Draft

Economic Impact of Public Sector Postharvest Research in the Storage, Processing, and Product Development of Potato and Sweetpotato

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Abstract

A sustained investment in impact assessment over time should generate information that is valuable on the allocation of resources to programmatic research areas. The lack of well-documented success stories in a thematic area of a mature agricultural research institute raises a red flag that returns are unattractive. The absence of documented success stories in CIP's postharvest research on storage, processing, and new product technologies for potato and sweetpotato is the subject of this paper. We review the pay-off to public sector expenditure on postharvest research on potato and sweetpotato in the United States and then revisit some of CIP's more important technologies since the program started in 1975. Three ways of modeling postharvest technical change are illustrated: reducing unit costs of processing, reducing postharvest crop losses, and expanding market demand for processed food products. After accounting for some bells and whistles, the bulk of the evidence from the review of both the U.S. and CIP's experiences strongly suggests that public sector investment in generating postharvest technologies on potato and sweetpotato is characterized by a relatively low rate of return. New product development is a particularly risky endeavor. Implications for program funding and structure are discussed.

Introduction

Evaluating the impact of impact assessment on raising funds for agricultural research is a formidable challenge. Although the role of impact assessment in generating resources for agricultural research is difficult to quantify, a concerted effort at ex-post evaluation of technological change over time in a mature agricultural research institute should generate useful information in taking decisions on

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programmatic research. In particular, an absence of well-documented rate-of-return studies in a broad thematic area suggests 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.

Since the early 1990s, the International Potato Center (CIP) has invested in the documentation of success stories using a case study approach featuring the heavy participation of NARS and a format of conventional project appraisal. Twelve case studies of the ex-post impact of CIP-related impact have been completed. Funds for impact assessment are scarce, and the expected size of economic benefits is an important criterion for selecting ex-post technologies for documentation. Some areas, such as disease-resistant breeding in potatoes, improvements in sweetpotato propagation, and integrated management of potato and sweetpotato storage pests, figure prominently in CIP's rate-of-return publication series. Conspicuous for their absence are storage, processing, and new product technologies from CIP's postharvest research on potato and sweetpotato. During the past 25 years, CIP has made a relatively small, but continuing investment in postharvest research.[1] In the 1970s and 1980s, postharvest research was organized as one of CIP's ten thrusts; in the 1990s as one of the six research programs, and, more recently, as one of ten projects in the institute's research portfolio.

The absence of documented success stories in CIP's postharvest research is the subject of this paper. Has postharvest research dug only dry holes or have rates of return been attractive but difficult to document? To address this question and provide perspective we briefly review the rich experience in the United States on the profitability of postharvest investment by the public sector on potato and sweetpotato. We then describe and discuss the economic fate of some of the major CIP-related postharvest technologies. Next we take stock of a stylized economic method for postharvest impact

[1] Data on expenditure on postharvest research were compiled in 1996 (TAC 1997). Investment across the 16 international agricultural research centers was estimated at about 6.5 million dollars equivalent to about 2% of the total CGIAR budget in 1996. The CGIAR expenditure on postharvest was concentrated in CIP, CIAT, and IITA, the three centers working on root and tuber crops. With a 25% share, CIP invested more than any other center. The amount of CGIAR investment is probably somewhat underestimated because some postharvest activities were not included nor were the administrative costs of research support.

evaluation to shed light on the issue of methods' limitations as a possible constraint to documentation. We conclude with a discussion of implications for future investment and program structure. We begin by revisiting some of the controversy of public sector investment in postharvest research in the next section.

Pros and cons of allocating public sector resources to postharvest research

At first blush, the lack of a well-documented rate of return study in the postharvest area after more than two decades of research is surprising. 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). This does not appear to an isolated experience. For example, in a recent review, Goletti and Wolf (1999) marshal evidence to suggest that public-sector investment in postharvest research and training is 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 1996 TAC review panel on harvest and postharvest problems also recommended more (selective) investment in postharvest research together with a shift in emphasis from "field" to "utilizable" production along "production-consumption" continuum. Increasing globalization and competitiveness reinforce trends towards 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.

