2006-1 Working Paper

Prospects for Enhancing Value of Crops through Public-Sector Research: Lessons from Experiences with Roots and Tubers

Thomas Walker, International Potato Center (CIP)
Keith O. Fuglie, International Potato Center (CIP)

CENTRO INTERNACIONAL DE LA PAPA • CIP

ISSN 0256-8748
Social Sciences
Working Paper
No. 2006 - 1

Working Paper

Prospects for Enhancing Value of Crops through Public-Sector Research: Lessons from Experiences with Roots and Tubers

Thomas Walker, International Potato Center (CIP)*
Keith O. Fuglie, International Potato Center (CIP)
* Currently affiliated to Michigan State University

The Social Sciences Working Paper Series is intended to advance social science knowledge about production and utilization of potato, sweetpotato, and root and tuber crops in developing countries to encourage debate and exchange of ideas. The views expressed in the papers are those of the author(s) and do not necessarily reflect the official position of the International Potato Center.

Comments are invited.

Prospect for Enhancing Value of Crops through Public-Sector Research:
Lessons from Experiences with Roots and Tubers

ISSN 0256-8748

International Potato Center
Apartado 1558, Lima 12, Peru
cip@cgiar.org • www.cipotato.org

Correct citation:
Walker, T.W. and K.O. Fuglie. Prospects for Enhancing Value of Crops through Public-Sector Research: Lessons from Experiences with Roots and Tubers. International Potato Center (CIP), Lima, Perú. 2005.

Produced by the CIP Communication and Public Awareness Department (CPAD)

Production Coordinator
Cecilia Lafosse

Design and Layout
Elena Taipe and contributions from Graphic Arts

Printed in Peru by Comercial Gráfica Sucre
Press run: 150
January 2006

Table of Contents

Abstract

As international agricultural research centers places greater emphasis on poverty reduction, a debate is underway whether higher priority should be given to research to “add value” to agricultural commodities through post-harvest innovations at the expense of the traditional emphasis given to agricultural production. In particular, post-harvest research is seen as a way of creating new markets for commodities that may be in surplus or are facing declining demand. In this paper we review the evidence on the economic benefits from past public investments in post-harvest research to increase value of two major food crops – potato and sweetpotato. For the review we draw upon the experiences of two research institutions: first for the United States public research system during the early 20th Century and then for the International Potato Center (CIP) since its post-harvest research program began in 1975. Most of the evidence from both the U.S. and CIP’s experiences strongly suggests that public sector investment in generating value-enhancing technologies for potato and sweetpotato has been characterized by a low rate of return. New product development is a particularly risky endeavor. Implications for investment by international agricultural research centers in value-enhancing agricultural research are discussed.

Keywords: Economic impact assessment; International agricultural research; International Potato Center, Post-harvest research; Potato (*Solanum tuberosum*); Sweetpotato (*Ipomea batatas*).

Acknowledgements

We are grateful to Gordon Prain, Dapeng Zhang and Maria Palacios for discussing the fate and prospects of some of the technologies discussed in the paper. We thank Princess Ferguson for editorial assistance and Zandra Vasquez for Secretarial support. The views expressed are solely those of the authors.

Prospects for Enhancing Value of Crops through Public-Sector Research: Lessons from Experiences with Roots and Tubers

Introduction

The system of international agricultural research centers (IARC) that comprise the Consultative Group for International Agricultural Research (CGIAR) has achieved notable successes in increasing productivity in food crop production, especially in cereals, in developing countries since the system was formed in the early 1960s (Anderson, Herdt and Scobie, 1988). As the CGIAR moves to place greater emphasis on poverty reduction, a key strategic question is whether the emphasis given to research on staple food crops should be reduced in favor of more research to "enhance value" of agricultural commodities. With an apparent global oversupply of grain putting downward pressure on farm prices, research to find new markets for agricultural commodities and reduce post-harvest costs may seem a more promising approach to raising the incomes of the rural poor. "Value-enhancing" research[1] can take many forms, including reducing post-harvest crop losses and other marketing costs, developing new products to increasing market utilization of agricultural commodities, and encouraging adoption of higher-valued commodities or more diverse agricultural production systems. Some CGIAR centers have in fact invested considerable resources in attempting to add value to food crops, especially for root and tuber crops, demand for which tends to fall as incomes rise. Goletti and Wolff (1999) suggest that IARC investment in post-harvest research and training is likely to be a high impact area. They recommend more investment not only because of high expected internal rates of return, but also because of the international public goods character of such research and because of potential favorable effects on poverty reduction, food security, health, and sustainable resource use. A CGIAR review panel on harvest and post-harvest problems also recommended more (selective) investment in post-harvest research together with a shift in emphasis from "field" to "utilizable" production along "production-consumption" continuum (TAC Secretariat, 1997). Increasing globalization and competitiveness reinforce trends processed products, more "exotic" characteristics in food, and diet diversification away from staples (Reardon et al., 2001). This changing external environment would also seem to favor the case for more investment in post-harvest research. On the other hand, a meta-analysis of rate-of-return studies in agricultural research in developing and developed countries shows that the vast majority of success stories analyzed come from production-related commodity research (Alston et al., 1998).' An absence of

[1] In this paper, we use the terms "value-enhancing research " and "post-harvest research" interchangeably.

well-documented rate-of-return studies in a broad thematic area may suggest that research in that area is not as productive as another area where success stories are numerous or larger in terms of net present value (Evenson, 2001). Moreover, post-harvest loss assessment is imprecise and often results in overestimates (Greeley, 1991), which may lend to overestimates of potential gains from post-harvest loss reduction. Furthermore, direct benefits from product development for niche markets are usually small and local, and the size of indirect benefits depends on the availability of production technologies that are adopted in response to end use expansion (Gottret and Raymond, 1999). These factors raise questions whether increased emphasis on post-harvest research is the right strategy for the CGIAR.

