	0.04	1.5	16
Plantains	80	1.3	77	17	0.1	0.7	na	na	na	na	na	na	na	–	–
Taro (raw)	73	1.9	98	19	0.2	1.2	28	61	1.0	7	514	0.13	0.04	1.1	4
Yams (raw)	74	2.1	101	21	0.2	1.0	20	69	0.6	-	600	0.10	0.04	0.5	9
Rice	73	2.0	109	18	0.1	1.1	10	28	0.2	374	28	0.02	0.01	0.4	0
Spaghetti	72	3.4	111	31	0.4	1.2	8	50	0.4	1	61	0.01	0.01	0.3	0
Sweetpotatoes	71	1.7	114	15	0.4	1.0	32	47	0.7	10	243	0.09	0.06	0.6	17
Common beans	69	7.8	118	66	0.6	1.4	50	148	2.7	7	416	0.14	0.07	0.7	0
Cassava	68	0.9	124	7	0.1	0.6	na	na	na	na	na	na	na	–	26
Fresh white bread	36	8.7	269	32	3.2	1.9	70	87	0.7	507	85	0.09	0.08	*1.2*	*trace*

Source: US Dept. of Agriculture (1975); Wu-Leung, Busson, and Jardin (1968), as presented in Horton (1988).
Note: na signifies not available.
[a] The percentages and quantities reported in Tables A4 and A5 may vary because of the different species of the particular root or tuber analyzed, whether the material was raw or cooked, or whether they refer to one or a group of roots and tubers, e.g. taro versus aroids, among other things
[b] Boiled unless otherwise indicated. Edible portions of potatoes and other root crops and plantains do not include peels.

Growth in root and tuber production has been driven by developments both on and off the farm. In South Asia, for example, the shift in potato production from rainfed cultivation in the hilly areas to irrigated, intensive cropping systems in the lowlands has been a major contributing factor. This shift was facilitated by, among other things, the potato's short vegetative cycle—meaning it fits well into tight rotations; the introduction of the seed plot cultivation technique; new and improved varieties; and, the massive expansion of cold storage capacity to over 8 million mt. That expansion provides farmers the infrastructure to store seed and table potatoes—in the former instance to ensure availability at planting and in the latter to enable them to capture higher prices in periods of seasonal scarcity (FAO, 1995; Horton, 1987).

Similarly, increases in cassava production in Sub-Saharan Africa have been made possible by the diffusion of improved varieties and integrated pest management schemes combined with improvements in processing equipment that overcome the crop's perishability and exploit strong off-farm demand. The surge in cassava production in Sub-Saharan Africa has also been attributed to the crop's low input requirements and drought tolerance. Recent studies have found that famine and hunger also have been prime catalysts as well as the crop's resistance to pests and diseases (Spencer and Associates, 1997). The growth in yam output has been largely due to the expansion of area planted from its traditional growing areas in the humid forests to the moist savannas (Manyong et al., 1996). Higher solar radiation, less pressure from pests and diseases, and lower costs of production due to less labor-intensive cultivation practices are considered to have induced this shift.**

Roots and tubers traditionally are food crops produced by small farmers but ones where cash sales are of increasing importance. Massive empirical evidence gathered over the last two decades clearly indicates that potato (Bottema et al., 1989; Dahiya and Sharma, 1994; Nolasco, 1992; Scott, 1985, 1988, 1988a), cassava (Nweke, 1992; Sarma, 1989; Spencer and Associates, 1997), and sweetpotato (Achata et al., 1990; Cabanilla, 1996; Dayal et al., 1995; Scott and Ewell, 1993) are all grown on a small scale. Some large potato farmers can be found in places like Colombia, Pakistan, Peru, and Egypt, but these tend to be exceptions rather than the rule. Analysis of farm survey results also shows that although farm households typically consume at least some of the roots and tubers that they produce—some cassava producers in Thailand being a notable exception—crop sales are extremely important in varying degrees across commodities and continents. Potato is the most commercial of the crops studied. Sales by small farmers in Asia can account for 60–90 percent of production (see, Dahiya and Sharma, 1994; Scott 1988). In Sub-Saharan Africa, potato sales are also important, though the share of production sold tends to be less than 50 percent (see Rasolo et al. 1987; Scott, 1988a). In Latin America, evidence from a series of studies clearly indicates the growing commercial orientation of production (see Scott, Basay, and Maldonado, 1997).

Sweetpotato and cassava are more traditionally considered subsistence, if not famine relief, crops. In the case of sweetpotato, however, emerging evidence from Asia shows that farmers are increasingly selling not just fresh roots, but also processed products as a way of improving their incomes (Peters, 1997; Peters and Wheatley, 1998). In the case of cassava, the body of evidence from Africa (Nweke et al., 1994) combined with earlier studies from Asia (Konjing, 1989) and Latin America (Janssen, 1986) document the global emergence of cassava as a cash crop. The sale of roots and tubers in both fresh and processed form is a strategy pursued by small farmers to increase their incomes.

Utilization trends

Trends in consumption, usage, and trade for roots and tubers are perhaps more complex and controversial than for production, area, and yield. For one, there are simply more categories to assess. Also, the information is less plentiful and reliable. General trends that merit mention include: i) growth in overall use of most roots and tubers (except sweetpotato); ii) big differences in growth rates and types of uses for different crops in different regions; and, iii) the general tendency—except for yam—for processing to assume greater importance than the fresh market.

Potato and yam are highly preferred foods in many developing countries where they are grown, whereas cassava and sweetpotato, generally speaking, have fared less spectacularly in developing country diets. Total use of potato for food in Asia, Africa, and Latin America grew sharply between 1982–84 and 1995–97 (Table A7). For yam, the increase was even greater in percentage terms but more modest in absolute values and was very much centered in West Africa. In the case of cassava, the increase in total use as food was from 70.7 to 92.5 million mt and heavily concentrated in Sub-Saharan Africa. Sweetpotato's use as food actually declined from 86.4 to 68.5 million mt, although this was offset by an increase in total feed use from 37.4 to 58.0 million mt. These shifts in usage of sweetpotato were due almost entirely to changes

** It should be cautioned that global and regional statistics for yam are highly linked to the data for Nigeria. Inconsistencies between production and consumption estimates in Nigeria (see Bricas and Attaie, 1998) suggest that while the trend in yam production is upward, the actual level of output and rate of growth are harder to establish with certainty. See also Dorosh (1988).

Table A6. Trends and projections for roots and tubers in developing countries, 1983–1996 and 1993–2020 according to two different scenarios.

	Cassava + other roots and tubers[a]			Potato			Sweetpotato and yam					
Category	**1983–96[b]**	**1993–2020A[c]**	**1993–2020B[d]**	**1983–96[b]**	**1993–2020A[c]**	**1993–2020B[d]**	**1983–96[b]**		**1993–2020A[c]**		**1993–2020B[d]**	
Growth rates in production (Average annual percent)												
Area	1.37[e]	0.73	0.94	2.42	0.51	0.84	-0.50[f]	(4.49)[g]	0.27		0.35	
Yield	0.46[e]	1.00	1.00	1.62	1.50	1.85	0.64[f]	(3.32)[g]	0.97		1.10	
Production	1.83[e]	1.74	1.95	4.08	2.02	2.71	0.14[f]	(7.96)[g]	1.25	(2.7)[h]	1.45	(2.9)[h]
Growth rates in domestic utilization (Average annual percent)[i]												
Food demand[j]	2.10	1.99	2.24	4.07	2.33	2.75	-0.65		0.44		0.50	
Feed demand	1.66	1 62	1.72	4.60	0.37	2.66	3.42		1.81		2.23	
Total use[k]	2.49	1.93	2 15	4.09	2.02	2.76	1.15		1.25		1.46	
Net trade[l]		20.1[lm]	20.1[lm]		-1.2[lm]	-4.6[lm]			0.6[lm]		0.4[lm]	
Value (Percent)												
All commodities[n]	2.5[o]	2.2[m]	2.4[m]	4.1[o]	3.9[m]	4.9[m]	3.9[o]	(1.1)[op]	2.7[m]	(1.2)[p]	3.3[m]	(1.4)[p]
Food crops[q]	4.0[o]	4.0[m]	4.2[m]	6.6[o]	7.0[m]	8.6[m]	6.2[o]	(1.8)[op]	4.8[m]	(2.1)[p]	5.8[m]	(2.4)[p]

Source: Historical trends: production and use FAO (1999 April, accessed July); Projections: IFPRI's IMPACT simulations as presented in Scott, Rosegrant, and Ringler (2000).
Note: Developing countries as defined by FAO.
[a] Other roots and tubers includes the aroids such as taro; however, for developing countries, cassava alone accounts for over 97 percent of the total of cassava plus other roots and tubers.
[b] Calculated using the three-year average during 1982–84 for 1983, and during 1995–97 for 1996.
[c] Baseline scenario.
[d] High demand/production growth scenario.
[e] Cassava only FAO (1999 April, accessed July).
[f] Sweetpotato only.
[g] Yam only FAO (1999 April, accessed July)
[h] Growth rates for yam only estimated outside IFPRI's IMPACT, but based on those simulations and historical trends.
[i] Refers only to utilization within the country and not to domestic production used for export.
[j] Includes fresh and processed food.
[k] Total food (fresh and processed), feed, and non-food, non-feed demand.
[l] Million mt.
[m] 2020
[n] Includes cassava, potato, sweetpotato, yam, other roots and tubers, rice, barley, millet, sorghum, wheat, maize, other grains, soybean, beef and buffalo meat, pigmeat, sheep and goatmeat, and poultry.
[o] 1993
[p] Yam only, 2020.
[q] Includes all roots and tubers, cereals, and soybean

in the crop's role in China's food systems as rising incomes increased the demand for meat, which in turn increased the demand for feed (Huang, 1999; Scott, 1992).

Per capita food demand remained modest (≤ 25kg/capita/yr) for all roots and tubers in all developing country regions, with the exception of cassava in Sub-Saharan Africa, where average per capita demand topped 100 kg/yr., and in Southeast Asia (33 kg/yr), and sweetpotato in China (45 kg/yr) (Table A8). Per capita potato consumption was highest in WANA (23 kg/yr) and Latin America (22 kg/yr). Annual yam consumption in Sub-Saharan Africa rose to 28 kg/capita. These commodity/regional disparities reflect a variety of factors on both the demand and supply side.

Growth in per capita food demand for potatoes has been particularly high in China, India, and other parts of Asia. In parts of India and Bangladesh, for example, as supply has expanded as described above, potatoes have become a seasonal staple. Consumption rises during the peak harvesting period, mid-January to mid-March, when

Table A7. Domestic utilization of roots and tubers by region, 1983 and 1996.[a]

	Cassava		Potato		Sweetpotato		Yam		All R&T	
Country/region[c]	**1983**	**1996**	**1983**	**1996**	**1983**	**1996**	**1983**	**1996**	**1983**	**1996**
					(million mt)					
Food										
China	1.5	1.6	10.5	19.4	72.4	54.8	na	...	85.7	77.0
Other East Asia	...	...	0.8	0.9	0.6	0.3	...	...	1.4	1.2
India	5.2	5.4	7.6	14.9	1.5	1.1	na	na	14.4	21.3
Other South Asia	0.5	0.2	1.8	3.1	0.8	0.4	na	na	3.4	4.3
Southeast Asia	14.1	16.1	0.7	1.6	4.4	4.0	...	...	19.7	22.3
Latin America	10.3	11.4	8.4	11.2	1.0	0.9	0.2	0.3	20.3	24.3
W. Asia/N. Africa	na	na	6.8	11.6	0.1	0.2	na	na	7.0	11.9
Sub-Saharan Africa	38.4	57.3	1.8	1.9	4.7	5.9	4.8	14.9	53.0	87.3
Developing	70.7	92.5	38.8	65.1	86.4	68.5	5.4	15.8	207.8	252.7
Developed	0.1	0.1	89.6	96.1	1.6	1.5	0.1	0.2	91.8	98.2
World	70.8	92.6	128.4	161.2	88.0	70.1	5.5	16.0	299.6	350.9
Feed										
China	1.3	2.6	7.7	14.5	36.4	57.1	na	na	45.5	74.3
Other East Asia	na	0.1	0.2	0.1	0.2	0.1	na	na	0.4	0.4
India	na	na	na	na	na	na	na	na	na	na
Other South Asia	0.2	0.1	...	...	...	...	...	...	0.2	0.1
Southeast Asia	0.7	0.6	...	...	0.3	0.3	...	...	1.0	1.0
Latin America	13.5	14.9	0.4	0.4	0.3	0.3	0.1	0.1	14.3	15.7
W. Asia/N. Africa	na	0.1	0.1	0.1	na	na	na	na	0.1	0.2
Sub-Saharan Africa	2.0	3.5	...	...	0.1	0.2	0.2	0.3	2.4	4.1
Developing	17.7	22.0	8.5	15.3	37.4	58.0	0.3	0.4	64.2	95.9
Developed	18.7	9.0	55.5	39.6	0.4	0.2	...	...	74.6	48.9
World	36.4	31.0	64.0	54.9	37.8	58.1	0.3	0.4	138.8	144.8

Source: FAO (1999 June, accessed July) as presented in Scott, Rosegrant, and Ringler (2000).
Note: R&T= roots and tubers; data for 1983 are the averages for 1982–84, and for 1996 the averages for 1995–97; ellipses (...) signify very small value; na signifies not applicable; totals may not sum due to rounding.
[a] Refers only to utilization within the country and not to domestic production used for export.
[b] All R&T includes cassava, potato, sweetpotato, yam, and other roots and tubers. For these other roots and tubers, utilization was less than 1.5 million mt for all uses in all regions, except for food use in Sub-Saharan Africa where in 1983 it totaled 3.5 million mt rising to 7.3 million mt in 1996.
[c] Other East Asia covers Hong Kong, Macau, Mongolia, North Korea, and South Korea. Other South Asia consists of Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka. Southeast Asia covers Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. Latin America covers Central and South America plus Mexico West Asia/North Africa (WANA) covers Algeria, Bahrain, Cyprus, Egypt, Gaza Strip, Iran, Iraq, Jordan, Kuwait. Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, Western Sahara, and Yemen Sub-Saharan Africa covers Central, West, Eastern, Northern, and Southern Sub-Saharan Africa.

over 70 percent of the annual crop is dug and prices are low. Potato is also appreciated for its nutritional characteristics, such as vitamin C and lysine (Scott, 1988; Woolfe, 1987).

Cassava is part of the traditional rural diet in many parts of Sub-Saharan Africa, particularly West and Central Africa (Adamu, 1989; Tshibaka and Lumpungu, 1989). As civil wars, natural disasters, and continued population growth have increased pressure on local food systems (Ezemenari, Nweke, and Strauss, 1998; Spencer and Associates, 1997), the crop is assuming greater importance as a supplementary staple, food security, and famine reserve crop in many parts of East and Southern Africa. In addition, cassava consumption has been bolstered in urban areas in West Africa by improvements in preparation and sale of processed products (Nweke et al., 1994).

Growth in consumption of yam has been largely due to its high status among rural and urban consumers (Bricas and Attaie, 1998), but the limited development of processed products has slowed expansion in urban areas up to now.

Trends in sweetpotato consumption/utilization have been dominated by developments in China where the apparent fall in per capita consumption as food masks the recent rise in domestic consumption of processed sweetpotato products, such as noodles made from starch, and sales of such products in foreign markets (Fuglie et al., 1999; Zhang, 1999). Feed use has risen from 10 percent of total supply in 1961–63 to some 45 percent in 1995-97, or over 50 million mt on an annual basis (FAO, 1999).

The emergence of processing of potato (FAO, 1995), cassava (Spencer and Associates, 1997), and sweetpotato (Scott, Wiersema, and Ferguson, 1992) for both food and non-food uses in developing countries is significant for various reasons. These uses open up marketing alternatives to the traditional sale of fresh roots and tubers. All things being equal, sale or use of fresh roots and tubers for processing effectively reduces downward pressure on producer prices at harvest caused by the often seasonal abundance of supply, thereby raising farm incomes to levels higher than they otherwise would have been or enabling the market to absorb greater surpluses without causing farm-gate prices to fall. Processing (e.g. slicing, chipping or drying) adds value at the farm level and reduces perishability and bulkiness, thereby facilitating sale of root-and-tuber-based products in the off-season and in distant markets. Processing also can help improve food security by generating employment and income for non-growers thereby enhancing their purchasing power to gain more ready access to food.

Table A8. Per capita utilization as food and feed, and percentage of calories and protein from roots and tubers as food, 1983 and 1996.

Country/ region[a]	Cassava		Potato		Sweetpotato		Yam		Total		Calories	Protein
	1983	1996	1983	1996	1983	1996	1983	1996	1983	1996	1996	1996
	kg per year										(percent)	
China	2	1	10	16	70	45	na	...	82	63	5.6	2.7
Other East Asia	...	...	13	12	10	4	...	...	24	17	1.8	1.4
India	7	6	10	16	2	1	na	na	20	22	1.3	0.9
Other South Asia	2	1	8	10	3	1	na	na	14	13	1.3	1.0
Southeast Asia	37	33	2	3	12	8	...	...	52	46	4.3	1.4
Latin America	29	25	24	25	3	2	1	1	57	54	4.3	2.6
W. Asia/N. Africa	na	na	28	34	0	0	na	na	29	35	2.3	1.6
Sub-Saharan Africa	102	106	5	4	12	11	13	28	140	162	20.1	8.0
Developing	20	21	11	15	25	16	2	4	60	57	5.4	2.6
Developed	0	0	75	75	1	1	...	...	77	76	4.3	3.3
World	15	16	28	28	19	12	1	3	64	61	5.1	2.8

Source: Scott, Rosegrant, and Ringler (2000).
Note: Data for 1983 are averages for 1982–84 and data for 1996 are averages for 1995–97; ellipses (..) signify very small values; na signifies not applicable; totals may not sum due to rounding. For other roots and tubers consumption was less than 2 kg/capita for all uses in all regions, except for food use in Sub-Saharan Africa, where other R&T totaled 9.2kg/capita in 1983, rising to 13.5 kg/capita in 1996.
[a] See footnote b, Table A7.

Projections to the year 2020

As part of the analysis for this study, a series of quantitative projections were generated for roots and tubers to the year 2020 —including growth rates and absolute values in production, utilization and trade— using an updated version of IFPRI's global commodity model IMPACT (see Section 3, *Appendix*). These projections were made: i) by commodity grouping, but disaggregating within roots and tubers; ii) as part of a multi-commodity model in which both physical outputs as well as monetary values are determined simultaneously; and, iii) by combining modeling expertise together with specific knowledge of these crops. Moreover, the calculations are for: i) a baseline scenario with conservative estimates of the influence of income changes, past production trends, and technology improvement on future demand and supply for roots and tubers, and ii) a high demand/ production growth scenario based on results of recent analyses of production and consumption trends for these commodities. This brief summary can only highlight a few of the principal findings for each scenario, see Scott, Rosegrant, and Ringler (2000, 2000a) for more details.

Baseline scenario. According to the scenario, projected annual percentage growth rates in food and feed demand are high, and highly uneven. Such growth rates are highest for potato: 2.02 for total demand, 2.33 for food demand (Table A6). Cassava also has strong growth rates for food (1.99 percent), feed (1.62) and total demand (1.93) (Table A6). Feed demand for sweetpotato (very little yam is used for feed) also has a high growth rate (1.81 percent).

Growth rates for food demand are all highest for Sub-Saharan Africa: 3.10 for potato; 2.74 for sweetpotato and yam; and, 2.49 for cassava and other roots and tubers (Scott, Rosegrant, and Ringler, 2000). These results reflect the dominant role that roots and tubers—particularly cassava—play in many African diets, the high status of potatoes and yams as preferred foods, strong population growth, and the extent to which these crops fit into the food systems in terms of, for example, input requirements, and soil and climatic conditions found in many parts of the region.

Projected production growth rates are solid, but they are also variable and driven by yield increases. Estimated growth rates in production 1993-2020 for potato (2.02 percent), sweetpotato and yam (1.25), and cassava and other roots and tubers (1.74) are dominated by growth rates in yield (1.50, 0.97, and 1.00 respectively) (Table A6). In relation to recent actual trends in production for these crops, these estimated production growth rates can be characterized about half that for potato, a quarter higher than for sweetpotato and yam, and nine-tenths of the rate for cassava (Table A6).

According to the baseline scenario, the total value of roots and tubers (summing cassava plus other roots and tubers, potato, sweetpotato and yam) as a share of the total value of all the major food commodities is projected to fall from 10.5 percent in 1993 (Table 5) to 8.8 percent in 2020 (Table A6). Much of this decline is attributable to the fall in price for sweetpotato, and in the newly estimated levels of prices for cassava (Table A9). Higher than previously estimated prices for maize and rice in 2020 (see Rosegrant, Agcaoili-Sombilla, and Perez, 1995) also are driving this result (Table A9). Even these rather conservative baseline estimates clearly indicate the role of roots and tubers in the food systems of developing countries will not drastically deteriorate over the next three decades.

High demand/production growth scenario. This scenario envisions more rapid growth in production and usage for roots and tubers in the years ahead. On the usage side, growth is grounded in modest increases in the effect of incomes on the demand for these commodities. On the outlook for supply, this scenario projects slight increases in the rate of productivity improvement and a more rapid expansion in area planted for these crops on a selective basis. For example, virtually all the increase for cassava comes from Sub-Saharan Africa, while for potatoes, the added growth is largely in China and India. It should be emphasized that while this scenario is more optimistic, at the regional and subregional level many of the associated growth rates in production, area and yields are virtually identical to the baseline scenario (see Scott, Rosegrant, Ringler, 2000). Furthermore, all of the more rapid projected increases are well within the range of recent trends in production and usage for roots and tubers in developing countries.

Projected growth rates for production of cassava and other roots and tubers (1.95 percent), potato (2.71 percent), and sweetpotato and yam (1.45 percent) are considerably faster than those of the baseline scenario of 1.74, 2.02 and 1.25 percent respectively (Table A6).

The faster growth in cassava production is largely attributable to an additional 1.3 million ha in area planted in Sub-Saharan Africa (Scott, Rosegrant, and Ringler, 2000). For potatoes, higher growth rates result from faster growth in output in China, 2.72 percent versus 1.49 percent, and in India 3.67 percent versus 3.10 percent, both in turn resulting from stronger expansion in area planted. Stronger growth in area planted in Sub-Saharan Africa (mostly yam) and higher yields in China (China produces no yam) account for the accelerated growth rate for production of sweetpotato and yam (Scott, Rosegrant, and Ringler, 2000).