On the other hand, the lack of success stories in postharvest research at CIP would not be viewed by some observers as unexpected. A meta-analysis of rate-of-return studies in agricultural research shows that the vast majority of success stories analyzed with a project appraisal framework come from production-related commodity research (Alston et al., 1998). Postharvest loss assessment is imprecise and often results in overestimates (Greeley, 1991). Moreover, direct benefits from product development in niche markets are usually small (only approaching one or at best a few million dollars in net present value). 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).

Globalization is a two-edged sword. For example, 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 from least-cost competitors that usually are the subject of more research investment than are root and tuber crops. For example, private sector investment, particularly in the United States, in value-enhanced traits will make it more difficult to compete with maize in several common and well-defined end uses. Although the share of value-enhanced crops in the United States is 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.

The potential for crowding out the private sector with public sector research is another "can of worms" that is related to understanding the conditions for and context of market failure. As with economic development, postharvest research should be the domain of the private sector. The incentives for private sector investment in postharvest research sometimes makes justification of public sector expenditure tricky and also raises the problem of attribution in establishing who did what to whom when success occurs.

Returns to investment in potato and sweetpotato postharvest technologies in the United States

The United States is the only developed country where both potatoes and sweetpotatoes have been nationally or regionally important. The motivation for surveying the U.S. experience about the impact of public sector investment in potato and sweetpotato postharvest research centers on the possibilities of establishing some lessons that could be applicable to contemporary developing country conditions. In particular, sweetpotato fits 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 hundred thousand farmers. 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 postharvest 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 made potatoes considerably more expensive and dealt a severe blow to the starch-making industry in the Northeast of the country. 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 postharvest research has 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. Government-supported, postharvest (and breeding) research that is acknowledged to have made a difference.

- 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, 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, USDA researchers 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 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 small mom and pop 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 a 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)." The program 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). In general, varietal change was substantially faster for chipping than 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 that bright (Smith 1955). 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. Per capita consumption of fresh potatoes stabilized at about 50 lbs and increasingly consisted of baked potatoes. By the mid-1990s about the same amount of potatoes were destined for frozen French fry consumption as were consumed fresh. In defiance of Bennett's law, average per capita potato consumption has gradually increased over time.

Sweetpotato

Sweetpotatoes were a regionally important crop in South of the United States during colonial times and throughout the 19th Century. Sweetpotatoes in parts of the South 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.

In 1938, the desirability of government investment in postharvest research was highlighted in the Agricultural Adjustment Act that provided the legal foundation for the founding 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 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 (USDA, 1971, p. 5).

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

Productivity growth in sweetpotato has been sluggish. The desirability of improving sweetpotato yield is a recurring theme in the history of the crop (Edmond and Ammerman, 1971). Even with geographic specialization and increasing area of the crop under irrigation, average national yields are between 15-20 t/ha. Yields did not begin an upward trend from 6 t/ha until 1955. A threefold increase in productivity growth in 45 years would seem like good performance; however, it pales in comparison to growth achieved in other crops. Potato yields at the turn of the century were also stagnating at a level of 5 t/ha before the advent of technological change, mainly inorganic fertilizer and healthy tuber seed. Nowadays, national average potato yields are superior to 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 prices in the 1990s consistently approaching or exceeding $U.S.30/kg, 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 for the fresh market.[2] Sweetpotato has steadily declined in importance. From the high of a million hectares in 1932, growing area has decreased to slightly less than 100,000 hectares 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 lines in the story on storage research in sweetpotato could be taken almost verbatim from our earlier account on potato. Sweetpotato researchers from the USDA visited ventilated storage houses (presumably for other crops) in the mid-Atlantic and northern States and incorporated their best features in demonstration structures that were built in the South in 1912 (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

