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THE IMPACT OF POSTHARVEST RESEARCH

by

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LIST OF ABBREVIATIONS

ACIAR	Australian Center for International Agricultural Research
ARO	Advanced Research Organization
BMZ	German Ministry for International Cooperation
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIFOR	Center for International Forestry Research
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CIP	Centro Internacional de la Papa
CIRAD	Centre de Coopération Internationelle en Recherche Agronomique pour le Développement (France)
CSIRO	Commonwealth Scientific and Industrial Research Organization
GASGA	Group for Assistance on Systems relating to Grain After Harvest
GTZ	German Society for Technical Cooperation
ICARDA	International Center for Agricultural Research in the Dry Areas
ICLARM	International Center for Living Aquatic Resources Management
ICRAF	International Center for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Center
IFPRI	International Food Policy Research Institute
IIMI	International Irrigation Management Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute

IPGRI	International Plant Genetic Resources Institute
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
NARS	National Agricultural Research Service
NRI	Natural Resources Institute, University of Greenwich (UK)
TAC	Technical Advisory Committee
UAF	University of Agriculture and Forestry (Vietnam)
WARDA	West Africa Rice Development Association

SUMMARY

While research on the improvement of agricultural production has received considerable attention and funding, until recently postharvest activities have not attracted much attention from international research organizations. However, there is an emerging consensus on the critical role that postharvest systems can play in meeting the overall goals of food security, poverty alleviation and sustainable agriculture particularly in developing countries. This study provides preliminary evidence on the impact of postharvest research on these goals; furthermore the study argues that postharvest research at international agricultural research organizations is justified by its international public good nature.

Several global trends highlight the increasing importance of postharvest activities and research in this field. The first trend is urbanization, particularly in developing countries. As people live farther away from where food is prepared, they increasingly rely on smooth transport, storage, processing, and marketing systems to give them access to a secure food supply. The reduced time for food preparation and the increased demand for processed food increases the need of developing healthy, affordable food products, and appropriate processing systems to provide food to the rapidly growing urban population in developing countries. The second trend is a contraction of the agricultural sector, measured both by a declining agricultural GDP as a share of total GDP and a declining labor force engaged in agriculture. Alternative rural income sources are essential to limit rural-urban migration. Postharvest activities such as processing and marketing can provide much needed employment for those who exit the agricultural sector. Research on policies, institutions, and technologies to strengthen the development of rural agroenterprises would directly contribute to the strengthening of the rural economy even within a contracting agricultural sector. The third trend is toward a more liberalized international trade system and an increasing orientation of developing countries toward export markets as a source of economic growth. Participation in international markets requires relatively sophisticated marketing, information, and transportation networks. Successful competition requires quality control and product standardization. While for large companies, it is economically feasible to develop sophisticated marketing strategies, smaller producers will greatly benefit from methods and technologies that allow them to compete in international markets. Finally, a trend toward improved infrastructure and communication network opens new market opportunities for the poor farmers in developing countries. However, to

make such opportunity operational, more research on appropriate technologies to store, transport, process, and ensuring quality will be necessary.

The International Agricultural Research System, and the CGIAR in particular, have made several contributions to postharvest research in the past, belonging to the four broad areas of product quality, harvest and storage, utilization and marketing, and policies and institutions. Other organizations, most notably FAO, ACIAR, IDRC, GTZ, CIRAD, NRI, and USAID have also contributed and supported postharvest research projects. The review of some of these projects and their impact points to an overall positive contribution. The study concludes presenting five reasons that justify an increased commitment to postharvest research by the International Agricultural System and the CGIAR in particular.

- **High internal rates of return.** The rates of return on postharvest research are on average comparable to rates of return from production research, and thus make an about equal contribution to income growth for every dollar spent on research. Furthermore many improvements, for example in human health, have important non-monetary value which is excluded from internal rate of return calculations. The economic impact of postharvest research investments is encouraging, and does not warrant a continued discrimination against such activities in funding allocations.

- **International public good character.** Should postharvest research be carried out by the private or by the public sector? The answer is that the CGIAR system should mainly come into play when postharvest research has the character of an international public good, which means that private investors would not provide sufficient funding because they cannot appropriate the research gains. When research has public good character, but is only relevant for a reduced geographical area, it should be undertaken by national research organizations. Only when a public good has widespread international applicability should it be part of the CGIAR effort.

  Examples of such international public goods in the postharvest area abound. CIAT’s cassava project is an example where a methodology for rural enterprise development was applied in several Latin American countries, and is being adapted for other regions as well. IRRI’s simple rice drying technology has been copied and modified by small manufacturers. R&D costs for such technology cannot be easily recuperated by the private sector, and public investment is needed as a catalyst for private innovation. Public goods are underfunded by the private sector, and are thus candidates for public or multilateral funding. IFPRI's research on policies and institutions can be replicated in a variety of countries that experience similar constraints to the development of postharvest systems.

- **Effect on poverty.** Postharvest research contributes to reducing poverty by enhancing income earning opportunities for poor people, and by providing time-saving processed foods to the urban poor. One of CIAT's foci is the research on the establishment and strengthening of small-scale rural agroindustries and complementary support services. This provides income opportunities for smallholders and for landless laborers, which tend to be among the poorest strata in developing countries. Participatory research methods for identifying markets, developing postharvest technology options and selecting appropriate organizational schemes for small rural enterprises are products that are non-location specific. Cross-case and cross-country analysis of experiences, lessons learned and best practices are in high demand by development practitioners at the local level.

  Reduced wastage during storage reduces food and income losses for farmers. In the case of tropical fruit, improved storage technology opens up new markets for products from developing countries and thus creates income opportunities and reduces poverty. In addition, processed convenience foods reduce the amount of time the poor, and especially urban women, have to spend preparing meals. Improved processing that leads to more convenient foods thus frees up time for other activities such as wage work, contributing to poverty reduction.

- **Effect on food security and health.** Postharvest research contributes to food security and health in several ways. Improved storage technologies, such as biological pest control or controlled atmosphere storage reduce postharvest food losses. Reducing losses increases the amount of food available for consumption. The project dealing with biological control of the larger grain borer reduces losses in on-farm storage for smallholders, and thus enhances food security.

  The reduction of cyanide potential in cassava is an example where postharvest research had a important effect on food safety, since a significant proportion of the African population suffers from cyanide-related diseases. Micronutrient-enhanced staple crops will contribute to the fight against malnutrition while saving resources for other health-related programs.

- **Effect on sustainable use of resources.** Postharvest research contributes to sustainability by finding alternatives to chemicals which have polluting effects on the environment, and are hazardous for human health. Thus alternative pest control mechanisms for grain storage reduce the need for pesticides, which reduces pollution, minimizes accidents with pollutants, and also lowers pesticide residues in food consumed by humans.

  The reduction of postharvest food losses in itself contributes to sustainability. Reducing waste of already produced food is more sustainable than increasing production to compensate for postharvest losses. Increasing production leads to more intensive farming or to an expansion of the area under cultivation, both of which may have negative effects on the environment especially when poor rural households tend to farm in fragile ecosystems or marginal land.

  Natural resource management research that seeks to reduce environmental degradation of soil and water resources and conserve biodiversity, benefits from close links to research on market. Value adding opportunities that enhance the value of key commodities would also increase income generation for improving welfare and providing farmers with the financial resources for investment in resource enhancing technologies.

As the significant contribution of postharvest research to CGIAR goals such as poverty reduction, food security and sustainability becomes clear, and in the light of high rates of return, the very skewed allocation of funds to production versus postharvest topics cannot be justified. Since so far, relatively little has been invested in postharvest research, there is potential for large impacts as constraints and bottlenecks are removed. It would thus be desirable to re-examine current funding priorities and to allocate a larger proportion of resources to the postharvest area.

1. INTRODUCTION

Improving agricultural production is essential to achieve a sustainable development process that will contribute to reducing poverty and enhancing food security and income growth. Research at CGIAR and other institutions has contributed to make this development possible. High yielding varieties and new production technology have vastly increased the world’s agricultural potential and provided rural income sources and affordable food for large parts of the population. But the production of food and other agricultural products does not end when the crop is harvested. Increasingly, agricultural products are not consumed in their raw form, and postharvest activities such as transport, storage, processing, and marketing account for a growing part of their final value.

While research on the improvement of agricultural production has received considerable attention and funding, until recently postharvest activities have not attracted much attention from international research organizations. One reason for this lack of consideration and funding may be that postharvest systems include very diverse activities, including product quality, harvest and storage, utilization and marketing, and policies and institutions. Given the complexity of the postharvest systems, it seems difficult to pinpoint the entry point for investment in research and for evaluation of impact of postharvest research. Yet, there is an emerging consensus on the critical role that postharvest research can play in meeting the overall goals of income growth, food security, poverty alleviation, and sustainable agriculture particularly in developing countries.

The objective of this paper is to motivate the interest in postharvest research and to provide an assessment of the impact of this research in terms of income growth, poverty alleviation, food security, and sustainable agriculture in developing countries. While there is a large body of literature on the impact of production research , the studies on the impact of post-production research are still few and lacking a unifying method. The impact literature presented in this paper is certainly incomplete and constitutes only a first attempt to organize the material available to the authors at this stage. The expected contribution of the paper is to provide information relevant to the following two questions:

1) What is the impact of postharvest research on the goals of growth, poverty alleviation, food security, and sustainable use of natural resources?
2) Does postharvest research share the characteristics of an international public good and does it justify a larger investment in this type of research by the international agricultural research system and the donor community?

The two questions are conceptually distinct. Postharvest research might well have an impact comparable or even superior to that of production research, yet it might well be lacking the nature of international public good. In such a case, the current low investment by the international agricultural research system, and the CGIAR in particular, is understandable. On the other hand, if postharvest research in developing countries has important public good characteristics that make it unprofitable to private sector investment in those countries, then there is a stronger case for expanding international support to this type of research. Before trying to provide some elements of an answer to these complex questions, we provide some basic definitions of postharvest research and some general background.

1.1 DEFINITION AND BACKGROUND

In a study led by M. Arnold (1996), the CGIAR Technical Advisory Committee has identified four broad areas within which to classify postharvest research.

Product Quality. This area comprises research on nutritional quality and industrial processing characteristics of primary products, including gene identification and germplasm enhancement.

Harvest and Storage research encompasses postharvest loss reduction, for example through harvest mechanization, improved storage facilities, pest and disease management, and germplasm enhancement to increase product resistance.

Utilization and Marketing. This area includes the development of new products, and product diversification through new processing techniques for both primary products and by-products. Consumption and nutrition studies serve to identify new markets for products.

Policies and Institutions research investigates the institutional and policy framework which enhances agricultural production, including the agribusiness sector, infrastructure and small-scale enterprises. This includes larger issues such as the impact of macroeconomic and trade policies and political stability as well as micro arrangements for production and processing.

Traditionally, postharvest research has mostly concentrated on topics from the first two areas; product quality and harvest and storage. Much attention is focused on the reduction of postharvest losses. Experts typically cite approximate figures for minimum overall losses around 10 percent for durable crops such as cereal grains and grain legumes, and 20 percent for other staples such as yams or cassava (National Research Council, 1978). Reducing these losses could increase world food availabilities substantially, which led to a concentration of early postharvest research in this area.

Very few studies actually attempt to estimate postharvest losses empirically. In a review of these studies, Martin Greeley (1986) finds that when actual research is carried out to determine losses instead of relying on expert opinions, the resulting figures tend to be much lower, around 5 percent for grain. According to Greeley, traditional postharvest systems tend to be fairly efficient since poor farmers cannot afford to waste food. When traditional food production or consumption patterns are changed, however, these traditional postharvest systems often become inadequate and require changes to avoid food losses and inefficiencies.

The green revolution resulted in vastly increased grain production in many developing countries, especially in the wet season, when it is difficult to dry grain properly. Traditional postharvest systems were not equipped to dry and store such large quantities, and postharvest losses increased. These losses can be diminished by better harvest, drying, transport and milling techniques, by combating storage pests, or by making grains more resistant to mold.

When developing new technologies, it is essential to take into account that food handling, storage, and conservation are highly cultural specific (National Research Council, 1978). Therefore loss reduction cannot only rely on technologies, but must be socially and culturally acceptable, as well as economically viable.

In addition to developments on the supply side, food consumption has also changed. Most foods, including starchy staples such as grains and tubers, are not consumed in their primary form but require some processing. Other food products such as fruits and vegetables, meats, and dairy products play an increasingly important role in agricultural production. Because they are more perishable, they require more sophisticated postharvest operations than most grains and tubers. Thus, postharvest activities beyond loss reduction are receiving more attention from researchers and policy makers. Non-edible agricultural products such as flowers also need well organized marketing chains to reach the market in time.

Rather than concentrating on isolated topics such as storage or drying technologies, an emphasis on the whole postharvest system can help identify bottlenecks and constraints, and increase the impact of research in each area (Young, 1991; GTZ, 1998). This systems approach has led research and assistance organizations to try to characterize existing postharvest chains in developing countries. Additionally, domestic and international marketing services need to be strengthened, especially to improve market access for smaller and marginal producers.

It is important to realize agricultural production does not end at harvest time; rather there is a production-consumption continuum which includes a variety of postharvest activities (Arnold, 1996). Rural producers need effective connections to the next links on the postharvest chain. Research thus does and should not stop with the reduction of post-harvest losses, but include institutional arrangements, processing industries, enterprise development, market information systems, and commercialization.

As government involvement in the economy changes, there is a new need to redefine its roles and policies to allow for development of the private sector. Governments need to define their position towards both large multinational agribusiness firms, and small urban and rural processing enterprises, which often operate in the informal sector. A better understanding of institutions and arrangements in this area is needed to allow capacity building and the formulation of effective policies.