In this paper we review the experiences of two efforts by public sector research institutions to add value to root and tuber crops and draw lessons from these experiences to the current debate on the role of agricultural value-enhancing research in the CGIAR. The first case study reviews the experience of the United States public agricultural research program in the first half of the 20th Century to increase utilization of potato (*Solanum tuberosum*) and sweetpotato (*Ipomea batatas*). The motivation for surveying the U.S. experience about the impact of public sector investment in potato and sweetpotato post-harvest research centers on the possibilities of establishing some lessons that could be applicable to contemporary developing country conditions. The United States is the only developed country where both potato and sweetpotato have been nationally or regionally important. The second case study reviews the impact of research on storage, processing, and new product development at the International Potato Center (CIP), one of the CGIAR centers. Over the past 25 years, CIP has made a modest but continuing investment in post-harvest research first for potato and later also for sweetpotato. However, in both the U.S. and CIP experiences, clear-cut successes of public sector post-harvest research turn out to be hard to identify. A key lesson we draw from the review is that the CGIAR should approach agricultural post-harvest research cautiously and selectively.

CASE 1: RETURNS TO POST-HARVEST POTATO AND SWEETPOTATO RESEARCH IN THE UNITED STATES

The United States is the only developed country where both potato and sweetpotato have been nationally or regionally important. In particular, sweetpotato fit the description of a semi-subsistence crop of regional importance. As late as the 1950s, about half of production in the United States was consumed on-farm. Potatoes became a staple in the early 19th century and were cultivated by several million small farm households. Geographic specialization in production also took more time for potato and sweetpotato (in the 1930s) than for other major field crops. For our purposes, the first part of the 20th Century is the most interesting period not only because of the structure of farm production and the low productivity levels but also because of government initiatives in post-harvest research. We limit our review to technologies related to storage, processing, and product development.

Potato

By the early 19th century, potatoes were being extensively cultivated for multiple end uses including animal feed and starch. The late blight epidemic of the 1840s (which affected not only Europe but the US as well) caused potato prices to rise and dealt a severe blow to the starch-making industry in the Northeast of the country (Bidwell, 1925). The industry subsequently recovered, and small starch mills were an important outlet for potatoes particularly in years of surplus production in Maine, the first state to specialize in potato production.

The history of potato production and consumption in the United States is punctuated by several examples where public sector investment in post-harvest research resulted in commercial success. In a very comprehensive and highly readable account of the development of the potato industry in the Red River Valley of North Dakota, Lynda Kenney (1995) vividly describes the practical impact of technological change and the role of different actors in the development of the potato industry. Government-supported, post-harvest (and breeding) research that is acknowledged to have made a difference includes the following:

- In the 1930s, potatoes were stored in underground root cellars that were highly susceptible to condensation that damaged the crop. Farmers knew that this problem could partially be resolved by ventilation, but ventilation, in turn, led to shrinkage. Research on the principles of temperature and humidity control resulted in improved methods of storage in traditional root cellars made of wood. This research initiative was a joint state and federal effort, and it was partially based on discoveries from federally-supported agricultural engineers working on the same problem in Maine. "By the 1940s, the importance of potato storage improvements in the Red River Valley was as significant to the many farmers growing potatoes as bettering production practices and enhancing product quality. Soon the prevalence of inventive building methods and availability of innovative materials instigated the construction of aboveground storage warehouses" (Kenney, 1995, p.101). Although the benefits from improvements in traditional storage were short-lived, this research easily qualifies as a success story in terms of size of impact and attribution. Public sector researchers also figured prominently as one of several institutional actors in the design of aboveground storage.
- A chemical sprout inhibitor Sprout Nip (CIPC) developed by the Pittsburg Plate Glass Company and Cornell University in the early 1960s significantly changed the seasonality of potato storage and marketing. The effectiveness of CIPC was never in doubt; the

efficacy of its application to tons of stored potatoes was the problem (Sawyer, 1962). In the Red River Valley, the Pittsburg Plate Glass Company invested in contract research with farmers to come up with an economical way of applying CIPC. After three years of experimentation, aerosol fogging was found to be the most effective method. The use of Sprout Nip spread rapidly throughout the valley. "Preventing potatoes from sprouting while they are in storage completely revolutionized the marketing of Valley potatoes…growers and processors were able to store potatoes nearly 12 months instead of the five to six months" (Kenney, p. 187). This invention has all the makings of a success story, but more information is needed on the role of researchers at Cornell University.

- In 1956, researchers at the US Department of Agriculture found a way (based largely on a pre-cooking treatment) to reconstitute dehydrated potato flakes to make acceptable mashed potatoes (Willard et al., 1956). Several plants in the Red River Valley started production in the early 1960s. Demand for dehydrated potato flakes peaked in the mid-1970s. Only the most competitive plants characterized by an aggressive marketing strategy survived. Presently, about 10% of national production is dehydrated.
- Potato chips were first prepared in the United States in 1853. With a high ratio of volume to weight, chips were bulky, were difficult to distribute, and were prepared in an urban cottage industry setting characterized by family and household business operations. Modern industrial application was spurred on by the invention of the wax paper bag, the mechanical peeler, and frying technologies (Talburt and Smith, 1975). Significant contributions to the chipping industry in the 1930s are attributed by Kenney to Ora Smith, a professor at Cornell University, but we have not been able to find collaborating evidence to support this claim.
- By 1950, chips accounted for the lion's share of potatoes destined for processing. With the release of Norchip in 1957, round potatoes with high solids content were increasingly grown in the Red River Valley. Indeed, "the Red River Valley went from a relatively small supplier of potatoes for chipping to the largest supplier in the world, thanks to Dr. Robert Johansen and his Norchip variety (L. Currie as cited in Kenney, p. 213)." Potato breeding at North Dakota State University was characterized by the highest rate of return of any public sector potato breeding program in North America in the 2nd half of the 20th Century (Walker and Fuglie, 1999). Farmer adoption of chipping varieties was substantially greater than varieties developed for any other end use including the fresh market.

In spite of these success stories, per capita consumption of potatoes had been falling since the 1920s in accordance with Bennett's law that refers to the "natural" decline in the importance of staple food crops with economic growth. By the mid-1950s the prospects for reversing this trend were not bright (Smith, 1956). Surprisingly enough, Smith's pessimism (more characteristic of an economist than a commodity scientist) was misplaced. The rising opportunity cost of time mainly from women's increasing labor market participation fueled the demand for innovation in food preparation. Two private sector breakthroughs, microwave ovens and frozen French fries, led to a turnaround in potato per capita consumption. By the 1990s, per capita consumption of fresh potatoes had stabilized at about 23 kg/year and increasingly consisted of baked potatoes. In defiance of Bennett's law, average annual per capita potato consumption (fresh and processed) gradually increased over time, from 48 kg in 1960 to 64 kg by 1995 (Economic Research Service, 1999).