IMPACT simulations indicate that higher food and feed uses will account for the faster growth in total use for potato, cassava and other roots and tubers, and sweetpotato and yam.

For potato, the jump in use is almost entirely due to faster growth in food use in China, 2.78 percent versus 2.20 percent, and in India, 3.80 percent versus 3.10 percent (Scott, Rosegrant, and Ringler, 2000). Nevertheless, overall average annual per capita use of potatoes in developing countries will rise only modestly beyond the level projected in the baseline scenario—from 16.2 to 18.1 kg. For cassava and other roots and tubers, the big shift is projected to occur in Sub-Saharan Africa. Additional increases in per capita food demand are projected —to 134.8 kg/yr instead of the 124.4 kg/yr foreseen in the baseline scenario—in spite of rapid population growth (Scott, Rosegrant, and Ringler, 2000). Similar higher increases in per capita demand in Sub-Saharan Africa are calculated for sweetpotato and yam; although for developing countries as a whole, per capita demand is projected to fall from 18.8 to 14.5 kg/yr (Scott, Rosegrant, and Ringler, 2000).

Roots and tubers' share in the projected value of all the commodities considered is projected to remain constant, comparing 1993 (Table 5) and 2020 (Table A6). This result represents the combined effect of the faster growth rates in production and a moderately slower rate of decline in prices for these commodities (see Table A9), with the bulk (0.75) of the increase due to faster production (Table A6, HDP scenario).

Table A9. Estimated world prices for roots and tubers, and selected other commodities, late 1980s, 1993, and 2020 (baseline and HDP) scenarios.

Commodity	Price (US$ per metric ton)					Price changes (percent)	
	1987/89	1989/91	1993	2020A[a]	2020B[b]	1993 to 2020A	1993 to 2020B
Potato	180	110	160	137	145	-14	-9
Sweetpotato and yam[c]	na	na	91	70	82	-23	-10
Sweetpotato	82	76	80[d]	56[d]	69[d]	-30	-14
Yam	105	137	135[d]	105[d]	115[d]	-22	-15
Cassava and other roots and tubers[c,e]	na	na	54	46	48	-15	-11
Cassava	66	68	na	na	na	na	na
All roots and tubers	na	na	113	91	99	-19	-12
Wheat	144	144	148	133	133	-10	-10
Maize	104	124	126	123	123	-2	-2
Other grains	na	na	122[c]	105[c]	106[c]	-14	-13
Barley	128	114	na	na	na	na	na
Sorghum	93	124	na	na	na	na	na
Millet	132	158	na	na	na	na	na
All rice	284	292	286	265	266	-7	-7
Soybean	265	234	263	234	235	-11	-11
Beef	na	na	2023	1768	1771	-13	-12
Beef and buffalo meat	1458[c]	2226[c]	na	na	na	na	na
Pigmeat	na	na	1366	1209	1212	-11	-11
Sheep and goat meat	1652[c]	2099[c]	2032[c]	1842[c]	1845[c]	-9	-9
Poultry	na	na	1300	1157	1159	-11	-11

Sources: 1987/89 - TAC (1996: Annex II); 1989/91 - Rao (1993); 1993, 2020A, 2020B - Scott, Rosegrant, and Ringler (2000).
Note: na signifies not available.
[a] Baseline scenario.
[b] High demand/production growth (HDP) scenario.
[c] Composite price.
[d] Prices for sweetpotato and yam calculated outside IFPRI's IMPACT, but based on TAC (1996, 1997a), IMPACT simulations and historical trends.
[e] These figures are for cassava and other roots and tubers such as taro. For developing countries, cassava alone accounts for over 97 percent of the total.

Summary

Based on their agronomic, raw material, and nutritional characteristics as well as an analysis of recent trends in production and utilization, we have estimated future growth rates in supply, demand, and the economic values of root and tuber crops to the year 2020. The largest absolute increase in root and tuber production will take place in Sub-Saharan Africa (cassava and yam, primarily) under both scenarios. China will account for the bulk of additional sweetpotato output, and both China and India are projected to harvest two-thirds or more of the additional potatoes produced. Furthermore, increases in root and tuber production will be driven by demand for food in the case of potato (both fresh and processed) and yam. Processed food products such as noodles made from starch and non-food uses such as feed will be much more important for cassava and sweetpotato.

Although we believe the outlook for future production and use of roots and tubers in developing countries described here is realistic, it is by no means guaranteed. For sustained development of the root and tuber sectors in Asia, Africa, and Latin America, the continuous generation and diffusion of improved production and postharvest technology—linked to improvements in food marketing systems beyond the farm gate (McCalla, 1998)—is essential. This entails capitalizing on opportunities to expand usage and overcoming key production and postharvest constraints (see Section 4).

Appendix - The structure and operation of IFPRI's IMPACT

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) was developed at the International Food Policy Research Institute (IFPRI) as a research tool in the analysis of the relative performance of commodities in the international market as they are affected by changes in the economic and social structures of countries and regions. The original structure of IMPACT was based upon existing global trade models such as IFPSIM (Oga and Gehlar, 1993), SWOPSIM (Roningen, Sullivan, and Dixit, 1991), OECD/MTM (OECD 1991), and the FAO World Food Model (FAO, 1986), with extensions that permit long-term projections of prices, supply, demand, and trade. In its present structure, IMPACT is (1) partial equilibrium with its focus on the agricultural sector; (2) global, covering 37 countries and country groups, (Table A10) and 18 commodities; (3) nonspatial (and thus cannot be used to analyze trade patterns); and, (4) synthetic, because of its use of key parameters derived from other studies. Despite its focus on agricultural commodities, relationships have been incorporated in the model to link income growth in the agriculture and nonagriculture sectors.

The model uses a system of supply and demand elasticities, incorporated into a series of linear and nonlinear equations, to approximate the underlying production and demand functions. Sectoral growth multipliers are used to determine the intersectoral effects of changes in income in agriculture and nonagriculture sectors. A typical country or regional sub-model consists of a set of these equations for each commodity, as well as the equations that link the agriculture and nonagriculture sectors (see Rosegrant, Agcaoili-Sombilla, and Perez, 1995; Scott, Rosegrant, and Ringler, 2000, 2000a for details).

The use of the IMPACT model to generate this new set of 2020 projections for roots and tubers involved an extended set of collaborative procedures. These included multiple consultations among the authors of this report, and between the lead author and representatives of the other CGIAR Centers (CIAT, IITA and, albeit to a much lesser extent, IPGRI).

Table A10. Selected parameters of IFPRI's IMPACT.

Countries/region	Projected average annual growth rate (percent), 1993–2020	
	Population	Income
Developed Countries		
USA	0.77	2.2
EC 12	0.01	2.2
Other Western Europe	0.26	2.3
Japan	-0.02	2.1
Australia	1.01	2.2
Other developed countries	1.48	2.2
Eastern Europe	-0.02	1.6
Former Soviet Union	0.07	1.6
Developing Countries		
Latin America		
Argentina	1.09	3.2
Brazil	1.12	3.2
Colombia	1.40	3.2
Mexico	1.31	3.2
Other Central and South American countries	1.59	3.0
Sub-Saharan Africa		
Madagascar	2.97	3.8
Nigeria	2.67	3.2
Northern Sub-Saharan Africa	2.79	3.3
Central and Western Sub-Saharan Africa	2.70	3.8
Southern Sub-Saharan Africa	2.46	3.2
Eastern Sub-Saharan Africa	2.56	4.5
West Asia and North Africa		
Egypt	1.56	3.2
Turkey	1.24	4.5
Other West Asian and North African countries	2.33	3.2
South Asia		
India	1.30	5.1
Pakistan	2.44	4.6
Bangladesh	1.50	4.5
Other South Asian countries	2.27	4.6
Southeast Asia		
Indonesia	1.19	4.9
Malaysia	1.64	5.3
Myanmar	1.45	4.0
Philippines	1.61	5.0
Thailand	0.63	5.4
Vietnam	1.44	5.0
Other Southeast Asian countries	1.95	4.0
East Asia		
China	0.72	5.6
South Korea	0.61	3.8
Other East Asian countries	1.03	2.4
Other Developing Countries	1.46	4.9

Source: Countries/regions: Rosegrant, Agcaoili-Sombilla and Perez (1995); parameters: IFPRI's IMPACT simulations, baseline scenario, as presented in Scott, Rosegrant, and Ringler (2000a).

Note: Subregions in Sub-Saharan Africa are defined as follows: Northern Sub-Saharan Africa covers, Burkina Faso, Chad, Djibouti, Ethiopia, Mali, Mauritania, Niger, Somalia, and Sudan. Central and Western Sub-Saharan Africa covers Benin, Cameroon, Central African Republic, Comoro Islands, Congo, Côte d'Ivoire, Dem Rep. of the Congo, Gabon, The Gambia, Ghana, Guinea, Guinea-Bisseau, Liberia, São Tomé, Senegal, Sierra Leone, and Togo. Southern Sub-Saharan Africa covers Angola, Botswana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Réunion, Swaziland, Zambia, and Zimbabwe Eastern Sub-Saharan Africa is composed of Burundi, Kenya, Rwanda, Tanzania, and Uganda All other regional groups follow FAO classifications

Section 4 – Opportunities for roots and tubers

Opportunities for expanded use of roots and tubers lie in three categories: (1) fresh and processed for human consumption; (2) fresh and dried for animal feed; and, (3) starches for food and non-food uses. Roots and tubers in fresh form generally have little competitive overlap on either the supply or demand side. They are typically cultivated in different production systems and agro-ecologies and for distinct market segments. Processed products (feed/starch) made from roots and tubers (primarily cassava and sweetpotato) not only compete with maize, sorghum, wheat, but also with each other in raw material and product markets, particularly in East and Southeast Asia. However, in fresh and processed form they constitute an interlocking and critical component of the food economies in developing countries (Scott, Rosegrant, and Ringler, 2000). Table A11 lists opportunities for expansion for each commodity.

Cassava

Fresh and processed cassava for human consumption
Fresh roots can be consumed or sold in their natural form, or utilized or marketed with some level of postharvest treatment to extend their shelf life. The market includes preprocessed cassava, where roots are peeled and in some cases precooked, vacuum packed, and frozen. In other cases (e.g. USA and EU fresh cassava markets), cassava roots are paraffin-coated. Fried cassava chips produced in small quantities in several countries also fall within this category. Cassava leaves, which are high in protein and contain important quantities of vitamin A, are consumed as a fresh vegetable in several African countries, Brazil, and Indonesia.

Opportunities for these types of products are mostly confined to those countries where fresh cassava is a traditional food . A small but lucrative export market already exists, mainly from Central America, to supply the ethnic demand for these more expensive products in North America and Europe (Henry, 1998; Taylor and Phillips, 1998). As incomes rise, demand will increase. Using molecular techniques to genetically suppress the rapid postharvest deterioration of cassava roots would be a breakthrough development, improving product quality and substantially reducing market risk.

Cassava roots processed into traditional products fall into two categories: flour-based and starch-based products. They are generally assumed to be income inelastic, i.e. a rise or fall in income has little or no effect on quantities consumed per capita, and, as countries urbanize and incomes rise, demand decreases. However, the poorest income classes increase their cassava consumption when income levels improve, as is the case for *farinha de mandioca*, the toasted flour consumed throughout Brazil (Henry and Gottret, 1996). Evidence from West Africa shows that with certain traditional products, such as *gari*, growing urbanization and increased incomes can have a positive effect on consumption (Ezemenari, Nweke, and Strauss, 1998; Spencer and Associates, 1997). Medium-term demand is likely to expand, especially in rural and poorer urban markets in Africa. With growing urbanization and changing consumer preferences, opportunities exist for penetrating higher-value niche markets with improvements in product quality and presentation particularly in East, Central, and Southern Africa (dTp Studies, Inc., 1998).

Although industry currently uses small volumes of cassava flour, interest has increased in using high-quality cassava flour as a partial substitute for wheat in food and non-food products (Damardjati, Widowati, and Dimyati, 1992; Kapinga et al., 1998; Ostertag et al., 1996; Salas, Guzmán, and Aquino, 1996; Westby and Graffham, 1998). It is already technically feasible to substitute cassava flour totally or partially for wheat flour and grain-based starches in food products such as soup mixes, meat products, cookies, and noodles. Improvements in raw material quality and cost through the introduction of better varieties as well as gains in technical and economic efficiency in processing should open markets for cassava-based food products in Sub-Saharan Africa, Southeast Asia, and parts of South America.

Table A11. Selected opportunities for expanding utilization of roots and tubers and their relative potential in developing countries, by commodity and by region.

Crop	High	Moderate	Low
Cassava	- Starch and derived products in Southeast Asia and Latin America (LAC) - Traditional processed products for human consumption in Sub-Saharan Africa (SSA) - High value added snack foods in urban LAC and Asia	- Dry roots for animal feed in Southeast Asia and LAC - Food and non-food (e.g., adhesives, plywood) uses of flour - Fresh prepared roots in urban tropical LAC and for export	- Fresh roots for direct human consumption in LAC - Traditional processed products in LAC and Asia
Potato	- Fresh tubers for direct human consumption in China, India and SSA - Processed products in Asia and LAC	- Fresh tubers for direct human consumption in LAC and Pakistan	- Tubers for animal feed (outside China)
Sweetpotato	- Fresh roots for direct human consumption in SSA - Starch in China - Fresh roots and vines for feed in China and Vietnam	- Fresh roots and vines for feed in parts of Southeast Asia, Oceania, and LAC	- Fresh roots for direct human consumption in China and Southeast Asia - Flour in Asia and LAC
Yam	- Fresh tubers for direct human consumption in West Africa	- Fresh tubers for direct human consumption in East and Central Africa - Improved traditional processing for human consumption in West Africa	- Processing for animal feed - Processing for flour in bread making, especially for *Dioscorea alata*
Other roots and tubers	- Processing of canna in the Andean region	- Improved canna starch in China and Vietnam - Improvement of traditional products processed from Andean roots and tubers in the Andean region and from aroids such as taro in Oceania	

Source: Compiled for this study.
Note: Columns should be read downwards.

Animal feed

Cassava has been used traditionally for on-farm animal feeding in its fresh form. The FAO Food Balance Sheets (FAO, 1996) show that the portion of fresh cassava roots used on-farm for animal feed is relatively low and that it decreased from 4.3 percent of total world production in 1981 to 3.4 percent in 1994. This was mainly a response to industry's greater demand for cassava roots for processing into starch.

Thailand, and to a lesser extent other Asian countries such as Indonesia, have commercially produced cassava chips for animal feed since the early 1960s (Phillips, 1973), principally for export to the EU. Currently, the low prices required to compete in the EU market overshadow prospects for cassava exports to participate (FAO, 1995: 65-66), but the growing demand for livestock products in Asian countries suggests an opportunity for cassava as a source of feed carbohydrates. Latin America entered this market in the early 1980s, taking advantage of the growing local demand for animal feed (Lynam, 1989). Compared with sorghum and maize, dry cassava's lower protein content means it enters minimum cost feed rations at a price 82–86 percent that of sorghum. Cassava starch processing by-products contain high levels of fiber and carbohydrates and can also be used for animal feed. Cassava leaf meal is an important source of beta-carotene that has potential in feed for poultry (Buitrago, 1990).

Cassava's economic potential for use in animal feed depends mainly on how well it competes with its major substitutes: sorghum and maize. For dry cassava to compete in price, productivity levels must be enhanced by introducing varieties with higher starch content and by management practices that reduce production costs.

Starch
Almost all the principal industries have a use for starch. Thus a large increase in demand follows the industrialization process. The world starch market grew from 15.1 million mt in 1980 to 33.7 million mt in 1993 (Maneepun, 1996), cassava starch having an estimated 6 percent share (Ostertag et al., 1996). Starches in the mass market compete mainly based on price, and in the specialized market, based on their functional properties. Currently, cassava starch competes well with maize starch on price basis. However, from 1981–95, cassava starch prices increased annually by 2.2 percent, compared with only 1.3 percent for maize prices.

Recent articles compare the functional properties of starches from different sources (Maneepun, 1996; Balagopalan et al., 1988). Cassava starch is appreciated for its neutral taste and odor, and the transparency, smoothness, and viscosity of the gel. These findings suggest considerable growth potential for starch production from cassava, especially in rapidly urbanizing and industrializing countries. Industry has shown interest in modifying cassava starch's functional properties through genetic transformation, which will likely be achieved within the next five years and will open up new potential markets for the crop. This has already begun to occur in Thailand (Titapiwatanakun, 1998) and more recently Vietnam (Goletti, Rich, and Wheatley, 1999).

Other uses
In the non-food industry, cassava flour has the greatest potential as a low-cost adhesive for labels and boxes and in manufacturing plywood, particularly in Southeast Asia and parts of South America. This market will depend on future developments in relative wheat and cassava prices. Product research is required to penetrate it.

Potato

Fresh and processed potato for human consumption
Potato consumption has surged in much of Asia in the past 20 years, particularly in South Asia, although even current absolute per capita consumption levels of less than 20 kg/yr are modest in comparison to potato consumption in developed countries. As incomes increased, consumers opted to diversify their diets away from cereals to include more vegetables, particularly potato. Consumers like the bland taste of potato—it combines well with a wide variety of tastes and culinary practices (Woolfe, 1987)—and it provides key vitamins and enhances the protein quality of wheat and rice. With continual population growth, rising incomes over the medium- to long-term, and the modest levels of current potato consumption, opportunities for increasing potato consumption in fresh form are excellent. These opportunities can be exploited because, with improved productivity and marketing arrangements, prices for potatoes fall relative to other food commodities. Historical evidence from Bangladesh bears out this observation (Bouis and Scott, 1996; Horton, 1987).

In Latin America, historically high levels of per capita potato consumption in fresh form in Peru (Herrera and Scott, 1992), Bolivia (Zevallos, 1997), and parts of Ecuador, Colombia, and Guatemala show possibilities for more modest market growth. Traditional potato processing in southern Peru and parts of Bolivia (Yamamoto, 1988), similar to solar-dried, labor-intensive potato processing in India (Sikka, 1990), will persist, but continue to decline as a share of total utilization.

The growth in consumption of processed potato products also offers tremendous opportunities for expansion. In India, parts of Asia, West Asia and North Africa, and Latin America, factors such as urbanization, rising incomes, tourism, female participation in the work force, and advertising schemes launched by multinational fast food chains will boost consumption (Fuglie, 1994; Scott, Basay, and Maldonado, 1997; Zhang et al., 1999). However, globalization and the associated market liberalization could also generate more rapid increases in imports of potatoes from developed or other developing countries. This has already happened on a limited scale in Costa Rica (Vargas, 1995), Sri Lanka (Khatana, 1998), and Brazil (FAO, 1998). Imports of processed potatoes only became commonplace in many of these countries in the past 5–10 years. Whether this pattern of trade will level off into a specialized niche by catalyzing improvements in domestic production or evolve into a broader, growing presence in these markets is hard to determine.

Animal feed
Potatoes are not widely used as animal feed in developing countries. Instead, small quantities of unmarketable and inedible tubers are often fed to household livestock and vines are used as fodder. However, in some landlocked interior provinces of China, a large share of potato production is still used as pig feed because of abundant supply, low prices, and isolation from domestic centers of maize production and global markets. In other developing countries, potatoes are typically too highly prized and highly priced as a food commodity to permit widespread use as feed. Outside China, use of potatoes as feed is unlikely to grow in the future. If potato prices fall markedly

in these locations, greater human consumption in fresh or processed form would undoubtedly occur first before expansion in use as feed.

Starch

The global market for potato starch is in transition. Major changes in the Common Agricultural Policy (CAP) in the EU are intended to phase out subsidies on potato starch production. The glut of potato starch in Western Europe may have resulted in surpluses in Eastern Europe currently being sold, or dumped, on markets in the Far East (C. Oates, personal communication). Several developing countries, such as Peru (Fano et al., 1998; Gomez de Zea and Wong, 1989), have imported potato starch from developed countries in the past. With subsidies being phased out and the global market becoming more competitive, the continued profitability of these exports is increasingly in doubt.

Production of potato starch in developing countries is heavily concentrated in China (Gitomer, 1996), largely at household or village level, and is most commonplace in geographically isolated (e.g. mountainous) areas (Ye and Rozelle, 1993). Small quantities of potato starch are also produced using traditional methods in the Andean region (Yamamoto, 1988) and in South Asia (Sikka, 1990).

Market opportunities for potato starch in developing countries are limited, unless some unique chemical attribute is identified in the future. The most likely scenario is that village or traditional production of potato starch will gradually decline in importance.

Sweetpotato

Fresh and processed sweetpotato for human consumption

Opportunities for increased human consumption of fresh sweetpotato roots are most promising in Sub-Saharan Africa. Strong continental population growth, modest absolute income levels for large segments of consumers, and declining farm size will contribute to a growing use of fresh roots and, in certain areas, of leaves for human consumption. Many of the same factors will offer more modest opportunities for expanded consumption of fresh sweetpotato roots in Egypt. In Latin America, opportunities for the growth in per capita consumption will be confined to pockets of the rural population such as in Brazil, Haiti, and the Dominican Republic. In China, Vietnam, and much of South Asia, consumption of fresh roots will probably continue to decline. Consumers in South Asia will switch to more preferred foods, including potato. For Southeast Asia (e.g. Indonesia, Philippines), future trends in consumption in various forms are less predictable.

In recent years, sweetpotato processing into starch (to make noodles) has emerged as a major use in China (Fuglie et al., 1999; Timmins et al., 1992) and, albeit to a considerably lesser extent, Vietnam (Prain, Wheatley, and Nguyen, 1997). Current research must investigate how to feasibly improve quality and lower unit costs, or channel output into emerging specialized niche markets. Such opportunities are likely to be greatest in China (Fuglie et al., 1999) where abundant supplies of raw material, a rapidly growing starch market, and mechanisms for introducing and diffusing technological improvements are much further advanced than in Indonesia, Papua New Guinea or the Philippines, for example. Future economic trends in Southeast Asia will also help determine whether shifts in relative prices and exchange rates, and the pace of technological innovation, will change the market for this type of product into a more regional or a highly localized one.