Table 1.1 shows the destination of food expenditures in the United States in 1995. While at the turn of the century US farmers received about 60 percent of the consumer's food dollar, today they receive about 20 percent (Austin, 1995). The rest is broken down as follows:

Table 1.1–What a Dollar Spent on Food Paid for in 1995

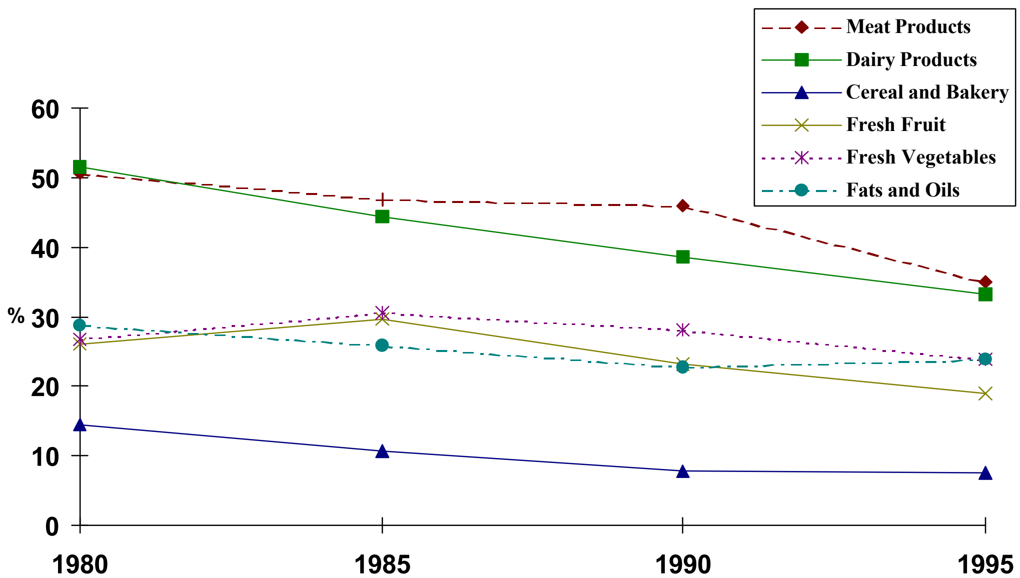
Destination	Amount Received (%)
Farm	22
Labor	37
Packaging	9
Intercity transportation	4.5
Depreciation	3.5
Advertising	3.5
Fuels and electricity	3.5
Before tax profits	4
Rent	3.5
Interest (net)	2
Repairs	1.5
Business taxes	3.5
Other costs*	2.5

Source: German and Park 1996, from Elitzak, H. 1995. Food Cost Review. USDA-ERS, Food and Consumer Economics Division, April 1996.
Includes food eaten at home and away from home
*Includes property taxes, insurance, accounting, professional services, promotion, bad debts, and many miscellaneous items.

About 78 percent of the US consumer's food dollar thus goes to postharvest activities, while the farmer receives 22 percent. Figure I.1 shows the farms' share in the retail prices of different products in the US. It is striking that from 1980 until 1995, the farm share continued to decrease, although the food sector was already highly developed in 1980. Processing and other postharvest activities such as marketing are thus still gaining importance even in industrialized countries.

Meat and dairy products show a relatively high farm share around 36 percent in 1995. Cereal and Bakery products have the lowest farm share, which means that postharvest activities contribute a large component of the value added of these products. Even in the case of relatively unprocessed foods such as fresh fruits and vegetables, postharvest value added makes up around 80 percent of the product's final value. In the case of fresh produce, well-organized transport and marketing, as well as sophisticated storage technology are essential and capture a large share of consumers' expenditures.

Figure 1.1–Farm share of retail price



Source: Food Review. Sept. - Dec. 1997. USDA - ERS.

1.2 GLOBAL TRENDS

While in developing countries the share of postharvest activities in total value added of food products tends to be lower, there is a tendency towards greater importance of postharvest operations. Food and agricultural raw material processing already is an important sector in most economies. Several recent international trends contribute to making postharvest activities, and research in this field, even more important. The following section will present the trends on urbanization, contraction of the agricultural sector, trade, income and dietary change, scientific progress, infrastructure, and environment.

Urbanization

One of the trends contributing to the rising importance of postharvest activities is high rural-urban migration: when countries industrialize, people move from rural areas to the cities. About 39 percent of the population of low- and middle-income countries was urban in 1995, and this share has been growing at about 3.3 percent since 1980. In high-income economies, the urban population has become stable at about 75 of the total population (World Bank, 1997). The urbanization trend in developing countries is thus likely to continue.

As people live farther away from where food is produced, they increasingly rely on smooth transport, storage, processing and marketing systems to give them access to a secure food supply. The urban poor need affordable and nutritious food with a longer shelf-life than many traditional foods consumed in the countryside. By analyzing postharvest systems and reducing inefficiencies through better organization and new technologies, postharvest research helps to ensure a continuous supply of food products in cities. Advances in processing and more efficient marketing chains furthermore often lead to significantly reduced consumer prices for basic foods.

In the cities, families tend to have less time for food preparation, and demand for processed food rises (Jaffee and Gordon, 1993). Especially women's opportunity cost of time increases, which leads to a higher consumption of meals prepared outside the home. These meals are often consumed at food stands in the streets, where nutrition and hygiene standards are usually not controlled. Kennedy and Reardon (1994) find that as urban African women have less time for food preparation, traditional grain consumption decreases, and that consumption shifts to "faster food" grains such as rice or wheat, with a marked increase in meals purchased from street vendors. Government policy will eventually have to deal with this mostly informal prepared food subsector, which leads to a need for research to identify optimal policies.

Thus the importance of processing grows as a consequence of urbanization. More than 50 percent of the value of cereal products consumed in urban areas is added in postharvest handling and processing. For cereals consumed in rural areas, processing accounts for about 25 percent of farmers' costs and time (Greeley, 1991). There is room for important contributions in developing healthy, affordable food products and appropriate processing systems to provide food to the rapidly increasing urban population in developing countries.

Contraction of the Agricultural Sector

Urbanization goes hand in hand with a relative contraction of the agricultural sector. In low-income countries, agriculture accounted for 34 percent of GDP and 73 percent of the labor force in 1980. In 1990, agriculture's share of the labor force had fallen to 69 percent, and in 1995, the agricultural sector only accounted for 25 percent of GDP in low-income countries. In high income countries in contrast, agriculture accounted for only about 2 percent of GDP and 5 percent of employment in 1995 (World Bank, 1997). Labor displaced by shrinking agricultural employment usually migrates to the slums of the big cities, hoping to find better opportunities for upward mobility there.

Since direct employment in agriculture decreases, alternative rural income sources are essential to limit rural-urban migration. Postharvest activities such as processing and marketing can provide much needed employment for those who exit the agricultural sector. Rural processing facilities and small enterprises can increase value added in rural areas, provide alternative income sources for the rural population, and contribute to overall economic growth (Austin, 1995; Fellows, 1997). Policies to encourage small agribusiness formation and investment in rural areas require market studies to identify opportunities, and viable appropriate technology development.

Often, food and feed processing are carried out by large companies. These companies only contribute to local development if there are significant linkages to the local economy and to other sectors. Frequently several stages of production are linked through vertical integration, for example in contract farming. Governments have to provide a regulatory framework that enables farmers, and employees to share in the benefits of advances in processing to avoid negative effects on income distribution. Research into contract farming and institutional development enables policy makers to design institutional arrangements in such a way that they benefits all actors.

Trade

International trade is growing fast, and with GATT liberalization and market reforms, less developed countries are increasingly looking toward export markets as a source of economic growth. Participation in international markets requires relatively sophisticated marketing, information and transport networks. Successful competition requires quality control and product standardization (Jaffee and Gordon, 1993). Even domestically, national producers often have to compete with growing quantities of imports and need to change their marketing strategy. Products have to be cheaper or better than the competition's, which leads to a need for the modernization of food processing.

In many developing countries, especially in the Asia-Pacific region, food production has increased dramatically due to the green revolution. Food surpluses have to be stored or sold at home or abroad, which requires new technologies and institutions. Postharvest research contributes to both better storage and trade facilities (Johnson, 1998).

International trade in products produced by food manufacturing industries worldwide has a value of more than $205 billion (in 1990), which is about three times the value of trade in bulk agricultural commodities. Yet this trade is highly asymmetric, with less developed countries exporting mainly unprocessed products or products at low levels of processing, while developed countries export most processed foods. This is partly due to supply-side factors such as technical or marketing skills. Demand-side factors include tariff structures and non-tariff barriers such as food standards, ingredient laws, and labeling and packaging requirements (Matthews, 1994).

Exporting processed foods with higher value added is a good opportunity for creating employment and income growth (Austin, 1995). To be able to compete in processed foods markets, producers in less developed countries need market information, capacity for innovation, quality control, and supply guarantees, among other factors, which have to be developed through research. Furthermore, the diversification of consumer tastes has led to the multiplication of niche markets, for example for ethnic foods, which is an opportunity for developing countries. To be able to take advantage of these opportunities, producers need better marketing services and information. While for large companies, it is economically feasible to devise sophisticated marketing strategies, smaller producers will need assistance to be able to seize the opportunities of growing international trade.

Opening to international competition implies changing incentives and production patterns. Domestic prices for basic staples change, requiring development of new products and information about their nutritional characteristics. Increased livestock production requires large quantities of feed, which can displace traditional crops. To avoid a negative impact on vulnerable populations, possible effects of opening markets, such as rising prices for basic staples, need to be understood (Ingco, 1997; Islam and Valdes, 1990).

Income and Dietary Change

Another trend is related to the connection between growing income and the composition of the diet. As people’s income increases, the share of their calories that they derive from starchy staples declines, and consumption of higher value foods increases (Poleman, 1994). These higher value foods include fresh and processed fruits and vegetables, meats, fish, dairy products and vegetable oils. They tend to have shorter shelf-lives than starchy staples, and require a well organized postharvest chain to insure freshness. In addition, higher incomes also allow people to buy more prepared convenience foods, which further increases the importance of processing, long shelf life, transportation, and packaging.

Scientific Progress

Scientific progress has led to improved processing techniques for food and feed, and to new industrial applications which use agricultural inputs. Agricultural products with improved taste, appearance, shelf-life, and resistance to storage pests have made storage and transport easier. This has for example enabled farmers in tropical countries to produce valuable crops such as tropical fruit for the export market, thereby increasing their incomes. Better grain storage techniques and postharvest pest management allow developing countries with humid tropical climates to compete in world grain markets with virtually insect-free exports from temperate zones.

Biotechnology has also increased the pharmaceutical uses of many plant and animal species. These new technologies have led to new opportunities in marketing and processing (Jaffee and Gordon, 1993; Austin, 1995). Improved processing techniques for palm oil allow it to compete with other vegetable oils for a wide variety of end uses, which has allowed the main producers in South East Asia to multiply their exports. Malaysian smallholders, who grow much of the oil palm under contract, have benefited through rising incomes (Wolff, 1998).

Infrastructure

As infrastructure in many developing countries improves, it opens up new markets and opportunities for farmers. Better roads and access to water and energy allow for increased processing in rural areas (Treillou et al., 1992). New developments in information technology allow for quick access to market information through telecommunications. Internet is increasingly proving itself as a means for gaining market information via programs such as FEWS, but also for market negotiations through trade associations web sites. A recent initiative by FAO, the internet-based Information Network on Post-Harvest Operation (INPhO) will be discussed in chapter 2. Farmers and processors need access to these new sources of information to be able to produce for rapidly changing markets (Jaffee and Gordon, 1993). Better access to domestic and international markets made possible by improved infrastructure has considerable effects on the development of postharvest technologies related to storage, processing, and quality control. Moreover, the new opportunities open by better infrastructure may well relate to commodities that are more likely to benefit from postharvest research. In the case of Madagascar, it was shown that an improvement in transportation infrastructure makes profitable to export roots and tubers (see Goletti and Rich 1998). However, to make such opportunity operational, better technologies to store, transport, process, and grade roots and tubers will be necessary.

Environment

The growing importance of environmental concerns also presents opportunities and challenges for postharvest research. Consumers demand reductions in pesticide use, which requires new alternative technologies for storage pest and disease control. Pollution from processing plants and waste from aquaculture and livestock feedlotting are growing problems that need to be dealt with (Johnson, 1998). At the same time, demand for organic and biodegradable packaging presents new opportunities, for example for starch producers (Austin, 1995; Arnold, 1996).

Since investment in postharvest research has been rather low compared to investment on production research, there are many problems that can be easily solved, and where research can have a large impact. Many already existing technologies can be adapted to local conditions in developing countries. Modern research technologies can be applied to problems such as postharvest quality control, where much work remains to be done. Particular research challenges for the future include more efficient energy use; safe, affordable, effective, and reliable alternatives to chemicals; and improved food safety (Johnson, 1998). Another important task lies in the incorporation of economic and policy analysis into postharvest systems research (Goletti and Rich 1998).

1.3 PRIVATE VERSUS PUBLIC GOOD

As these international trends increase the importance of postharvest activities, there is also a growing need for research. Some of this research will be carried out in the private sector. For example, agribusiness firms themselves find it necessary and worthwhile to engage in final product development, market studies, and the search for improved processing technologies. Furthermore, national agricultural research systems (NARS) study local postharvest systems for certain crops that are important for the domestic economy, such as rice in Thailand. This information is often highly location-specific and therefore only of interest to local producers.

Certain types of postharvest research, however, have international public good character. This research has widespread benefits that are not easily reduced to only the clients of a commercial firm. Furthermore, this research can benefit poorer populations, thus contributing to goals such as poverty alleviation and income growth. When less food is lost, resources are used more efficiently, and value is added at the community level, postharvest research also contributes to making development more sustainable.