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[2] End use diversification is usually perceived to be associated with market buoyancy and more elastic demand that imply brighter prospects for the commodity. Japan more than any other country is characterized by 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 have been particularly active in promoting the crop (Duell, 1992). In spite of a diversified portfolio of end uses, production in Japan has declined from 7.1 million tons in 1955 to about 1.1 million tons in the late 1990s. Similar trends have taken place in other East Asian countries, such as South Korea and Taiwan. Sweetpotato produced domestically has been replaced partially by sweetpotato produced abroad in developing countries where the roots are processed into starch that is, in turn, exported to Japan, South Korea, and Taiwan. Starch is then converted into sweetpotato noodles. This international trade increases the demand for high dry matter sweetpotato varieties, and also generates demand for waste-water disposal technologies.

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.

Also like the potato breeding story of the success in selecting for chipping varieties, there is a success story in targeting breeding that expanded utilization. At the start of the 20th Century, consumers in the Northern cities preferred dry-fleshed types and the more northern producing districts of the South, mainly in the mid-Atlantic region, had a monopoly on dry-type production. In the 1920s and 1930s preferences started to shift to moister, darker fleshed types in response to greater nutritional awareness about the importance of Vitamin A. These changing preferences were reinforced by the release of Unit 1 Porto Rico with a "deep salmon pink, high carotene, high provitamin A flesh" (Edmond and Ammerman, p. 5). This strain, i.e., somatic mutation, of a well known clone was released by the Louisiana State Experimental Station and was aggressively promoted by that state's Sweetpotato Commission. Moist-fleshed types quickly replaced dry-fleshed types in the northern urban markets that were increasingly supplied from production in the Deep South.

A similar situation prevails in Sub-Saharan Africa today. People prefer dryer, lighter-fleshed varieties those which contain only negligible amounts of provitamin A. For sweetpotato to be an effective vehicle in improving Vitamin A intake either preferences have to change or the linkage between beta-carotene content and moistness has to be broken.

Lessons from the U.S. experience

This rapid historical appraisal of returns to public sector investment in postharvest research on potato and sweetpotato highlights some tendencies or patterns that can be generalized into six lessons. None of these lessons are that new or profound, but they bear repeating. First, increasing commercialization and international trade does 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.

Secondly, 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.

Thirdly, successful production research and extension is needed to improve productivity to drive raw material costs down. Without a cheap source of raw material, processing will not be an economic proposition.

Fourthly, the growing competitiveness of the U.S. economy spelled the demise of several commodity end uses that were prevalent in the 19^{th} 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 19^{th} 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.

Fifthly, 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.

Lastly, like much production research, postharvest research conducted in one state did have a regional or even national public goods character. Several instances of regional spill-over were described.

CIP’s experience in postharvest storage, processing and product development

CIP was founded in 1971, and by 1975 postharvest research was firmly established as one of CIP’s nine “thrusts” in its programmatic organization. With the addition of sweetpotato to CIP’s potato mandate in

1987, the priority for postharvest research was strengthened because, unlike potato, sweetpotato was widely perceived to fit the conditions of a starch staple. Potato dominated CIP's postharvest 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 discuss on some of the more interesting technologies that were developed by CIP and its partners from the perspective of prospects for ex-post impact assessment.

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 outside of China because the crop can usually be produced throughout the year in niche environments that seasonally complement the planting(s) in 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

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 postharvest research started at CIP in the mid 1970s, the initial focus was on technologies to reduce losses in consumer potatoes in the Andes of Central 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 traditionally 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, 1964), scientists in the postharvest program designed and tested diffused light storage (DLS) in the late 1970s. Compared to traditional dark storage, sprout length was reduced from about 20 cms to 2 cms, 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.

The beauty (and perhaps the Achilles Heel) 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 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.

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 has not lived up to its early expectations. It has been easier for NGOs and government extension staff to work with a fixed recipe and 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.

Nonetheless, 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.

Evaporative Cool Storage

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 plains of India and Pakistan and in the Red River Delta of Vietnam are harvested in March, the month 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 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 investigated using 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 maintained beneath the store and potato tubers are cooled as evaporating water is drawn into the storage structure. During 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., 1998).