Sweetpotato flour shows more limited commercial promise. It has been tested in East Africa as a substitute for cassava in composite flour (Hagenimana and Owori, 1997), and in Indonesia as a replacement for imported wheat flour (Peters and Wheatley, 1998), but earlier attempts to introduce a similar product in Cameroon (Odaga and Wanzie, 1992) and Peru (Espinola et al., 1997) floundered because of its high price, uneven quality, and more general supply chain difficulties. Opportunities for this product are thus considered to be more limited in these locations. Whether the pilot scale production becomes a niche market, a major segment, or fizzles out because it cannot compete will depend on economic events, local production patterns, and the pace of improvement in a cluster of technologies.

Animal feed

Over the past 30 years, sweetpotato production for animal feed in China has risen from about 10 percent to 45 percent or more (Huang, 1999; Timmins et al., 1992). This momentum has raised interest in its longer-term prospects. An optimistic scenario shows continued geographic isolation of the inland provinces, China's unwillingness to run up a huge import bill for feed, higher global maize prices, and continued strong demand for meat. This would induce sufficient technological innovations to sustain or expand using sweetpotato for feed in China and potentially elsewhere in Asia (e.g. Papua New Guinea, Vietnam).

In parts of Sub-Saharan Africa and Latin America, the prospects for expanding use of sweetpotato foliage for livestock production in small-scale mixed farming systems have attracted attention. Diagnostic survey work documented the importance of foliage as a feed component (Peters, 1997) and identified high performance and high quality clones in the CIP-Lima germplasm collection (León-Velarde et al., 1997). To assess the depth and breadth of such opportunities, we must observe the impact of globalization on feed and dairy markets, the pace of technological change in sweetpotato versus substitute crops, and the policy environment, all of which together may constitute a scenario favorable or less conducive to sweetpotato development.

Yam

Fresh and processed yam for human consumption
Yam accounted for 55.3 percent of total root and tuber consumption in West Africa and 4.1 percent of that in Central Africa during 1975–84 (Gebremeskel and Oyewole, 1987). Average per capita consumption was 99.4 kg/yr in West Africa and 10.5 kg/yr in Central Africa. These figures underrate the importance of the crop when considering regional concentrations of usage within countries (Dorosh, 1988a). In southeast Nigeria, for example, Nweke et al. (1992) established that people in major food-producing rural areas consumed 757 calories per capita per day from yam, compared to 345 from cassava, 298 from rice, 185 from wheat, and 149 from grain legumes with lower, but comparable, figures in urban areas.

Studies during 1984–85 in southeastern Nigeria (accounting for 42 percent of world yam production), showed a positive expenditure elasticity of demand for yam at all expenditure levels (Nweke et al., 1992). They concluded that yam would continue to have a high market potential and that "since yam is own-price elastic, production research to increase supply is likely to increase quantities consumed at low-income levels." Dorosh (1988a) also noted a positive income elasticity of demand for yam for most people in the yam zone, a negative impact of urbanization on per capita consumption, and a relatively high own-price elasticity of demand. He further postulated that increasing population density in the forest zone might lead to decreasing soil fertility and favor cassava over yam.

Yam production was essential to the survival and well being of many generations of people in the tropics and continues to be highly important for ensuring sustainable food security and income generation. The yam tuber remains dormant during the unfavorable agro-climatic period between one harvest and the next planting season. Thus the fresh tuber has a longer shelf life than other roots and tubers, ensuring food supply even at times of usual scarcity. Tubers are also often dried for even longer storage and later milled into flour for reconstituting into a stiff paste, which is eaten with soup. The growth pattern of the yam plant guarantees tolerance.

Yam and derived yam-based products are expensive and still prey to competition from imported products. Yam-based products must be diversified. Research is needed to improve the technical processing systems at all levels and to better understand market and consumer demands. The development of yam-based products could further promote this tuber (Attaie, Zakhia, and Bricas, 1998).

Other roots and tubers

Prospects for continued use of other roots and tubers vary by subgroup. Here, we divide them into: (1) tannia, taro, yam bean, and other tropical roots and tubers and, (2) Andean roots and tubers such as canna, achira, arracacha, ulluco, oca, and mashua, among others.

Taro and tannia. Taro (*Colocasia*) is the 14th most consumed vegetable worldwide. FAO estimates annual production in developing countries is about 5.7 million mt (FAO, 1998). Annual figures for tannia (*Xanthosoma*) are lower but fail to record much of the production outside of the Caribbean, namely in Africa and Asia where tannia production has been increasing rapidly and has in some cases overtaken taro. Commodity specialists indicate that production figures for these commodities, where they exist, tend to underestimate the extent, volume, and value of taro and cocoyam output (P. Eyzaguirre, IPGRI, personal communication). These data problems are most acute where aroids occupy niches and small gardens or swampy areas or are grown under commercial tree crops. In such systems studies have shown that they are often the main item in the diet and they help to account for the overall profitability of some tree crop systems by providing additional food sources and income while the tree crops mature.

Taken together, the edible aroids are a major staple food and vegetable of tropical regions. Aroids also have an established place in the production systems and food cultures of countries with large and intensive agricultural economies such as China, India, and Japan. China, Ghana, and Nigeria each produce well over a million mt of taro a year. Burundi, Côte d'Ivoire, Japan, Madagascar, Papua New Guinea, Philippines, and Thailand are all important producers, with official production figures in excess of 100,000 mt annually. IPGRI specialists consider that these production data most likely reflect the taro that enters into the market and ignore the quantities produced for subsistence. They also assert that West African production figures are low given that taro is an important crop in the region's humid eco-zone.

Aroids under intensive cultivation are processed into starch and are also grown as high-value market vegetables for urban markets. Recent studies have shown that other parts of the plant —leaves, stalks, and the inflorescence— are grown as high-value market vegetables in addition to the corms and cormels. In the Netherlands, taro is even cultivated in greenhouses for production of leaves for use as food by immigrants from the Caribbean, West Africa, Asia, and Oceania. Opportunities to promote and support the use of aroids under tree crops or in niches may make a major contribution to the food security of farmers in the tropics. The growing recognition of the commercial value of aroids as a vegetable for urban consumers and for processing, and even export, provides additional incentives to better document and support the use and further deployment of these genetic resources in ecosystems. Their multiple uses, the great diversity in cultivars, and the potential to deploy both New and Old World aroids in a range of environments indicate a vast and largely untapped potential for research on aroids.

Andean roots and tubers. These crops are traditionally consumed in both fresh and processed form. Prospects for noteworthy increases in per capita fresh consumption usually have less potential than for processed products. For example, achira has made the jump from traditional to modern use in Colombia where it is processed into starch and then into biscuits and widely consumed as a local snack food (Hermann, 1994). More importantly, canna starch is used to make highly popular noodles in parts of Vietnam (Hermann et al., 1997) and China. Technical improvements aimed at improving starch quality and extraction efficiency could expand this use considerably. Arracacha has become popular in the form of instant food in Brazil and efforts to improve quality and consumer appeal through packaging and promotion are well under way in Peru.

Commercial interest is growing in exploiting the export potential of Andean roots and tubers as 'ecological foods' where an absence of chemical inputs in their cultivation and a variety of dietetically interesting compounds (e.g. fructans) could well find appeal in Europe or North America. Nonetheless, except for canna and ulluco, all the Andean roots and tubers are currently produced and consumed in only small amounts and thus even large percentage increases are unlikely to radically alter their relative importance compared with other food commodities. Given that most of the Andean roots and tubers are grown by small-scale, resource-poor farmers, efforts to expand market potential are well justified from the perspective of poverty eradication and sustainability of biodiversity.

Summary

Opportunities for expanding utilization and in turn production of roots and tubers fall into three broad categories: 1) fresh or processed form for human consumption; 2) fresh and dried for animal feed; and, 3) starches for food and non-food uses. A synthesis of these opportunities by crop and by region indicates increasing specialization by commodity and by location.

Opportunities for potato and yam will be highly concentrated in fresh or processed form for human consumption. Potato use for animal feed and starch in any appreciable quantities will be important only in China. Opportunities for yam in the form of starch are still in the initial stage of definition and development. Opportunities for potato will be greatest in South and East Asia, WANA, and Latin America. Opportunities for yam will be concentrated in West Africa.

Opportunities for cassava and sweetpotato are more complex. In Sub-Saharan Africa, opportunities are by far the greatest in fresh or processed form for human consumption. In Asia and Latin America, however, animal feed and starch constitute the most promising areas for expansion.

For the aroids and Andean roots and tubers, opportunities are also varied. Fresh and processed roots and tubers for human consumption will continue to be important in parts of Southeast Asia and Oceania as well as in isolated locations of the Andean region. Potential for starch-derived products for food and non-food uses is attracting increased attention. Realizing these opportunities for any of these crops in any of these forms is contingent upon a number of factors, but in particular overcoming the most important constraints.

Section 5 – Constraints to the development of roots and tubers

Realizing the projected growth rates in production as well as exploiting the opportunities for expanded utilization and market penetration will require overcoming a series of constraints. Whereas at the most superficial level all roots and tubers alike face constraints to production and use, the precise nature and primary focus of these constraints varies considerably from crop to crop. Broadly speaking, supply-side factors (e.g. diseases, insects, managing the release of potatoes onto the market) are more prominent for potato and yam. Demand-side factors (e.g. competitiveness as raw material for feed or industrial uses) are of greater importance for cassava, sweetpotato, and other roots and tubers.

For the purpose of this brief review, each of the commodities will be analyzed for technical, socioeconomic, and policy and institutional constraints. We also will attempt to assess the probability of success in overcoming these constraints. We will conclude this analysis by presenting a consolidated set of constraints across commodities.

Cassava

Technical constraints

Certain constraints are inherent in the biological characteristics of cassava. These include:

Lengthy growing season. The growth period of cassava is typically 10 months from planting to harvest, but can vary between 6 and 24 months, depending on the climatic and soil conditions. This long cropping cycle is a comparative disadvantage in relation to other crop staples, such as beans, rice, and maize, which have growing cycles of 3–4 months, and has serious implications for the time required for technology development, testing and adaptation in systems, and for the multiplication of improved varieties.

Low multiplication rate. Cassava's vegetative reproduction system depends on segments ("stakes") cut from the stems of mature plants. Each plant can produce 8 to 12 of these stakes. While one hectare of cassava generates planting material for just 10 ha in one year, both maize and rice can generate planting material for 1,600 ha, or a multiplication rate 160 times higher than cassava. Sexual cassava seed is only being used in cassava breeding programs and, so far, has no commercial application (Henry and Iglesias, 1993). While rapid multiplication techniques are available, their employment is expensive. Compared to grain crops, therefore, the multiplication rate for new planting material is very slow and this has a marked constraining effect on the rate at which "seed"-based improvements can be transferred to the farmer.

Bulky planting material. To plant one hectare of cassava, 1000 kg of stakes are necessary, whereas, for example, a hectare of maize only needs 25 kg. The practical difference is renting a truck or horse and cart, versus carrying the seed home in a bag.

Region-specific constraints. In addition, recent regional reviews of cassava development undertaken for Africa, Asia, and Latin America have identified for each continent a set of the most important technical constraints to the production and market development of the crop.

Sub-Saharan Africa. Spencer and Kainaneh (1997) identify declining soil fertility, insufficient and poor planting material, the lack of well-adapted varieties, and pests and diseases as the major production constraints that farmers face in trying to maintain cassava's important food security role as population continues to grow, and as they seek to improve their incomes by exploiting opportunities for processed products in rapidly growing urban markets.

Declining soil fertility is closely related to the shortening of fallow periods as farmers adapt their production systems to demographic and market pressures. Insufficient and poor-quality planting material is a constraint, particularly in the drier agro-ecosystems into which cassava has extended over the past three decades. Pests and diseases are important causes of yield losses in cassava in Africa. Cassava mosaic disease, cassava bacterial blight , cassava anthracnose disease, root rots, and brown streak virus are considered to be the diseases of greatest economic importance. Among the pests, the cassava green mite and the larger grain borer are predominant. Associated with these agronomic constraints is the lack of well-adapted varieties. Beyond tolerance to the major biotic and abiotic pressures present in the principal cassava agro-ecosystems, earlier bulking varieties, with suitable quality characteristics for the predominant end uses, are required.

The urbanization of Africa offers farmers new opportunities to generate income by supplying the crop to entrepreneurs that process the roots into starch, flour, or chips for food, feed, and industrial uses. However, realization of the true potential of cassava in these emerging markets requires reliable technical, economic, and market information on each product. This sort of information, systematic and well-analyzed, is largely lacking in Africa. Traditional transformation processes, most often managed by women, are labor intensive and the high labor requirement is considered the principal constraint to providing competitive products. Cassava's postharvest perishability is a universal constraint to its use both as a fresh food and as a raw material for processing. This negative characteristic raises market margins, reduces product quality, and conditions the location and size of processing operations.

Asia. Cassava markets in Asia are highly diversified, and competition is principally with coarse grains. Key elements in maintaining cassava's competitive edge in the future will include production efficiency and profitability, conservation of the resource base, processing efficiency, and the development of markets for specialized products.

In Asia, pest and disease constraints are less severe than in Africa or Latin America, but a major challenge for farmers is the maintenance of soil fertility and control of erosion (Hershey et al., 1997; Howeler, Oates, and Costa Allem, 1999). In Asian upland cassava production systems, nitrogen and potassium are usually limiting nutrients, while erosion control is considered indispensable for sustaining longer-term productivity. It is estimated that alleviating these two constraints would increase yields by 33 percent (Henry and Gottret, 1996). In addition, labor productivity can be improved through further mechanization of land preparation and harvest, and through weed control using herbicides or mechanization.

Cassava chips or pellets and native starch, the primary processed products of the crop, have a relatively low value. Narrow profit margins demand efficient processing and, to the extent possible, economies of scale. Technically, these constraints can be reduced through the development of varieties with higher starch content and less susceptibility to postharvest deterioration. Alternatively, exploiting specialty markets, in which specific physicochemical and functional properties are required, can add value to cassava products and increase farm-gate prices.

Latin America. For cassava and cassava products to capture a share of the growing market for starch for food and non-food uses as well as for animal feed, crop productivity and efficiency need to be improved (Hershey et al., 1997). As in the case of Asia and Africa, a major constraint to higher yields is low soil fertility. Phosphorus and potassium are the limiting soil nutrients. The control of soil erosion in cassava-based production systems is also vital to ensure long-term productivity. The potential increase in yields through alleviating these constraints would be in the order of 28 percent (Henry and Gottret, 1996). Cassava in Latin America has evolved with a complex of pests and diseases, and these can cause serious crop losses. The economically most important diseases at the present time are root rots and cassava bacterial blight . The cassava green mite and whiteflies are the pests that, on a continental scale, cause greatest reductions in productivity. Weeds not only reduce the yields of cassava but are also expensive to control.

Breeding and varietal selection programs have illustrated the low yield potential of landrace varieties. Large productivity gains will be achieved when the potential of elite materials is combined to provide varieties acceptable to both farmers and purchasers. Relative abundance of land in parts of Latin America is leading to the emergence of a medium-scale farm sector involved in cassava cultivation. Increases to labor productivity in this sector will be achieved through the partial mechanization of production activities.

Postharvest constraints are acute in Latin America. Market options are limited, often to a single form of traditional utilization, where poor quality and low processing efficiency restrain market expansion. Diversifying market opportunities and developing processing and production systems that conform to the emerging needs of the food and non-food industries are major challenges.

Socioeconomic constraints

Farmer characteristics. Several studies have analyzed the factors influencing the adoption of cassava production and processing technologies (Gottret, Henry, and Dufour, 1997; Gottret, Henry, and Duque, 1993; Henry, Izquierdo, and Gottret, 1994; Henry, Klakhaeng, and Gottret, 1994). These found that farmer characteristics, such as age, years of formal education, experience, and the like, did not have a significant effect on the adoption of production or processing technology. However, membership of producer and/or processor cooperatives or associations is the most important characteristic explaining technology adoption. Land or processing plant tenure has a positive effect on the adoption of technology. Farmers or processors with a good supply of family labor will be less likely to adopt machinery-related technology, or other technology which reduces the need for labor, such as herbicide use in cassava production (Henry, Klakhaeng, and Gottret, 1994) or gravity distribution in starch processing plants (Gottret, Henry, and Dufour, 1997).

Farm characteristics. The majority of cassava throughout the world is grown under adverse climatological and soil conditions (El-Sharkawy, 1993), and on relatively small, poor farms in marginal areas. These adverse conditions imply, among other factors, a high level of production risk. Therefore, the incentives for small cassava farmers to adopt improved technologies are reduced. A further aspect, for which little information exists, is the fact that, except in parts of Thailand, Indonesia, and Malaysia, cassava areas are scattered within regions (Henry, 1991). The consequence of this is that the speed of adoption in a given geographical zone is often slow.

Markets. Most traditional cassava markets are confined to a few products, can only absorb given quantities of roots, and have relatively low demand elasticities (Henry and Best, 1995). This implies that higher consumer incomes resulting from more rapid economic growth will have only limited effect on the quantities of cassava demanded. These adverse market conditions imply a high level of market risk at the farm level, and, therefore, constrain the development potential of cassava. It has been shown that the removal of constraints on the demand side can have a major impact on the adoption of improved technology on the supply side (Gottret, Henry, and Dufour, 1997; Henry, Klakhaeng, and Gottret, 1994).

Policy and institutional constraints

Investment in, and orientation of, research and development. In most countries, cassava research and development activities receive limited resources, compared to crops such as rice and maize. For this reason, cassava has often been called an "orphan crop." The limited resources that are available are most often directed to the production component. Only a few programs include socioeconomic and/or postharvest R&D activities. A proper integration among cassava production, processing, and market research aspects is difficult to obtain under these conditions. To a large extent cassava technology development has been "scientist-and/or extensionist-oriented." The incorporation of farmer participatory or "client-oriented" approaches has been limited.

Absence of a cassava "lobby." In most countries, formal cassava producer or processor organizations to represent the interests of the cassava sector simply do not exist. This has been partially responsible for the low level of government priority for the sector. Moreover, in many countries, the sector has suffered periodically from the negative indirect effects of governmental interventions targeted to crops like rice, corn, and wheat. This has resulted in severe market distortions, which further increase the market risk faced by cassava farmers and processors (Henry et al., 1995).

Access to credit. Small-scale cassava farmers typically have little access to credit. Although formal adoption studies have not found a significant relationship between adoption and access to credit (Henry and Gottret, 1995), further analysis of this issue needs to be undertaken because farmers often mention the lack of financial resources as a deterrent to planting or processing more cassava.

Access to markets. Recent research has identified the restrictive nature of trade policies with respect to imports of cassava products, such as movement of starch into the EU (Henry, 1998). Trade liberalization and reform could reduce or remove the constraint on cassava starch exports from developing countries to these markets. In North America, a small number of very large firms dominate the starch-based products industry, constituting an additional barrier to entry (Taylor and Phillips, 1998). Similarly, it has been argued the export promotion schemes or producer subsidies for competing products marketed in cassava-producing countries have the effect of reducing access to domestic markets (Best, 1996).

The initiative led by the International Fund for Agricultural Development (IFAD) to develop a Global Cassava Development Strategy (Plucknett, Phillips, and Kagbo, 1998) is an important attempt to overcome aspects related to these policy and institutional constraints.

Potato

Technical constraints

Constraints resulting from the potato's by biological characteristics include:

- Low multiplication rates for seed.
- Difficulties (and expense) associated with maintaining seed quality through various multiplications because of the plant's susceptibility to soil and airborne diseases.
- Bulkiness of seed, i.e. 1–2 t/ha is the typical seed requirement.

- Phytosanitary restrictions on movement of germplasm, seed, and fresh table potatoes.
- Perishability, though potatoes can be kept at ambient temperatures for several months in tropical highlands or temperate growing areas (e.g. northern China, Chile), fresh tubers quickly deteriorate in tropical or subtropical environments.

Late blight. Caused by the fungus *Phytophthora infestans*, the new strain of late blight that originated in Mexico and has already infected farmer's fields in North America and Western Europe now constitutes the most important threat to increased potato production in developing countries. There is special concern about late blight in those regions and countries, such as China and Argentina, where potato production has created pockets of monoculture at certain times of the year. This leaves fields, plants, and farmers highly vulnerable to potentially devastating outbreaks of the disease.

Bacterial wilt. Caused by *Ralstonia*, this disease is second only to late blight in importance. Bacterial wilt is particularly important in the warmer, more tropical growing areas in the developing world.

Seed systems. Developing countries, with only a few notable exceptions such as India and Chile, continue to struggle to organize and then sustain viable seed systems for the rapid multiplication of improved varieties or the regular production and distribution of certified seed (see, e.g. Crissman and Uquillas, 1989). The hindrance here is a combination of human resource limitations in technical areas, the shortage of managerial expertise in the public sector, and policy and institutional constraints related to the minor importance often given potatoes by policymakers. This last factor is a manifestation of the limited share of resources allocated to potato in what often are already understaffed and underfunded agricultural research and extension services in many developing countries.

Insect pests. The importance of specific pests varies by region. Aphids, for example, are a major constraint in Asia, while tuber moth and Andean potato weevil do the most damage in South America.

Socioeconomic constraints

Farm surveys in a number of countries over the past two decades have identified various constraints of a socioeconomic nature. These include the following:

Production costs/credit. Potatoes are not only labor-intensive but can be highly capital-intensive through the application of purchased inputs in the form of seed, chemical fertilizers, and pesticides. In such an economic environment, smaller growers often find it difficult to stay in potato production, given their relatively limited access to credit and their frequent reluctance to assume the risks that taking out loans may imply (see, e.g. Rodriguez, 1996).

Price volatility. As potato production has become increasingly commercially oriented, growers have become increasingly vulnerable to abrupt changes in output prices (see Herrera and Scott, 1993; Maldonado, Wright, and Scott, 1998). These price changes include within-year (seasonal) movements that some evidence suggests have become less pronounced, but at the same time have become more erratic (see, e.g. Scott, 1988). In addition, year-to-year price movements are of increasing concern. These boom–then–bust gyrations can have particularly disastrous consequences for smaller growers who may lack the financial staying power of larger producers.

Market access. Growers are concerned about their access to emerging markets within national boundaries, such as to the processed product segment—an important one, given the universal popularity of french fries and chips—or the potential market for potato exports. The extent to which access to these markets is restricted by exclusive contracts with foreign suppliers or trade restrictions in foreign markets serves to dampen interest in expanding domestic potato production.