Sweetpotato

Sweetpotatoes were a regionally important crop in southeastern United States during colonial times and throughout the 19th Century. Sweetpotatoes in parts of the southeast even attained the status of a staple food crop (Gray, 1933). Gray further states that sweetpotatoes figured prominently in the diets of the poor and that they were destined for diverse end uses, including beer and bread, and even supplemented corn in fattening livestock. However, the crop became even more important in the early 20th century. Growing area increased by about 40% to over a million acres at the height of the Great Depression in 1932. Sweetpotato assumed its traditional role as a "hard times" crop. Two-thirds of the largest crop ever produced was consumed on-farm.

Prior to 1930 sweetpotato also fits the image of a forgotten crop in terms of scientific research. However, it was increasingly receiving attention. George Washington Carver, who is credited with the discovery of more than 100 sweetpotato-related products, stated in 1936 that:

> There are but few if any of our staple farm crops receiving more attention than the sweetpotato, and indeed rightfully so-the splendid service it rendered during the great World War in the saving of wheat flour will not soon be forgotten. The 118 different and attractive products (to date) made from it are sufficient to convince the most skeptical that we are just beginning to discover the real value and marvelous possibilities of this splendid vegetable.
> (George Washington Carver, 1936, as cited in Hill et al., 1992)

In 1938, government investment in post-harvest research was highlighted in the Agricultural Adjustment Act. It provided for the establishment of four regional laboratories with a mandate to conduct research on new uses and markets for crops perceived to be in surplus (Southern Regional Research Center, 2001). Expanding the industrial use of food crops was the main target, and applied chemistry was viewed as the means to that end. The Southern Regional Research Laboratory (now the Southern Regional Research Center) was opened in 1941. Priority commodities were cotton, sweetpotato, and peanuts. The Sweetpotato Products Division figured as one of the initial seven research groups.

The achievements of the Southern Regional Research Center (SRRC) are impressive and include 8,755 publications and 1,035 patents. The website of the Center also lists 30 of their most used inventions. About half of these pertain to cotton and some, such as frozen concentrated orange juice, are well known to the public and have undoubtedly justified the public expenditure in the SRRC. However, only one relates to sweetpotato: precooked dehydrated sweetpotato flakes. This processing technology and the end use of mashed sweetpotatoes are similar to what occurred in potatoes. But, unlike potatoes, there is no commercial demand for the dehydrated sweetpotato flakes; the product is now sold for institutional purposes only.

Starch production is one of the seemingly natural end uses of the so-called starchy staples like sweetpotato. The absence of commercial starch production from sweetpotatoes in the United States cannot be attributed to a lack of government investment:

> In the late 1930s and early 1940s interest was aroused in the South in the possibilities of developing a commercial sweetpotato starch industry. Federal and State agencies successfully solved the technical aspects of starch manufacture from this crop, and plant breeders developed productive varieties with high starch contents. In small-scale commercial trials, sweetpotato starch proved quite suitable for use in certain adhesives, in bakery products, in textile sizings, in cosmetic manufacture, and in laundry products. However, the costs of producing raw stock remained so high that farmers could not grow and handle the crop at prices the extraction plants could afford to pay, and starch production on a commercial basis failed to materialize. Other crops, such as waxy corn and waxy sorghum, contain starches similar to those of the sweetpotato, and they can be grown for starch productions and handled by mechanized methods far more cheaply than sweetpotatoes. Also, seeds of grain crops are more easily handled and stored for prolonged periods than are sweetpotatoes (US Department of Agriculture, 1971, p. 5).

The importance of a stable supply of low-cost raw materials is a recurring theme in the literature on post-harvest product development and in case studies of failed prospects (Wheatley et al., 1995; Meerdink, 1995; Fuglie, 2003). Sweetpotato could not compete with corn as a source of raw material for starch. The growth in productivity of corn in the 20th century also led to the demise of the potato starch industry in the United States.

The desirability of improving sweetpotato yield has been underscored in reporting the history of the crop (Edmond and Ammerman, 1971). There was virtually no productivity growth in sweetpotato prior to the mid 1950s. Average yields in the US had stood at 5-6 t/ha since estimates were first published in the 1860s. With geographic specialization and increasing area of the crop under irrigation, average national yields increased to 15-18 t/ha between 1950 and the mid 1990s. But sweetpotato has lagged far behind potato in productivity growth. Potato yields at the turn of the century were also stagnating at 5 t/ha before the advent of technological change, especially inorganic fertilizer and healthy tuber seed. At present, national average potato yield approaches 40 t/ha. Competitive pressures from Canada have also increased the demand for efficiency associated with high yields in commercial potato production in the United States.

Not surprisingly, sweetpotato prices to growers are now about three times higher than prices received by potato producers. With sweetpotato prices in the 1990s consistently approaching or exceeding US$300 per ton, it is easy to see how the high costs of raw material would limit the feasibility of alternative uses. About two-thirds of the crop is consumed fresh, and the main processed product is canned sweetpotatoes made from lower grade produce. In spite of the high prices offered to growers, sweetpotato has steadily declined in importance. From the high of a million acres in 1932, growing area decreased to slightly less than 90,000 acres in the 1990s.

Declining importance has not dampened researchers' enthusiasm for product development. New products developed since World War II include frozen pie mix, turnovers, breakfast foods, crackers, candy, sweetpotato puree, chips, snacks, and baby food. Of these, only baby food can be considered a commercial success (Johnson et al., 1992).

The story on storage research in sweetpotato seems to be similar to potato. In 1912, USDA researchers conducted on-farm demonstrations with improvements in ventilated storage in the mid-Atlantic and northern States (Edmond and Ammerman, 1971). Ten years later, hundreds of such structures dotted the countryside. Subsequent research on building materials, construction design, and heating systems resulted in optimal temperature and relative humidity that prolonged storage life and minimized losses. The description in Edmond and Ammerman (1971) on the storing and curing of sweetpotatoes suggests large positive returns on the initial research with diminishing returns to storage research over time largely because the initial research was quite successful.