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. 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. 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. Construction costs of ECS would have to be reduced by at least 30% per ton of potatoes stored before many farmers would likely find them a profitable alternative to their traditional methods (Fuglie et al., 1998).

Processing and product development

The fate of case studies in the product development manual

One of the outstanding products of the CIP postharvest program is *A Manual on Product Development: Adding Value to Root and Tuber Crops* (Wheatley et al., 1995). The manual was developed jointly by postharvest specialists in 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 are about 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 lower in price and higher in quality in developed temperate country agriculture than in tropical developing countries. 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 $U.S. 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 (Gunther, 2001). Producing potato chips should be a more viable proposition for developing countries. However, 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 teething 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 and strings was.

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 postharvest program carried out research to improve the drying efficiency of traditional processed products that are usually sun dried. No introduced method worked that 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 the 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 in an NGO with the dual objectives of improving the welfare of the urban poor and the development of agriculture and 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 has had some successes, it did not live up to expectations and has not been replicated. Justifying the belief that one can learn more from failure than from success, Scott et al., (1993) point out twelve lessons learned from the M-6 experience.

Processing and product development on sweetpotato in East Asia

Product development in sweetpotato 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 (Fuglie and Oates, 2001). 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 postharvest utilization constraints due to their bulkiness and perishability.

Cassava is usually a lower cost source of raw material than sweetpotato so the potential for sweetpotato processed products is greatest in subtropical regions, such as Southwest China, where cassava production is limited by frost. 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 market opportunities for sweetpotato starch and noodle processing in rural areas. However, processing technology was labor intensive and starch extraction rates were 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 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) breeding new crop varieties for high starch yield, and 3) developing new food products from sweetpotato, and 4) improving efficiency of sweetpotato as animal feed.

By the mid 1990s several farm machinery manufacturers in Sichuan Province had adopted improved designs for starch and noodle processing and extended these machines to small enterprises in rural China (Gong, 1996). The new machines improved starch recovery, reduced unit labor use, and gave a higher starch purity and better noodle color (Gong, 1996). The use of sweetpotato for starch and noodle production became an increasingly important and commercial undertaking in major sweetpotato-producing areas of China, such as 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. Strong evidence of attribution is another missing ingredient in this potential success story of improved processing equipment. To what extent was CIP's role instrumental in the development of the processing machinery?

The issue of attribution also looms large in another success story in sweetpotato product development in Sichuan (CIP, 2000). Zhou Guang-you, a graduate in food science and a government employee, accompanied a CIP sweetpotato postharvest team on a visit to Ganba where he worked in 1990. Processing of sweetpotato into starch for noodle production is a common practice in the Ganba Township. Two years later he attended a training course in Ganba on sweetpotato processing and organized by the postharvest scientists from the Sichuan Academy of Agricultural Sciences and from 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 kgs of fresh sweetpotato worth US$0.25 are processed into 1kg of starch that is transformed into 14 packets of instant noodles valued at U.S.$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 equivalent to about one-third of one% of Sichuan Province's annual fresh production. Whether or not a visit and a training course are sufficient to claim partial attribution in impact assessment is debatable. 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.

Framework for economic impact assessment of postharvest technical change

The scarcity of postharvest rate of return studies in the project appraisal literature could be partially attributed to the need for specialist expertise in modeling postharvest technological change. Identifying sources of benefits from technological change and modeling benefits in a multi-market setting can be a complex undertaking that requires skill, imagination, and good survey data. Modeling improvements in product quality is one of the thornier issues in the literature (Alston, et al., 1998).

A sampling of this complexity is illustrated below for the types of postharvest technological change we have described. We distinguish among at least three ways in which technology can improve postharvest utilization. First, new technologies can save inputs (labor, capital, energy, etc.) or reap economies of scale. Second, new technologies can reduce commodity waste. Examples are improved storage methods that reduce losses and processing methods that increase nutrient extraction rates. Finally, there are technologies that create new products to serve new markets.