Policy and institutional constraints

Many of the technical and socioeconomic constraints to potato production have branches, if not their roots, in questions regarding government policy and institution-building. Two points merit special attention here.

Sector development. In many developing countries, government policy towards the potato sector is at best characterized as one of benign neglect. Whereas other commodity groups have managed to interest government to the point of garnering public financial support for integrated strategies for crop improvement, marketing schemes that include product promotion both at home and abroad, and industrialization, potato producers are more often than not left to their own devices. Noteworthy exceptions are the very proactive stance taken by local authorities in Argentina regarding foreign investment in potato processing and the competitiveness accord agreed to by members (e.g. producers, traders, processors, input suppliers) of the potato sector in Colombia.

Technology transfer. Privatization in many developing countries has meant drastic downsizing in the ministries of agriculture. One consequence has been a bare-bones research program for potatoes, with no organizational mechanisms to diffuse results. Whereas the private sector has filled this space with some other crops in developing countries, potato —with few exceptions (Qaim, 1999)—has rarely attracted the same degree of private sector interest, particularly in the area of seed/varietal diffusion.

Sweetpotato

Technical constraints

Sweetpotato nevertheless has its own set of inherent biological characteristics that limit production increases and influence postharvest prospects, e.g. lower quality roots dampen the potential for conversion into economically viable value-added products. These include:

Bulkiness/perishability. Sweetpotato roots are bulky. Their weight, low value-to-volume ratio in fresh form and propensity to incur shrinkage as well as pest and disease damage after harvest discourages transport and drives up marketing costs.

Low multiplication rates. Sweetpotato multiplies slowly, but not as slowly as potatoes, for example; sweetpotato planting material consists of vine cuttings that require roots to start but can cover a much larger area with much less seed. Still, the process of building up an adequate supply of planting material is much more time-consuming than for the cereals.

Phytosanitary restrictions. The process of international germplasm evaluation for sweetpotato got underway much later than for the other major food crops. This complicated, multi-location exercise—in terms of screening for both agronomic and postharvest traits— is handicappted by phytosanitary restrictions on the movement of germplasm.

Dry matter content/yields. A consensus has emerged among sweetpotato scientists that improvement in dry matter content—highly correlated with extractable starch—will provide one essential ingredient to greater use. Closely linked to this characteristic is yields, in that the two together enable sweetpotato producers to reduce their per-unit costs as a source of raw material in processing.

Weevils/pests. Root quality, as well as quantity, is affected by weevil infestation. *Cylas brunneus* and *C. puncticollis* are particularly acute in parts of East Africa where the long dry spells following completion of the crop's vegetative cycle are conducive to build-ups of the weevil population. Weevil (*C. formicarius*) is also a problem in the Caribbean and parts of South America.

Viruses. In more humid growing areas, sweetpotato viruses can devastate crops. Relatively little is known about sweetpotato viruses such as sweetpotato feathery mottle virus, making the task of tackling this constraint more formidable.

Socioeconomic constraints

High per unit costs as raw material. For sweetpotato to become more widely used in processed form, higher yields—in starch equivalent terms—are necessary to bring down the cost of the roots as a source of raw material. Without these lower costs, expanding sweetpotato utilization will either be dependent on identifying new, commodity-specific uses that will greatly reduce if not eliminate the competition with other sources of raw material, or be marginalized to niche markets where sweetpotato's peculiar traits are of paramount importance.

Low status/stigma. Consumption of fresh sweetpotato is often handicapped by the crop's low status and the associated stigma of being "poor people's food" (Woolfe, 1992). Counteracting this widespread perception will require either processing to disguise sweetpotato's presence or an educational/promotional campaign (see, e.g. Low et al., 1997) that can bring to consumers' attention the various nutritional attributes of both roots and leaves, which are often completely overlooked. One such attribute is the plant's high vitamin A content.

Small, resource-poor producers. Farmers who cultivate sweetpotato are typically among the poorest farm households in a region or country. They rarely have collective representation before policymaking bodies, and their lack of commercial status—the crop is not imported or exported to any appreciable extent—contributes to their isolation from research and extension.

Supply chain linkages. Sustained improvements in sweetpotato production are often highly contingent upon access to new markets and the development of processing and marketing activities that go with that, and vice versa. The interdependence of these supply chain linkages generates additional inertia that can be a much more difficult task to overcome than merely developing marginal improvements in yield potential, for example, that can and will be taken up by growers regardless of what happens at other points in the food chain.

Policy and institutional constraints

Odd crop out. Sweetpotato has not benefited from the long tradition of research applied to potato and, to a lesser extent, cassava. One major reason is that sweetpotato, although produced in developed countries such as the USA and Japan, has not had the historical importance for developed countries as a group that potato has experienced. Conversely sweetpotato, while grown in nearly 100 developing countries, does not have the status as a leading basic staple in an array of countries that cassava benefits from, however modestly. The end result is that sweetpotato has not attracted nearly the breadth and intensity of research that, once under way, attracts new investments and young scientists as a field of professional endeavor. This comes at a time when research budgets are falling and research programs are hard-pressed to demonstrate results in the short run in order to justify continued support. That support is much easier to achieve when the pipeline of previous research provides a much more fertile base to build on.

Policy neglect. Sweetpotato is rarely the focus of policy initiatives aimed at spurring agricultural development. More often than not, the crop attracts little interest from policymakers for the reasons already alluded to. Recently, there are signs that this situation is changing on a selective basis. Uganda offers one example (Scott et al., 1999).

Absence of industry forum. In nearly all sweetpotato-producing countries, the various participants in the sector—growers, processors, traders, researchers—operate in isolation. No forum brings these various interest groups together, develops a common strategy, and organizes to push for its implementation with policymakers, bankers, industrial and export lobbies, among others.

Weak national programs. Most national programs for sweetpotato research are in reality subunits in the root and tuber program at best—where more established (i.e. cassava) and prestigious (i.e. potato or yam) crops within these resources-limited organizations capture most of the scarce funding. This constraint severely handicaps technology development and transfer at the national level. China is perhaps a noteworthy exception in this regard (TAC, 1997). But even in the Chinese case, the strengths of the national sweetpotato program are well below those of the cereal programs (CIP, 1997:8–9), and they are largely concentrated on the production-oriented side with postharvest research—an area of considerable importance—noticeably understaffed.

Yam

Technical constraints

Constraints to yam improvement caused by biologcal characteristics include:

- Bulkiness and perishability of tubers, in particular planting materials for production of ware yams (large tubers for market or home consumption) are derived from the edible portion, the tuber, which is expensive and bulky to transport.
- Low and tedious multiplication rates. The multiplication ratio in the field is very low (1:10) compared, for instance, to some cereals (1:300). These propagules could also serve as sources of virus diseases, nematodes, and fungi unless appropriate measures are taken.
- Long dormancy (with respect to cropping cycles).
- Phytosanitary restrictions limiting germplasm exchange.

Genetic improvement. The main obstacles encountered in sexual hybridization of yam for genetic improvement include the scarcity of flowering, poor synchronization of male and female flowering phases, and lack of efficient pollination mechanisms. Advances have been made in studies of reproductive biology of yam, especially at the Central Tuber Crops Research Institute (CTCRI), Trivandrum, India, and IITA, Ibadan, Nigeria (Abraham and Nair, 1990; Akoroda, 1983, 1985, 1985a; Sadik and Okereke, 1975). However, further work is required to ensure that the genetic diversity locked up in non-flowering desirable genotypes is exploited. Flowering genotypes of species like *D. alata, D. bulbifera, D. cayenensis* and *D. rotundata* are generally dioecious. Female flowers tend to be more limited than male, especially for *D. alata* (Martin, 1976), and sterility is quite common.

As compared to genera of other major food crops, there have been rather limited genetic studies of the genus *Dioscorea* which would guide decision-making in setting strategies for genetic improvement. The few yam breeding programs reported in the literature have relied on selections from landraces and hybridization of desired genotypes within and between species (Abraham et al., 1986; Doku, 1985; Sadik and Okereke, 1975) without the benefit of the predictive value of knowing the genetics of the characteristics being sought from species that are predominantly complex polyploids.

Improvements in screening methodologies are required to increase the efficiency and effectiveness of selection for resistance to pests and pathogens, e.g. nematodes (*Scutellonema, Pratylenchus, Meloidogyne*), viruses (mosaic, shoe string, etc.), anthracnose, blight, leaf spots (*Colletotrichum, Fusarium*), tuber rots (*Aspergillus, Botryodiplodia, Erwinia*), and insects (beetles, mealy bugs, scales, etc.).

Management of propagules. In yam, maturation of the fruit and seeds continues long after the plant has senesced (Okoli, 1975; Onwueme, 1978). Research has established that viability of yam seeds deteriorates during storage at room temperature and germination can reach a low of 30 to 40 percent one year after harvest (IITA, 1975). Further experiments showed that cold treatments, especially when combined with desiccation over silica gel, reduced the germination percentage and increased the number of days to onset of germination and to 50 percent germination.

The early clonal (observational) trials are particularly constrained by the low multiplication ratio of the tubers, leading to a long period before multi-locational yield trials can be established. Yam researchers face the challenge or burden imposed by perishability of the tuber which is both the edible portion and the organ for field propagation. The cost of planting material, susceptibility to storage loss, and attractiveness to pilferage have deterred many researchers from devoting most of their efforts to yam. Breeding programs have suffered most, owing to the need to expose materials to various conditions, favorable or unfavorable, for purposes of evaluation while ensuring that special materials are preserved and unnecessary losses are prevented.

As a vegetatively propagated crop, the selection scheme for yam involves repeated evaluation of clones selected from a seedling nursery or the germplasm collection over several years in clonal trials, ending with on-farm testing. For yam there is the natural break in the evaluation cycle each year due to dormancy in the tuber after harvest. A storage period of up to four months of desirable propagules is quite normal for most yam selection programs before the subsequent season. Severe losses are often incurred at this stage. Some of these losses are advantageous to the selection process as materials that are most susceptible to storage pests and pathogens are thus weeded out. Nonetheless, there is often a proportion of the losses that most researchers would like to carry to the next season but that first have to endure the challenges of the storage period. Indeed, it could be argued that the lack of sustained effort in yam research and the low level of such activity in the African national programs are largely due to this inability to maintain propagules of the relevant genotypes over long periods. A single storage period between one harvest and the next planting season makes a great deal of difference to the future of yam research projects. It is therefore imperative for yam research programs to provide good facilities for tuber storage at an appropriate location which would offer some measure of flexibility and security.

Cultivation practices. Land preparation for yam cultivation varies considerably depending on the region, the soil properties, and the purpose of the cultivation. The preference for large tubers in traditional yam production districts of West Africa imposes heavy demands on the production system. For instance for the production of "ceremonial" yams (very large tubers used in traditional ceremonies) in Nigeria, very large mounds (and consequently low plant population) and tall stakes are essential.

The absence of a formal seed system has a major influence on the productivity of the production system and the overall profitability of yam cultivation.

In many cultivars, emergence after planting is slow and staggered, especially where a mixture of tuber portions (head, middle and tail) is planted. Ground cover during the first four months is slow. These considerations have implications for weed control and soil erosion. In addition, increased pressure for land has necessitated an intensification of cropping patterns resulting in decreasing yields of yam in some areas, due to a lack of essential nutrients or an increase in pest and disease levels in soils under short fallow.

Many aspects of production—planting, weeding, staking, and harvesting—are very labor intensive and most are unsuited to mechanization.

Diseases and pests. Most pathological causes of losses in storage can be attributed to an interplay of nematodes (*Scutellonema bradys*, *Meloidogyne* spp., and *Pratylenchus* spp.), fungi, and bacteria, moderated by physical factors of the environment such as temperature and humidity. These losses typically originate from pre-harvest invasion or infection and/or damage during harvest and transit. The mapping in a geographical information system (GIS) of yam-growing areas infected with nematodes in West and Central Africa has revealed a concentration of infested fields in areas where the length of fallow was less than 4 years (Manyong and Oyewole, 1997). Hence intensification of yam cultivation would benefit immensely from selection and breeding for host plant resistance to prevalent pests in addition to other elements of crop productivity.

Pests and diseases during growth and postharvest storage have a major influence on productivity of yam cultivation. Among the various diseases and pests that afflict yam, viruses impose a double limitation in the forms of reduced field performance and restricted exchange of germplasm. Yields from heavily infected plants are lower than from apparently healthy ones and infected setts lead to heavily infected plants (Martin, 1976). Anthracnose disease (caused by *Colletotrichum gloeosporiodes*) continues to be a major threat to cultivation of *D. alata* in Africa (Akem and Asiedu, 1994) and the Caribbean (CARDI, 1992). Pest and disease pressures, especially from viruses, anthracnose disease, nematodes, and storage pests, have been responsible for major losses of food from susceptible varieties in the field and in storage leading to reduced supply to markets and therefore higher prices.

Harvesting and handling after harvest. The sizes and shapes of yam tubers and the nature of the soil have important influences on the ease and efficiency of harvesting. Care is needed to dig the yam out of the soil with minimal damage so as to avoid excessive bruising, which will provide entry points for pests and pathogens. Storage systems differ widely, but generally it is essential that the storage barn ensures adequate ventilation, shade, and protection from direct rain.

The major sources of loss during storage are physiological, due to respiration, transpiration, and sprouting; and pathological, due to activities of pests and pathogens. For the export market, as well as storage for in-country sales later in the year, a long dormancy period is preferable. Once dormancy is broken, labor is required to ensure that vines are detached from tubers as they emerge and elongate. Failure to do so will lead to rapid loss in tuber quality.

Losses during storage have negative impact at several stages in the cycle of yam production and utilization. Producers are concerned about tuber quality from harvest until ware yams are passed on to traders. Even more critical for the producers is the quality of seed yams which influences heavily the area and performance of the next season's crop. Revenue from sale of yam tubers both for local consumption and for the export market are influenced by the quality of yam tubers over the extended periods of storage under various environmental conditions. Eventually yam consumers feel the impact of all these, both directly through their own short-term storage as well as indirectly through the fluctuations in price over the year.

D. alata exhibits more agronomic flexibility than *D. rotundata* and *D. cayenensis* in the major production area of West Africa, especially in multiplication ratio and availability of planting material. However the texture of its cooked tubers renders it less suitable than others for preparation of the most preferred food form for yam in the region, which is a paste produced by pounding the freshly boiled tuber.

Methods that have been developed, with differing levels of efficiency, for extension of the dormancy include application of gibberellic acid, irradiation, and refrigeration. Most of these are not available for small-scale operators although feasibility of commercial application has been demonstrated in Trinidad (Clarke and Ferguson, 1985). It would seem that selection for long dormancy in breeding programs would be useful. This would, however, exacerbate another problem. The other side of dormancy concerns production. Irrespective of when yam is planted, the critical starting point for the growing season is when the dormancy ends and sprouts are initiated. Thus there is a compulsory break from harvesting to the next planting during which even multiplication of planting materials can not be carried out. This is serious when one considers the painfully slow multiplication of yam. Moreover, losses incurred during storage of seed yams could largely be obviated if there was more flexibility in control of sprouting date.

Germplasm exchange. Major breeding activities in progress at IITA and CTCRI could benefit from exchange of promising genotypes. Many countries could also benefit from introduction of improved germplasm. Quarantine regulations require that international exchange of vegetative yam propagules be conducted using materials for which viruses have been eliminated. The plantlets regenerated *in vitro* are tender and often lost during the establishment phase in the national research programs. Microtubers can be produced under the aseptic conditions of *in vitro* tissue culture. Such small tubers are hardier and easier to handle by national programs except for two major limitations —dormancy and irregular sprouting. An artificial means of regulating sprouting would open this avenue for international distribution of improved white yam genotypes developed at IITA. Until recently, the lack of appropriate and routine indexing for *D. alata* had been a major bottleneck to germplasm exchange.

Germplasm conservation. There are many difficulties in maintaining collections of *Dioscorea* species (Degras, 1993). Losses from various national collections over time have been severe (Ng and Ng, 1994). *In situ* conservation is fraught with risks. Butenko et al. (1984) reported successful cryopreservation of *D. deltoidea*. Botanical seeds are of limited usefulness for species of *Dioscorea* owing to limitations in flowering and problems in maintaining viability.

For conservation in field genebanks the accessions are vegetatively propagated through planting setts (including minisetts) of underground tubers or aerial tubers. Plants are grown in the fields for the entire growing season, which lasts from six to nine months depending on species and genotype. Then the mature underground tubers are dug up, or aerial tubers are plucked, and stored for several months in a traditional yam barn, under shade in open air before the next planting. This method of maintaining germplasm has several advantages. However, the field genebank is costly to maintain properly and takes up a great deal of space. Furthermore, the collection is exposed to a lot of hazards, both in the field and during tuber storage, which may lead to genetic erosion. Diseases such as anthracnose, nematodes, and yam beetles are major field disease and pest problems of concern to field maintenance of yam germplasm. If an anthracnose epidemic occurs at an early growing stage, it could cause the complete loss of susceptible germplasm. During tuber storage bacterial and fungal infections on tubers are serious threats to germplasm.

Socioeconomic constraints

In many yam-growing areas, the most serious constraints to productivity are the high costs of planting material and of labor for field operations such as land preparation, planting, staking, weeding, and harvesting (Nweke et al., 1991; Robin et al., 1984).

Yam are a major source of cash income for a wide range of smallholders, including women who are very active in the marketing of yam and yam products. The lack of innovative postharvest technologies that could reduce food losses and create new products with higher value-added constraints efforts to increase incomes from marketing and processing of yam.

Policy and institutional constraints

Yam has generally suffered from neglect with respect to institutional arrangements and policy decisions related to crop production and marketing. In fact, government policies such as the ban on export of yam from some African countries are counterproductive. In many areas, poor infrastructural facilities and poor access to markets are the major challenges to expansion in production of yam and its profitability (Robin et al., 1984).

Other roots and tubers

Other tropical roots and tubers such as tannia, taro, and yam bean, as well as their Andean counterparts such as achira, arracacha, oca, and ulluco, also face a range of technical, socioeconomic, and institutional constraints.

Technical constraints

Other roots and tubers are also constrained by their biological characteristics that result in:

- Bulkiness and perishability.
- Low multiplication rates for the clonally propagated species (e.g. oca, ulluco), although not for those that are seed propagated (e.g. maca, ahipa).
- Sour, bitter taste (for some Andean roots and tubers).

Diseases and the shortage of disease-free planting material are important constraints to farmers where taro leaf blight, beetles, and root rot are endemic. The spread of taro from a few clones means that in some island countries the genetic base of taro and tannia is quite narrow; accordingly there is little resistance to pest and diseases. For example in the islands of Polynesia, taro, the once staple food, has all but disappeared due to outbreaks of leaf blight. Farmers have switched to *Xanthosoma* but still prefer the more easily digestible taros, which are primordial in their food cultures. Documenting the range of diversity and adaptation in taros, broadening the genetic base of taro cultivation, provision of disease-free planting materials, and plant protection are among the priority constraints that research can address.

A concise list of technical constraints for Andean roots and tubers (ART) is hard to prepare given that "...each of them belong to a distinct botanical family, they differ considerably in life form, propagation method, chemical composition, utilization, storage behavior..." (Hermann and Heller, 1997:5). That said, some examples of the most noteworthy technical limitations include the following.

Cool-temperate Andean tubers (Table A12): oca, ulluco, mashua are constrained by their long vegetative cycle and the fact that tuber formation only occurs in days shorter that 13–14 hours. Subtropical ART like arracacha are frost sensitive. Arracacha yields can be severely damaged by fungi, nematodes, and acari attack; oca output by weevil.

Socioeconomic constraints

Unknown by consumers. With the exception of arracacha, achira, and ulluco, most ART are simply unknown commodities to many, if not most, consumers, even in the Andean region. In many instances, this lack of knowledge is accentuated by a crude classification of these crops as "rural, poor people's food."

Poor presentation; limited processing. Coordination problems in local supply chains and the logistical challenge of shipping aroids in fresh, perishable form from the South Pacific to distant consumption centers have hampered past efforts aimed at developing export markets for aroids such as taro in developed countries (Bjorna, 1992). Overcoming these constraints could expand the currently modest volume in high value trade to complement growth in local consumption. Alternatively, small quantities of tannia are processed into chips both for local consumption (Bjorna, 1992) and for sale as exotic, high-priced, snack foods in affluent niche markets abroad. But, this lucrative segment seems likely to remain a minor share of total future utilization.

Table A12. Attributes of Andean roots and tubers.[a]

Common name[b]	Propagule[c]	Starch content[d] (%)	Undesirable compounds	Yield (mt/ha)	Growth period (months)
Subtropical (1000–2500 m altitude)					
Arracacha	St	12–20	None	12–16	10–14
Yacon	St	0[e]	None	40–60	10–12
Achira	Rh	12–18	None	30–80	10–12
Mauka	St	18–25	Raphids[f]	20–50	12–18
Ahipa	S	9–14	None	30–50	5–10
Cool-temperate (2500–4000 m altitude)					
Oca	T	10–15	Soluble oxalate	10–40	6–9
Ulluco	T	<10	Mucilage	5–20	6–9
Mashua	T	<10	Isothiocyanates	30–60	6–9
Puna or Cold steppe (4000–4500 m altitude)					
Maca	S	na	na	10–15	8–9

Source: Hermann and Heller (1997).
Note: na signifies not available.
[a] All of the crops listed here are perennials except maca which is a biennial.
[b] Only the most widely used common names are given here; see Table A1 for further details.
[c] Only the agriculturally used propagules are indicated, Rh=rhizome, S=sexual seed, St=basal stem, T=tuber.
[d] In % of edible fresh matter.
[e] Yacon dry matter is mostly oligo-fructans.
[f] Raphids are needle-shaped oxalate crystals causing astringency.

Certain ART could expand their consumer appeal were inexpensive processing techniques readily available to make them more acceptable, or transform them into heavily disguised alternatives. In effect, processing of arracacha into instant foods and dips would greatly enhance its commercial viability in Brazil, as pilot trials have shown (Santos and Hermann, 1994). Ironically, the noteworthy appeal of arracacha for direct consumption and resulting high prices for raw material in Brazil have discouraged more widespread processing. Appropriate postharvest techniques (such as sun drying) could reduce the perishability and improve the appearance of crops such as oca.