The US experience with sweetpotato product development does not appear to be unique. End use diversification is often perceived as a way to strengthen market demand for staple food crops by supplying products with more elastic demand. Japan more than any other country worked to expand end use diversification in sweetpotato. The crop is used not only for fresh consumption but also for starch, animal feed, processed foods, and fermented stock for alcohol production. Small businesses were particularly active in promoting the crop (Duell, 1992). In spite of a diversified portfolio of end uses, however, production in Japan declined from 7.1 million tons in 1955 to about 1.1 million tons in the late 1990s. The share used by processing industries fell even more rapidly, accounting for only about 5% of production by 2000 (Food and Agriculture Organization, 2003). Similar trends have taken place in South Korea and Taiwan. Sweetpotato produced domestically in these countries has been partially replaced by sweetpotato produced in poorer countries (especially China) where the roots are processed into starch or noodles, that are, in turn, exported to Japan, South Korea, and Taiwan. Domestic sweetpotato production in these countries would likely fall further if trade barriers against imported starch were reduced (Fuglie and Oates, 2003).

Lessons from the U.S. experience

This rapid historical appraisal of returns to public sector investment in post-harvest research on potato and sweetpotato in the US highlights some tendencies or patterns that we generalize into six lessons.

- First, increasing commercialization and international trade do open up new opportunities that occur from time to time. Returns to storage research on both potatoes and sweetpotatoes were almost assuredly greater in the first three decades of the 20th century than in the last three decades. Breakthroughs on potato product development in the 1950s in both the private and public sectors were founded on more basic research on frozen food and dehydrated processing technologies. Dehydrated potato flakes and frozen French fries drew heavily on inventions in processing of frozen and dehydrated foods. Without the abrupt rise in the institutional demand for dehydrated potatoes in World War II, these product innovations would have been delayed.
- Second, globalization can close markets as well as open them. The growing competitiveness of the U.S. economy spelled the demise of several commodity end uses that were prevalent in the 19th Century. In starch production, potatoes and sweetpotatoes could not compete with corn. Nor could they compete with small grains in formulating animal feed. They were in a large sense protected by poor road transport in the relative isolation of the 19th century. An analogy can be made to globalization today.

The road to import substitution and new product development from home-grown commodities will be paved with many dry holes if globalization proceeds at a fast pace.

- Third, the returns to research on product development are commodity specific. In particular, sweetpotato has been a particularly risky choice for new product development. Dozens of products but few success stories are described in the literature, and those that are commercially viable pertain to small niche markets.
- Fourth, plant breeding can contribute to commercial impact in processed products or even in changing consumer preference in the fresh market. On the other hand, the starch experience in sweetpotato indicates that significant advances in breeding may not be sufficient to ensure competitiveness.
- Fifth, successful production research and extension is needed to improve productivity to drive raw material costs down. Without a cheap and reliable source of raw material, processing will not be profitable.
- Finally, like much production research, post-harvest research conducted in one state did have a regional or even national public goods character. Several instances of regional spill-over were described.

CASE 2: SUCCESSES AND FAILURES OF CIP'S POST-HARVEST RESEARCH FOR CROP STORAGE, PROCESSING AND PRODUCT DEVELOPMENT

CIP is one of the CGIAR member institutes with a mandate to conduct research on tropical root and tuber crops.[2] CIP was established in 1971 in Lima, Peru, to conduct research on potato improvement in developing countries. By 1975 post-harvest research was firmly established as one of CIP's nine "thrusts" in its programmatic organization. With the addition of sweetpotato to CIP's research program in 1987, the priority for post-harvest research was strengthened because, unlike potato, sweetpotato was widely perceived to fit the conditions of a starchy staple. Potato dominated CIP's post-harvest agenda in the 1970s and 1980s; sweetpotato has commanded most of the attention in the 1990s. Research on storage has focused on potato; research on product development and processing has centered on sweetpotato. In this section, we examine the impact of some of the technologies that were developed by CIP and its partners over this period.

Storage

Demand for storage in both potatoes and sweetpotatoes is reflected in price seasonality. With the exception of China, price seasonality in sweetpotatoes is limited in the tropics and subtropics

[2] CIP conducts research on potato, sweetpotato, and Andean root and tuber crops. Other CGIAR institutes that research root and tuber crops include the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria, and the International Center for Tropical Agriculture (CIAT) in Cali, Colombia. Since its founding in 1967, IITA has researched

because the crop can usually be produced throughout the year in niche environments that seasonally complement the main season(s). In potatoes, price seasonality is prevalent in the sub-tropics, and storing bulky tuber seed presents challenges and opportunities. We discuss two of CIP's most concerted efforts at improving potato storage.

Diffused light storage for potato seed

Relatively flat prices throughout the year are a characteristic feature of tropical highland potato production destined for the ware (i.e., consumer) market and indicate limited returns to storage. However, when the post-harvest research started at CIP in the mid 1970s, the initial focus was on technologies to reduce losses in ware potatoes in the Andes of Peru (Rhoades et al., 1991). Subsequent research on farmer storage practices showed that farmers were quite knowledgeable about storage concepts, and that they did not regard losses as a major problem. Shrunken or insect-infected potatoes were processed using traditional methods into more storable products or were fed to animals. The real storage problem was tuber seed of new high-yielding varieties, mainly *tuberosum x andigenea* crosses. With farmers' traditional dark storage, stored seed sprouted and shrank excessively. Seed health was compromised, and the potatoes had to be desprouted by hand before planting. Applying the principle that light inhibited sprout elongation (Dinkel, 1963), scientists in the post-harvest program designed and tested diffused light storage (DLS) in the late 1970s. Compared to traditional dark storage, sprout length was reduced from about 20 cm to 2 cm, and yields increased by about 15% in multi-location on-station trials. On-farm trials led to similar results: significantly shorter, more vigorous sprouts and a yield advantage of about 10% equivalent to about 1.0-1.5 t/ha.

An important advantage of diffused light storage is that it is a principle that can be adapted to many circumstances (Jarvis, undated). There is no fixed recipe for storage design, but some critical level of light intensity must be maintained to prevent excessive sprouting. Diffused light storage is particularly suited to small farm households. Ideally, one can use the diffused light principle to adapt to existing conditions of home storage without building costly structures outside the home where potatoes are traditionally stored. CIP promoted the farmer adaptation of diffused light storage not only in the Andes and other tropical countries.