Let's consider a commodity that has dual uses: direct use as food (fresh market) and use in manufacturing to make other processed food or non-food products (processing market). Changes in supply, demand, or technology in either market will influence the equilibrium quantities and economic welfare in both markets.

The welfare effects of changes in processing technology are illustrated in Figures 1a and 1b. Figure 1a shows how equilibrium prices and quantities are determined in the fresh and processed product markets under perfect competition. The two markets are shown back-to-back in the diagram. D_f is consumer demand for the fresh product, and D_p is demand for the processed product. S_f is the farm supply schedule which supplies the fresh market and raw material for processing. The difference between S_f and D_f is potential excess supply for processing ($ES_{potential}$). With existing processing technology, the actual quantity extracted through processing is ES_{actual}, with the difference in processing waste. The supply curve for the processed product is found by adding the marginal costs of labor, capital, and other materials for processing (C_p) to ES_{actual}. Equilibrium price in the processed product market, P_p, is given by the intersection of ($ES_{actual} + C_p$) and D_p. The equilibrium price in the fresh market, P_f, is determined by the intersection of Q_{pc} and ES_{actual}. At P_f, Q_{ft} is total commodity supply, Q_{fc} is quantity delivered to the fresh market, and Q_{pt} is quantity delivered to processers. The difference between potential and actual excess supply ($Q_{pt} – Q_{pc}$) is waste material, which could be used for animal feed.

The three types of technical change in processing described in the model are shown graphically in Figure 1b. A reduction in marginal processing cost C_p results in a downward shift in the supply curve of the processed product, and is shown by arrow 1. An improvement in the quality of the processed product shifts the demand curve D_p outward (arrow 2). An increase in the extraction rate pivots ES_{actual} downward toward $ES_{potential}$ (arrow 3). Sometimes, a single innovation such as an improved processing machine may have elements of all three types of technical improvement, so it may be difficult to distinguish these sources of technical change independently. In Figure 1b, the three technical changes together shift the equilibrium in the processed product market from the point labeled A to point B. This results in an increase in the quantity of processed product produced and an increase in raw material delivered to processors by farmers. The price of the processed product falls and the farm-level commodity price rises. Farmers increase crop output, and consumer of the fresh product decreases.

The effects of technical change in processing on producer and consumer welfare depend critically on what type of technical change is most dominant and in the price responsiveness of supply and demand. For the case of a reduction in processing cost, whereas product quality and extraction rates remain unchanged, equilibrium price in the processed product market falls as quantity supplied by processors increases and the price in the fresh market rises due to the increase in commodity demand from processors. Consumers of the processed product gain area A and consumers of the fresh product lose area B. Farmers gain area B+C in producer surplus. Net welfare gain is area A+C; B is a transfer from consumers of the fresh product to farmers. Since constant marginal costs of processing and competitive pricing are assumed, processor profits are necessarily zero and they experience no change in welfare because of cost-reducing technical change.

An improvement in processed product quality results in an increase in price in both markets. Consumers of the processed product gain while consumers of the fresh product lose. Farmers benefit from the expansion in demand and resulting higher prices for the farm commodity.

An improvement in utilization efficiency (extraction rate) in processing may lead to a fall in farm price despite an increase in the quantity of processed product supplied by processors. By making more efficient use of the raw material, processors reduce cost and pass on the cost savings to consumers of the processed product in the form of lower prices. But they also reduce the amount of the commodity required to manufacture a unit of the processed product. How processors' total demand for the commodity will be affected depends on whether the reduction in utilization per unit of processed product is offset by growth in total product processed. Improved utilization efficiency can result in a net reduction in processor demand for the farm commodity, and the price in the fresh market falls. Consumers in both markets benefit from lower prices, but farmers lose due to reduced demand for the farm commodity. However, this result depends on assumptions about the price responsiveness of supply and demand. If demand for the processed product is sufficiently elastic, then the scale effect (the increase in total quantity demanded due to its lower price) may offset the reduction in utilization of the raw commodity per unit of processed product produced. Where demand for the processed product is perfectly elastic, the scale effect is sufficiently large such that processor demand for the commodity rises, and thus farmers benefit from higher prices.