This paper explores the contribution of international postharvest research to the goals of poverty alleviation, food security and sustainable growth. This includes not only ensuring the availability of an adequate amount of food, but also its spatial and timely availability, improving quality and lowering cost. The systems approach, including the whole postharvest chain from farmer to consumer, presents new challenges for researchers, and requires much interdisciplinary and interinstitutional cooperation (see Ferris et al., 1997). Apart from designing better postharvest technologies and processes, there is an increasing need for more insight into policies and institutions. This research does not only benefit a specific population, rather it can lead to insights which benefit policy makers and producers in general.

1.4 ORGANIZATION

After highlighting the importance of postharvest activities, this paper surveys postharvest research carried out by different organizations. Chapter two focuses on research within the CGIAR system. Although, with a few exceptions, it has not been a priority, most centers are involved in some postharvest research, especially over the past few years. Chapter three presents methodologies than can be used to evaluate the impact of postharvest research. Assessing the impact of research is always a challenging task, but even more so in the case of postharvest activities, where the impact tends to be diffused and not easily separated from other influences. Nevertheless, several studies have managed to study the impact of this research. Chapter four reviews the literature on the impact of postharvest research, and the final chapter provides the main conclusions.

2. POSTHARVEST RESEARCH AT CGIAR CENTERS

Although most CGIAR funding (about 95 percent) is devoted to production research, there are some projects with a postharvest focus. The main centers involved in these activities are CIAT, CIP, IITA, IRRI, and IFPRI. After providing an overview of postharvest research within the system, this chapter briefly explores the research at each of the centers that are most active in postharvest research.

When the TAC study team led by Dr. Arnold produced its report on postharvest research within CGIAR in 1996, most centers were covering some harvest and postharvest problems in their research, usually closely related to their individual mandates. Most activities in the postharvest area focused on the genetic improvement of quality and storage characteristics, and some development of harvest, drying and storage technologies. The TAC report recommended more research in other postharvest areas, especially related to the efficiency of product utilization.

2.1 OVERVIEW OF CGIAR POSTHARVEST ACTIVITIES

Table 2.1 shows CGIAR research in each of the four areas of postharvest research: product quality, harvest and storage, utilization and marketing, and policies and institutions. Product quality is the category which fits most easily into the commodity centers' traditional focus on breeding. The CGIAR grain improvement programs contain grain quality. CIMMYT, ICARDA, ICRISAT, IITA, IRRI and WARDA, the centers with cereal crop mandates, all engage in this type of research to some extent. In general, the breeding objectives contain aspects of milling and baking quality, starch quality, and more recently nutritional characteristics. CIP, CIAT and IITA are likewise working on the improvement of roots and tubers, taking into account root shape and size, dry matter content, starch and nutritional quality, and toxicity factors. ICRISAT and CIAT are also studying quality characteristics in legumes.

Harvest and storage contains the areas of loss reduction and storage pest management on which a large proportion of postharvest research has focused in the past. IRRI's efforts in rice harvesting and grain drying equipment have been notable in this area. Another area is genetic pest and disease tolerance, which is related to product quality considerations. One example in this area is CIAT's bruchid resistance project which is part of the bean improvement project.

Utilization and marketing is an area that has received relative attention; some centers have undertaken research in the areas of market studies and new product development. CIAT and IITA, in collaboration with other institutions, have research which includes new uses and processing technologies of cassava; CIAT's work is described in more detail below. ICRISAT has devoted some effort to improving sorghum and millet processing. Most commodity centers have studied local postharvest systems. Another important area that has received some attention is the study of crop by-products, for example for animal feed.

The last area, policies and institutions, is also gaining importance as many developing countries search to promote agricultural development and economic growth through market-based strategies. Especially IFPRI can make significant contributions in this area. The existing research programs on market reforms, agricultural diversification, and micronutrients highlight the importance of research and investment policies to promote postharvest activities, and the linkages between production, processing, and consumption within the context of domestic and international markets.

Each of the following section focuses on the priorities and areas of concentration; major projects and achievements, and future plans of one center.

Table 2.1–Postharvest Research at CGIAR Centers

Center	Product Quality	Harvest & Storage	Utilization & Marketing	Policies & Institutions
CIAT	Breeding: Beans for cooking qualities and nutritional value; Cassava for nutritional value, low toxicity, storage life, and starch qualities; Forage for nutritional value and availability; Rice for food qualities	Bean resistance to bruchids; Cassava: dried chips and fresh roots (plastic bag) storage	Cassava flour and starch processing technologies, marketing, product development, feasibility/impact analysis and waste water treatment	Organization of small agro-industries; Design of an integrated approach to product development; Seed production enterprise organization for beans and forages; Institutional cooperation through training of NARS personnel.
CIP	Breeding potato for tropical processing, and Sweetpotato for processing qualities	Potato: rustic storage systems for ware tubers	Potato marketing methodologies; Sweetpotato processing and marketing; characterization, marketing and processing of Andean Tubers.	
IITA	Screening methods for quality evaluation; nutritional quality and safety of traditional foods	Harvesting technologies; Storage systems; Pest management	Small-scale processing technologies and socioeconomic assessments	
IFPRI	Micronutrient enhancement to fight malnutrition	Efficiency of private and public storage	Marketing structure of milling industry, oil processing, sugarcane processing, fish and meat processing.	Price policy, Inspection and quality control, Contract farming, Access to information.
CIMMYT	Breeding wheat for product suitability	Maize storage pest management		
IRRI	Breeding rice for cooking and tasting qualities	Small stripper harvest systems	Rice micromills for household needs and women's income in remote villages	Improvement of rice milling systems in SEA cooperatives and enterprises

Source: Based on Arnold, M. 1996. "Harvest and Postharvest Problems in Agriculture, Forestry and Fisheries - The CGIAR Contribution to Research - ". CGIAR Document No.: SDR/TAC:IAR/96/5.

It does not provide an exhaustive list of the centers' activities, but rather highlights a few interesting activities for each.

2.2 CIAT

Priorities and Areas of Concentration

Beyond the genetic improvement for quality traits in beans, rice and tropical forages, most of CIAT's postharvest research has been concentrated on cassava. In Latin America and particularly Asia, cassava is losing importance as a food staple. It requires very time-consuming processing and preparation methods, and it spoils quickly. An increasingly urban population has less access to fresh cassava, while other foods are available and easy to prepare. In Asia, rice the preferred staple is now widely available. On the other hand, cassava is a small farmer crop with potential as an additional income source. CIAT has therefore focused on identifying markets and developing technologies for small-scale processing of cassava.

CIAT has developed a methodology for the development of cassava products, and the development of production processes and markets for these products. It consists of four stages: identification of opportunities, lab and prototype research, pilot-scale testing, and expansion to commercial-scale operation. With CIP providing their experience on potato and sweetpotato, this methodology has been documented for roots and tubers and used for training of national program personnel. The integrated cassava project (see chapter 4) is one example where this approach was used to identify market opportunities, and to develop commercially viable processing systems to take advantage of these opportunities.

Apart from its postharvest research on cassava, CIAT also works in beans, especially in the areas of breeding for improved cooking and nutrition characteristics and resistance to bruchids. In addition, it has studied the organization and setting up of farmers’ seed production enterprises for bean and forage seeds.

Some Major Projects and Recent Achievements

• *Dry chips for the animal feed market.* In the early 80s, CIAT introduced dry cassava chip production on the North Coast of Colombia in collaboration with the Integrated Rural Development Fund. This project, which was subsequently replicated in Ecuador and Brazil, is described in greater detail in chapter 4.

• *Conservation of fresh cassava for human consumption.* Apart from using cassava for animal feed, another strategy to increase demand is by making it more convenient for human consumption in fresh form. CIAT and the Natural Resources Institute (NRI) developed a storage technology that demonstrated its technical and economic feasibility in pilot tests in Northern Colombia. Because of urban distribution and farmer organization problems, the storage method has not been widely adopted, although marketing intermediaries have incorporated components of the postharvest handling technology. It has also been successful in pilot tests in Paraguay, and has being modified by the NRI for local marketing conditions in Ghana.

• *Cassava flour for the food industry.* A research project, financed by IDRC, developed a process for the production of high-quality cassava flour for human consumption in Colombia. Market studies and industrial trials demonstrated that this flour can find markets in food and non-food applications with either price or quality advantages over other flours. This technology is also being employed by a farmers’ union in Ecuador; and five plants have being installed in Peru and two in Nicaragua.

• *Cassava starch.* This program focuses on sour or fermented starch; it is carried out jointly with CIRAD-AMIS (Montpellier). There was a need for loss reduction and product quality improvement for traditional small-scale producers in Colombia. Improvements have been transferred successfully by NARS to processors in Colombia, Ecuador, Paraguay and Honduras. The starch’s self-raising characteristics could open up important niche markets in dietary and gluten-free products.

Future Plans

While during the past 15 years, CIAT's postharvest research agenda has focused mainly on cassava processing and marketing, especially of cassava-based flours, feeds and starch, and storage and conservation of fresh roots for human consumption, recently attention has shifted. CIAT is now taking its integrated project mode one step further, applying a similar market-driven approach to identify market opportunities, suitable technology options and appropriate organizational schemes for postharvest agroenterprises at the micro-regional level. Its new agroenterprise development project specifically targets smallholders in fragile environments. As a consequence, the research is incorporating issues related to enterprise and institutional organization, including policy.

CIAT's Agroenterprise Development Project aims to link smallholders to growth markets and motivate farmers to invest in the conservation of the resource base through the promotion and strengthening of rural agroenterprises. The project's purpose is to "develop, in collaboration with partners, methods, tools, and institutional models for the design and execution of agroenterprise project that integrate market opportunities and postharvest technologies with environmentally sound production practises" (Ostertag et al., 1997).

This project, initiated in 1996, will generate four types of outputs: a) methods for market opportunity identification and development; b) information and technology for postharvest processing where smallholders have a comparative advantage; c) options and recommendations for the design of efficient and effective organizational schemes for small-scale agroenterprises and their support services; and d) institutional models and policy options for the establishment and strengthening of rural agroenterprises and their support systems at the microregional level.

Selection for quality related traits will maintain importance in CIAT's germplasm improvement projects on cassava, beans, rice and tropical forages. Breeding for micronutrients dense beans (iron and methionine) and cassava (vitamin A, C, and iron, calcium and zinc in leaves) is continuing (see the section on IFPRI below). Particular emphasis will be placed on selection and genetic manipulation for specific cassava starch functional properties, targeting the specific needs of the food and non-food industries. For forages, quality characteristics for multiple end uses are under consideration, including livestock production, soil fertility maintenance, erosion control and a source of firewood.

2.3 CIP

Priorities and Areas of Concentration

The emphasis of postharvest research at CIP has begun to shift from equipment to market research. Efforts are focused on particular products to maximize their impact at specific locations. There are postharvest projects both for potatoes and sweet potatoes; postharvest research on Andean roots and tubers is done as part of a more general effort to conserve and characterize these crops.

The concentration of CIP’s postharvest research is on technology generation, adaptation (processing and storage) and evaluation, market and consumption research, nutrition studies, small enterprise development, and priority setting for breeders.

Some Major Projects and Recent Achievements

• *Potatoes.* Initially, research focused on technology development, but was not very successful. Since then, the focus has shifted to understanding postharvest systems, and collaborating with agencies with local expertise. A number of marketing studies were carried out in Latin America, Asia and Africa to analyze potato food systems, and some small-scale processing research was undertaken. Market research identified large, growing markets for French fries and chips in many developing countries, where small and medium-sized enterprises have become active.

Diffused light storage systems for seed potatoes were developed, a system that has been adopted by NARS throughout the developing world. Now the emphasis is on consumer (ware) potato storage.

• *Sweet potato.* Together with NARS, CIP worked out research priorities and systematized the knowledge base. Asia accounts for 85 percent of sweet potato production. Due to demographic and economic trends in the region, the fastest growing markets are in animal feed, and processed starch- and flour-based products such as noodles. Research has thus focused on enabling the poor to benefit from growth in sweet potato participation in these markets.

In Africa, a project in collaboration with NRI and NARS in Uganda and Kenya developed pilot enterprises for sweetpotato flour, and fresh sweet potatoes, which are used as inputs to other products. In Peru there are projects with Dutch funding which investigate the use of sweetpotato vines and flour as animal feed. CIP's global germplasm collection also serves for studies of improved postharvest qualities.

• *Andean roots and tubers.* Research has focused on collecting and characterizing the germplasm of crops such as oca, mashua, olluco, canna etc. Postharvest research is an aid to in situ conservation of these crops, and identifies characteristics that are useful to the food industry.

Future Plans

In 1993 it was decided that postharvest research would focus on storage and marketing for potatoes, and on processing and animal feed uses for sweet potato. Since there is strong private sector interest in potato processing, there is less need for CIP activities in that area. Because the fresh sweet potato market is declining while feed and processed product uses are gaining importance, emphasis will be on the latter, except for some attention to storage of weevil-damaged roots.

2.4 IITA

Priorities and Areas of Concentration

IITA still maintains a strong focus on germplasm quality and technology generation, although in the future research will focus somewhat more on processing efficiency and marketing studies. The priority activities include characterizing postharvest food systems and markets to identify constraints and opportunities for the crops in IITA's mandate. The center develops food products with improved nutritional value, and identifies the qualities its crops have for different end uses. IITA is also working on developing, testing and disseminating technology packages for increased utilization of its mandate crops.

Some Major Projects and Recent Achievements

• *Cassava.* Projects related to cyanide testing equipment and issues of cassava safety are described in greater detail in chapter 4. IITA was able to release improved cassava varieties with low cyanide content to NARS in Western Africa. It also developed processes for production of high-quality cassava flour that were adopted by farmers and processors in 4 Nigerian states, and by new flours processing sites in Uganda.