The results of early adoption studies suggested considerable potential for the technology. By 1984, several thousand small potato farmers in Peru, Sri Lanka, the Philippines, Guatemala, and Colombia were using DLS. However, adoption of DLS did not lived up to its early expectations. It has been easier for NGOs and government extension staff to work with a fixed recipe and

cassava, sweetpotato, and yam. CIAT (founded 1968) has a global mandate for cassava research. Both IITA and CIAT also conduct post-harvest research for these crops.

construct demonstration structures than to work with farmers to adapt the principle of diffused light to their particular conditions. CIP has not carried out any adoption surveys on DLS in the 1990s, but anecdotal evidence from the Andes suggests that efforts focusing on building structures have not been successful.

Nevertheless, DLS easily qualifies as an economic success story. Based on the data presented in Rhoades et al. (1991) and the perception of sluggish adoption in the late 1980s and 1990s, the internal rate of return on investment would most likely be impressive in the range of 30-50%, but with a relatively small net present value between 3 and 5 million U.S. dollars. These estimates are very similar to those obtained for conventional (and successful) integrated pest management projects. They get off to a quick start but are hard to scale up (Walker and Crissman, 1996).

Evaporative cool storage for ware potatoes

Cool season production in the subtropics of South and Southeast Asia is not only where potato production is expanding at the fastest rate but is also characterized by sharp seasonality in price. Potatoes on the Indo-Gangetic plains of India, Pakistan, and Bangladesh and in the Red River Delta of Vietnam are harvested in February and March, the months of seasonal low prices. Prices rise sharply until September when the rainy season production comes in from the hills. Temperatures in May often exceed 40 degrees C, and in South Asia large-scale refrigerated storage is common especially for seed potatoes. Small-scale rustic farm storage plays an important role in meeting potato storage needs for a few months after harvest. These rustic farm stores provide a low cost means of meeting storage needs and also enable small farmers to benefit more directly from storage. But a significant constraint facing rustic farm stores is the high rate of losses from transpiration, pests and diseases. Presumably, there would be scope for an intermediate technology that would be more effective than rustic storage but less expensive than cold storage.

Beginning in the mid-1980s, scientists from the Indian Central Potato Research Institute and the International Potato Center began working on ways to improve on-farm potato storage methods. Since weight and moisture losses in farm stores are due mostly to high ambient temperatures, scientists tested evaporatively-cooled structures to lower temperatures inside a store and thus reduce losses from transpiration. In evaporative cool storage (ECS) a pan of water is placed beneath the store and potato tubers are cooled as evaporating water from the pan is drawn into the storage structure. From 1993 to 1996, ECS was tested in 40 on-farm trials in Uttar Pradesh under farmer-managed conditions and compared with farmers' traditional, "clamp" methods of storage (Fuglie et al., 2000).

The results of the trials verified that with good management, ECS performed significantly better than farmers' rustic storage methods. Average losses after three months of storage were reduced from around 24% of initial weight in farmers' clamps to 10% in ECS. For a typical 10-ton store, this implies that an additional 1.4 tons of potatoes could be marketed each year. Another advantage of ECS is that they can extend the duration that a farmer can maintain on-farm storage from three months to four months, enabling him or her to benefit from seasonally higher crop prices. However, ECS involves higher construction and maintenance costs compared with farmers' methods. Capital costs of ECS for a 10-ton store amounted to 21,000 Rp stored compared with only 1,000 Rp using the farmers' traditional storage method: an increase in capital outlay equivalent to more than 4 tons of potatoes. Acceptance of the technology by farmers depends on whether the benefits from lower losses and higher prices are sufficient to offset the additional storage construction costs. Benefit-cost analysis found that construction costs of ECS would have to be reduced by at least 30% before many farmers would likely find them a profitable alternative to their traditional methods (Fuglie et al., 2000). Further refinements to ECS to reduce construction costs or extend their use to store other crops would improve their profitability relative to farmers' rustic storage methods.

Processing and product development

The fate of case studies in the product development manual

One of the outstanding products of the CIP post-harvest program is *A Manual on Product Development: Adding Value to Root and Tuber Crops* (Wheatley et al., 1995). The manual was developed jointly by post-harvest specialists in CIP and CIAT and distills CIAT's experience in product development in cassava and CIP's experience in potato and sweetpotato. Part 1 of the manual is divided into seven units on opportunities, lessons, and guidelines for product development. The importance of checklists of criteria for the screening of products and the need of a pilot plant are emphasized. Case studies of product development are summarized in Part II. The first five are about cassava, and the second five center on potato and sweetpotato. Two of the last five were selected to illustrate what went wrong and what not to do. The other three were on-going concerns at the time the manual was being developed. Unfortunately, these three product development initiatives have not panned out and are no longer functioning.

Product development is especially difficult in potatoes because the commodity is generally higher in price and lower in quality in tropical developing countries compared with temperate developed countries where potato processing is widespread. The principal end uses in demand are frozen French fries, the most visible and rapidly growing segment of the market, and potato chips (crisps). Producing frozen French fries is characterized by large economies of scale with plant size about US$25 million. Large French fry processors operate on very small margins. For every dollar sold of French fries in a fast food restaurant, only 2.5 cents accrue to producers; processors receive 6 cents, and the restaurant retains 90 cents (Guenthner, 2000). Producing potato chips should be a more viable proposition for developing countries. However, due to their high volume to weight ratio, potatoes have to be chipped in urban areas close to the centers of consumption. Rustic processing of potatoes in rural India – one of the case studies reported in the product development manual – was characterized by several technical problems (Nave and Scott 1991), but one of the underlying reasons for the limited success of the project was the lack of respect for geographic advantage in processing chips.