Conclusions

The absence of success stories of well documented economic impact of postharvest research at CIP points to an unattractive rate of return on investment in technologies related to potato and sweetpotato storage, processing, and new products. However, not all success stories that could have been documented have been documented. Diffused light storage of seed potatoes is the one technology that clearly qualifies as an ex-post success story. The economic and adoption performance of improved machinery for starch processing in China is also being studied at this time. Fermented sweetpotato silage for pig feed in Vietnam is promising and could eventually become a success story. Moreover, some areas of production research would also be considered unattractive by the criterion of the number and size of documented success stories. Lastly, postharvest project appraisal can be complex and is not for the feint of heart.

These caveats, notwithstanding, the bulk of the evidence from the review of both the U.S. and CIP's experiences strongly suggests that returns to public sector investment in generating postharvest technologies on potato and sweetpotato have been low. New product development is a particularly risky endeavor.

The gradual trend towards increasing end use diversification in both potato and sweetpotato can most effectively be accommodated by targeted varietal improvement such as CIP's current emphasis ion high dry matter in sweetpotato. With the exception of China for sweetpotato and a handful of countries in Southeast Asia for potato, fresh consumption will be the dominant end use for many years to come. In China, the returns to training in postharvest research would appear to be higher than more direct initiatives aimed at technology generation.

Our findings also have some implications for program funding and structure. Donor interest in product development in neglected root and tuber crops in an international agricultural research center should be manifested in special project funding. This area is too risky to fund from core resources.

Organizationally, the commodity improvement concept 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 postharvest research. The evidence on success stories indicates that the pay-off from investing in postharvest research 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 the root and tuber crops so that flexibility to respond to the most important opportunities is enhanced and economies of scale in research on (at times) competing commodities are exploited. Pooling resources could also help preserve critical mass in these times of declining real budgets for agricultural research.

References

Alston, J. M., G. W. Norton and P.G. Pardey. 1995. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting.* Ithaca, NY: Cornell University Press.

Alston, J. M., M. C. Marra, P.G. Pardey and T.J. Wyatt. Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D. 1998. EPTD Discussion Paper No. 38. IFPRI, Washington, D.C., USA. 44 p.

Alston, J.M., G.W. Norton, P.G. Pardey. 1998. Science Under Scarcity. Principles and Practice for Agricultural Research Evaluation and Priority Setting. CAB International, The Hague, The Netherlands.585 p.

Best, R., H. Sarria and B. Ospina. 1991. Establishing the dry-cassava industry on the Atlantic coast of Colombia. In: Pérez-Crespo, C.A. (ed.). Integrated cassava projects, Chapter 8. Working Document No. 78. CIAT, Cali, Colombia. p. 112-127.

CIP. 2000. Stories from the field. Intenational Potato Center: Annual Report

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

Duell, B.R. 1992. Sweetpotato Product Innovations by Small Businesses in Kawagoe, Japan. In: Sweetpotato Technology for the 21st Century Technology. Eds. Walter A. Hill, Conrad K. Bonsi and Philip A. Loretan. Tuskegee University: Tuskegee, Alabama. p. 381-388.

Edmond, J.B. and G.R. Ammerman. 1971. Sweetpotatoes: Production, Processing, Marketing. The AVI Publishing Company, Inc., Westport, Connecticut. 334 p.

Fuglie, K. O., V. Khatana, S. Ilangantileke, J.P. Singh, D. Kumar, and G. Scott. 2000. "Economics of Potato Storage in Northern India," *Quarterly Journal of International Agriculture* 39, 2: 131-148.

Gray, L.C. 1933. History of Agriculture in the Southern United States to 1860, Vol.II, Carnegie Inst. Wash. Publ. No. 430.