• *Soybean.* A ten year program funded by IDRC has been focused on the use of soybean in improving diets. Most of the work involved training groups in soybean processing particularly fortification of traditional products. This work also developed equipment for processing and has conducted a number of impact surveys on processing at various levels from household to medium scale and large scale industrial processing.

• *Banana and Plantain*. Research on these crops developed methods for germplasm screening. A range of products using banana and plantain as inputs were developed; some of them were adopted by farmers and processors.

• *Yams.* Promotion of yam using improved traditional techniques to produce high value yam flour. This study involves both specific varieties and methodologies for maintaining supply and quality.

• *Training.* In several workshops and demonstrations, IITA demonstrated the importance of postharvest technology and product development to policymakers, producers, processors, retailers and marketing agents. More than 500 NARS staff were trained in postharvest technologies, and a training guide and a newsletter were created.

Future Plans

As new collaborative projects are initiated with the cooperation of other centers such as CIAT, CIP, NRI and CIRAD, there is a shift towards a new, more market-oriented systems approach to postharvest research. It is accompanied by a transition from a technology-driven approach to a more participative approach.

2.5 IFPRI

Priorities and Areas of Concentration

IFPRI's mission is to identify and analyze alternative national and international policies for meeting food needs on a sustainable basis, with particular regard for low-income countries and poor people, and for the sound management of the natural resource base that support agriculture. Its strategy consists in organizing and undertaking research in a manner that will generate international public goods -knowledge relevant for decisionmakers both inside and outside the countries where the research in undertaken and expected to result in large benefits to society. This strategy is pursued primarily through integrated multicountry research programs (MP). These research programs are designed as multiyear comparative research efforts that are typically implemented in several countries. MP's share a set of policy problems for which international strategic research is needed and likely to have broad benefits and for which research is of critical importance to many developing countries.

In the past, IFPRI was active in policy related studies on cassava which were subsequently used for priority setting. Currently, there is no MP specifically devoted to postharvest research. Policy issues related to postharvest research are, however, embedded in a number of MP including the programs on output market reforms, agricultural diversification and export promotion, and agricultural strategies for micronutrients.

Some Major Projects and Recent Achievements

Program on Output Market Reforms The main objective of this program is to understand the institutional, structural, and policy-related factors that impede the process of transition from a system dominated by extensive state intervention in the domestic distribution of agricultural products to a more market-oriented system. As such, the research in this area has considered several postharvest activities, including storage, milling (rice, wheat, maize), processing (oilseeds, sugarcane), and transportation. Key findings on private storage behavior in Bangladesh have contributed to an improvement of the management of public foodgrain stock, saving considerable resources for the country. In the case of milling in Viet Nam, the complexity of the rice milling industry involving a variety of small, medium, and large private enterprises was found to be an efficient and flexible response to an export system dominated by state owned enterprises. The absence of competition in the groundnut oil industry in Senegal was found responsible for low prices paid to farmers. The subsidization of large state wheat mills in Egypt protracted the adoption of obsolete technology, thus contributing to large inefficiencies.

Program on Agricultural Diversification and Export Promotion. The main objective of this program is to identify more effective marketing, infrastructure, and institutional policies to facilitate the adjustment of farmers to change in incentives arising from long-term structural changes in agricultural markets. Within this program several issues in postharvest technologies have been considered, related to agro-processing as a strategy for rural industrialization, quality control in the context of linkages with international markets, and structural changes in the pattern of demand and their effects on livestock and fisheries. In the case of agro-processing, a recent study on starch processing in Viet Nam has pointed out the considerable gains from investment in industrial uses of food crops such as cassava. Quality control aspects have also been found limiting the link of banana industry in Indonesia with the rest of the world. The structural changes in the diet of Asia and other developing countries, with their increasing consumption of livestock and fish has pointed out the importance of post-production technology development in order for developing countries to benefit from such momentous changes.

Agricultural Strategies for Micronutrients This program investigates the feasibility and cost-effectiveness of breeding for micronutrient-rich staple food crops.. IFPRI coordinates this project and collaborates with a broader group of nutritional professionals that are looking at methods such as nutrition education, fortification, and supplementation. The opportunity of breeding micronutrient-rich staple food crops is directly related to the category of product quality enhancement. If successful, this research will lead to policies and programs that reduce micronutrient deficiencies and improve health and productivity, particularly of the poorest segments of society.

Future Plans

During the past few years, IFPRI has become more actively interested in postharvest research. Its researchers are part of CGIAR working groups on postharvest research related to roots and tubers and some research is starting now to be fully devoted to postharvest research, such as in the case of starch processing and food processing in Viet Nam. This movement is likely to be continued in the future and a more focused research program on postharvest research is currently under discussion.

2.6 IRRI

Priorities and Areas of Concentration

IRRI concentrated mostly on the more traditional CGIAR approaches of breeding and technology development. Breeding objectives include postharvest quality considerations, as well as nutritional values. Technology development includes harvesting and milling machinery.

Some Major Projects and Recent Achievements

• *Breeding*. Apart from yield improvements, IRRI is now also incorporating quality factors such as cooking and tasting qualities into its breeding objectives, as well as micronutrient enhancement.

• *Technology development.* New successful technology developments include small stripper harvester systems and rice micromills for households. The main aim is to reduce rice losses during all stages from harvest to storage, and to maintain high food quality. The micromills furthermore helps women in remote villages to mill paddy locally while saving transport costs, time and labor, and providing an additional income source.

2.7 COOPERATION WITH OTHER CENTERS AND INSTITUTIONS

There is a good record of cooperation among centers on postharvest activities. One such example is roots and tubers research. CIAT, CIP and IITA cooperate in the development of a new methodology for market-based identification and development of new uses for cassava, and in research on production and processing technology. On many projects, CGIAR centers cooperate with other Advanced Research Organizations (ARO) as well as with NARS in Latin America, Africa and Asia. These AROs include organizations such as NRI from Britain, the Australian ACIAR, and CIRAD-SAR from France. Moreover, cooperation on postharvest issues has involved NGOs such as World Vision, Sasakawa , and CARE.

Recently, IDRC has promoted a new initiative, the Small Grants Fund of the Global Collaborative Post-Production Research Network to encourage and provide seed funding for the identification and building of partnerships for research and development activities in the post-production sector. Grants must bring together partners from at least one national research system institution (defined to include universities, non-governmental organizations, public research organizations and the private sector) in a developing country with at least one international agricultural research centre (IARC). Links with the private sector should be emphasized. Proposals including more than one international agricultural research centre and the participation of institutions from developed countries that can bring specialized skills are also encouraged. Research proposals will relate to interventions in the production-consumption continuum, and demonstrate a clear market and client oriented approach. Particular emphasis will be paid to value-added and gender-related issues. Research must be replicable and relevant in more than one country, and in accordance with the research priorities of the region. The methods and techniques to be used to ensure participation of client groups and gender differentiation in data analysis need to be clearly stated.

Grants should be focused on those key commodities and ecoregions identified by the Consultative Group for International Agricultural Research (CGIAR) centres. These include the mandated commodities whose germplasm the CGIAR centres hold in trust, and other products (including tree products, livestock and fish) considered key by the CGIAR in terms of their income generating or resource conserving potential in priority ecosystems.

Cooperation with NARS is also important both in identifying new areas of research, and in implementing them. NARS are usually responsible for adaptive research, and for the dissemination of new technologies and information. NARS training is a major component of the centers' work.

A new vehicle for facilitating cooperation and dissemination of information is the new FAO initiative, INPhO, the Internet-based Information Network on Post-Harvest Operations. The idea behind INPhO is to provide institutions, government, and non-governmental organizations and the private sector – all groups that could have a part to play in post-harvest management – with a place to store, share, and access information. While information on post-harvest management has always existed, it has been dispersed widely throughout the world, with no central access point. The launching of INPhO marks the first effort to improve global access to the broadest range of information on post-harvest management. The initiative, still in its 2-year pilot phase, has been supported with GTZ and CIRAD funding and has already established collaborative contacts with a numbers of other organizations involved in postharvest research including GASGA and IARC such as CIAT, IRRI, CIP, IITA, and IFPRI.

2.8 FUTURE AREAS OF EMPHASIS

As recommended by the TAC, the postharvest research focus within the CGIAR system is broadening to a systems approach which looks at the whole postharvest continuum. This means increased involvement in market studies, development of new end uses, and processing. Postharvest enterprises can be an important source of rural income and employment which can help to slow down rural-urban migration. To decide which areas should be prioritized in future postharvest research, it is important to evaluate past efforts. The following chapter gives an overview of the existing methodology available to measure the economic impact of postharvest research. Chapter 4 provides examples of impact studies that evaluate postharvest research projects from each of the four areas of emphasis.

3. METHODOLOGY

Resources for agricultural research are scarce. To ensure that scarce resources are allocated in a manner that maximizes their impact on economic growth and poverty reduction, policy makers need reliable indicators which allow them to compare the benefits from very different types of research. Research evaluation can be carried out ex post, to account for the effectiveness of past research; and ex ante, as a basis for setting priorities and allocating research resources (Alston, Norton and Pardey, 1995).

Measuring the impact of a research project is a difficult task, but particularly in the case of postharvest research. The benefits of a new technology are often very dispersed, with complex effects on other activities. Thus a new threshing machine may reduce postharvest losses, the value of which would be relatively simple to assess. In addition, this new machine may reduce the labor required for threshing, in which case family labor could be dedicated to other income-earning activities, and/or education, leisure, etc. A farm family may be able to expand the area under cultivation, increasing overall production and marketed surplus. These indirect effects are related to the new technology, but their value can be extremely difficult to measure.

In contrast to the relatively well-developed literature on evaluating the impact of production research, relatively little has been written specifically about the impact of postharvest research. Methodologies for the evaluation of farm production research have been developed since the 1950s, but it was not until the early 1980s that this methodology was adapted for postharvest research.

3.1 SURPLUS DISTRIBUTION MODELS

Initially, some evaluation attempts simply consisted of determining the retail value of the change in output brought about by technical change. Much of the current methodology is based on a simple economic surplus model, often referred to as the linear elasticity model. It can show both the total amount of benefits, and their distribution between producers and consumers. Julian Alston reviews both the basic model and its modifications to include multiple factors, several stages of production, or multiple product markets in a 1991 review article. These models are briefly described below, as well as their applications to postharvest research.

Figure 3.1 shows the basic model of research benefits in a closed economy[1]. The demand curve is D; S_0 and S_1 are the supply curves before and after a research-induced technical change. The initial equilibrium is at point a, with price P_0 and quantity Q_0; after the supply shift the new equilibrium is at b. Total benefit from technical change is the area between the two supply curves and below the demand curve, or area I_0abI_1. It is the sum of the reduced cost of the original quantity produced, plus the economic surplus from increased production and consumption. The change in consumer surplus consists of area P_0abP_1, and the change in producer surplus equals P_1bI_1 minus P_0aI_0.

Typically, the benefits shown in Figure 3.1 would represent annual flows; calculating total benefits would require aggregating over time. The model abstracts from demand and supply responses, lengths of run, and lags in research, development, and technology adoption.

The model also abstracts form the question of market level. When measuring the distribution of research benefits at the farm level, “producers”

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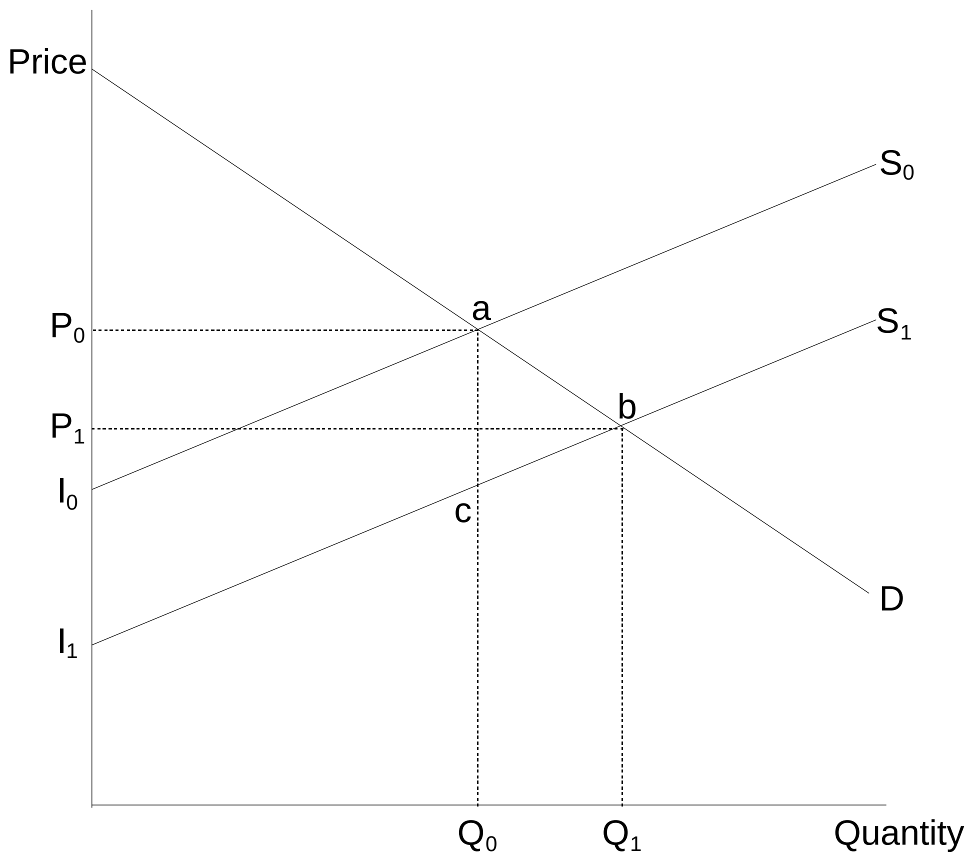
[1] For a more detailed description of the models, their underlying assumptions, as well as algebraic calculation of benefits please refer to Alston (1991).

include only farmers, while “consumers” also include all post-farm activities such as processing and marketing. Measured at the retail level, these post-farm activities would be included in producer surplus. Thus, the choice of market level in this model implies a choice about vertical surplus aggregation among different stages of production. Similarly, the basic model contains implicit choices about horizontal aggregation: all suppliers and demanders at a given market level are aggregated.