The development and attempts at commercialization of dehydrated crops in a packaged mix in Peru is another CIP-related product development experience that is instructive (Scott, et al., 1993). In the late 1970s, the post-harvest program carried out research to improve the drying efficiency of traditional sun-dried processed products. No introduced method worked well. Moreover, farmers did not see sun drying as problematic. Attention then shifted to the large-scale production of *papa seca* (dried potato), one of the traditional products, in a community-run processing plant. The consumer market was too small to support an industrial application, and the price of the raw material was too high. These two negative experiences in the late 1970s with the processing of traditional products supposedly highlighted the need for new product development. Incorporating processed potatoes in highly nutritious mixes with other crops became the new focus. After some testing an "M6" mix combining potato (30%) with rice, oats, barley, and corn flour was found to be the most suitable. A pilot processing plant was built at CIP's highland research station in Huancayo in 1984. The mix was evaluated in consumer surveys and found to be acceptable but expensive. The technology was modified, and commercial testing took place as a project led by a non-government organization (NGO) with the dual objectives of improving the welfare of the urban poor and the development of rural cottage industry. With larger scale commercial production, M6 morphed into M5 and soon became M4 and another new product, *Chicolac*. "The process of experimentation and new product development was accompanied by an evolution in project goals. Gradually, the improvement of living standards among the poor; peasant productivity levels, and, rural food security received lower priority. Instead, the project increasingly focused on the need for profitability to sustain operations" (Scott et al., 1993, p. 156). Although the commercial pilot project had some successes, it did not live up to expectations and has not been replicated.

Processing and product development on sweetpotato in East Asia

Product development in sweetpotato in China faces brighter prospects than in potato in general and in East Asia in particular. Sweetpotato and cassava are widely used as a source of starch by food and non-food industries in Asia. Sweetpotato is also used extensively for animal feed in China and Vietnam, and cassava converted into pellets for animal feed emerged as a major export commodity for Southeast Asia in the 1980s. Nevertheless, root and tuber crops face significant post-harvest utilization constraints due to their bulkiness and perishability.

Cassava is usually a lower cost source of raw material than sweetpotato in tropical regions so the potential for sweetpotato processed products is greatest in subtropical regions, such as Southwest China, where cassava production is limited by frost (Fuglie, 2003). In the late 1980s and 1990s CIP together with partners from Chinese national research institutions worked on improving utilization of sweetpotato for food industries in China. Surveys showed that Chinese rural households had a long tradition of using sweetpotato to extract starch and produce noodles, mainly for home consumption. Economic reforms introduced in China in the 1980s opened up commercial opportunities for sweetpotato starch and noodle processing in rural areas. However, processing technology was labor intensive, the average starch extraction rate was low, and starch was of poor quality (Wheatley et al., 1997). While sweetpotato roots and vines are also used extensively as pig feed in China, nutrient uptake and feed storage conditions were found to be poor. CIP concentrated its efforts on 1) developing small-scale machinery for improved starch extraction and noodle production, 2) improving efficiency of sweetpotato as animal feed, 3) developing new food products from sweetpotato, and 4) breeding new crop varieties for higher starch yield.

By the mid 1990s several farm machinery manufacturers in Sichuan Province had adopted improved designs for starch and noodle processing equipment and extended these machines to small enterprises in rural China (Gong, 1996). The new machines improved starch recovery, saved labor, and gave high starch purity and better noodle color (Gong, 1996). The use of sweetpotato for starch and noodle production became an increasingly important commercial undertaking in major sweetpotato-producing areas of China, especially in Sichuan and Shandong provinces. However, the future for small-scale starch and noodle producers in China is uncertain. Economies of scale and quality factors favor large-scale enterprises, especially in noodle production and snack foods. Strong evidence of attribution is another missing ingredient in this potential success story of improved processing equipment. There are many players in the sweetpotato processing story, including local governments and especially private entrepreneurs. It is difficult to determine how instrumental was the role of CIP in the development and dissemination of processing improvements.

The issue of attribution looms large in another success story in sweetpotato product development in Sichuan (International Potato Center, 2001). Zhou Guang-you, a university graduate in food science and a government employee, accompanied a CIP sweetpotato post-harvest team on a visit to Santai County where he worked in 1990. Processing of sweetpotato into starch for noodle production is a common practice in the Santai. Two years later he attended a training course on sweetpotato processing organized by the post-harvest scientists from the Sichuan Academy of Agricultural Sciences and CIP. Zhou recognized the opportunity of sweetpotato to penetrate into the instant noodle market that was based on wheat flour. Zhou quit his government job and started an instant sweetpotato noodle enterprise that is based on the following conversion rate: 6 kg of fresh sweetpotato worth US$ 0.25 are processed into 1kg of starch that is transformed into 14 packets of instant noodles valued at US$ 5.00.

Zhou's company currently holds 19 patents on sweetpotato noodle processing, employs 500 people, and can produce 10,000 tons of instant noodles a year, equivalent to about one-third of one percent of Sichuan's annual sweetpotato production. Whether or not a visit and a training course are sufficient to claim partial attribution in impact assessment is questionable. What is more certain is that well-focused training in present-day Chinese conditions appears to be sufficient to mobilize local entrepreneurs to assess and take advantage of local opportunities in product development.

One other emerging success story warrants some comment. In animal production, the use of simple fermentation methods for sweetpotato roots and foliage was found to significantly improve nutrient uptake and extend the "shelf-life" of sweetpotato for animal feed. Fermentation through ensilaging also reduced labor and energy costs of feed preparation, since roots no longer needed to be cooked and foliage did not need as much chopping (Peters et al., 2001). Fermented sweetpotato is a particularly interesting technology because of the large scope for saving women's and children's time in preparing pig feed. Early acceptance has been promising and with sustained adoption over time this research may satisfy the conditions of a success story.

Post-harvest agricultural research and globalization

Increased integration of the global economy would seem to open new opportunities for post-harvest agricultural research, such as exploiting comparative advantage and supplying specialty products for niche markets. Globalization has already benefited China's sweetpotato processing industry by opening up new markets in East Asia for starch and starch based products (Fuglie and Oates, 2003). Thailand's cassava industry as well responded aggressively to meet the rising demand for starch and modified starch in East Asia (Titapiwatanakun, 1994). But globalization can be a two-edged sword. In cassava, both CIAT and IITA have made well-known contributions to product development that have resulted in expanding the utilization of the crop and in stimulating adoption of production technology. The CIAT-related success story of the solar drying and processing of cassava for animal feed on the Coast of Colombia is probably the best-known and most analyzed case (Best et al., 1991). However, cassava processing for animal feed on the Atlantic Coast of Colombia was adversely affected by a more open economy that led to a surge in maize imports and has only recently recovered with devaluation of the Colombian peso (Gottret and Raymond, 1999). Globalization results in heightened competition for least-cost sources of raw materials for processing industries. Cereal crops such as maize and wheat typically receive considerably more research investment than tropical root and tuber crops. For example, private sector investment, particularly in the United States, in value-enhanced traits will make it more difficult for root and tuber crops to compete with maize in several common and well-defined end use markets. Although the share of value-enhanced crops in the United States is currently small at about 4% of total production, the market emphasis is concentrated on maize in the form of high oil corn, high amylose corn, corn high amino acids, waxy corn, white corn, and nutritionally enhanced corn (Jefferson et al., 2001). Success with these transgenic varieties will make maize more competitive in diverse end uses especially animal feed and starch.