Policy and institutional constraints

Only in the last decade have policymakers and national agricultural research systems begun to show systematic interest in ART, in part because of concerns over biodiversity. Without greater economic incentives to cultivate ART, many small farmers who currently plant these crops will switch to other, more remunerative commodities or be pushed out of agricultural production altogether. The end result as envisioned by this scenario is that ART will become extinct, or simply confined to biological museums or research genebanks. Given the long period of relative neglect up until now, a considerable effort will be required to bring to bear the tools of modern science to the benefit of these ancient crops.

Some spontaneous coalescence has occurred at the national level among the various interested parties (grower representatives, NGOs, researchers, processors, traders, exporters) working with these crops. The sustainability of such an effort and its refinement into an articulate voice regarding what, how, and by whom a program for the production-to-consumption development of these crops needs to be carried out remains a challenge to be met by all.

Summary

Constraints to roots and tubers can be organized under similar headings by research area, e.g. technical, socioeconomic, policy and institutions. Beyond certain similarities such as bulkiness and perishability, specific constraints often differ considerably (Table A13). Each

Table A13. Constraints to roots and tubers, by commodity.

Category	Cassava	Potato	Sweetpotato	Yam	Other roots and tubers
Technical	- Lengthy growing season - Low multiplication rate - Bulky planting material - Perishability (extreme) - SSA - poor soils, lack of planting material, CMD, CBB, mites, mealybug - Asia - poor soils, erosion - LAC - poor soils, root rots, CBB, mites, whiteflies & others	- Costs/difficulties of maintaining seed quality - Low multiplication rate - Bulky seed - Perishability - Late blight - Bacterial wilt - Seed systems - Insects, e.g. aphids	- Bulkiness/perishability - Low multiplication rates - Phytosanitary restrictions - Low dry matter, yields - Weevils - Viruses	- Bulky planting materials - Low multiplication rate - Long dormancy (with respect to cropping cycles) - Phytosanitary restrictions - Declining soil fertility - Staggered emergence - Interplay of virus, nematodes, fungi, and insect pests	- Bulkiness/perishability - High variability of biological characteristics - Poor presentation, e.g. sour, bitter taste - Subtropical ART frost sensitive - Taxonomy - Genetic diversity in collections
Socioeconomic	- Lack of producer organizations - Small farmers, marginal and dispersed growing areas - Limited traditional markets, risks for new products - Underdeveloped internal markets	- Production cost/credit - Price volatility - Market access	- High cost of raw material - Low status/stigma - Small, resource-poor farmers - Weak supply chain linkages	- Costly planting materials - Lack of processing technologies - High labor costs for production - Limited options for pest control - Underdeveloped international markets	- Unknown by consumers - Limited low-cost processing
Policy and institutional	- Limited resources for cassava research and development - No cassava 'lobby' for policy - Limited access to credit	- Limited sector development - Weak technology transfer	- Odd crop out[a] - Policy neglect - No industry forum - Weak NARIs	- Policy neglect - Little research on *Dioscorea* - Limited manpower and other resources for research and development - Gender bias	- Historical research neglect

Source: Compiled for this study.

Note: ART = Andean roots and tubers; CBB = cassava bacterial blight; CMD = cassava mosaic disease; LAC = Latin America and the Caribbean; NARIs= national agricultural research institutes; SSA = Sub-Saharan Africa.

[a] Not produced in developed countries to any appreciable extent, not the most important food in many developing countries either.

crop has its own particular diseases, pests, and problems with planting material. For example, cassava's long production cycle, inherent low multiplication rate, and physical stake characteristics have a major negative effect on technology development, on-farm adaptive research, improved varietal diffusion, lag time to technology adoption, production costs, and cash flow management. Some research issues do overlap, such as in the postharvest area with processing and marketing. But, as will be seen in Section 6, the commodity-specific requirements of biochemical or technical (e.g. machinery) research cannot be ignored. Moreover, marketing constraints, for example, in the form of information on the prospects for starch in developing-country markets is one likely area for synergy, but the Centers' current limited human resources severely constrain exploiting that possibility.

Section 6 – Current research in and with the CGIAR on roots and tubers

Research on roots and tubers in the CGIAR covers an array of topics, each with a highly commodity-specific content (Table A14). For cassava research, CIAT has a global mandate for germplasm improvement and regional responsibility in Latin America and Asia; IITA has a regional responsibility in Africa. The global mandate for potato, sweetpotato, and Andean roots and tubers belongs to CIP, and for yam to IITA. IPGRI works with national programs and other international partners to ensure the safe conservation and sustainable use of the genetic resources of various roots and tubers, including those mentioned above and aroids such as taro. IFPRI is collaborating with CIAT, CIP, and IITA on commodity projections, research on nutrition, and on agro-enterprise issues related to cassava, and to a lesser extent, sweetpotato. The second part of this section presents a synthesis of research on roots and tubers by organizations both in and outside the CGIAR in collaboration with these Centers.

Cassava

Collection, characterization, and conservation of genetic resources. A *Manihot* germplasm collection is held at the CIAT headquarters in Cali, Colombia, both in a field collection and *in vitro*. The 5500 accessions represent about 75 percent of the genetic diversity of cassava; 300 accessions of wild *Manihot* species are maintained. The morphological and isozyme characterization of the base collection is complete and molecular characterization is underway. A core collection of 640 clones representing the range of genetic diversity has been established. Priority research areas include: standardization of cryopreservation as a long-term germplasm maintenance tool; determination of genetic relationships among *Manihot* species for more effective conservation and use; characterization of the core collection for root and starch quality traits; and, safe duplication of the core collection.

IPGRI's work on cassava involves testing of complementary conservation and use strategies for germplasm in collaboration with CIAT. It aims to develop a toolkit for selecting the most appropriate conservation techniques and methodologies for cassava based on biological, socioeconomic, and legal considerations.

Development of biotechnological tools for cassava improvement. CIAT has assembled a molecular linkage map and identified DNA-based markers for characterizing *Manihot* diversity to formulate efficient and effective conservation strategies and to contribute to the use of cassava genetic resources. Molecular marker methodologies are used in the study of *Manihot* genepool structure, and for the tagging of traits with relevance to breeders. Molecular marker-assisted selection is being adjusted so breeders can incorporate this tool into their improvement programs for more efficient selection. A routine protocol for genetic transformation of cassava is being developed, and is starting to be used in research to modify traits with highly restricted variability within the cassava germplasm (e.g. starch quality, resistance to stem borer, and cyanogen content).

CIAT is a founder member and host of the Cassava Biotechnology Network (CBN), which brings together individuals and organizations involved in cassava-related biochemical and molecular research. The network provides opportunities for collaboration with organizations from developing and developed countries. The collaborators place emphasis on linking biotechnology research on cassava to resolving farmers' priority constraints. Examples of collaborative research initiated through this mechanism are: (1) the saturation of the cassava molecular map using gene sequences isolated in other species; (2) mapping of genes involved in postharvest deterioration defense mechanisms; (3) developing genotypes with modified starch quality characteristics using genetic transformation; (4) developing a set of microsatellites for genetic characterization; (5) gene tagging of relevant traits and genetic transformation for pests with unknown sources of resistance; and, (6) micropropagation for the production of clean seed.

Table A14. Current research on roots and tubers in the CGIAR, by commodity.

Area	Cassava	Potato	Sweetpotato	Yam	Other R & T
Genetic collection, characterization, and improvement	- Collection, characterization of genetic resources - Development of biotechnological tools for germplasm management and improvement: genome characterization and modification - Genepool development for agro-ecologies; character improvement, variety development	- Genetic conservation - Development of biotechnological tools for potato germplasm management and improvement: genome characterization and modification; - Development of improved clonal materials and hybrid populations	- Breeding for high dry matter - Development of biotechnological tools for sweetpotato germplasm management and improvement: genome characterization and modification - Conservation & characterization of genetic resources	- Development of biotech tools (molecular markers, cell/tissue culture, molecular diagnostics) for yam improvement and dissemination - Collection, characterization, documentation, utilization, and conservation of genetic resources	- Collection, study, and preservation of genetic resources
Integrated pest and disease management	- Integrated disease management of CBB, root rots, CAD, CMD, cassava frogskin disease, etc. - Integrated pest management of CGM, cassava mealybug, whiteflies, etc.	- Late blight - Bacterial wilt - Viruses, e.g. PVY - Integrated management of potato aphids, Andean potato weevil	- Control of viruses such as SPFMV - Integrated management of sweetpotato weevil	- Integrated control of diseases such as YMV, YAD, rots - Integrated control of pests such as *Scutellonema bradys*, *Meloidogyne* spp.	- No constraint for most crops - Nematodes
Planting material	- Storage and management of planting material	- Propagation of clonal planting material - Sexual potato propagation	- Improved germplasm distribution	- Manipulation of dormancy - Increasing the multiplication ratio - Shoot/vine propagation	- Improvement of multiplication rates in some crops
Crop and soil management	- Erosion control - Soil fertility maintenance	- Erosion control	- Pilot work on erosion control		
Postharvest utilization	- Enterprise development - Improvement in traditional processing - Establishment of functional properties underlying principal end-use requirements - Organizational schemes: small-large processing - Small-scale starch extraction processes, marketing and enterprises	- Marketing and trade in fresh potato and processed products - Price analysis - Country case studies - Marketing methods	- Product/enterprise development - Improvement in traditional processing - Establishment of functional properties underlying principal end-use requirements - Small-scale starch extraction processes, marketing and enterprises - Marketing methods	- Storage - Processing - Marketing of yam products - Control of browning reactions during processing - Establishment of functional properties underlying principal end-use requirements	- Study of marketing and consumption trends - Processing - Enterprise development - Improvment in traditional processing
Impact	- *Ex-post*: Integrated R&D in LAC - *Ex-ante*: Cassava germplasm	- *Ex-post*	- *Ex-post* - *Ex-ante*	- *Ex-post*	
Global characterization and trends	- Production, area, yield, data base, and prices - Characterization of cassava production, processing, marketing, and utilization	- Trends analysis - Production in rice-wheat systems - Commodity projections - Database on prices, etc.	- Trends analysis - Commodity projections - Database on production, area, yield, prices, and processing	- Characterization of yam production systems in SSA (constraints, opportunities, etc.) - Gender analysis - Trends analysis	- Assess the potential to promote wider use

Source: Compiled for this study.

Note: CBB = cassava bacterial blight; CAD = cassava anthracnose disease; CMD = cassava mosaic disease; CGM= cassava green mite; LAC = Latin America and the Caribbean; SPFMV = sweetpotato feathery mottle virus; SSA = Sub-Saharan Africa; YMV = yam mosaic potyvirus; YAD = yam anthracnose disease.

Building on its long experience with tissue culture work for germplasm delivery in Africa, IITA continues to improve methods for rapid multiplication of cassava propagules for large-scale delivery of germplasm. Improved cassava germplasm has been tested by collaborating NARS, and several selected genotypes have been released and are being cultivated by farmers. Progress is also being made in the regeneration and transformation of cassava with emphasis on African cassava germplasm and in the development of cryopreservation protocols for long term preservation of cassava by fast freezing.

In the area of molecular genetics, four segregation mapping populations have been generated with a view toward tagging genes conferring resistance to African cassava mosaic disease (CMD), cassava bacterial blight (CBB), and those involved in cyanogenesis and food quality. The main objectives have been to use the identified molecular markers in marker-assisted breeding. Amplified fragment-length polymorphism (AFLP) and microsatellite markers are being used for genotyping the parental lines and the segregation populations. Phenotypic data for these traits are also being gathered, which will be used to determine the linkage between traits and molecular markers.

Research is ongoing into the characterization of enzymes and genes regulating the accumulation of cyanogenic compounds. The aim here is identifying biochemical differences that can be used as markers for low cyanogenic potential in cassava.

Genetic relationships among cassava clones with varying levels of resistance to CMD have been established using random amplified polymorphism DNA (RAPD) markers. Studies show that RAPD markers are good molecular markers for evaluating the genetic diversity in African cassava germplasm.

Germplasm improvement. Through this research, CIAT aims to improve and stabilize production in the most important cassava-growing regions in Asia and Latin America to make it more competitive for present and future markets. Germplasm is developed for improved yield, quality, and resistance to or tolerance of major pests, diseases, and abiotic stresses. Genepools for acid soil savannas, subhumid, humid, mid-altitude, highland, and sub- and semi-arid tropics are enhanced by the recombination of selected parental material after evaluation in representative environments, where the principal traits of interest are consistently expressed at levels appropriate for selection. Major research priorities include the development and use of research tools to shorten the breeding cycle (e.g. molecular marker-assisted selection and farmer participatory evaluation at early stages of the breeding cycle). New sources of resistance to major biotic and abiotic constraints and favorable alleles for root quality traits are constantly being incorporated through recombination and selection.

African landraces are being used at IITA to broaden the genetic base of cassava breeding populations with African-adapted genepools. The traits being emphasized are resistance to cassava mosaic disease (CMD) and cassava green mite (CGM); storage root quality, such as high dry matter for suitability for direct consumption ("boil and eat"), and processing for flour, branching habit, and foliage quality. Seed families of local cultivars from national programs are also evaluated to utilize their favorable traits. At the same time, genes from Latin American materials are incorporated particularly when developing source populations for the semi-arid and mid-altitude agro-ecologies. The characterization of the elite cassava germplasm for food quality has also provided parental materials that are now being used to enhance food quality traits for specific end uses. Several landraces resistant to CMD and CGM have been incorporated into IITA's breeding populations and introductions from Latin America to diversify resistance and make further progress that would prove difficult for the disease and pest to circumvent. CGIAR scientists are also conducting several genetic studies aimed at elucidation of the inheritance of pest and disease resistance and important agronomic and food quality characteristics. A study, combining conventional and molecular approaches, has begun on the genetics of CMD resistance in African landraces relative to the original source of resistance that came from a wild *Manihot* species.

IITA uses both locally collected and introduced germplasm for the development of cassava populations adapted to the mid-altitude agro-ecologies in East and Southern Africa. Selection of resistant genotypes is also being strengthened through the activities of the Eastern and Southern Africa Research Center (ESARC), the Eastern Africa Rootcrop Research Network (EARRNET) and the Southern Africa Rootcrop Research Network (SARRNET). With regards to genotype by environment interaction, rationalization of selection and testing sites as well as germplasm distribution areas has already begun. For EARRNET and SARRNET countries, site characterization and rationalization trials have been initiated to improve the efficiency of cassava improvement in targeting specific agro-ecologies in the Eastern and Southern Africa regions, as well as to identify similar screening/selection sites within these regions. The international testing of improved cassava genotypes across West Africa offers a means for germplasm exchange and generating information on the performance of a range of leading genotypes across West Africa, along with the opportunity to study genotype by environment interactions, monitor variation in the prevalent diseases and pests as well as determine the stability of genetic resistance to the major diseases and pests. In addition, a first generation geographic information system for root and tuber crops in SSA, using mapping software (PC ARC/INFO v. 3.4.2 and ArcViewR Version 2), has been developed and is called the Tuber and Root [Crops] Information System (TRIS). This system and the findings of Collaborative Study of Cassava in Africa (COSCA) have further helped in identifying attributes of genotypes that could best suit the conditions in the countries where germplasm is distributed.

Integrated pest and disease management (IPDM). In this research CIAT seeks to develop economically and environmentally sustainable management practices through the deployment of adapted varieties and biological, botanical, and cultural control practices. Activities include identifying and quantifying pest and disease complexes, developing component technologies, and developing integrated pest management (IPM) implementation strategies using farmer participatory research (FPR) techniques. Priorities for disease research include CBB, CMD, root rots, and the cassava frogskin virus. Priorities for pest research are CGM, whitefly, mealybug, stemborers, and the cassava burrowing bug.

At IITA several new sources of resistance to CMD and CGM have been identified in landraces from West Africa. The establishment of the heterotic patterns of these resistant landraces has enabled their efficient utilization for maximization of heterosis and hybrid vigor in genetic improvement. Screening through the germplasm and advanced breeding lines, sources of resistance to CBB and anthracnose disease have been identified. In addition, sources of resistance to cassava brown streak disease (CBSD) of East and Southern Africa have been identified among improved genotypes. A major achievement is the production of breeding materials (which may also be used directly as varieties) with multiple pest and disease resistance encompassing the major biotic stresses of the crop.

Biological control of mealybug in the cassava-growing regions of Africa. Pests and diseases cause on average 30–40% losses in African agriculture. Pesticides are too expensive and difficult to obtain, and they cause too much environmental damage. Therefore, in addition to resistant varieties, IITA has worked on developing environmentally safe plant health methods, including the successful biological control of the cassava mealybug. Recent estimates of the benefits gained from this work showed that between US$400–600 has been gained for every dollar spent on these research efforts.

Development of sustainable, cassava-based production systems. CIAT's research on cassava integrated crop management generates information on new technology options for maintaining and enhancing soil fertility. It also quantifies the magnitude of soil degradation in cassava-based systems. Developing farmer participatory research techniques for selecting and adapting particular technologies for soil fertility maintenance and soil erosion control is a basic component of this research.

IITA has begun research at benchmark areas for the humid forest in Cameroon and in Nigeria to address the issue of soil fertility and sustainability of cassava production systems. Also, there are new studies on the improvement of cropping systems and practices for cassava expanding into new areas, such as the semi-arid zone. In addition, some long-term experiments (1991–1996) on various agronomic and physiological aspects of cassava production systems in the lowland savanna and forest-savanna transition zones have yielded results that will be used to formulate sustainable production packages.

Finally, a fundamental objective for IITA is sustaining links with NARS. This takes place through including farmers in realizing highly effective research and development; partnership through information exchange such as collaborators' meetings including the International Society of Tropical Root Crops—Africa Branch (ISTRC—AB); training; and joint research endeavors.

Enterprise development, processing and marketing. At CIAT this research currently emphasizes the development of institutional models and local policy options to establish and strengthen small-scale, rural cassava enterprises and their support systems. Other research components are market opportunity identification, technology selection and product quality enhancement, and entrepreneurial organization. Both in the 1980s and in recent years, IFPRI has worked with CIAT and to a lesser extent IITA on assessing trends and prospects for cassava.

IITA's research on postharvest includes development of processing equipment, for example, for the production of *gari*, the coarse meal that is made from ground, fermented, and roasted cassava. Such equipment can be used by village groups. As a result, processing losses have been reduced by more than 50 percent, and the amount of labor required to produce a certain amount of *gari* reduced by more than 70 percent. Furthermore, the COSCA studies documented the wide array of preferences and end uses for cassava in Africa. These findings gave impetus to placing greater emphasis on root quality. Genotypes suited to preparation of specific traditional food products and nontraditional products have received more attention. Greater attention has been given as well to high dry matter and starch content, starch quality, low cyanogenic potential, high beta-carotene content, and mealiness of the root after boiling.

Cassava databases and impact assessment. CIAT maintains databases on cassava production, prices, and utilization. Ex-ante studies on the impact of research projects, in particular genetic improvement, are also conducted. Ex-post studies on the socioeconomic and institutional impact of selected research and development interventions are undertaken as well.

Potato

Potato research at CIP is organized to cover problem areas with the highest scores in a recent priority-setting exercise (Walker and Collion, 1997), and includes work on impact, genetic resource conservation, and the interface between potato production and natural resources.

Conservation and characterization of potato genetic resources. CIP maintains comprehensive wild and cultivated potato germplasm collections, using modern conservation methods, and develops core collections. It also characterizes the collections and evaluates representative samples to identify desirable traits by conventional and non-conventional methods to facilitate their utilization by breeders. A computerized database on the collection is maintained and regularly updated. The outputs are generation of seed stocks and pathogen-tested clonal materials for worldwide distribution, a wild potato collection that includes those species that are becoming extinct or are under-represented in the CIP collection, and genetic assessment through DNA-based technology of the degree of genetic representation in the core cultivated potato collection. Other outputs are *in vitro* conservation of the reserve and core cultivated potato collection, determination of the genetic stability of materials conserved by this method, and worldwide availability of the computerized database through the Internet. IPGRI is working with CIP on cryopreservation research for long-term storage of potatoes and also publishes guidelines on the safe movement of potato germplasm.

Integrated control of late blight. This research develops, adapts, and integrates technologies for the control of late blight (LB) caused by *Phytophthora infestans*. Using conventional and biotechnological methods, breeding populations and advanced clones with durable resistance to LB will be produced. Component technologies will be developed for disease management under the conditions encountered by farmers in developing countries. Integrated disease management (IDM) methods are being designed and implemented through collaboration with national research institutes, government and non-government extension agencies, and farmers. Expected outputs include potato populations and clones with stable resistance to LB, adaptation to a range of conditions found in potato production areas in developing countries, and high yields.

Integrated control of bacterial wilt. This project documents known integrated control practices used by farmers (rotation, sanitation, seed selection, etc.) in selected potato agro-ecoregions where bacterial wilt (BW) is a severe constraint, and then verifies them in yield trials. It selects potato progenies developed in past years with tolerance to BW and promotes IDM of the wilt through a better understanding of disease transmission and control in different production systems, along with the use of resistant potato varieties.

Expected results include: (1) IDM packages specific for given agro-ecologies; (2) documentation of components of BW control practiced by farmers in selected agro-ecologies; (3) validation of components of BW control practiced by farmers; (4) high-yielding potato varieties with resistance to bacterial wilt for use in IDM; (5) better knowledge of disease transmission and control in different production systems; and (6) case studies on IDM.

Control of potato viruses. This research aims to continue to identify and characterize the most important viruses and virus-like agents that affect potato, an essential step for developing diagnostic tools. Sensitive, low-cost methods for large-scale detection will be developed. Genes that confer resistance to the main viruses will be identified and used to develop adapted resistant cultivars, through traditional breeding and biotechnological approaches. Other aims are to study epidemiological factors that affect the spread of viruses, and to train national scientists in virus identification, detection, and control techniques.

Expected outputs include potato cultivars derived from CIP populations with combined resistance to potato leaf roll virus (PLRV), potato virus X (PVX), and potato virus Y (PVY), which will be released by national programs. Improved, user-friendly techniques for virus detection will be made available. New cultivars will be developed carrying host genes for virus resistance and/or introduction, through genetic engineering, of host virus resistance genes into already adapted but susceptible cultivars. Finally, a better knowledge will be gained of resistance mechanisms and virus interactions with other pathogens to develop durable resistance (e.g. to PLRV).