Figure 3.1–Surplus distribution in the basic model of research benefits

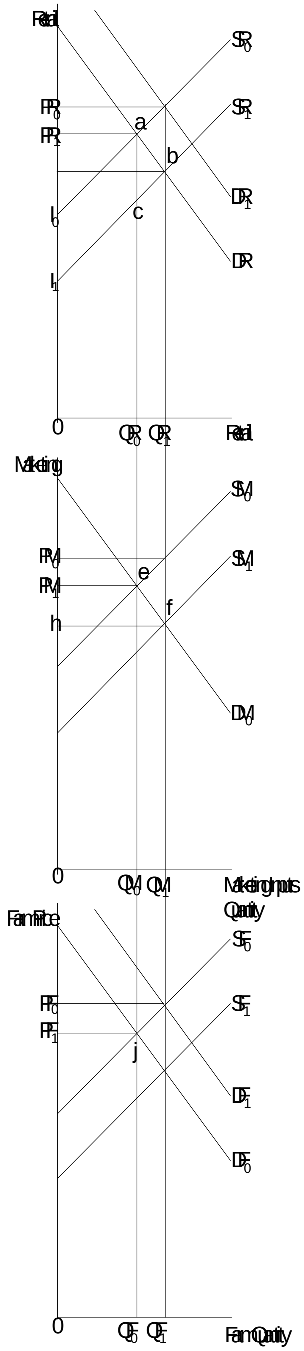


Source: Alston 1991.

This basic model can be extended to analyze vertical market relationships including postharvest activities by treating the different stages of production as if they occurred simultaneously. This model can represent two inputs, for example a farm product and marketing inputs, which are used in fixed proportions to produce one retail product. Figure 3.2 shows these three markets. The retail supply function is the vertical sum of the marketing and farm supply functions. Similarly, farm demand is the difference between retail and marketing demand.

Figure 3.2–Research benefits with postharvest activities

Source: Alston 1991.



Initially, equilibrium is defined by the intersection of retail supply and demand at point a. If now, due to advances in postharvest research, the supply function for marketing inputs shifts down to SM_1, it affects the equilibrium in all three markets. Retail supply shifts down by the same amount per unit to SR_1. The demand for the farm input shifts up, also by the same amount, to DF_1. All quantities increase, marketing and retail prices fall, and the price of the farm product increases.

The total welfare gain consists of the area I_0abI_1, with a change in consumer surplus of PR_0abPR_1, and a change in producer surplus of PR_1bcd. The change in producer surplus includes a change in surplus to marketing input suppliers of PM_1fgh, and a change in farm surplus of PF_1ijPF_0. These results can be extended to any number of factors of production.

In this model, the distribution of benefits is independent of which curve shifts first, as long as all shifts are parallel. Therefore in this model, farmers would be indifferent about where new technology applies, and where the money to fund research is collected. Maximizing total benefits will automatically maximize farmers' benefits.

If technical change resulted in a change in the production function such that the proportions of inputs needed for the retail product changes, it would result in non-parallel shifts in the supply curves. This factor-biased technical change could be incorporated into the model, although calculating the welfare effects becomes more complicated in such a scenario. In that case the distribution of benefits depends on where in the production chain technical change takes place.

Another extension of the model applies to horizontal market relationships. It allows to disaggregate the benefits of different types of producers or consumers, for example in different locations, or several income groups. This enables researchers to include trade in the model, studying the distribution of research benefits or costs among several countries, or to include spillover effects. These multi-market models can furthermore be combined with multi-factor models.

Multi-market cases can be incorporated into a general equilibrium framework, or alternatively the effects in different markets can be added up. It is important to keep in mind the danger of double counting, especially where products are connected by substitution or complementarity in production or consumption. These models become extremely complicated, especially when there are several sources of market displacement, or several relationships, for example between consumption and production of different goods.

3.2 APPLICATIONS TO POSTHARVEST RESEARCH

The Australian Center for International Agricultural Research (ACIAR) is a valuable exception in the general scarcity of impact studies. As a result of taking a more balanced approach to the R&D evaluation, ACIAR has also the highest level of funding for postharvest research, currently at 15 percent of total budget. As part of an effort to increase the transparency of resource allocation between different research projects, this organization has devised an Information System which generates information to help in priority assessment, both for production and postharvest research. This System includes evaluations of all ACIAR projects, for which ACIAR's Economic Evaluation Unit has designed a project development assessment methodology. It includes several guidelines for estimating the welfare effects of postharvest research, many of which build on methodology described in the Alston article. Depending on the nature of the research and on the economic characteristics of the commodity in question, different factors have to be taken into account in the valuation process. ACIAR has developed the following list of categories:

Changes in Postharvest Costs

This model applies only to commodities that require minimal processing, and that are used in fixed proportions with the postharvest inputs. The product is only graded on the farm; postharvest activities include mainly transport and storage. Examples of such commodities include many vegetables. Postharvest research leads to a reduction in postharvest costs, which leads to a shift in the supply curve, as in the welfare change models above. This is a relatively simple, but reasonably accurate model that has been discussed for example by Freebairn, Davis and Edwards (1982).

Wastage Reduction

This category includes commodities which require processing besides storage and transport, but without complex substitution relationships. In these cases, the commodity often changes between the time it leaves the farm and the time it reaches consumers, and there is significant wastage. This is the case with tropical fruits. Research on these commodities often focuses on reducing postharvest losses, for example by defining optimal storage temperatures and handling procedures. New wastage reducing technology is usually associated with increased costs. ACIAR has done work on a simple version and clear application method of this model. Most postharvest research at ACIAR falls into this category.

Health Impacts of Research

There is increasing awareness of the potential health impacts of some postharvest activities, for example pesticide use, or aflatoxin problems. There is a need to evaluate the gains from research in these areas. Lubulwa and Davis (1994b) have estimated the social costs of the impacts of fungi and aflatoxins. One of the impact studies presented in the next chapter deals with the health benefits of reducing the incidence of hydrogen cyanide, a toxic substance, in cassava. In another paper Lubulwa and Davis (1994c) review different methods to include environmental and human health impacts in agricultural research evaluations.

There are three ways to estimate the human welfare benefits of research. The first consists in calculating the reduction in total years of life lost (World Bank, 1993). The second is to estimate the monetary cost of the disease (Crowley et al., 1992). This can either be done through the willingness-to-pay method, where a survey establishes the value people place on disease reduction; or by the human capital method, which equates the benefits of research with the reduction in productive capacity lost to a disease. Davis and Lubulwa have designed a third method, which evaluates the impact of the research on the labor market or the market for medical services (Davis, J. S. and Lubulwa, G. 1993).

New Product Development

Some postharvest research results in the development of a new product or commodity. Estimating the gains from this research as the value of the new product will overestimate the gains. Instead, the alternative uses of resources devoted to the production of the new product need to be taken into account. Examples for new products include transgenic crops, such as the Flavr Savr tomato described in the next chapter, and new uses for commodities, such as dried cassava chips used as animal feed.

Multiple Products Related Through Production or Consumption

Most agricultural commodities require some processing. In processing, the production of two or more goods can be linked, for example because they use a common input. Thus, different dairy products all use milk as an input.

When there is a production (or consumption) relationship between the products, it has to be taken into account in the modeling. These relationships can take three forms: a) substitution in consumption, such as between butter and cheese; b) substitution (or complementarity) in production, for example when milk is used to produce both butter and skim milk powder; and c) competition or substitution between products in the use of specialized factors, like between using milk for butter and skim milk powder, and using milk for cheese (Alston, 1991).

These cases can be evaluated using the multi-market model described by Alston (1991), although it is sometimes difficult to avoid double counting when adding up effects across markets. Alternatively, a general equilibrium approach can model related markets. It remains difficult to disentangle effects among related commodities, especially when technical change leads to two or more simultaneous market displacements.

Change in Quality

Alston's surplus distribution model can be modified to account for changes in product quality. This change in quality can either be incorporated by treating product characteristics as products in themselves, or by treating different qualities of one product as different products. The latter approach is more restrictive, but also more practicable. However, the large substitution effects both in consumption and in production of different quality products are very difficult to measure, especially ex ante. These measurement problems complicate the application of this variation of the model, and often make welfare effects intractable.

The most common approach to modeling changes in quality is to introduce an ad hoc shift in the demand for the product in question, induced by the change in quality. While simpler, this is incorrect conceptually. Technical change is a change in supply, not demand conditions, and it would be more desirable to model it as such. Additional work will be needed to improve the existing modeling techniques.

Lemieux and Wohlgenant (1989) use a linear elasticity model for an ex ante evaluation of the economic impact of porcine sematotropin (PST). PST occurs naturally in pigs. When supplemental PST is administered, it leads to faster weight gain, better feed efficiency, and leaner meat. The authors estimate the effect on process and quantities of pork at retail and farm levels, and on producers' and consumers' net benefits.

The authors take into account several of the complex interrelationships between markets, including a) interrelationships between pork and hog markets, b) interrelationships between pork and other meats, c) interrelationships between domestic and international markets for hogs and pork, d) intertemporal effects through different adoption rates and different lengths of run for supply adjustment, and e) shifts in consumer demand from production of leaner pork. They estimate the short, intermediate, and long run changes in consumer and producer surplus from the new product.

3.3 ECONOMETRIC ESTIMATION OF A COST FUNCTION

Econometric estimation of cost or production functions is another possibility to obtain the returns to research. While usually data availability restricts the applicability of this method, the following is a case where the method was successfully applied. Stranahan and Shonkweiler (1986) estimate a translog cost function to evaluate the impact of postharvest research on citrus processing in Florida, specifically in the frozen concentrate orange juice market. Most of the research was carried out by the Florida Department of Citrus (FDOC), a self-financed, state-regulated industry organization. It developed frozen concentrate orange juice, and cost-reducing processing technologies and product improvements (FDOC and private research).

While econometric techniques are often limited to the macro-level because of data availability problems, in the Florida citrus case, input prices, total cost, and cost share data are obtainable. The authors therefore estimate a cost function C in conjunction with share equations.

$$C = c(Y,P,Z)$$

where Y is a given output, P stands for input prices, and Z represents R & D expenditures on citrus research. The first derivative of the cost function with respect to Z gives the negative shadow price of Z. Research may affect the cost shares of inputs by altering the variable cost function, or induce factor bias. It may also affect input usage neutrally, e.g. through organizational innovation.

The authors fit a translog cost function in conjunction with share of labor and share of materials equations for the years 1956 - 1980. For the quantity of R & D they use the average of deflated expenditures lagged one and six years. (The average lag for R & D payoffs is six months to 2 years for applied research, and 5 to 9 years for basic R & D). They use iterative seemingly unrelated regression to obtain the parameter estimates. Through the duality relationship between production functions and cost functions, the authors measure the returns to postharvest research.

3.4 SUMMARY

Table 3.1 provides a summary of methodologies that can be used to evaluate postharvest research.

Table 3.1–Methodologies for the Evaluation of Postharvest Research

Research Area	Type of Model	Comments
Product Quality		
Product Quality (Harvesting)	Multi-commodity vertical market model, related in consumption	Care is required if a simple increase in price model is used, substitution effects in production and consumption are complex
Human Health	Years of life lost, monetary cost, labor supply shift, or demand for health services	Models not well developed or applied, difficulty of valuing health in money terms
Harvest and Storage		
Wastage Reduction (Harvest, Diseases, Storage, Ripening, Disinfestation)	Multi-regional vertical market model	
Transport	Multi-regional vertical market model	Private sector relevance could be important since most research gains are appropriable
Utilization and Marketing		
New Product	Single or multi-regional multi-commodity supply shift model	Complex substitution effects in both production and consumption, difficult to carry out ex ante
Marketing	Single or multi-regional vertical market model	
Processing	Multi-regional vertical market model, probably factor-biased; econometric estimation of a cost function	Private sector relevance could be important since most research gains are appropriable; can be complex is several products are related in production and/or consumption
Policies and Institutions		
Policy/Regulation	Value of information model with saving in dead weight loss	Model not well developed and few applications
Environmental Issues	Single or multi-regional, multi-commodity supply shift model	Other areas also involve environmental issues

These are the most common methodologies for the evaluation of benefits from postharvest research.

3.5 TIMING MATTERS: DISCOUNTING, NPVS AND IRRS

The basic and more involved measures of economic impact presented so far tend to paint a static picture of benefits from research, capturing only the benefits accruing in one time period. Since research benefits often begin only after a considerable lag, while costs start much earlier, it is important to evaluate the benefits over a period of time.

Summary measures such as benefit cost ratios, net present values (NPV) and internal rates of return (IRR) evaluate the costs and benefits of a research project over time. Benefits and costs which occur in the future are valued according to their distance in time, a process called discounting. The discount rate is a type of interest rate which reflects a society's time preference. Adding up the discounted benefits associated with a project gives their present value.

The benefit cost ratio simply consists in dividing the present value of all benefits by the present value of all costs from a project. If benefits outweigh costs, this ratio will be bigger than one, which is a prerequisite for profitability. The net present value is a sum of all discounted costs and benefits associated with a project; it should be positive. Internal rates of return are computed by calculating the discount rate which would make the net present value of a project precisely equal zero.

While all of these measures have their advantages, the internal rate of return is convenient for research evaluation because it allows to compare and rank projects clearly, regardless of the magnitude of the initial investment (Alston, Norton and Pardey, 1995). It can furthermore be compared with the current interest rate to give a sense of a project's profitability and viability.