Goletti, F. and C. Wolff. 1998. The Impact of Postharvest Research. Markets and Structural Studies Division. International Food Policy Research Institute, Washington, DC, October.

Gong, Xifeng. 1998. Impact Evaluation of Sweetpotato Starch and Noodle Process 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. and M. Raymond. 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 1999.

Greeley, M. 1991. Postharvest Technologies: Implications for Food Policy Analysis. EDI Development Policy Case Series, World Bank.

Guenthner, J.F. 2000. Growers get 2.5% of french fry price. Spudman Magazine, Vol. 38, No. 5, p. 23.

International Potato Center (CIP). 2001. Turning Sweetpotato into Gold. In: Stories from the Field. Annual Report 2000. p. 14.

Jarvis, M. C. (undated). Diffuse-Daylight Seed Potato Stores: Light and Sprout Growth. Department of Chemistry (Agricultre), The University of Glasgow, Scotland, UK.

Jefferson, K., G. Traxler and N. Wilson. 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, 2001.

Johnson, L.D., S.K. Hunt and R.L. Colvin. 1992. Consumer Acceptability of Sweetpotato Yogurts. In: Sweetpotato for the 21st Century Technology. Eds. Walter A. Hill, Conrad K. Bonsi and Philip A. Loretan. Tuskegee University: Tuskegee, Alabama. p. 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, USA. 331 p.

Meerdink, M. 1995. Small-Scale agroindustry in developing countries; The case of sweetpotato starch in Peru. Graduate Thesis, Wageningen Agricultural University. Wageningen, The Netherlands. 63 p.

Nave, R. and Scott, G.J. 1991. Village-level potato processing indeveloping countries: A case study of the SOTEC project in India. CIP, Lima, Peru. 40 p.

Peters, D., Nguyen Thi Tinh, Tran Than Thuy, and Pham Ngoc Thach. 2002. "Fermented sweetpotato vines for more efficient pig raising in Vietnam," (forthcoming). AGRIPPA, FAO, Rome.

Reardon, T., J-M. Codron, L. Busch, J. Bingen and C. Harris. 2001. Global Change in Agrifood Grades and Standards: Agribusiness Strategic Responses in Developing Countries. (forthcomng). International Food and Agribusiness Management Review, 2(3).

Rhoades, R., R. Booth, E. Schmidt and O. Cuyubamba. 1991. Postharvest Technology Development with Farmers: The Diffused Light Storage Case. In: Planned change in farming systems: Progress in on-farm research (Ed. Robert Tripp). John Wiley & sons Ltd, Baffins Lane, Chichester, West Sussex PO19 1 UD, England. pp. 231-244.

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

Scott, G.J., D. Wong, and M. Alvarez. 1993. Improving village-level processing in developing countries: The case of potatoes. Ecology of Food and Nutrition, Vol. 30, pp. 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 Postharvest Problems in Agriculture, Forestry and Fisheries – The CGIAR Contribution to Research. FAO: Rome, Italy. 24 p.

Talburt, W.F. and O. Smith. 1975. Potato Processing (Third Edition). The AVI Publishing Company, Inc.,Westport, Connecticut. 705 p.

United States Department of Agriculture. 1971. Sweetpotato culture and diseases. Agriculture Handbook No. 388. U.S. Government Printing Office: Washington D.C. 74 p.

Walker, T. and K. Fuglie. 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.

Wheatley, C., G.J. Scott. R. Best and S. Wiersema. 1995. Adding Value to Root and Tuber Crops. A Manual on Product Development. CIAT Publication No. 247: Cali, Colombia. 166 p.

Wheatley, C., L. Lin, G. Sun, and B. Song. 1997. "Improving Small-Scale Sweet Potato Starch Enterprises in Sichuan Province, China," *Tropical Science* 37: 228-237.