Integrated management of potato pests. CIP's work aims to develop prototypes of integrated pest management (IPM) programs for the control of key potato insect pests of global or regional importance, and nematode species that reduce potato yields and favor the entrance of BW pathogens. The prototypes will emphasize host plant resistance and ecological approaches and thus reduce the use of chemical pesticides. Other aims are to generate potato cultivars resistant to or tolerant of pests; transformation protocol to build oligo-transgenic insect resistance in potato; and, transformed potato breeding lines and varieties with *Bacillus thuringiensis* (Bt) gene-mediated insect resistance. The IPM component technologies (control methods) for each of the integrated pests will be developed along with prototypes of IPM pilot units in well-characterized agro-ecosystems and IPM technology diffusion materials.

Propagation of clonal potato planting materials. This research analyzes past failures and introduces new sustainable systems adapted to local resources and capabilities. Strengthening informal systems practiced by farmers and participatory research approaches will play a greater role. The hypothesis is that improved varieties will diffuse faster and better if sufficient quantities of low-cost, clean planting materials are made available to farmers through informal seed systems. The aim is to develop institutionally sustainable seed systems that will provide healthy clonal propagating materials to farmers.

Sexual potato propagation. This activity seeks to increase the efficiency of the potato crop and expand potato cultivation in nontraditional areas of the tropics and subtropics. This entails the transfer of true potato seed (TPS) technology where lack of disease-free tuber seed is the principal factor limiting production. This research involves: a) developing TPS parental lines capable of producing high quality hybrid TPS for growing a potato crop which is early bulking with desired tuber quality and carrying stable resistance to late blight; b) production techniques for high quality hybrid TPS production; and, c) TPS utilization technologies for potato production. Outputs include methodology and components (genetic materials, TPS production technologies) for producing high quality hybrid TPS and its utilization for potato production, which will be evaluated and utilized in many countries. At least three countries in Latin America, two in Africa, and six in Asia will have viable TPS research and development activities in place by 2003. A number of TPS progenies with improved characteristics will be selected by CIP and distributed to collaborating NARS for evaluation and release.

Global sector commodity analysis and impact assessment for potato and sweetpotato. This research generates information that is useful in making decisions on research allocation and policy matters related to potato and sweetpotato improvement and utilization. Objectives include quantifying the agronomic, economic, social, and environmental effects of improved potato and sweetpotato technologies, documenting the rate of return and the poverty reduction potential of the research, and assessing the level and adequacy of investment in potato and sweetpotato crop improvement in developing countries. Price and production databases for priority-setting are being assembled and maintained. Databases on international trade and utilization, costs, and spatial potato production in the major potato- and sweetpotato-producing countries in the developing world are being constructed. Potato and sweetpotato crop improvement in a global context are being assessed. A policy evaluation of the extent and consequences of price instability in potato production is being undertaken. Outputs include *ex post* and *ex ante* case studies on the impact of CIP-related technologies, and databases on varietal releases, varietal adoption, and investments in potato and sweetpotato crop improvement in developing countries. Training materials will be developed on impact assessment and on marketing, and regional workshops will be held on marketing, processing, and trade. Finally, trends and projections for potato and sweetpotato production, utilization, and trade in developing countries are being calculated, analyzed, documented, and diffused in collaboration with IFPRI (see, e.g. Scott, Rosegrant, and Ringler, 2000).

Potato production in rice–wheat systems. The research that is under way at CIP assesses opportunities for expansion and the sustainability of potato- and cereal-based cropping systems in the Indo-Gangetic Plain. It diagnoses constraints to increasing and maintaining productivity in selected potato- and- cereal–based cropping systems, and generates crop and natural resources management information on how to alleviate the most important constraints identified in the selected cropping systems. Expected outputs include improved sustainability of rice–wheat–based systems on the Indo-Gangetic Plain by optimizing the potential of potato as a major diversification crop, and a diagnosis of threats to sustainability and constraints to productivity of potatoes in selected cereal-based cropping systems in eastern India (see, e.g. Bardhan Roy et al., 1999). Management options will be analyzed for alleviating priority constraints in selected cropping systems where sustainability is threatened.

Sweetpotato

Conservation and characterization of sweetpotato genetic resources. This involves maintaining comprehensive wild and cultivated sweetpotato collections using modern conservation methods and producing healthy planting materials. CIP's research here also includes assessing new methods for the conservation of sweetpotato genetic resources, characterizing the cultivated collection to select a core collection, and eradicating viruses from core accessions and evaluating them to identify sources of desirable traits. It also entails maintaining and updating a computerized database containing all available data on the collection. Outputs include a taxonomic identification of a wild *Ipomoea* collection, an improved seed multiplication methodology to produce enough seed from numerous sweetpotato cultivars for their conservation and distribution worldwide, and seed populations of cultivars containing specific traits. A sweetpotato collection is being maintained with duplicate identification completed with genetic diversity defined by DNA fingerprinting within cultivars from Latin America, Asia, and Africa. A sweetpotato core collection is also being created with a corresponding computerized database made available worldwide through the Internet.

IPGRI is working in collaboration with CIP and national programs on research to improve the management of sweetpotato collections in Asia and the Pacific through the Asian Network on Sweet Potato Genetic Resources (ANSWER). This includes work on *in vitro* slow growth storage of sweetpotato involving national program partners in a number of Asian countries; the development of a complementary conservation strategy for sweetpotatoes; sweetpotato field genebank management; RAPD markers; and the introduction of the use of microsatellite markers for sweetpotato germplasm.

Breeding for high dry matter in sweetpotato. This activity seeks to improve sweetpotato production and utilization through the development and adoption of high dry matter/starch varieties with good adaptability to low-input farming systems. The diverse sweetpotato germplasm at CIP is being used to generate high dry matter parental clones through population improvement. A well-established, decentralized breeding framework combines these advanced parental clones to produce new varieties with a broader genetic background. These contribute to good adaptability to cope with locally important abiotic/biotic stresses in targeted environments. Project activities are closely linked with CIP projects on sweetpotato germplasm management and utilization. Outputs include varieties with high dry matter yield that have drought and virus tolerance. Other outputs are higher-quality raw materials for sweetpotato-based animal feeds, starch, and flour products, and a better understanding of inheritance of major agronomic traits in sweetpotato.

Integrated management of sweetpotato pests. This work aims to use IPM as a springboard to more sustainable crop management, and to take advantage of sweetpotato's environmentally friendly, low-input characteristics. It involves working closely with both partner organizations and users to develop community-based IPM programs within the broader context of integrated crop management (ICM). Outputs include participatory development of IPM/ICM technology and implementation in pilot units, Farmer Field School curricula or other farmer training systems and related didactic materials, and systems for training of field school facilitators including field manuals.

Control of sweetpotato viruses. This research has identified the virus transmitted by whiteflies (sweetpotato cholorotic stunt virus – SPCSV), and is developing methods of detection and control. Traditional and biotechnological procedures are being used to develop resistance to SPCSV. Expected outputs include higher yield of sweetpotato varieties, a low-cost reagent kit for virus detection, and better knowledge of virus diseases that affect sweetpotato.

Postharvest utilization of sweetpotato. This research focuses on improving the welfare of the rural poor by diversifying and expanding sweetpotato usage. This entails reducing processing costs and improving processes, using sweetpotato vines and roots more effectively, identifying new uses and product markets, and facilitating the adoption of improved germplasm by identifying materials with superior postharvest traits. Expected outputs are the development and provision of information on improved processes and more economical procedures for sweetpotato starch and flour; identification of superior clones; and, generation of knowledge on improved cultural practices, silage, and feeding techniques for sweetpotato roots, vines, and by-products as animal feed. Superior clones for use in producing starch and flour are also being identified. Training is being organized in the form of regional, national, and individually tailored activities using developed methodological/training materials on sweetpotato postharvest utilization.

Yam

Collection, conservation and genetic enhancement of plant biodiversity. In this work, IITA focuses on the collection and conservation of genetic resources for yam. Its objectives include evaluating and documenting the yam germplasm collection with botanical/biochemical/molecular descriptors, and measuring the response of different yam genotypes to physiological stresses and pests/diseases. The project further seeks to assess and understand the genetic variation in the yam germplasm collection; synthesize source breeding populations and parental lines; enhance safe movement of germplasm to research partners; and, on a wider scale, link IITA research on genetic resources with CGIAR system-wide initiatives.

IITA continues to diversify the genetic base of its breeding effort on yam. Moreover, in addition to regular on-station evaluation, on-farm farmer participatory evaluation has been initiated in Nigeria in collaboration with the National Root Crops Research Institute (NRCRI.) Collaborative trials are also being carried out with national root crop programs in several West African countries.

Research on the cryopreservation of yam is a new initiative. It is designed to develop simple cryopreservation protocols for the long-term conservation of the crop. Factors such as the use of different types and sizes of explant, cryoprotectants, encapsulation, dehydration, and thawing are being investigated.

A project undertaken jointly by IPGRI and IITA in West Africa consists of a baseline survey to obtain data on yam cultivation and social factors, a participatory diagnosis of farmers' seed tuber systems, the characterization of all material with the participation of stakeholders, and isozyme and molecular analysis. The project aims for a better understanding of farmers' practices in the domestication of wild yam as a prelude to setting up efficient participatory breeding programs. This work will be compared with a study on a similar process being conducted by IPGRI and partners on cocoyam (*Colocasia esculenta*) in China.

Crosses continue to be made between improved, cultivated yam breeding lines and landraces of yams from various countries and agro-ecologies in West Africa. Specific attributes derived from landrace cultivars which are desired in the progeny include adaptation to the mid-altitudes, resistance to anthracnose disease, good tuber quality, early maturity, and bulbil production. The objective is to combine these traits with the high yield potential and good agronomic background of the improved breeding lines.

Recombinant DNA, molecular diagnostics, and cellular biotechnology for crop improvement. IITA aims to improve and use existing *in vitro* transformation and regeneration systems for target crops and to develop and use embryo rescue techniques for yam. Research on pest resistance focuses on the mapping of genes that confer resistance to specific pests in *Dioscorea* spp. This will enhance breeders' capacity to produce pest-resistant yam through marker-assisted selection and allow them to develop monoclonal/monospecific antibodies, complementary DNA (cDNA) probes and/or polymerase chain reaction (PCR) techniques for important pathogens. Finally, the project seeks to enhance human resource capacity for biotechnology application in Africa.

Genome mapping has commenced for the purpose of identifying loci that affect desirable traits, using DNA markers such as restriction fragment length polymorphism (RFLP), RAPD, simple sequence repeats (SSR), and AFLP. Mapping populations have been developed for the purpose of identifying molecular markers that are linked with loci with effects on resistance to pests and disease and also for harvest (food quality) traits, with the goal of using marker-assisted selection in the longer term. Research has begun on the genetics of resistance to yam mosaic potyvirus and nematodes in *D. rotundata* and anthracnose in *D. alata*, combined with molecular analysis, and genome mapping for these traits.

The genetics of resistance to yam mosaic potyvirus (YMV) in *D. rotundata* and that of anthracnose in *D. alata* have been elucidated for the first time. In addition, among the five F1 mapping populations that have been developed for identification of molecular markers associated with resistance to YMV and nematodes in *D. rotundata*, one of these segregating populations was used to generate a genetic linkage map. Currently, RAPD, isozymes and AFLP single dose markers are being generated using this population. These markers are also being used to develop a genome map of female and male parents, using the Mapmaker computer program. Already, the female map comprises 12 marker loci, spanning four linkage groups. More markers need to be added to the map, because *D. rotundata* is a polyploid with n=10 (chromosome number).

Integrated control of pests and diseases. At IITA, work on yam pests and diseases includes viruses, fungal diseases, and nematodes. Yam viruses occurring in the yam-growing region of Nigeria have been identified. These are yam mosaic potyvirus, *D. alata* potyvirus, *D. dumetorum* potyvirus, *D. alata* badnavirus, cucumber mosaic cucumovirus,and three new isometric viruses tentatively named *Dioscorea* mottle, *Dioscorea* necrosis and *Dioscorea* chlorotic mosaic viruses. These appear to be representative of the viruses occurring in West Africa, as many of the viruses have been found in Ghana and Cameroon, and reported from Côte d'Ivoire. As more viruses are identified and characterized, the genotypes selected for international distribution are tested for all the viruses that are known. Screening of landraces and breeding lines for virus resistance is in progress. IITA has a comparative advantage in yam virus research.

IITA's collaborative work on fungal diseases involves diagnostic surveys to quantify the severity of infection. Laboratory, on-station, and on-farm trials also measure virulence and estimate its economic importance for different species. In addition, various integrated crop management techniques continue to be developed to inoculate yam plants and yam seeds against different nematode populations.

Improvement of yam-based production systems. This activity entails characterization of biological and socioeconomic constraints of yam-based systems. It also encompasses IITA's research to develop strategies for integrated control of pests and diseases, both in the field and during storage, and to improve soil fertility and reduce weed competition to enhance yam production. Outputs are yam genotypes with a high and stable yield of tubers with good food and storage qualities. These provide greater flexibility in the type of propagule, planting date, and storage time, and they promote yam as a new crop in non-yam producing areas.

Macrocharacterization of the agricultural systems in West Africa provides information on the relative importance of yams and the distribution of production in relevant agro-ecological zones. Yam-based cropping systems occupy 20% of the lowland humid and subhumid parts of the nine countries studied. Yams are grown in 38% of the areas where agricultural intensification is market-driven and in 62% of areas where it is population-driven. Yam production declines when land-use intensity increases and production is moving northward into the Guinea savannas where new land is available.

The gender implications for the development of resource management technologies for yam production have been investigated in the southern Guinea savanna zone of Nigeria. Women were found to play major roles in yam production and marketing. As a result, gender considerations should now be taken into account in technology development for sustainable yam production in West Africa.

Improvement of postharvest systems. This work characterizes food crop systems and identifies efficient intervention strategies, develops germplasm that is acceptable to end users, and develops and disseminates innovative harvesting, storage, and processing technologies. Furthermore, through this activity IITA seeks to establish more effective channels for the exchange of information and train postharvest researchers within the NARS.

Other roots and tubers

Taro and tannia. IPGRI provides technical backstopping in collecting, *ex situ* as well as *in situ* conservation, descriptor development and data documentation on the conservation and use of taro genetic resources in the Pacific region. IPGRI has also demonstrated how ethnobotanical methods applied to taro in China complement other methods for locating and measuring agro-biodiversity of the crop. By combining farmers' knowledge with genetic information, a research team identified taro cultivars at risk of genetic erosion. The team was also able to confirm the role of communities, cultural diversity, and multiple uses in maintaining taro diversity. The end result is a conservation and use strategy for taro in China, the world's largest producer of this crop. IPGRI is also conducting research on the *in situ* conservation of taro in Nepal and Vietnam and is examining the ethnobotany and genetic diversity of cocoyams (*Colocasia* and *Xanthosoma*) in West Africa, together with national program partners in Ghana and Cameroon.

Aroids fall outside the crop mandate of IARCs but there are global centers of expertise on taro and tannia. Cuba, India, Japan, Trinidad and Tobago, and USA (Hawaii) all have traditions of taro research and development. Cuba, Japan, and USA (Hawaii) carry out research from the agronomic to the molecular level. Cuba, for example, has a lead research institute, Instituto Nacional de Investigación de Viandas Tropicales (INIVIT), with a sophisticated research capability to address aroids as well as other tropical root crops. Other countries with scarce research resources such as Cameroon, Côte d'Ivoire, and Ghana have research centers where aroids are priority crops for research. Regional research institutes such as the Caribbean Agricultural Research and Development Institute, Barbados (CARDI) and the Institute for Research Extension and Training in Agriculture (IRETA), University of South Pacific, Western Samoa have regional research programs on edible aroids, as they are staple foods in the small island states. France and Australia also carry out research on aroids, mainly taro, in their respective tropical research institutes (e.g. Institute of Research for Development, formerly ORSTOM) and in technical assistance programs.

Other countries are awakening to the vast potential of aroids and initiating research and genetic resources work on these crops. Given the fact that the genetic bases of these crops are as yet poorly documented and inadequately conserved (just 5214 accessions of *Colocasia* and 861 accessions of *Xanthosoma*, see Cross, 1998), a network in support of the conservation, exchange, and deployment of taro and tannia genetic resources might be a starting point. The link between centers of expertise and countries where the crop is crucial for food security would add value to industrial, commercial, and subsistence uses of the crops.

Conservation and characterization of Andean roots and tubers (ART). In this work, CIP seeks to help national programs rationalize strategies for both *ex situ* and *in situ* conservation of ART. It involves collection, characterization, and preservation of biodiversity, with emphasis on four priority genera—*Oxalis, Ullucus, Canna,* and *Arracacia* (including their wild allies)—and material of *Mirabilis expansa, Pachyrhizus ahipa, Smallanthus sonchifolius, Tropaeolum tuberosum,* and *Lepidium* *meyenii* using gap-filling strategies. Other aims are to systematically assess the potential of ART to promote wider use in the subtropical and tropical highlands within and outside the Andean region through study of current marketing and consumption patterns, and identify latent demands these crops may satisfy in the future. Healthy planting materials will be produced for farmers' uses.

Expected outputs include improved *in situ* conservation and methodology to assess phenotypic diversity and guidelines for maintaining field and *in vitro* collections of ART. Publications will be released on the reproductive biology of oca, achira, arracacha, and yacon, along with techniques for seed production, and the material used in selection and breeding programs. Routine use will be made of descriptors for ulluco, oca, mashua, arracacha, achira, and yacon for establishing the value of accessions. Other outputs will be morphological characterization and, especially in the cases of achira and arracacha, starch characterization of a substantial part of the collection. One hope is to increase use of achira in Vietnam and of arracacha in Brazil, and broaden the genetic base of these crops.

IPGRI's regional group in the Americas, based at CIP, coordinates a network of 14 *ex situ* genebanks spread across Peru, Bolivia, and Ecuador. These genebanks conserve germplasm of nine species of roots and tubers. IPGRI assists in the evaluation of genebank procedures, the development of descriptors, data organization and standardization, the provision of hardware and software tools used to document the collections, and the assessment of training needs. In Hermann and Heller (1997), published by IPGRI, the geographical distribution, economic importance, diversity, nutritional properties, taxonomy, utilization, and conservation of four of the Andean roots and tubers are treated in detail.

Table A15 lists organizations inside and outside the CGIAR which carry out research on roots and tubers in collaboration with CGIAR Centers. It includes both NARS and Advanced Research Organizations and is organized by commodity and research area for easy reference. Many of these organizations, particularly those in developing countries, are actually funded to do this work either completely or, more commonly, partly by the Centers that they work with. The source of this information is the current Medium-Term Plans of the Centers.

Table A15. Projects, collaborators, and countries engaged in research on roots and tubers.

Cassava

Collaborators	Country
CIAT Project SB-1: Integrated conservation of neotropical plant genetic resources	
CNPMF/EMBRAPA	Brazil
INIVIT	Cuba
CIRAD	France
IRD	France
University of Paris	France
University of Georgia	USA
University of Washington, Saint Louis	USA
CIAT Project SB-2: Assessing and using agro-biodiversity through biotechnology	
CNPMF/EMBRAPA	Brazil
CENARGEN/EMBRAPA	Brazil
SCIB	China
CORPOICA	Colombia
CIGB-INIVIT	Cuba
Danish Royal Veterinary and Agricultural University	Denmark
CIRAD	France
IRD	France
CTCRI	India
Wageningen Agricultural University	Netherlands
ETH	Switzerland
Kasetsart University	Thailand
University of Bath	UK
University of Newcastle	UK
ILTAB	USA
Ohio State University	USA
University of Georgia	USA
University of Washington, Saint Louis	USA
CIAT Project PE-1: Integrated pest and disease management in major tropical agro-ecosystems	
IRD	France
ICIPE	Kenya
IITA	Nigeria
ETH	Switzerland
JIC	UK
NRI	UK
SCRI	UK
Boyce Thompson Institute	USA
University of California, Riverside	USA
University of Florida	USA
National programs	Brazil, China, Colombia, Cuba,

Contd.

Contd.

Collaborators	Country
	Ecuador, India, Paraguay, Philippines, Thailand
CIAT Project PE-5: Integrating improved germplasm and resource management for enhanced crop and livestock production	
CNPMF/EMBRAPA	Brazil
Universities and research institutes	China, Colombia, Indonesia, Philippines, Thailand, Vietnam
CIAT Project SN-1: Linking smallholders to growth markets for improved resource management	
CNPMF/EMBRAPA	Brazil
UNESP, Botucatu	Brazil
Guangxi Nanning Cassava Development Center	China
Universidad del Valle	Colombia
CIRAD	France
CTCRI	India
PRCRTC	Philippines
Kasetsart University	Thailand
TISTRC	Thailand
NRI	UK
PHI	Vietnam
NARS and NGOs	Colombia, Ecuador, Paraguay, Peru, Nicaragua
UPWARD	Netherlands, Philippines, Thailand, Vietnam
CIAT Project IP-3: Genetic enhancement of cassava	
CNPMF/EMBRAPA	Brazil
Instituto de Campinas	Brazil
CORPOICA	Colombia
INIVIT	Cuba
Kasetsart University	Thailand
IAS -	Vietnam
Thai Nguyen University	Vietnam
Auburn University	USA
Kansas State University	USA
NARIs	China, Ecuador, India, Indonesia, Malaysia, Panama, Paraguay, Philippines, Sri Lanka, Venezuela
NARS	Several countries in Asia and Latin America
CIAT Project BP-1: Assessment of past and expected impact of agricultural research	
CNPMF	Brazil
IFPRI	USA

Collaborators	Country
National research institutes	Latin America, Asia, Africa
IITA Project 6 Integrated management of cassava pests and diseases	
EMBRAPA	Brazil
IRD	France
GTZ	Germany
BBA	Germany
ICIPE	Kenya
SARRNET	Tanzania
EARRNET	Uganda
NRI	UK
JIC	UK
NARS	Several countries (25) in Africa, Europe, and America
IITA Project 14 Cassava productivity in the lowland and mid-altitude agro-ecologies of SSA	
Instituto de Investigaciones Agronomica	Angola
INRAB	Benin
CNPMF/EMBRAPA	Brazil
CNRST/ISRAT	Burkina Faso
INERA	Burkina Faso
Institute of Agricultural Research	Cameroon
University of Guelph	Canada
ICRA	Central African Republic
BRA	Chad
DRTA	Chad
CIAT	Colombia
INERA	Dem. Rep. of the Congo
IDESSA	Côte d'Ivoire
Royal Veterinary and Agricultural University	Denmark
Crop Research Institute	Ghana
Food Research Institute	Ghana
Ghana Atomic Energy Commission	Ghana
Savanna Agricultural Research Institute	Ghana
Centre de Recherche Agronomique	Guinea Conakry
CTCRI	India
JIRCA	Japan
National Plant Quarantine Service	Kenya
University of Nairobi	Kenya
Dept. of Agricultural Research	Lesotho
FOFIFA-DRA	Madagascar
Lunyagwa Research Station	Malawi
University of Malawi	Malawi
National Root and Tuber Program, Umbelusi Research Station	Mozambique
National Root and Tuber Crops Program	Namibia
INRAN	Niger

Contd.