3.6 DIFFICULTIES AND SOURCES OF BIAS

Difficulties in measurement are probably the most important source of bias in the evaluation of benefits from agricultural and postharvest research.

Measurement problems tend to augment with increased detail; and the costs of fine tuning may exceed benefits from improved resource allocation. Therefore many methodologies are more useful at a aggregate, program level (Alston, Norton and Pardey, 1995). In their recent meta-analysis of returns to agricultural R&D, Alston, Marra, Pardey and Wyatt (1998) note that not only benefits, but also costs are often measured incorrectly. They list several common errors.

One frequently made mistake consists in attributing all productivity growth in a specific area to local public-sector R&D expenditures on the commodity in question. This is likely to underestimates the true costs by excluding private sector R&D, basic research which constitutes a foundation for more applied research, extension costs, and spillovers from other areas.

Another bias stems from an (understandable) tendency to focus on evaluating successful projects. Often, for example when an improved variety is developed, many other varieties were investigated, even if they were not adopted. It is misleading to exclude the research costs for those unsuccessful varieties.

Furthermore, many people and institutions have several roles, for example in research, teaching and extension. It is very difficult to divide out costs under those circumstances, and to identify the sources of ideas.

Other sources of error include double counting of benefits, which was mentioned before. Spill-in or spill-out effects are another factor that is frequently excluded. Research benefits tend to be difficult to confine to one area, which is why they frequently have public good character and are undersupplied by the private sector. Sometimes these spillover effects may be small, and the cost of estimating their magnitude may outweigh any benefits from increased accuracy, but in other cases they can be substantial.

Misrepresenting the nature of the research-induced supply shifts is another common source of bias. It is not always clear whether technological change is neutral or biased, and choosing the wrong functional form for supply and demand curves introduces further inaccuracies. One final source of error lies in the timing of benefit and cost flows. Often there are considerable lags between research costs, development of new technology, technology adoption, and the beginning of benefit flows. These lags furthermore tend to be difficult to predict ex ante; but especially where discount rates are high, accurate timing is important for a reliable evaluation (Alston et al, 1998).

4. IMPACT STUDIES

Measuring the impact of postharvest research is difficult, and as the previous section shows, many of the methodologies are fairly recent. There are however a few studies which attempt to evaluate postharvest research. Not all of them follow a quantitative approach, where the economic benefits and changes in welfare are calculated in money terms. These quantitative studies have the advantages of being more easily compared, which is important for resource allocation decisions. But some of the more qualitative studies also convey a good sense of the importance of postharvest research, especially where benefits are not easily expressed in monetary values.

This chapter returns to the four categories of postharvest research that were presented in the introduction: product quality, harvest and storage, utilization and marketing, and policies and institutions. Two or three examples illustrate the types of projects that fall within each of these categories, and the economic impact associated with them. The examples are necessarily biased towards those projects whose impact has been evaluated. This may be a bias towards successful projects. Another bias is associated with the institution responsible for the project. ACIAR's exceptional database includes evaluations for every project funded by the center, and several of those will be included.

4.1 PRODUCT QUALITY

Traditionally, plant breeding has been focused on increasing production by producing more resistant, higher yielding cultivars. Breeding also seeks to improve the quality of a crop. This quality improvement can consist of reducing the harmful effects that some crops can have on human health, as is the case with the cassava project described below. Alternatively, breeding can also make a crop more resistant to postharvest pests and diseases, or enhance the nutritional value of a crop. The relatively new micronutrient enhancement project aims to reduce micronutrient malnutrition by enriching basic staples through plant breeding. A third example of product quality improvement is the Flavr Savr tomato. These tomatoes do not soften as quickly, which allows producers to let them ripen on the vine while keeping postharvest losses low.

Reduction of Hydrogen Cyanide Contents in Cassava

Cassava is the most important food crop in the humid and semi-humid tropics of Africa. The root contains glucosides called linamarin and lotaustralin. The glucosides are hydrolized by the enzyme linamarase, with liberation of cyanohydrins that can break down to highly toxic hydrogen cyanide.

When ingested, hydrogen cyanide can lead to acute intoxication and death. Regular exposure to sublethal quantities, ingested or inhaled during cooking, can cause epidemic spastic parapesis, in central Africa known as ‘konzo’; tropical ataxic neuropathy (TAN); worsening of iodine deficiency disorders such as goiter and cretinism; and risk of diabetes. An ACIAR-funded project aimed to reduce the negative health impact of hydrogen cyanide in cassava in Africa. Lubulwa (1995) makes an effort to evaluate the health benefits of this research.

The project’s objectives were:

- developing a simple, semi-quantitative screening technique for cyanide content;
- determining the influence of environmental and agronomic factors on cyanide levels of cassava plants;

- screening cassava germplasm for low or zero cyanide varieties and transferring these to IITA for incorporation in the cassava breeding program, eliminating high cyanide varieties;
- determining the relationship between bitterness or sweetness and high or low cyanide, and analyzing the chemicals causing bitter flavors;
- developing a cheap and simple method for estimating beta-carotene in cassava, so breeders can combine high beta-carotene (vitamin A) and low cyanide levels.

The objectives were met to varying extents. Scientists developed a simple screening method for cyanide potential, and although there were some reservations about it, it was subsequently improved. Progress was made in determining the influence of environmental and agronomic factors, but this topic needs further work. Genotypes were screened, and the ones containing low cyanide levels were forwarded to IITA. The relationship between bitterness and cyanide potential is complex. Cyanogenic glucose linamarin is bitter, but the correlation between bitterness and cyanogenic potential does not always hold, although bitter cultivars are more likely to be toxic. The components causing bitterness in cassava have not been identified. This area needs further work. A simple method for estimating carotenoids was developed, to enhance the nutritional value of cassava.

Normally, bitter cultivars are processed, and traditional processing lowers cyanide contents to safe levels. Because of changing socio-economic situations, people are often unable to follow traditional preparation methods because they tend to be very time consuming. This change in preparation procedures leads to an increase of the related diseases. Also, since bitter cultivars usually have higher yields, they account for a growing share of cassava cultivation.

Lubulwa calculates the monetary cost of the disease. Effects on quality of life or human suffering are very difficult to measure, and there is currently no methodology available to include these factors. There are two methods to evaluate the monetary cost of a disease. One is the human capital method, the other the willingness-to-pay method. Since the willingness-to-pay method cannot be used when people cannot perceive the risk that they are exposed to, the paper employs the human capital method. It equates the value of life with the present value of people's expected future earnings. The human health benefits of cassava cultivars low in hydrogen cyanide consist in the reduction in productive capacity lost.

The annual reduction in production losses is found to be equal to $A 1.1 million for the whole of Africa, with a NPV of $A 1 million calculated over a 30 year time span, after taking into account research costs, and an adaptive research lag of about 15 years. The internal rate of return of the base case is 13 percent per annum.

Sensitivity analysis shows that if the incidence of konzo and TAN were twice that of the base case, the net present value would equal $A 11.9 million, with an internal rate of return of 24 percent. Under the assumption that at the time when new varieties are introduced, 50 percent of all cassava in Africa will be produced using bitter high cyanide varieties, the NPV goes up to $A 19.3 million, and the internal rate of return equals 26 percent. As mentioned before, this evaluation does not take into account the effects on human suffering and quality of life, which are not easily quantified, but which contribute to the value of the research.

Micronutrient Enhancement to Fight Malnutrition[2]

More people worldwide are affected by some mineral or vitamin deficiency than by protein-energy malnutrition. Especially women and children are affected since they have elevated mineral and vitamin needs. These deficiencies are very widespread among the poor because they consume mostly starchy staples, which tend to contain insufficient amounts of micronutrients. Animal products, fresh fruits and vegetables are rich in bioavailable minerals and vitamins, but the poor often cannot afford them.

The four conventional ways to reduce micronutrient malnutrition are supplementation, fortification, dietary diversification and disease reduction. Plant breeding to enhance the micronutrient content in staple foods is a new fifth strategy being explored at CGIAR centers. The advantages of this fifth approach are that after a one-time investment in developing seeds the costs are minimal, and people receive the needed nutrients from their accustomed diet. Supplementation, fortification and education on the other hand are connected with ongoing costs. Furthermore, no change in consumer behavior is required for this new strategy.

One reason why nutritional qualities were not included in breeding objectives earlier on is that scientists assumed that nutrient-enhanced crops would be lower yielding. Farmers would need a price incentive to grow these crops, and poor consumers would not be able to pay this price premium for nutrient-rich food. Contrary to these expectations, nutrient-enhanced crops can in fact have higher yields.

Researchers at the University of Adelaide developed wheat that is better able to absorb zinc from the soil, which results in lower rates of root diseases, better growth, and higher yields. These wheat plants are now commercially

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2 Based on Bouis, 1996.

grown in Australia. Especially on zinc-poor soils, there varieties are more productive than other wheat varieties. The higher yields are only associated with mineral enhancement; vitamin A enhancement will not raise yields. It will therefore have to be bred into already high yielding varieties.

Initiated by IFPRI, CGIAR scientists developed a coordinated pre-breeding plan to increase the micronutrient density of five major staple crops (rice, wheat, maize, beans, cassava) between 1993 and 1996. Five core research institutes participated in this effort: the Waite Research Institute at the University of Adelaide in Australia, the USDA-ARS Plant, Soil and Nutrition Laboratory at Cornell University, and IRRI, CIMMYT and CIAT. Their goal was to develop a tool package for breeders to produce mineral and vitamin dense cultivars.

The actual breeding will be done in two phases. The first phase mostly involves research at the five core centers to identify promising germplasm, and to develop general breeding techniques for later adaptive breeding. The second phase consists mainly of adaptive breeding at national agricultural research institutes.

The cost of these plant breeding programs will be about $2 million per year for all five crops during the first phase. The costs of the second phase are difficult to estimate since they depend on the number of countries participating. Bouis (1998) assumes that the cost for each country will not be more than the $2 million per year estimated for the first phase.

This cost compares favorably with supplementation programs. Bouis (1996) gives the example of India, where as many as 28 million pregnant women may be anemic. A low estimate for the cost of iron supplementation including administrative costs is around $2.65 per person per year. A fortification program for half of the anemic pregnant women would cost about $37 million per year. Thus, the one-time cost of plant breeding is relatively low, although it is difficult to estimate the effect of nutrient dense cultivars on malnutrition. It will depend on farmer adoption, and on the amount of the nutrient that the body will in fact be able to gain from the new crops.

To get a better idea of returns on investments in breeding for micronutrient density, Bouis (1998) carries out a cost-benefit analysis of the introduction of zinc-enhanced wheat cultivars in Turkey. Turkey has many areas with zinc-deficient soils where important yield gains are to be expected from new cultivars, and data for these yield gains are available, which makes it possible to evaluate the benefits.

Bouis carries out his analysis as if all first-phase initial research costs (for all crops, nutrients and centers) accrued only to Turkey, and as if the only benefit of this research had been the development of zinc-dense wheat (i.e. as if none of the other crops had shown results). He assumes a net benefit of $1 for each person equivalent consuming zinc-dense improved wheat. Consuming zinc-dense wheat will supply enough zinc to some people, but some people may still be deficient if the zinc gained from wheat consumption is not sufficient. Breeding costs per year for both phases (a total of 10 years) are assumed to be $10 million, and maintenance costs $200 000 per year thereafter.

The net present value of developing zinc-dense wheat for Turkey under the assumptions above is $261 million, with an internal rate of return of 44%. With the more realistic assumption that only ten percent of the costs of the first phase are incurred by Turkey, and the same benefits as before, the net present value is $268 million, and the internal rate of return rises to 68%. Since it is to be expected that several countries will adopt these micronutrient-enhanced varieties, and since breeding programs for more than one crop will probably be successful, the benefits from the research program are expected to be much higher than those calculated in this extremely cautious example.

Flavr Savr Tomatoes

In 1994, the world's first genetically engineered food was introduced to supermarkets in the United States: the Flavr Savr tomato. Tomatoes are usually picked when they are green and firm enough to transport. Once at their destination, they are sprayed with ethylene, which stimulates ripening, but without achieving the flavor of a tomato ripened on the vine. As a result, tomatoes are often hard and flavorless when consumers buy them.

Calgene, a biotechnology company located in Davis, California, genetically engineered a better-tasting tomato by slowing down the softening process. Tomatoes become soft because of an enzyme called polygalacturonase (PG)that breaks down the cell walls. Because ripening tomatoes produce PG, they cannot be ripened on the vine without high losses in handling and transport. Through genetic manipulation, scientists at Calgene blocked PG production in tomatoes by introducing an anti-sense gene (FDA, 1994; Katz Miller, 1994). Therefore, the transgenic tomato can ripen on the vine while staying firm enough for transport.

The only changes in Flavr Savr tomatoes found in health and safety tests are slower softening, better maintenance of fruit intactness, and thus the possibility of being picked later. This allows either for more ripening on the plant, or for increased time for handling and transport. In processing, Flavr Savr tomatoes show improved consistency. They also demonstrate a decreased incidence of fruit rot and postharvest fungal diseases (Redenbaugh, 1992).

Because of concerns about the effect of genetically altered food on human health and the environment, Calgene sought FDA approval for Flavr Savr tomatoes, although this is not required by law. The FDA found that the health effects of consuming genetically altered tomatoes were not different from regular tomato consumption. No increased levels of toxins were found, nor lower vitamin A and C levels, nor were there allergic reactions (Redenbaugh et al., 1992; Katz Miller, 1994). Transgenic tomatoes also taste the same as regular tomatoes at equivalent stages of ripening.

Calgene has opted for a high degree of vertical integration with the aim of maintaining control of the crop. The tomatoes are grown under contract; and shipping and retailing are all done to Calgene's specifications. The aim is to ensure a quality product, especially initially, to establish a good reputation. Flavr Savr tomatoes are marketed under the Mac Gregor label, and Calgene wished to achieve some level of brand name recognition (Derrer, 1994).