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

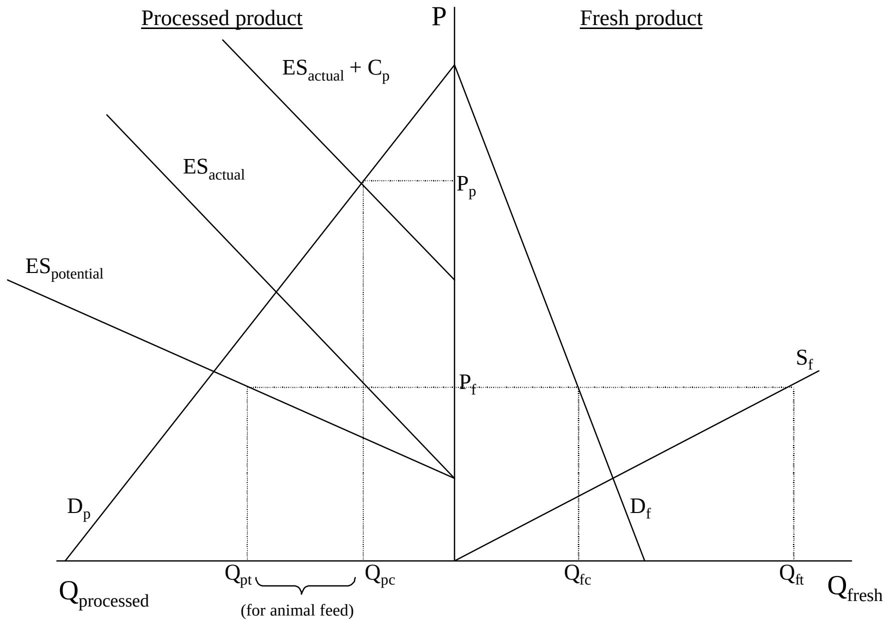

Figure 1A. Competitive equilibrium in fresh and processed product markets.

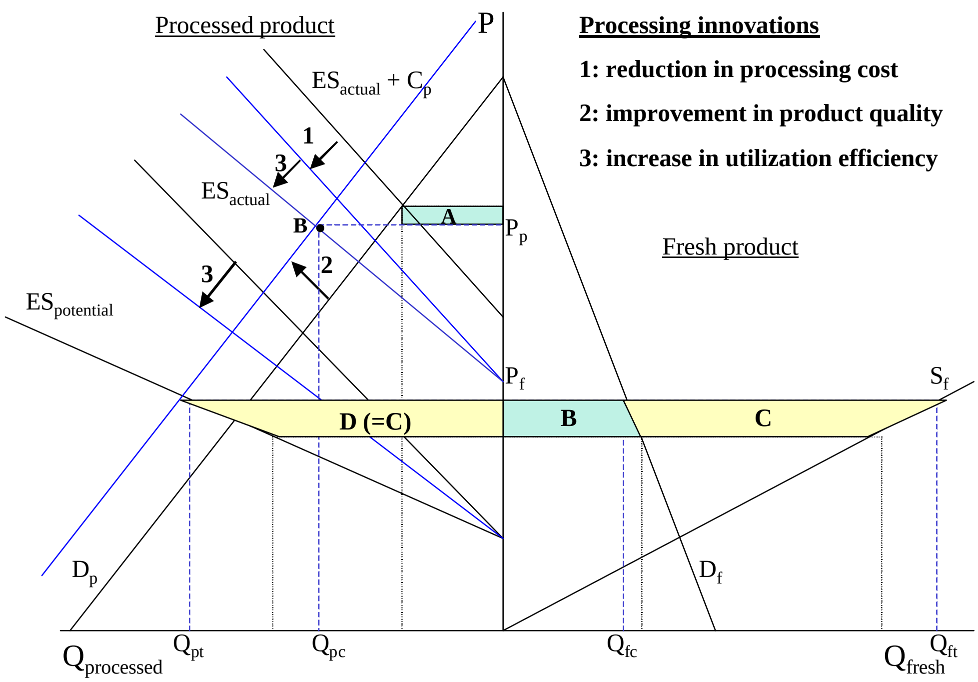

Figure 1 B. Sources of technical change in processed product market