Contd.

Collaborators	Country
Federal University of Technology	Nigeria
ICRISAT	Nigeria
ILRI	Nigeria
Institute of Agricultural Research	Nigeria
KNARDA	Nigeria
NCRI	Nigeria
University of Agriculture	Nigeria
NRCRI	Nigeria
ISAR	Rwanda
ISRA	Senegal
Institute of Agricultural Research	Sierra Leone
Rice Research Station	Sierra Leone
Medical Research Council	South Africa
Roodeplaat Vegetable and Ornamental Plant Institute	South Africa
University of the Witwaterstrand	South Africa
Horticultural Research Institute	Sri Lanka
Malkerns Research Station	Swaziland
University of Uppsala	Sweden
Institute of Environmental Protection and Agriculture	Switzerland
Swiss Federal Institute of Technology	Switzerland
National Root and Tuber Program	Tanzania
INCV	Togo
University of West Indies	Trinidad
Kawanda Agricultural Research Institute	Uganda
Makerere University	Uganda
NAAPRI	Uganda
University of Ibadan	Uganda
Cornell University	USA
Pennsylvania State University	USA
University of Illinois	USA
Ministry of Agriculture, Food and Fisheries	Zambia
Dept. of Research and Specialist Services, Chiredzi Research Station	Zimbabwe

Further IITA projects cover work on both cassava and yam; these are listed under Yam

Potato

CIP (1) Integrated control of late blight

Collaborators	Country
INTA, CICV-INTA, INTA-Balcarce	Argentina
PROINPA	Bolivia
INIA	Chile
Sichuan Academy of Agricultural Sciences	China
South China Agric. Univ.	China
South China Potato Research Center	China
Yunnan Normal University	China
CORPOICA	Colombia
INIAP	Ecuador
INRA	France
MPI-Gross-Luesewitz-Quedlimburg	Germany
CRIFC	Indonesia
INIFAP	Mexico
CPR-IPO-WAU	Netherlands
INIA	Peru
PCCARD-UPLB-IPB	Philippines
NARO	Uganda
SCRI	UK
Cornell University	USA
Purdue University	USA
CARE	Peru

CIP (2) Integrated control of bacterial wilt

Collaborators	Country
University of Queensland	Australia
CNPH/EMBRAPA	Brazil
CAAS, SCPC	China
Research Institute of Vegetables	Indonesia
World Education	Indonesia
MSIRI	Mauritius
Rothamsted Experiment Station	UK
UPWARD	ESEAP

CIP (3) Control of potato viruses

Collaborators	Country
Wageningen Agricultural University	Netherlands
Sainsbury Laboratory	UK
SCRI	UK
USDA-ARS	USA
NARS	Selected countries

CIP (4) Integrated management of potato pests

Collaborators	Country
IBTA-PROINPA	Bolivia
ICA-CORPOICA	Colombia
UMATA	Colombia
MIP-JAD	Dominican Republic
INIAP-FORTIPAPA	Ecuador
Plant Protection Institute	Egypt
IAV, INRA	Morocco
INIA, Universidad Nacional Agraria, University of Tacna, CARE, Valle Grande, CECOACAM, ARARIWA, TALPUY, Chincheros, CIED	Peru
INRAT, CPRA-Essaida	Tunisia
FONAIAP	Venezuela

CIP (5) Propagation of clonal potato planting materials

Collaborators	Country
Bangladesh Agricultural Research Institute	Bangladesh
IAR	Ethiopia
RIV	Indonesia
KARI	Kenya
NARC	Nepal
NPRCRTC	Philippines
NARO	Uganda
UPWARD, INSA, DRCFC	Vietnam

Contd.

Contd.

Collaborators	Country
PRAPACE	Burundi, Dem.Rep. of the Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Tanzania, Uganda
PRECODEPA	Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama
PRACIPA	Bolivia, Colombia, Ecuador, Peru, Venezuela
CIP (6) Sexual potato propagation	
TCRC	Bangladesh
EMBRAPA	Brazil
CAAS	China
INIAP	Ecuador
Department of Agriculture	Egypt
IAR	Ethiopia
CPRI	India
RIV	Indonesia
KARI	Kenya
INIA	Peru
Department of Agriculture	Philippines
INRAT	Tunisia
NARO	Uganda
CIP (7) & (12) Global sector commodity analysis & impact assessment for potato(*) and sweetpotato(**)	
INTA*	Argentina
CAAS*	China
CAAS**	China
Chinese Center for Agricultural Policy**	China
CIAD**	China
CPRI*	India
KARI**	Kenya
University of Nairobi**	Kenya
UPWARD**	China, Philippines, Vietnam
University of Philippines**	Philippines
ViSCA**	Philippines
NARO**	Uganda
Makerere University**	Uganda
PRACIPA*	Bolivia, Colombia, Ecuador, Peru, Venezuela
PRAPACE*	Burundi, Dep. Rep. of the Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Tanzania, Uganda
PRECODEPA*	Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama
PROCIPA*	Argentina, Brazil, Chile, Paraguay, Uruguay
Wageningen Agricultural University*	Peru, Netherlands
CIP (13) Potato production in rice-wheat systems	
Bangladesh Agricultural Research Institute	Bangladesh
CPRI	India
ICAR	India
West Bengal State Department of Horticulture	India
CIP (15) Conservation and characterization of potato genetic resources	
INTA	Argentina
IBTA	Bolivia
Univ. Austral	Chile
INIAP	Ecuador
MPI-Gross-Luesewitz-Quedlimburg	Germany
CGN	Netherlands
INIA	Peru
Universities in Cusco & Cajamarca	Peru
VIR	Russia
CPC	UK
USDA	USA
Sweetpotato	
CIP (8) Control of sweetpotato viruses	
Institute of Plant Virology	Argentina
Pernambuco Federal Rural University	Brazil
XSPRC	China
General Seed Potato Organization	Syria
NAAPRI	Uganda
CIP (9) Integrated management of sweetpotato pests	
University of Queensland	Australia
Delegación Provincial de Santiago de Cuba	Cuba
Est. Exp. De Viandas Tropicales de Camagüey	Cuba
Est. Exp. Jiquima de Holguín	Cuba
INIVIT	Cuba
INIFAT	Cuba
Inst. Sup. de Ciencias Agropecuarias	Cuba
Inst. Salesiano Agrop.	Dominican Republic

Contd.

Contd.

Collaborators	Country
Junta Agroempr. Dominicana	Dominican Republic
Prog. Nac. de Manejo Integrado de Plagas	Dominican Republic
Bogor Agric. Univ.	Indonesia
RILET	Indonesia
University Kristen Duta Wacana	Indonesia
Yayasan Mitra Tani	Indonesia
ICIPE	Kenya
KARI	Kenya
Ministry of Agriculture	Tanzania
NARO	Uganda
Makerere University	Uganda
Ministry of Agriculture	Uganda
AgriSense	UK
NRI	UK
Clemson University	USA
Hanoi Agricultural University	Vietnam
Institute of Tropical Biology	Vietnam
University of Agriculture and Forestry	Vietnam
CIP (10) Postharvest utilization of sweetpotato	
CAAS	China
CIAD	China
SAAS	China
CIAT	Colombia
CIRAD	France
HKU	Hong Kong
RILET	Indonesia
KARI	Kenya
JKUAT	Kenya
University of Nairobi	Kenya
IDRC	Kenya, Uganda, Canada
UPM	Malaysia
Wageningen Agricultural University	Netherlands
IITA	Nigeria
IIN	Peru
Universidad Nacional Agraria	Peru
NUS	Singapore
AIT	Thailand
Kawanda Agricultural Research Institute	Uganda
Makerere University	Uganda
NARO	Uganda
NRI	UK
Cornell University	USA
PHTI	Vietnam
VASI	Vietnam
ACIAR	Australia, Indonesia, Papua New Guinea, Vietnam
PRAPACE	Burundi, Dep. Rep. of the Congo, Eritrea,

Collaborators	Country
	Ethiopia, Kenya, Madagascar, Rwanda, Tanzania, Uganda
CIP (11) Breeding for high dry matter in sweetpotato	
Bangladesh Agricultural Research Institute	Bangladesh
TCRC	Bangladesh
SAAS	China
XSPRC	China
CTCRI	India
ICAR	India
RILET	Indonesia
KNAES	Japan
KARI	Kenya
University of Nairobi	Kenya
UPWARD	Kenya
RTIP	Tanzania
NARO	Uganda
Makerere University	Uganda
NCSU	USA
USDA-Charleston Vegetable Lab.	USA
VASI	Vietnam
CIP (16) Conservation and characterization of sweetpotato genetic resources	
INTA	Argentina
CNPH	Brazil
XSPRC	China
NARC	Japan
USDA	USA
IDEA	Venezuela
Sweetpotato networks in Asia and Africa	
IPGRI (C10) *Ex situ* conservation technologies and strategies. Sub-project: Molecular characterization of sweetpotato landraces	
MARDI	Malaysia
UPM	Malaysia
ViSCA	Philippines
IPGRI (C10) *Ex situ* conservation technologies and strategies. Sub-project: Identification of duplicates in sweetpotato field genebanks	
MARDI	Malaysia
Yam	
IITA Project 13 Improvement of yam-based production systems	
INRAB	Benin
Department of Agricultural Research	Botswana
INERA	Burkina Faso

Contd.

Contd.

Collaborators	Country
IRAD	Cameroon
ICRA	Central African Republic
DRTA	Chad
IDESSA	Côte d'Ivoire
CSRS	Côte d'Ivoire
CIRAD	France
INRA	France
IRD	France
National Agricultural Research Institute	The Gambia
University of Frankfurt	Germany
Crops Research Institute	Ghana
Savanna Agricultural Research Institute	Ghana
University of Ghana	Ghana
IRAG	Guinea
Ministry of Agriculture	Malawi
INRAN	Niger
National Seed Service	Nigeria
NRCRI	Nigeria
University of Ibadan	Nigeria
IAR	Sierra Leone
ETH	Switzerland
Agricultural Research Institute	Tanzania
ITRA	Togo
International Institute of Parasitology	UK
Natural Resources Institute	UK
University of Reading	UK
Wye College, University of London	UK
University of East Anglia	UK
Ministry of Agriculture	Zanzibar

IITA Project 1 Short Fallow Systems (includes work on cassava)

INRAB	Benin
UNB	Benin
IRAD	Cameroon
Other NARS in West Africa	

IITA Project 2 Agro-ecosystem development strategies and policies (includes work on cassava)

INRAB	Benin
IRAD	Cameroon
NCRI, Badeggi	Nigeria
NRCRI	Nigeria
Other NARS in West and Central Africa	

IITA Project 9 Improving Postharvest Systems (includes work on cassava)

Développement Rural	Benin
DRHFV	Benin
INRAB	Benin
Université Nationale du Bénin	Benin
CERAT	Brazil
University of Campinas	Brazil

Collaborators	Country
Royal Veterinary and Agricultural University	Denmark
Food Research Institute	Ghana
Ministry of Agriculture	Ghana
Ministry of Rural Extension	Ghana
Sasakawa Africa Association	Ghana
Sasakawa Global 2000	Ghana
TechnoServe	Ghana
WIAD	Ghana
KARI	Kenya
KIRDI	Kenya
FOFIFA	Madagascar
Wageningen University	Netherlands
Guinness Breweries	Nigeria
IAR&T	Nigeria
TechnoServe	Nigeria
Karolinska Institute, University of Stockholm	Sweden
University of Uppsala	Sweden
ARI	Tanzania
TFNC	Tanzania
ITRA	Togo
Kawanda Agricultural Research Institute	Uganda

IITA Project 10 Farming systems diversification (includes work on cassava)

IRAD	Cameroon
Other NARs in West and Central Africa	

IITA Project 15 Recombinant DNA, molecular diagnostics and cellular biotechnology for crop improvement (includes work on cassava)

KUL	Belgium
Cassava Biotechnology Network	Colombia
CIRAD	France
University of Frankfurt	Germany
SARRNET	Malawi
EARRNET	Uganda
NRI	UK
JIC	UK
Auburn University	USA
University of California, San Diego	USA
National Yam Programs in West Africa	

IITA Project 16 Conservation and genetic enhancement of plant biodiversity (includes work on cassava)

CIRAD	France
Plant Genetic Resources Centre	Ghana
SARRNET	Malawi
University of Ibadan	Nigeria
ITRA	Togo
EARRNET	Uganda
JIC	UK
Root and tuber crop programs in West and Central Africa	

Contd.

Contd.

Other roots and tubers

Collaborators	Country
CIP (17) Conservation & characterization of Andean root and tuber crops	
ICIMOD, CNPH-Arracacha Program, CONDESAN	e.g. Brazil, Nepal, Vietnam,
IDRC	Bolivia, Ecuador, Peru, Canada
COSUDE	Bolivia, Colombia, Ecuador, Peru, Switzerland
IPGRI (C02) Support to plant genetic resources programs and regional networks in Asia, the Pacific, and Oceania	
Sub-project: Conservation and use of taro in the Pacific	
AUSAID	Australia
South Pacific Commission	
IPGRI (C11) *In situ* conservation of crop plants and their wild relatives	
Sub-project: *In situ* conservation of agricultural biodiversity	
National program	Nepal
National program	Vietnam
IPGRI (C13) Human and policy aspects of plant genetic resources conservation and use	
Sub-project: Ethnobotany and genetic diversity of cocoyam (*Colocasia* and *Xanthosoma*) in West Africa	
IAR	Cameroon
University of Ghana	Ghana
National Crops Genetic Resources Centre	Ghana
IPGRI (C13) Human and policy aspects of plant genetic resources conservation and use	
Sub-project: Locating and assessing taro diversity	
CAAS – Institute of Vegetables and Flowers	China
CAAS – Biotechnology Institute	China
Kunming Institute of Botany	China

Source: Compiled for this study from the Centers' Medium-Term Plans.

Summary

Current research on and with the CGIAR on roots an tubers covers a broad spectrum of activities — from germplasm collection and conservation to impact assessment, from production to utilization. In virtually every one of these areas, CGIAR Centers, national collaborators in developing countries, and scientists in advanced research organizations in developed countries are working together to overcome key constraints and capitalize on emerging opportunities for these crops. At the same time, however, the commodity- and location-specific nature of these efforts also merits mention as it reflects the growing regional specialization of production and utilization of roots and tubers noted in previous sections.

The vast majority of this work involves institutions in the public sector, with as yet relatively little private sector participation. Nevertheless, the organizations in developing countries include a growing number outside national agricultural research institutes (NARIs), in particular non-governmental organizations as well as universities. Given the elaborate and extensive matrix of activities and actors involved in research on roots and tubers world-wide, growing interest exists in identifying possible mechanisms for improving efficiency or increasing impact in work with these commodities.

Section 7 – Alternative scenarios for future synergy in research on roots and tubers

Previous sections described in some detail the similarities and dissimilarities of the root and tuber crops as they relate to trends, projections, opportunities, constraints, and research strategies. Our focus here is on identifying potential gains in efficiency that can come from working together, while remaining aware of limitations and constraints. Some research has little to gain from developing across-species projects.

Complementarity and synergy with the private sector, and a coordinated strategy among the CGIAR Centers to achieve that, will be a key to bringing the best of science to the beneficiaries we seek to serve. Whereas there is widespread concern about the effects of intellectual property rights on access to technology in the developing world, there is also reason to believe that the goals of the private and public sector are not always incompatible. Developing the framework for working together to establish mutually beneficial outputs should begin immediately, at the current preliminary stages of private sector interest in roots and tubers.

Table A16 details a number of activities where complementarity and synergy can make the CGIAR system more effective in research on roots and tubers. In broad terms, these activities cover the areas of: (1) database development for production, processing, trade, and consumption statistics; (2) germplasm management; (3) safe movement of germplasm; (4) genetic improvement, especially relating to molecular techniques; (5) bioinformatics; (6) biosafety; (7) vegetative propagation constraints; (8) starch studies; (9) integrated pest management; (10) geographical information systems; (11) capacity-building; (12) public awareness efforts; (13) involving the private sector in research and research support; and (14) policy support. While there are already a number of inter-Center collaborative activities, it is apparent from this list that there is much more that could be done. How to accomplish this integration is the subject of the following sub-section.

Implications for research organization

We believe that our vision for root and tuber crops, along with the supporting material presented in this Annex and associated documents, makes a strong case for the potential of these crops in future food security and the elimination of poverty, and for the CGIAR's continued and energetic involvement in that effort. A further question now needs to be posed: *Is root and tuber research in the CGIAR organized in a way that can best support the efforts of our partners in realizing the true development potential of these crops?*

The Inter-Centre Review of Root and Tuber Crops of 1995–96 was followed by a number of important changes in the CGIAR (TAC, 1997). First, the CGIAR as a whole had been, and remains, under financial pressure, which resulted in large reductions in resources and shifts in allocation. Second, the CGIAR adopted a project-based research management system that led to the reorganization of root and tuber research within the individual Centers. While this new system is still being implemented, some important changes in the organization of research on root and tuber crops have already taken place. For example, CIAT's cassava program and IITA's tropical root and tuber program have been eliminated. In 1996, the Inter-Centre Committee for Root and Tuber Crop Research (now renamed the Committee for Inter-Centre Root and Tuber Crop Research, or CICRTCR) was formed. The group has members from CIP, CIAT, IPGRI, and IITA, and it currently functions under the leadership of CIP. Its associated working groups concern themselves with biotechnology, phytosanitary regulations, and postharvest processing and marketing. These groups focus on areas of common interest and potential collaboration and seek to exploit these opportunities through joint activities, using the Centers' own resources or additional donor funding.

Collaboration also takes place through some of the broader CGIAR undertakings, such as the system-wide genetic resources and integrated pest management programs. In the present arrangement, the research

Table A16. Complementarity and synergy among organizations in research on roots and tubers.

Area, Activity	Collaborating Centers (plus appropriate NARS)	Purpose of activity	Mechanism of collaboration	Benefits of collaboration
Data base management				
Sampling methods for vegetatively propagated crops	IPGRI, CIAT, CIP, IITA	Uniform criteria for sampling	Electronic conferencing; workshops	Efficiency through shared methods
Studies on the cost of conservation	CGIAR	Identify areas for improved management efficiency	Contracted special studies; workshops	Design of more cost-effective conservation strategies
In vitro collection techniques	Safe transfer to site of conservation	Develop safe and cost-effective collection techniques for vegetative samples	Exchange of information through electronic conferencing; workshops	More effective collection methods
Cryopreservation research	IPGRI, CIAT, CIP, IITA, EMBRAPA, national programs in China (sweetpotato) and Nigeria (yam)	Resolve common problems in cryopreservation	Consolidated laboratory facilities and rationalization of research based on Centre expertise	Cost savings; improved assurance of safekeeping; efficient use of conservation resources
Seed generation of vegetatively propagated crops	CIAT, CIP, IITA, IPGRI	Benefits from comparing experiences across crops	Collaborative population genetics studies and modeling	Efficient and scientifically based conservation of genetic diversity
Safe movement of germplasm				
Refining protocol and developing appropriate recommendations to quarantine authorities	CIAT, CIP, IITA, IPGRI national quarantine authorities	Reduce risks of pest/ pathogen transfer across regions; awareness and efficiency of regulatory compliance	Shared methodologies and information; development of diagnostics	Coordinated quarantine research
Genetic improvement				
Comparative genomics	CIAT, CIP, IITA, other biotech networks	Identify key genes common across crops, e.g., related to starch characteristics, root bulking, carotenes, postharvest deterioration	Shared methodologies and information based on gene homology	Efficiencies from shared resources; understanding gene function; possibilities of sharing key genes across crops
Character improvement	CIAT, IITA, other biotech networks, AROs	Identify root/tuber gene promoters; develop genes for transformation	Shared laboratory work; exploiting capacity and expertise of each Centre's labs	Efficiencies from shared resources; understanding gene function; possibilities of sharing key genes across crops

Contd.

Contd.

Area, Activity	Collaborating Centers (plus appropriate NARS)	Purpose of activity	Mechanism of collaboration	Benefits of collaboration
Bioinformatics				
Database development	CIAT, CIP, IITA	Improve access to genetic information on roots and tubers	Build on SINGER information management system	More effective research from efficient access to information
Biosafety				
Coordinated development of biosafety protocols, esp. genetically modified organisms	CIAT, CIP, IITA, IPGRI, private sector, regulatory agencies	Identify biosafety issues particular to roots and tubers	Electronic conferencing; workshops	Improved biosafety
Vegetative propagation constraints				
Research on methods for farm-level quality "seed" production; rapid propagation methods	CIP, CIAT, IITA	Improved vegetative propagation rates of disease-free planting material	Training, research and development; shared experiences and research	Faster distribution of varieties with fewer disease problems
Starch studies[a]				
Starch processing (small-and medium-scale)	CIAT, CIP, IITA	Improve efficiency and product quality, reduce pollution, link small-scale producers with growth markets	Special project	Efficient use of resources, greater impact, more efficient interaction with partners
Starch markets and trade	IFPRI, CIAT, CIP	Identify growth markets/ products and regional trade trends	Special products	Better research prioritization (feedback to genetics/biotech and postharvest research)
Characterization of starch functional and biochemical properties across root and tuber germplasm	CIAT, CIP, IITA, NRI	Identify the range of starch properties useful to industry, using common methods, and producing a unified database	Special project	Unified information in common database, generated by common protocols
Integrated Pest Management				
Whitefly IPM (underway/active)	CIAT, IITA, CIP, ICIPE, AVDRC	IPM of whiteflies based on common principles across crops	System-wide IPM project	Research excellence; shared resources; entomology and virology collaboration
Whitegrubs IPM (task force)	CIAT, IITA, CIP, ICRISAT, ICIPE	Develop control technologies	System-wide IPM project	Shared expertise; improved understanding of pest problems

[a] These and other starch-related projects could be combined into one large "initiative" for funding purposes. This would also provide the vision with a major thrust that might prove attractive to donors.