The genetically altered tomatoes do not have to be labeled in the store. They are sold at a price premium which consumer seem to willing to pay for the better flavor and quality. Likewise, processors such as Campbell Soups have shown interest. The international rights are owned by Zeneca Ag Products.

The Flavr Savr story shows that private investment can lead to significant improvements in produce quality. In this case, both flavor and postharvest characteristics such as shelf-life and processing behavior were improved. Here, the research benefits Calgene, but also consumers who enjoy better tomatoes, farmers who grow a higher value crop, and shippers and retailers due to reduced wastage. It may eventually enable third world farmers to overcome their distance from markets, and thus to compete more effectively in the tomato market.

4.2 HARVEST AND STORAGE

This is perhaps the most traditional part of postharvest research. It deals mainly with the reduction of postharvest losses through improved harvest, drying, milling, storage, and transport technologies. Storage is important even for relatively durable commodities such as grain, where wastage can be reduced through new drying and pest management systems. The first example in this section deals with small scale rice drying technology in Asia, and the next three examples are about grain storage. ACIAR has funded several projects which focus on grain storage technology, namely on improved pesticide use and on ways to reduce the reliance on pesticides, such as controlled atmosphere storage. Several donors, including FAO, GTZ, DFID have been involved in the control of larger grain borer, a pest attacking maize in Africa. The third example will look at an impact study of the work done by DFID in Ghana and Tanzania, while the fourth example focuses on reduction of postharvest losses during storage through biological pest control. The example shows how the introduction of a pest's natural predator is a way to preserve more food while reducing the adverse health and environmental effects from pesticides.

Populations in both industrialized and developing countries consume increasing amounts of fresh fruits and vegetables. These commodities represent new challenges for postharvest researchers because of their high perishability, especially since international trade is growing very quickly. New storage techniques for tropical fruit have resulted in extended postharvest lives and reduced wastage. This development is especially important for many developing countries who are well suited to produce and export these goods because of climatic conditions, but who are far from US and European markets.

Small Scale Rice Drying and Threshing Technologies

While the private sector can and does participate in postharvest machinery development, the following are examples where small scale machinery development had an important public good component. Scientists developed technology that was later adapted and modified by users and manufacturers, and is now in widespread use. Public research and manufacturer and user innovation came together in such a way that they complemented each other.

The SRR dryer was developed at the University of Agriculture and Forestry (UAF) in Vietnam in 1995 as part of a project that counted with GTZ funding and IRRI technical assistance. In the two and a half years after its introduction, more than 650 models of the SRR dryer have been sold at about US$100 each. They are used primarily by farmer families to reduce the time spent sun drying rice in the wet season. Using the dryer reduces the labor required to dry one ton of paddy from 46 person hours to only 7 hours. A survey of 44 dryer owners found that this enabled children to spend more time studying, and adults to engage in more profitable activities such as field or factory work.

The cost of drying (measured as the opportunity cost of family labor) was reduced from 10 percent of the value of the crop to about 3.5 percent. Use of the dryer also reduced losses through lower germination and discoloration. Furthermore, farmers have found many additional uses for the dryer, for example as a fan in poultry production.

The SRR dryer is extremely simple, easy to maintain, and easy for manufacturers to copy. Since it is so easy to copy, no private company would have developed it because it could not have recuperated the R&D costs. This means that the development of the SRR dryer had public good characteristics, and would have been undersupplied by the private sector.

Another drying technology with a similar success story is the Vietnamese flatbed dryer. The development of this dryer goes back to one unit in Phu Tam Village in 1983. Dr. Hien, who installed that first unit, based his design on IRRI and University of the Philippines developments.

When the dryer was introduced, farmers were expanding rice production to two growing seasons. They had no technology for drying rice in the wet season, and often entire harvests spoiled. Initially, rice dried on the flat bed dryers sold at a discount compared to the price for sun-dried rice. But selling it at a low price was still better for farmers than letting the crop spoil.

In contrast to family-operated SRR dryers, the flat bed dryer is operated by contractors who charge about 5 percent of the value of the crop. These operators, as well as manufacturers, improved the design of the dryer. The better design combined with experience in using the dryer has led to quality improvements, and now flat bet dried rice sells at a 5 percent price premium compared to sun-dried rice.

One improvement made to the dryer is the replacement of the original wood-burning furnace with a device based on local cooking stoves which burns rice hull. Another improvement is in the use: instead of bagging the rice on the dryer, users load it onto the floor after drying. Bagging is easier once the rice cools down, and it allows them to dry three batches per day instead of two.

Similarly successful examples of technology development include a Philippine rice thresher, which was modified from its original oxen-pulled version and fitted on top of a jeep, and a mechanical reaper for the rice harvest. These examples show the importance of public research as a catalyst for private innovation. Furthermore, public involvement reduces the risk associated with innovation, allowing small manufacturers to become involved in technology development. While some other postharvest R&D can be carried out by the private sector, innovations such as the two dryers require public investment.

Grain Storage: Pesticides and Controlled Atmosphere Systems

In the tropics, with high temperatures and humidity, stored grain is exposed even more to insect attacks than in temperate climates. While traditionally in many Southeast Asian countries grain was harvested once a year and stored until the next season, this system has changed since the Green Revolution. The introduction of high yielding varieties of maize and rice, combined with irrigation, has allowed multiple cropping. When grain is harvested in the wet season, drying and storage become more difficult. Moist grain attracts even more insects than properly dried grain.

Various measures can be taken both on-farm and off-farm to reduce insect damage. Farmers can use more insect-resistant varieties, minimize pre-harvest infestation, and use harvesting, threshing and handling methods that minimize kernel damage, and therefore susceptibility to insect attack (Chudleigh, 1991).

Off-farm measures include proper drying and careful handling and transport. During storage itself, well designed storage facilities, good maintenance and cleanliness, inspection of inputs, and management procedures can reduce insect damage. In addition, the grain can be treated with protectant insecticides, stored under inert conditions (such as carbon dioxide atmospheres), and fumigated and aerated. While the need for insecticides can be lowered by combination with some of the other techniques mentioned above, “insecticides (grain protectants) have been found to be necessary, convenient and cost effective” (Chudleigh, 1991:5).

One ACIAR project had the objective of improving the chemical pest control methods for grain storage in humid tropical areas, specifically Australia, the Philippines and Malaysia. In his 1991 study, Chudleigh evaluates the project’s present and future benefits for the three countries. Another project, reviewed by Ryland (1991), tested the technique of storing grain under plastic covers for prolonged periods of time.

In Australia, the main objectives of the first project were to develop grain protectants and combinations of protectants for the storage of various grains, as well as determining residue levels for different application rates. Research was carried out by the Entomology Branch of the Queensland Department of Primary Industries, in conjunction with CSIRO. Scientists defined the effects of temperature, moisture and grain type on the efficacy of individual insecticides, and developed the capacity to minimize residue levels. The main crops benefitting from the research are peanuts, maize, rice, navy bean and mungbean. Reduced insect infestation allows Australia to compete in export markets with grains from temperate zones, where insects are less of a problem.

Malaysia and the Philippines are not net exporters of grain, and their main benefits will be from a reduction in grain losses. In the Philippines, research was carried out at the National Post Harvest Institute for Research and Extension, and the National Food Authority (NFA); and in Malaysia at the Malaysian Agricultural Research and Development Institute. In both countries it concentrated on central government store applications, although commercial and farm storage systems may also benefit. Researchers studied malathion (a popular insecticide) resistance and substitution of newer materials. They developed new grain protectant treatments for the grain itself and for storage bags, with chemicals acceptable to the health authorities.

Evaluating the project over a period of twenty years, starting in 1982-83 when it began, gives a net present value of $A 11.4 million (in 1990 $A), and an internal rate of return of 43% (under most likely loss reduction assumptions). This estimate includes Philippine, Malaysian and Australian benefits, and takes into account the overall project costs, including ACIAR and research institution costs. Some types of benefits have been excluded from the analysis because they are difficult to quantify. This applies to Australian benefits from insect free grain exports, which allow it to compete with grain from cold climates. Even under the most conservative expectations about future loss reductions, the NPV of the project remains $A 1.1 million, with an internal rate of return of 16%.

Because of their large rice and maize production, the Philippines benefit most from the new technologies. Since Australia’s tropical rice, maize and peanut industries are not very big, and the amount of grain stored in that climate is small, Australian benefits are relatively small. There could be spillover effects for the rest of the world, particularly other parts of Asia, Africa or Latin America, although insect strains and environmental conditions vary. Two countries where potential benefits are significant are Thailand and China, both of which produce enormous quantities of grain.

Another project within the ACIAR grain storage program deals with long term grain storage under plastic covers. It tested a controlled atmosphere storage technique consisting of initial fumigation of bagged grain (paddy rice, milled rice, or maize) with carbon dioxide, followed by storage in sealed, custom-made plastic enclosures.

This project was a collaborative effort including CSIRO in Australia, the Philippines National Food Authority, and the National Paddy and Rice Authority of Malaysia. It targeted those ASEAN countries which maintain rice stocks as strategic food reserves. The Philippine NFA maintains a stock reserve of about 1.5 million metric tons; Malaysian authorities handle, store and distribute about 800 000 tons; and the Indonesian National Logistics Agency stores about 5-6 million metric tons of milled rice.

The Controlled Atmosphere Storage Technique (CAST) is possible with modest technological inputs which are readily available in ASEAN countries. The technique is expected to have a neutral impact on labor requirements. There may be some increased employment opportunities for women in testing and monitoring sealed bags. Overall, there are opportunities for growing labor productivity and for more stable, better-paid employment. In the future, CAST will probably have an impact on private sector traders and farmer groups. As government intervention in the grain industries is reduced, the private sector is expected to participate more actively in long-term grain storage.

In evaluating the project, Ryland assumes that the CAST system will become the standard grain storage system in ASEAN over the next 10 years, with volumes increasing from 174 000 tons to 2.1 million tons. At current adoption levels, the net present value of the project is around $A 3.27 million, expected to rise to $A 9.2 millions by 1990 (in 1990 dollars) as adoption increases. The internal rate of return under current adoption levels is 29.9 percent, expected to rise to 37.8 percent. The adverse environmental effects of alternative fumigants may actually hasten the switch to carbon dioxide; and environmental concerns alone may justify an increase in controlled atmosphere storage.

Control of the Larger Grain Borer in Tanzania and Ghana

The larger grain borer (LGB) is a storage pest that affects traditional maize and cassava storage systems; it is originally from Central America. During the late 1970s it was accidentally introduced into Africa, where it spread rapidly. Trade is on the main ways in which LGB spreads. It was first detected in Tanzania and then spread to East Africa, West Africa and has begun to head South, although Zimbabwe and South Africa have not been affected as yet.

LGB causes substantial losses to maize thus making storage difficult over long periods of time, compromising both food security and lowering the quality of grain destined to sales. The potential benefits of controlling LGB arise from the combined impact of a number of inter-related components, including reduced losses, improved quality, reduced need to sell early at a lower prices, and reduced need to secure alternative food supplies to compensate for losses (see DTZ Pieda Consulting 1998).

Several organizations have been involved in research activities to deal with the LGB since the early 1980s, including FAO, GTZ, and NRI with DFIF funding. Research activities falling into four broad categories have been pursued over the years and include i) the most suitable combination of chemicals to reduce the damage; ii) improved monitoring and early detection schemes; iii) storage methods; and iv) biological control through introduction of predators. The four approaches are not mutually exclusive; each method has advantages and disadvantages briefly summarized in Table 4.1.

Table 4.1–Aspects of LGB Research

Research area	Advantages	Disadvantages
Chemical	Highly effective if correctly applied Insecticides can be developed to control a range of storage pests	Costs of insecticide Needs to be applied soon after detection of LGB Difficulties and costs of getting insecticide to remote locations quickly enough Ineffective if under-applied; harmful if over-applied Potential environmental damage and/or effects on health
Monitoring	Allows early detection and can be used to ensure that unaffected areas are still free of the problem Low cost	Needs to be implemented in conjunction with other control measures
Storage methods	Removing maize from cob makes it harder for the LGB to bore into and also makes insecticide treatment more effective	Removal from cob is labour-intensive and time-consuming and needs to be done at a time when farmers are already busy with harvesting Storage off the cob leaves grain more susceptible to other pests Requires farmers to change from traditional storage methods and there will be costs associated with obtaining new storage containers
Biological	Low cost No harmful effects Predator spreads naturally	The predator does not reproduce at as rapid a rate as the LGB The predator is susceptible to the insecticides used to control LGB and so the benefits may be offset if insecticides are used in conjunction with biological control

Source: DTZ Pieda Consulting, 1998.

An impact study conducted by DTZ Pieda Consulting in 1998 concluded that the benefits from the LGB research in Ghana and Tanzania have more than offset the cost incurred by DFID and other organizations. Furthermore, the total benefits would be still higher if the benefits to other African countries (most notably, Benin, Kenya, and Togo) were taken into account. Total expenditures on LGB research have been of the order of BP 15.2 million at 1998 prices, of which BP 5.4 million have been funded by DFID or its predecessor, ODA. Gross savings computed only for Tanzania and Ghana amount to nearly BP 17 million, an amount which would more than offset the total LGB research expenditures of all aid organizations.

Biological Control of Maize Storage Pests in Africa

The German Society for Technical Cooperation (GTZ) and the German Ministry for Cooperation (BMZ) have invested in numerous projects for integrated commodity storage protection, especially in Africa. The projects are oriented towards the BMZ's priorities of poverty reduction, protection of natural resources and the environment, and primary and continuing education. By reducing food losses, these projects furthermore make a direct contribution to increased food security.