Conclusions

The relatively few well documented success stories of post-harvest research at CIP and other CGIAR centers suggests that research investment in post-harvest technologies have yielded a relatively low rate of return. However, not all success stories have been adequately documented. Diffused light storage of seed potatoes is the one technology that clearly qualifies as an ex-post success story but which has not been formally assessed using a project appraisal framework. The development of improved machinery for starch processing in China is another candidate for a successful post-harvest research project. Fermented sweetpotato silage for pig feed in Vietnam is also promising and could eventually become a success story. Nevertheless, post-harvest project appraisal can be complex and attribution of impact especially difficult.

These caveats notwithstanding, the bulk of the evidence from the review of both the US and CIP's experiences strongly suggests that returns to public sector investment in generating post-harvest technologies for potato and sweetpotato have been low. New product development is a particularly risky endeavor. Public-sector investments in commercialization of new products may also serve to "crowd-out" private-sector investments by increasing the level of competition in risky and niche markets.

The gradual trend towards increasing end use diversification in both potato and sweetpotato can most effectively be accommodated in the CGIAR centers by targeting varietal improvement for specific end use traits, such as CIP's current emphasis on high dry matter in sweetpotato. In China, the returns to training in post-harvest research may be higher than more direct initiatives aimed at technology generation given the emergence of a dynamic entrepreneurial sector in this country. It cannot be emphasized strongly enough, however, that success in value-enhancing research will only be successful if farm productivity is high so that raw material costs to processors is kept low. Value-enhancing research is no substitute for low commodity prices.

Organizationally, the IARC model of commodity improvement is an excellent one for bringing diverse disciplines together for research aimed at a shared objective. However, it may not be the most efficient one for post-harvest research. The evidence on success stories indicates that the pay-off from investing in post-harvest research for root and tuber crops has been higher for cassava than for potato and sweetpotato. To profit from these differences in commodity prospects, research resources should be pooled (perhaps in the form of the sharing of scientists) across centers conducting research on root and tuber crops so that flexibility to respond to the most important opportunities is enhanced and economies of scale in research are exploited. Pooling resources could also help preserve critical mass in these times of declining real budgets for agricultural research.

REFERENCES

Alston, J. M., Marra, M. C., Pardey, P.G., Wyatt, T.J. 1998. Research Returns Rredux: A Meta-analysis of the Returns to Agricultural R&D, EPTD Discussion Paper No. 38 (International Food Policy Research Institute, Washington, DC).

Anderson, J., Herdt, R.W., Scobie, G.M. 1988. Science and Food: The CGIAR and Its Partners (World Bank, Washington, DC).

Best, R., Sarria, H., Ospina B. 1991. Establishing the dry-cassava industry on the Atlantic coast of Colombia, in: C.A. Pérez-Crespo (Editor), Integrated Cassava Projects, Working Document No. 78 (International Center for Tropical Agriculture, Cali, Colombia) pp. 112-127.

Bidwell, P.W. 1925. History of Agriculture in the Northern United States, 1620-1860 (Government Printing Office, Washington, DC).

Dinkel, D.H. 1963. Light-induced inhibition of potato tuber sprouting, Science 141, 1407-1408.

Duell, B.R. 1992. Sweetpotato product innovations by small businesses in Kawagoe, Japan, in: W.A. Hill, **C.K. Bonsi and P.A. Loretan** (Editors). Sweetpotato Technology for the 21st Century Technology (Tuskegee University, Tuskegee, Alabama) pp. 381-388.

Economic Research Service. 1999. Potatoes Briefing Room. ERS internet website at *http://www.econ.ag.gov/briefing/potato* (US Department of Agriculture, Washington, DC).

Edmond, J.B., Ammerman, G.R., 1971. Sweetpotatoes: Production, Processing, and Marketing (AVI Publishing Company, Westport, Connecticut).

Evenson, R.E. 2001. Economic impacts of agricultural research and extension, in: B. Gardener and G. Rausser (Editores), Handbook of Agricultural Economics, Vol. 1 (Elsevier Science Press, Amsterdam) pp. 574-616.

Food and Agriculture Organization. 2003. Food Balance Sheet, FAOSTAT internet website at *http://apps.fao.org* (Food and Agriculture Organization of the United Nations, Rome).

Fuglie, K., Khatana, V., Ilangantileke. S., Singh, J.P., Kumar, D., Scott, G. 2000. Economics of potato storage in northern India, Quarterly Journal of International Agriculture 39, 131-148.

Fuglie, K., Oates, C. 2003. Starch markets in Asia: Constraints and opportunities, in: M. Hermann and K. Fuglie (Editors), Sweetpotato Post-Harvest Research and Development in China (International Potato Center, Lima, Peru) forthcoming.

Fuglie, K. 2003. Economic prospects for root and tuber crop utilization for starch and animal feed in Asia, in K. Fuglie (Editor), Progress in Potato and Sweetpotato Research in Indonesia (International Potato Center, Bogor, Indonesia) pp. 157-170.

Gray, L.C. 1933. History of Agriculture in the Southern United States to 1860, Vol.II, Carnegie Institute Washington Publication No. 430 (Carnegie Institute, Washington, DC).

Goletti, F. Wolff, C. 1998. The impact of post-harvest research. Markets and Structural Studies Division (International Food Policy Research Institute, Washington, DC).

Gong, X. 1996. Impact evaluation of sweetpotato starch and noodle processing innovations in Sichuan Province, PR China, Mimeo, Department of International Cooperation and Business Industry Development, (Chinese Academy of Agricultural Sciences, Beijing, China).