Contd.

Area, Activity	Collaborating Centers (plus appropriate NARS)	Purpose of activity	Mechanism of collaboration	Benefits of collaboration
Integrated Pest Management				
IPM - Soil pathogens	CIAT, CIP, IITA	Develop control technologies	Special projects	Shared expertise; improved understanding of soil pathogen problems
IPM - Cassava bacterial blight and CMD	CIAT, IITA	Develop control technologies; introgression of CMD resistance into LAC germplasm; marker-assisted selection	Special projects	Shared expertise: improved understanding
IPM - Biological control	All Centers	Exchange of natural enemies across crops (entomopathogens)	Systemwide IPM or inter-Center project	Shared expertise & reduced pesticide use; exchange of biocontrol agents
IPM - Principles and procedures specific to roots and tubers	Some or all Centers	Gain efficiency from combining knowledge and resources on IPM	Inter-Center projects	Research efficiency; broad application of results
Geographical Information Systems				
Mapping production zones for roots and tubers (area, biophysical traits, socioeconomic criteria)	CIAT, CIP, IITA, IFPRI	Integrate information from biophysical and socioeconomic databases in different Centers	Special projects	Better criteria for research prioritization
Mapping of pest and disease outbreaks	CIAT, CIP, IITA	Discover theory and principles related to pest and disease outbreaks	Special projects	Improved prediction ability, linked to pest and disease management
Capacity-building				
Training	CIAT, CIP, IITA, AROs	Improve capacity of local institutions; address problems and opportunities more effectively	Network merging; joint network activities; joint training exercises; develop training plans for 1/2/3 year periods	Improved research capacity in developing countries
Participatory research methods	All Centers	Exchange experiences and adjust methodologies for client participation in research planning and development	Workshops; joint research projects	Improved research design with higher probability of adoption
Network development	CIAT, CIP, IITA	Make networks more efficient by synergies across crops	Network strengthening and restructuring	Efficiencies in research planning

Contd.

Contd.

Area, Activity	Collaborating Centers (plus appropriate NARS)	Purpose of activity	Mechanism of collaboration	Benefits of collaboration
Public awareness				
Coordinated dissemination of information about roots and tubers	All Centers	Generate interest in funding research and market development	Websites; joint publications; unified approach to donors	Improved awareness of importance of roots and tubers for development; industry investment in root and tuber development
Private sector research initiatives in roots and tubers				
Jointed strategies to motivate private sector investment; research prioritization which includes CGIAR mission	All Centers	Maximize benefits to CGIAR mission from private sector	CGIAR policies on intellectual property rights (IPR) and collaboration of Centers with private sector	Resources and motivation of private sector channeled to benefit developing countries
Policy Support				
Understand and communicate to policymakers the impact of trade and economic policy options on root and tuber sector	CIAT, CIP, IFPRI, IITA	Educate public and policymakers of importance of roots and tubers for development objectives	Special studies directed toward roots and tubers	Consideration of the beneficiaries in root and tuber sector

Source: Compiled for this study.

strategies for each of the root and tuber crops are developed and executed independently by the Center with the corresponding "mandate." Once the strategies have been laid out, the corresponding project managers seek opportunities for collaboration among the Centers. See Table A17 for strengths and vulnerabilities of the present root and tuber research organization. It is worth bearing in mind that some observers might think of the "vulnerabilities" as strengths. The system of "mandates" for certain crops and competition between Centers for funding, for instance, can be perceived as a strong point.

Finally, the 1998 review of the CGIAR itself presented a series of recommendations about the organization and management of research at the CGIAR level, with suggestions about the consolidation of the system and a possible merging of Centers (CGIAR, 1998).

In the light of these developments, we outline here for further discussion and study three scenarios for organizing future synergy in root and tuber research in the CGIAR as well as a framework within which to analyze their relative merits. In any scenario for the future, we want to preserve the several strengths that the current organization affords, while discarding the vulnerabilities. The authors of this document advance no favorites among the scenarios, but we do propose an analysis of each of the options in order to more clearly assess the costs and benefits—financial and otherwise—associated with each. In order for comparisons to be made among the scenarios, a set of criteria could be drawn up and the scenarios "scored" for each criteria, according to whether a change from the present situation would be viewed as positive or negative. Some example criteria could include economies in research infrastructure and operational costs, administration, and management; ability to deliver effective support to national programs; degree of integration of commodity and natural resource management research; and, the costs of making the transition to the chosen scenario.

Table A17. Strengths and vulnerabilities of the present organization of research on roots and tubers in the CGIAR.

Strengths	Vulnerabilities
The multi-commodity Centers, CIAT and IITA, have achieved intra-Center synergy and economies of scale through cross-commodity projects.	The concept of "mandates" and "responsibilities" for certain crops leads to territoriality and competition for resources.
Three Centers, CIAT, CIP, and IITA, have systemwide responsibilities for natural resource management research in eco-regions where their respective commodities are important, thus furthering the integration of commodity and resource management research.	The absence of a mechanism for interaction during the planning and prioritization of research, and before resources are allocated, reduces opportunities for identifying greater levels of synergy and possibilities for sharing resources.
For potato, sweetpotato, and cassava, global germplasm research is advanced by CIP's and CIAT's location at the respective crops' center of origin.	Differing organizational structures and institutional cultures hinder collaboration and smooth communication between Centers.
The Centers' representation and research capacity in secondary centers of diversity address regional constraints and opportunities, and provide global coverage and support to NARs.	The absence of a common "outreach" strategy (strategy for interacting with our partners) leads to inefficiencies in our relations with NARS and collaborators in developed countries.
The Centers have a research infrastructure and a knowledge base in place on which to base future research.	The move to project-based research at CIAT, CIP, and IITA has reduced the level of internal integration among research areas (germplasm, crop management, and postharvest processing and marketing), and the level of communication and collaboration between these Centers.
The CICRTCR provides a mechanism for cross-Center dialogue from which joint activities can be initiated and, potentially, a means of providing greater participation of stakeholders in decision making.	The resource allocation process for roots and tubers, which is undertaken by the individual Centers, leads to an overall resource allocation, at the level of the CGIAR, which may not be targeted to resolving the most important constraints or realizing the most important opportunities afforded by this group of commodities as a whole.

Source: Compiled for this study.

The three scenarios

Continued informal collaboration. The first of our scenarios would build on the existing organization but modify it to reduce the effects of its vulnerabilities. The role of the CICTRCR would be strengthened, converting it to a permanent mechanism for incorporating the views and needs of our partners. Each Center would dedicate resources to a common fund for financing or "seeding" projects of common interest in program areas that had been assigned high priority. The collaborative projects could either be commissioned by the CICRTCR itself or generated through a competitive bidding mechanism. Under this scenario, there would be organizational adjustments within the individual Centers, in terms of both inter-Center relations and the costs of projects.

A global collaborative root and tuber program. A convening Center would oversee a wide range of global collaborative root and tuber research that would constitute the System-wide Root and Tuber Crop Program (SRTCP). The SRTCP would be governed by a directing committee drawn from the participating Centers and from non-CGIAR organizations and national and regional representatives with interests in root and tuber research. This committee would construct a common planning, prioritizing, and evaluating framework that would be used to develop global, high-priority research projects in those specific areas where past experience has shown individual Centers, and organizations outside the CGIAR, lack sufficient expertise or infrastructure to undertake, let alone capture, the gains from such endeavors. This would include work on biotechnology, post-production research (e.g. research on starch, feed, and agro-enterprise development), and institutions and policy.

The specific intent would be to realize efficiencies and achieve greater impact by closer collaboration between Centers in these fields, as well as between the Centers and their collaborators in developed and developing countries. The SRTCP would provide an organizational mechanism whereby the potential breakthroughs related to research on root and tuber crops could be more effectively captured, to the benefit of small farmers and low-income consumers worldwide. These projects would constitute the global program. The projects would be funded by core resources from each participating Center, and managed by the global program. In this scenario, the SRTCP would not represent the totality of root and tuber research. Individual Centers would continue to mount their own projects in those areas where collaboration provides no benefits.

A root and tuber Center. This is the most ambitious of the scenarios: a single Center devoted to research on roots and tubers. It also would be the most costly in terms of its establishment, although in the medium term the transaction costs of collaboration among the existing Centers that presently do root and tuber research would be virtually eliminated. Creation of this Center would require the naming of a board and selection of management. We envisage the adoption of a decentralized approach to research and outreach, making use of the infrastructure already in place. Once the Center's research strategy had been established, the new organization would decide on placing research projects in the most appropriate existing facilities of the CGIAR Centers that presently are conducting root and tuber research, or other CGIAR Centers, or third party organizations.

The CGIAR, roots and tubers, and the future

Options 1 or 2 could be accomplished within the present organizational framework of the CGIAR. The last option, the creation of a root and tuber Center, would need to be debated and agreed upon at the level of the CGIAR.

The adoption of any of the scenarios would have profound effects, not only on the Consultative Group and its constituent members, but also on roots and tubers—the potato, sweetpotato, cassava, yam, and Andean crops—and the two billion plus people in developing countries who rely on them for their staple foods, for their livelihoods, and even for their survival. These are the most vulnerable people in the global society, and the CGIAR is one of the few organizations that consistently looks out for their interests.

Acronyms and abbreviations

AB-DLO	Research Institute for Agrobiology and Soil Fertility, Netherlands
ACIAR	Australian Centre for International Agricultural Research
AFLP	amplified fragment-length polymorphism
AHI	African Highlands Ecoregional Program
AIT	Asian Institute of Technology
ALAP	Asociación Latinoamericana de la Papa
ANSWER	Asian Network on Sweet Potato Genetic Resources
APA	African Potato Association
ARARIWA	Asociación Arariwa para la Promoción Técnico Cultural Andina
ARI	Agricultural Research Institute, Tanzania
AROs	advanced research organizations
ART	Andean roots and tubers
AUSAID	Australian Agency for International Development
AVRDC	Asian Vegetable Research and Development Center
BBA	Biologische Bundesanstalt, Institut für Biologischen Pflanzenschutz, Germany
BRA	Bureau de Recherche Agricole du Ministère de l'Agriculture, Chad
Bt	*Bacillus thuringiensis*
BU	Brabender units
BW	bacterial wilt
CAAS	Chinese Academy of Agricultural Sciences
CACOM	Central American Common Market
CAD	cassava anthracnose disease
CAP	Common Agricultural Policy of the European Union
CARDI	Caribbean Agricultural Research and Development Institute, Barbados
CARE	Cooperative for Assistance and Relief Everywhere
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza
CBB	cassava bacterial blight
CBN	Cassava Biotechnology Network
CBSD	cassava brown streak disease
cDNA	complementary DNA
CECOACAM	Central de Cooperativas Agrarias de Cañete y Mala, Peru
CENARGEN	Centro Nacional de Recursos Genéticos, Brazil
CERAT	Centro de Raizes Tropicais, Brazil
CGIAR	Consultative Group on International Agricultural Research
CGM	cassava green mite
CGN	Centre for Genetic Resources, Netherlands
CIAD	Center for Integrated Agricultural Development, China
CIAT	Centro Internacional de Agricultura Tropical
CICRTCR	Committee on Inter-Centre Root and Tuber Crops Research (formerly the ICRTCR)
CICV	Centro de Investigación en Ciencias Veterinarias, Argentina
CIED	Centro de Investigación, Educación, y Desarrollo, Peru
CIGB	Commission International des Grand Barrages

CIP	Centro Internacional de la Papa
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CMD	cassava mosaic disease
CMPGR	Caribbean Committee for the Management of Plant Genetic Resources
CNPH	Centro Nacional de Pesquisa de Hortaliças, Brazil
CNPMF	Centro Nacional de Pesquisa em Mandioca e Fruiticultura Tropical, Brazil
CNRST	Centre National de la Recherche Scientifique et Technologique, Burkina Faso
CONDESAN	Consortium for the Sustainable Development of the Andean Ecoregion
CORPOICA	Corporación del Instituto Colombiano Agropecuario
COSCA	Collaborative Study of Cassava in Africa
COSUDE	Swiss Agency for Development and Cooperation
CPC	Commonwealth Potato Collection, SCRI, UK
CPRA	Centre de Perfectionnement et de Recyclage Agricole de Saïda, Tunisia
CPR-IPO-WAU	Centre for Plant Breeding and Reproduction Research, Research Institute for Plant Protection, Wageningen Agricultural University, Netherlands
CPRI	Central Potato Research Institute, India
CRIFC	Central Research Institute for Food Crops, Indonesia
CSRS	Centre Suisse de Recherches Scientifiques
CTCRI	Central Tuber Crops Research Institute, India
DRHFV	Direction des Resources Humaines de la Formation et de la Vulgarisation, Benin
DRTA	Direction de la Recherche et de la Technologie Agricoles, Chad
EARRNET	Eastern Africa Rootcrop Research Network
EC	European Community
EMBRAPA	Empresa Brasiliera de Pesquisa Agropecuária, Brazil
EPHTA	Ecoregional Program for the Humid and Sub-humid Tropics of Africa
ESARC	Eastern and Southern Africa Research Center, Uganda
ESEAP	East and Southeast Asia and the Pacific, CIP region
ETH	Centre Suisse de Recherches Scientifiques
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Database
FOFIFA	Centre National de Recherche Appliquée au Développement Rural, Madagascar
FONAIAP	Fondo Nacional de Investigaciones Agropecuarias, Venezuela
FOODNET	Postharvest and Marketing Research Network for Eastern and Central Africa
FORTIPAPA	Fortalecimiento de la Investigación y Producción de Semilla de Papa en el Ecuador
FPR	farmer participatory research
FW	fresh weight
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GILB	Global Initiative on Late Blight
GIS	geographical information system
GRENEWECA	Genetic Resources Network for West and Central Africa
GTZ	Deutsche Gessellschaft für Technische Zusammenarbeit
ha	hectare
HDP	High demand/production growth scenario
HKU	Hong Kong University
IAR	Institute of Agricultural Research, Cameroon
IAR	Institute of Agricultural Research, Ethiopia
IAR	Institute of Agricultural Research, Sierra Leone
IARC	international agricultural research center
IAR&T	Institute of Agricultural Research and Training, Nigeria
IAS	Institute of Agricultural Sciences, Vietnam
IAV	Institut Agronomique et Vétérinaire, Morocco
IBPGR	International Board on Plant Genetic Resources
IBTA	Instituto Boliviano de Technología Agropecuaria
ICA	Instituto Colombiano Agropecuario

ICAR	Indian Council for Agricultural Research
ICIMOD	International Centre for Integrated Mountain Development
ICIPE	International Centre for Insect Physiology and Ecology
ICM	integrated crop management
ICRA	Institut Centrafricain de la Recherche Agronomique, Central African Republic
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICRTCR	Inter-Centre Committee on Root and Tuber Crop Research in the CGIAR (subsequently the CICRTCR)
ICW	International Centers' Week
IDEA	Instituto Internacional de Estudios Avanzados, Venezuela
IDESSA	Institut des Savannes, Côte d'Ivoire
IDM	integrated disease management
IDRC	International Development Research Centre, Canada
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IFPSIM	International Food Policy Simulation Model
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIN	Instituto de Investigación Nutricional, Peru
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
ILTAB	International Laboratory for Tropical Agriculture Biotechnology
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INCV	Institut National des Cultures Vivrieres, Togo
INERA	Institut National d'Etudes et de Recherches Agricoles, Burkina Faso
INERA	Institut National d'Etudes et de Recherches Agricoles, D.R. Congo
INIA	Instituto Nacional de Investigaciones Agropecuarias, Chile
INIA	Instituto Nacional de Investigaciones Agropecuarias, Peru
INIAP	Instituto Nacional de Investigaciones Agropecuarias, Ecuador
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico
INIFAT	Instituto Nacional de Investigaciones Fundamentales de Agricultura Tropical, Cuba
INIVIT	Instituto Nacional de Investigación de Viandas Tropicales, Cuba.
INRA	Institut National de Recherche Agronomique, France
INRAB	Institut National de Recherches Agronomiques, Benin
INRAN	Institut National de Recherches Agronomiques du Niger, Niger
INRAT	Institut National de la Recherche Agronomique de Tunisie
INSA	National Root and Tuber Crop Improvement Institute, Vietnam
INTA	Instituto Nacional de Tecnología Agropecuaria, Argentina
IPB	Institute of Plant Breeding, Philippines
IPDM	integrated pest and disease management
IPGRI	International Plant Genetic Resources Institute
IPM	integrated pest management
IPR	intellectual property rights
IRAD	Institute of Agricultural Research for Development, Cameroon
IRAG	Institut de la Recherche Agronomique de Guinee, Guinea
IRD	Institute of Research for Development (formerly ORSTOM)
IRETA	Institute for Research Extension and Training in Agriculture, University of South Pacific, Western Samoa
ISAR	Institut des Sciences Agronomique du Rwanda
ISNAR	International Service for National Agricultural Research
ISRA	Institut Senegalais de Recherches Agricoles, Senegal
ISRAT	Institut de Recherche en Sciences Appliquées et Technologies, Burkina Faso
ISTRC	International Society for Tropical Root Crops
ISTRC–AB	International Society for Tropical Root Crops–Africa Branch
ITRA	L'Institut Togolais de Recherche Agronomique, Togo
JIC	John Innes Centre, UK
JIRCA	Japan International Research Center for Agricultural Sciences
JKUAT	Jomo Kenyatta University of Agriculture and Technology, Kenya

KARI	Kenyan Agricultural Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KNAES	Kyushu National Agricultural Experimental Station, Japan
KNARDA	Kano Agricultural Research and Development Association, Nigeria
KUL	Katholieke Universitet Leuven, Belgium
LAC	Latin America and the Caribbean
LB	late blight
MAFF	Ministry of Agriculture, Fisheries and Food, UK
MARDI	Malaysian Agricultural Research and Development Institute
MERCOSUR	Common Market of South America
MIP-JAD	Programa de Manejo Integrado de Plagas, Dominican Republic
MPI	Max Planck Institute, Germany
MSIRI	Mauritius Sugar Industry Research Institute
NAAPRI	Namulonge Agricultural and Animal Production Research Institute, Uganda
NAFTA	North American Free Trade Agreement
NARC	Nepal Agricultural Research Council
NARIs	national agricultural research institutes
NARO	National Agricultural Research Organization, Uganda
NARS	national agricultural research systems
NCRI	National Cereal Research Institute, Nigeria
NCSU	North Carolina State University, USA
NPRCRTC	Northern Philippine Root Crops Research and Training Center
NRCRI	National Root Crop Research Institute, Nigeria
NRI	Natural Resources Institute, UK
NUS	National University of Singapore
OECD	Organization for Economic Cooperation and Development
ORSTOM	Institut Français de Recherche Scientifique pour le Développement en Coóperation (subsequently IRD)
PCCARD	Philippine Council for Agriculture and Resources, Research and Development, Philippines
PCR	polymerase chain reaction
PHI	Post Harvest Institute, Vietnam
PHTI	Post Harvest Technology Institute, Singapore
PLRV	potato leaf roll virus
PRACIPA	Programa Andino Cooperativo de Investigación en Papa, CIP network
PRAPACE	Programme Régional de l'Amélioration de la Culture de la Pomme de Terre et de la Patate Douce en Afrique Centrale et de l'Est, CIP network
PRCRTC	Philippines Root Crop Research and Training Center
PRECODEPA	Programa Regional Cooperativo de Papa, CIP network in Central America and the Caribbean
PRGA	Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation
PROCIPA	Programa Cooperativo de Investigaciones en Papa, CIP network in Southern Cone
PROINPA	Proyecto de Investigación de la Papa, Bolivia
PVX	potato virus X
PVY	potato virus Y
RAPD	random amplified polymorphism
RECSEA-PGR	Regional Collaboration in South East Asia on Plant Genetic Resources
REDARFIT	Andean Network on Plant Genetic Resources
REMERFI	Mesoamerican Network of Plant Genetic Resources
RFLP	restriction fragment length polymorphism
RILET	Research Institute for Legumes and Tubers, Indonesia
RIV	Research Institute for Vegetables (formerly Lembang Horticultural Research Institute), Indonesia
RTIP	Root and Tuber Improvement Program, Ministry of Agriculture, Tanzania
SAAS	Sichuan Academy of Agricultural Sciences, China
SADC	South African Development Community
SAFTA	South Asia Free Trade Association
SARRNET	Southern Africa Rootcrop Research Network
SCIB	South China Institute of Botany

SCPC	Southern China Potato Center, China
SCRI	Scottish Crop Research Institute, UK
SGRP	System-wide Genetic Resources Programme
SGS	southern Guinea savanna
SINGER	CGIAR System-wide Information Network on Genetic Resources
SPGRC	Southern African Development Community (SDRC) Plant Genetic Resources Centre
SPCSV	sweetpotato cholorotic stunt virus
SPFMV	sweetpotato feathery mottle virus
SRTCP	System-wide Root and Tuber Crop Program
SSA	Sub-Saharan Africa
SSR	single sequence repeats
SWOPSIM	Static World Policy Simulation, modeling framework
TAC	Technical Advisory Committee of the CGIAR
TALPUY	Grupo de Investigación y Desarrollo de la Ciencia Andina, Peru
TCRC	Tropical Crops Research Center, Bangladesh
TFNC	Tanzania Food and Nutrition Centre
TISTRC	Thailand Institute of Scientific and Technological Research Centre
TPS	true potato seed
TRIS	Tuber and Root [Crops] Information System
UMATA	Unidad Municipal de Asistencia Técnica Agropecuaria, Colombia
UNB	Université Nationale du Benin
UNESP	Universidade Estaduale Paulista, Brazil
UPLB	University of the Philippines at Los Baños
UPM	University Putra Malaysia
UPWARD	Users' Perspective with Agricultural Research and Development
USDA	United States Department of Agriculture
VASI	Vietnam Agricultural Science Institute
VIR	Vavilov Institute, Russia
ViSCA	Visayas College of Agriculture, Philippines
WANA	West Asia and North Africa
WIAD	Women in Agricultural Development, Ghana
WTO	World Trade Organization
XSPRC	Xuzhou Sweet Potato Research Center, China
YAD	yam anthracnose disease
YMV	yam mosaic potyvirus

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