Gottret, M.V. Raymond, M. 1999. An analysis of a cassava integrated research and development approach: Has it really contributed to poverty alleviation? Paper presented at "Evaluación del Impacto a la Investigación Agrícola en la Mitigación de la Pobreza", CIAT, San José Costa Rica. 14-16 September.

Greeley, M., 1991. Post-harvest technologies: Implications for food policy analysis. EDI Development Policy Case Series (World Bank, Washington, DC).

Guenthner, J.F. 2000. Growers get 2.5% of French fry price, Spudman Magazine 38: 23.

Hill, W.A.; Bonsi, C.K.; Loretan, P.A., (Editors), 1992. Sweetpotato Technology for the 21st Century (Tuskegee University Press, Alabama).

International Potato Center. 2001. Turning sweetpotato into gold, in: Stories from the Field, Annual Report 2000 (International Potato Center, Lima, Peru) pp. 14.

Jarvis, M.C. (undated), Diffuse-daylight seed potato stores: Light and sprout growth, Department of Chemistry (Agriculture), The University of Glasgow, Scotland.

Jefferson, K., Traxler, G., Wilson, N. 2001. The economics of value enhanced crops: Status, institutional arrangements and benefit sharing. Paper prepared for the 5th ICABR International Conference, Biotechnology, Science and Modern Agriculture: a New Industry at the Dawn of the Century, Ravello, Italy, June 15.

Johnson, L.D., Hunt, S.K., Colvin, R.L. 1992. Consumer acceptability of sweetpotato yogurts, in: W.A. Hill, C.K. Bonsi and P.A. Loretan (Editors) Sweetpotato for the 21st Century Technology (Tuskegee University, Alabama) pp. 415-419.

Kenney, L. 1995. The Past is Never Far Away: A History of the Red River Valley Potato Industry (Red River Valley Potato Growers Association, East Grand Forks, Minnesota).

Meerdink, M. 1995. Small-scale agroindustry in developing countries: Case of sweetpotato starch in Peru, Graduate Thesis (Wageningen Agricultural University, Holland).

Nave, R., Scott, G.J. 1991. Village-level potato processing in developing countries: A case study of the SOTEC project in India (International Potato Center, Lima, Peru).

Peters, D., Nguyen Thi Tinh, Tran Than Thuy, Pham Ngoc Thach. 2001. Fermented sweetpotato vines for more efficient pig raising in Vietnam.AGGRIPA. Rome: Food and Agriculture Organization, *www.fao.org/docrep/article/agrippa/x9500e10.htm.*

Reardon, T., Codron, J-M., Busch, L., Bingen, J., Harris, C. 2001. Global changes in forthcoming agrifood grades and standards: agribusiness strategic responses in developing countries, International Food and Agribusiness Management Review, 2.

Rhoades, R., Booth, R., Schmidt, E., Cuyubamba, O. 1991. Post-harvest technology development with farmers: The Diffused light storage case, in: R. Tripp (Editor) Planned Change in Farming Systems: Progress in On-farm research (John Wiley & Sons, West Sussex, England) pp. 231-244.

Sawyer, R.L. 1962. Chemical sprout inhibitors, Potato Handbook 7: 5-9.

Scott, G.J., Wong, D., Alvarez, M. 1993. Improving village-level processing in developing countries: the case of potatoes, Ecology of Food and Nutrition 30, 145-163.

Smith, Ora. 1956. Recent developments in potato research in the United States, American Potato Journal 33, 60-66.

Southern Regional Research Center. 2001. History. http://msa.ars.usda.gov/la/srrc/.

TAC Secretariat, 1997, Harvest and Post-harvest Problems in Agriculture, Forestry and Fisheries - The CGIAR Contribution to Research (Food and Agriculture Organization, Rome).

Talburt, W.F., Smith, O. 1975. Potato Processing, 3rd Edition (AVI Publishing Company, Westport, Connecticut).

Titapiwatanakun, Boonjit. 1994. Thai cassava starch industry: current and future utilization. Paper presented at the International Meeting on Cassava Flour and Starch, International Center for Tropical Agriculture, Cali, Colombia, January 11-15.

US Department of Agriculture. 1971. Sweetpotato culture and diseases, in: Agriculture Handbook No. 388 (United States Government Printing Office, Washington, DC).

Walker, T.S., Fuglie, K. 1999. The economics of generating international public goods from investing in potato plant breeding, in: Impact on a Changing World, Program Report 1997-1998 (International Potato Center, Lima, Peru) pp. 249-254.

Walker, T.S., Crissman, C.C. 1996. Case Studies of the Economic Impact of CIP- related Technology (International Potato Center, Lima, Peru).

Wheatley, C., Scott, G.J., Best, R., Wiersema, S. 1995. Adding value to root and tuber crops: A manual on product development, CIAT Publication No. 247 (International Center for Tropical Agriculture, Cali, Colombia).

Wheatley, C., Lin, L., Sun, G., Song, B. 1997. Improving small-scale sweetpotato starch enterprises in Sichuan Province, China, Tropical Science 37, 228-237.

Willard, M.J., Cording, J., Eskew, R.K., Edwards, P.W., Sullivan, J.F. 1956. Potato flakes: a new form of dehydrated mashed potatoes, American Potato Journal 33, 28-31.

The International Potato Center (CIP) seeks to reduce poverty and achieve food security on a sustained basis in developing countries through scientific research and related activities on potato, sweetpotato, and other root and tuber crops, and on the improved management of natural resources in the Andes and other mountain areas.

THE CIP VISION

The International Potato Center (CIP) will contribute to reducing poverty and hunger; improving human health; developing resilient, sustainable rural and urban livelihood systems; and improving access to the benefits of new and appropriate knowledge and technologies. CIP, a World Center, will address these challenges by convening and conducting research and supporting partnerships on root and tuber crops and on natural resources management in mountain systems and other less-favored areas where CIP can contribute to the achievement of healthy and sustainable human development.
www.cipotato.org

CIP is a Future Harvest Alliance Center and receives its funding from a group of governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR).
www.futureharvest.org • www.cgiar.org

International Potato Center
Apartado 1558 Lima 12, Perú • Tel 51 1 349 6017 • Fax 51 1 349 5326 • email cip@cgiar.org