Reducing losses of already produced foods is a more rational approach to increasing food availability than loss compensation by increased production. The latter strategy implies the loss of already invested resources, and contributes to an over exploitation of fragile soils.

The cooperation among several national and international research institutes, and between bilateral and multilateral development projects is an opportunity to develop new concepts and produce innovative solutions. This is demonstrated by the case of *prostephanus truncatus*, also called larger grain borer. In 1984, the BMZ initiated a supra-regional project in collaboration with IITA to develop an integrated biological pest management system against the larger grain borer. Apart from conventional methods such as pesticides, the project developed a system based on the introduction of *teretriosoma nigrescens* (Tn), one of the larger grain borer's natural predators.

Estimates of postharvest losses due to the larger grain borer vary considerably, which makes it difficult to calculate the economic impact of the biological control strategy. Estimates vary because methodologies are different across different studies, and because the situation changes dramatically from region to region. In an effort to evaluate loss reduction projects, the GTZ therefore financed several Ph.D. dissertations to obtain better data.

The GTZ's impact study uses maize production data from Togo, Benin and Guinea; it is based on a forthcoming dissertation by Schneider. The cost benefit analysis takes into account the dynamic predator - prey relationship between the pest and the control organisms, facts about the present distribution of both pest and predator, and different reports about the evolution of maize losses under various storage systems.

Taking into account only the reduction in storage losses due to the larger grain borer as benefits; and research costs associated with breeding and releasing, the GTZ calculates an internal rate of return of 1 percent over ten years, or 68 percent over 20 years. The benefit cost ratio over 10 years is 1 : 1.3, while over 20 years it is 1 : 57. After an initial lag, the biological control system produces very significant economic benefits from loss reduction.

Benefits from the introduction of Tn also include a reduction in external costs such as medical treatment costs and opportunity costs of work lost because of incorrect use of phytosanitary products. Every year, farmers in Togo, Benin and Guinea spend about DM 660 000 on storage pesticides. About 500 users annually suffer poisoning, with medical and opportunity costs of about DM 10 000.

Furthermore there are benefits from reduced pesticide pollution, especially in rivers. While the chemical R&D costs are mostly born by the manufacturers, both Togo and Benin will save considerable extension costs for the introduction of new chemical treatments. These benefits are very difficult to quantify. If they could be included in the cost benefit analysis, the returns to investments in biological control mechanisms would be even more impressive. Since different organizations including NRI, IITA, GTZ etc. worked on this storage problem, it is virtually impossible to separate the effect of each project and each organization.

To find long term solutions to postharvest problems, it is essential to take into account the complete socio-cultural and socio-economic situation. Several institutions, including FAO, IDRC, GASGA and GTZ support the systems approach to postharvest management where solutions are developed taking into account social, cultural, economic and technical constraints. Whether in analyzing a problem or in finding a solution, a participative approach is a fundamental condition for acceptance and adoption of innovations by the target group, which can significantly improve the rentability of technical cooperation measures in the postharvest sector.

Storage and Handling of Tropical Fruit

Tropical fruit are an important and rapidly growing export market for developing countries. Especially when they are exported to Europe and the United States, these products have to be transported far from their places of origin. Improved handling, transport and storage technologies can lower wastage and raise the profitability of these highly perishable crops.

ACIAR funds postharvest tropical fruits research which is carried out both in Australia, and in several South East Asian countries. Since parts of Australia also have a tropical climate, the benefits of ACIAR research are shared by Australian and by South East Asian producers. ACIAR projects include both basic research about the postharvest physiology of tropical fruits, and the development of technologies to prolong storage life and improve handling.

Lubulwa and Davis[3] evaluate six projects, two of which were still in progress at the time of evaluation[4]. These projects include:

- Use of calcium to inhibit ripening and senescence of fruits,
- Postharvest physiology of, and technology for bananas in South East Asia,
- Chemical controls of fruit disease,
- Cool storage, controlled atmospheres and chemical controls,
- Non-chemical controls of fruit disease, and
- Development of simple edible coatings for the postharvest life extension of fruit.

The projects' internal rate of return varies between 21 percent for the use of calcium to inhibit ripening and senescence, and 48 percent for the postharvest banana technology. The new technologies succeeded in significantly reducing wastage in most cases. Depending on pre-research practices, the percentage of fruit production lost in postharvest activities varies, as does the percentage reduction in losses. The banana project for example reduced losses from 33 percent to 13 percent in Malaysia and the Philippines, and from 30 percent to 10 percent in Australia. In most cases, postharvest costs increased slightly as a result of the new technologies.

In a different impact study, Chudleigh (1998) evaluates two ACIAR postharvest projects on tropical fruits. One of them, titled "Mango Characteristics in the ASEAN Region" emphasized factors affecting storage life, including postharvest diseases and storage and packing procedures of mangoes and other tropical fruit. The project's outputs included recommended storage

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[3] In Lubulwa and Davis (1994a), and Davis and Lubulwa (1994a).

[4] The projects cover one or several of the following commodities: mango, avocado, longan, lychee, rambutan, mangosteen, durian, green coconut, papaya, bananas.

conditions for mangoes, as well as fruit treatments such as the hot benomyl dip, longan and lychee fumigation, and maturity guidelines for mangosteens.

The other project, called “Postharvest Handling technology: Tropical Tree Fruits”, had two components. The physiology component had the objectives of establishing commercially applicable harvesting indices, refining storage recommendations for mangoes, and defining optimum storage regimes for five other fruit. The disease component identified infection mechanisms and organisms, disease control measures, and treatments.

The two main beneficiaries were Thailand and Australia; about 48 percent of the gains were in Thailand, and 52 percent in Australia. The total project costs were A$1 683 092 (nominal). Evaluating over a 30 year time period with a discount rate of 5 percent, the projects’ net present value is A$ 93 million, or A$ 42 million with a 10 percent discount rate. The projects’ internal rate of return was about 64 percent. When only taking into account the benefits realized by 1996/97, the net present value was A$ 30 million, and the internal rate of return was 63 percent.

4.3 UTILIZATION AND MARKETING

Apart from improving the product itself and from preventing postharvest losses by improved harvest and storage technologies, utilization and marketing is an area where especially agricultural products have seen rapid change in recent years. With improved processing technologies, agricultural products have a multitude of uses. Fairly different commodities can become substitutes, which increases competition and makes commodity markets even more dynamic.

In an era where international trade in agricultural commodities is facilitated by ever improving transport facilities, precise and reliable marketing becomes crucial to ensure timely delivery and continuous availability of perishable products. Packaging plays a crucial role in facilitating transportation, protecting fragile products such as fruit, regulating ripening, and simplifying storage, product identification, inventory control, invoicing and marketing (Studman, 1996a).

The first example for this section deals with a product that was once an important staple in Latin America: cassava. After losing much of its demand due to trends like urbanization, new drying technology promoted by CIAT makes cassava into animal feed, for which there is s strong demand. The development of a new use for an old commodity thus led to an important new income source for smallholders. Second, an example from beef processing shows that in the livestock sector, improved processing and packaging technologies can have a large impact on both consumer and producer welfare. The third example is about the sorghum milling technology, initially developed for African countries with support by IDRC. The fourth example illustrates how the starch industry allows small farmers to access both the domestic and the international market in Vietnam.

Dried Cassava Chips as Animal Feed

Cassava, which in Africa is still one of the most important staples, has lost much of its traditional market in Latin America, the region where it originated. Traditional food crops such as roots and tubers often face a decreasing demand in the course of urbanization and income growth. Cassava becomes less attractive because of its high marketing margin, high perishability, and because substitutes become widely available.

Dry cassava chips for incorporation in animal feed were initially developed in Asia, where the industry has been very successful. Demand for animal feed tends to grow as income rises because consumption of animal products increases. While other cassava technologies such as improved fresh root storage benefit mostly urban consumers, the drying technology was found to benefit mostly cassava producers (Janssen, 1986). Based on Asian success stories, a program was created to introduce dry cassava chip production into South America.

The Integrated Cassava Project (ICP) combined research on cassava production and processing, with the development of markets for cassava products. Once farmers were linked to a secure, more profitable market for cassavas, it was hoped that they would adopt improved, reduced-cost production technologies. Best, Henry and Gottret (1994) evaluate this project. In 1981, a pilot plant began to produce dried cassava chips, and starting in 1984 the project began its commercial phase. By 1994, 150 cassava drying plants operated on the North Coast of Colombia, with a production of 35 000 tons per year.

This production has generated US$ 22 million of additional income between 1984 and 1991. Of that income, small farmers received 69 percent, and processors received 10 percent. The project cost US$ 1.2 million. For every dollar invested, the project generated US$ 18 (not discounted). In recent years, these gains have been threatened by cheap cassava product imports from Indonesia.

This cassava project was later replicated in Ecuador, and also in Brazil, where Ospina P.; Gottret, Pachico and Leite C. evaluated it. In Brazil, the project was implemented in the northeastern state of Ceará, one of the country's poorest, where cassava is the main food source. In dry years cassava is especially important for food security. The main market for cassava are the small-scale, communal-type processing plants, which produce farinha de mandioca, a basic staple product.

Between 1990 and 1996, the cassava project generated about $451 000 of additional income. The cassava supply in several of the years was much below average due to a drought, which lowered the potential income from cassava processing. The main beneficiaries were cassava producers (69.4 %) and processors (20.1%). New employment was created at the plants, and plant workers received about 5.6 percent of total benefits. Most benefits stayed in rural communities, and almost 90 percent of all producer benefits went to small farms.

In a survey of farmer groups, Ospina P. et al. identified other community effects from the new technology. Some of the farmers' most frequent responses were that now they had alternative and/or complementary feed sources for animals in the community. Many answered that they had gained an alternative market for cassava. The project created employment, and cassava producers receive more cash income than before. Important benefits were in the area of community empowerment: new services, projects, training, credit and infrastructure had been brought into the community. The community itself was better organized than before, and learned how to develop community projects.

Women stressed that their workload was reduced, since farinha processing is mainly a female task. The cash income from cassava chips has enabled them to buy things for the house and the children, send children to school, and pay for health services. Some people even improved their house or built a new one.

Lowering Beef Processing Costs through Improved Packaging

While most of the previous examples are in developing country settings, this one is from the US. A study by Mullen, Wohlgenant and Farris (1988) examines the effect of shifting from boxed beef to tray-ready beef, where beef is cut into retail cuts by the packer before being vacuum wrapped. This reduces the amount of beef processing necessary at the retail outlet. It can be modeled as a downward shift in the supply of marketing inputs, or as cattle-saving technical change.

Using a two-product (beef and beef by-products), two-input model of the beef subsector, the authors estimate changes in consumer and producer surplus resulting from the change in beef packaging. While the conventional approach is to assume no substitution between farm and marketing inputs, the authors use an estimate of the elasticity of substitution of 0.1. Allowing even this limited input substitution has a large effect on the distribution of surplus gains.

Tray-ready beef was more profitable than boxed beef by 5.1 cents per pound in retail in 1984. Using USDA price spread data, the authors estimate that the total gain in surplus from changing the technology was $ 845.6 million, both from increased production and lowered processing costs and prices. This gain is distributes as follows: producers receive 57 percent, beef consumers 42 percent, and consumers of beef by-products receive 1 percent. When the elasticity of substitution between farm and marketing inputs is assumed to equal zero, the producers gain 72 percent, beef consumers 27 percent, and consumers of beef by-products 1 percent.

Regardless of assumptions about the elasticity of substitution, the new technology resulted in a large total gain for society. It is important to keep in mind when evaluating this technical change that technical change in processing can be cattle-saving, which reduces the farmers' share of the total benefits. While the study does not specify the cost of developing the new technology, it is an example which shows that changes in postharvest can have an important positive impact on both consumers and producers, although it may be difficult to determine the exact distribution of benefits.

The Development of Sorghum Milling Industry in Africa

The research and development work on sorghum milling in Botswana that IDRC supported through two projects between 1976 and 1980 has been part of an informal network of projects in Africa and other regions. The projects have revolved round the perceived need to promote the production and utilization of small grains and grain legumes, particularly sorghum and millet, that are well adapted to the drier parts of Africa and constitute staple food for large rural populations. A major constraint to this development lies in the difficulty of dehulling the grains prior to grinding into flour. Thus the main focus of the projects has been on the development of a simple mechanicall dehulling device. In the mid 1970's, the Botswana government decided to address its concern about the trend away from locally produced sorghums towards imported maize. The Ministry of Agriculture asked the Botswana Agricultural Marketing Board (BAMB) to investigate the possibilities of processing sorghum. The traditional method of milling by hand was lengthy and inefficient. The meal produced had to be eaten quickly, otherwise it could become rancid on account of the high moisture content – a result of the soaking which is an integral part of the traditional process. Mechanical dehulling and grinding could be done without wetting the grain. BAMB contacted IDRC to develop a suitable village level milling system for processing sorghum to produce sorghum flour (Hardie, 1982). Between 1978 and 1980, various prototypes of a scaled-down dehuller were developed and tested. The research effort led to a system consisting of a dehuller that could operate on a batch or continuous-flow basis, incorporating a fan and cyclone for collecting the bran, a harmmermill, and a water-cooled diesel engine to drive both machines.

The benefits obtained from the development and adoption of such technology consist in: i) facilitating increased consumption of domestic sorghums, thus increasing food security and decreasing dependence on imports and foreign exchange expenditures; and ii) releasing women and children's time for more economically and socially rewarding activities.

The evaluation of the aggregate effect of this technology development in 1982, only 4 years after the initiation of the project showed an internal rate of return of 20% (see Hardie 1982). The benefits did not include the estimate of output from the milling units that were established in 1982 and subsequently and which would have had a tendency to reduce the unit “overhead” administrative and technical costs.

The evaluation of the project stressed several determinants of success. First, the strong commitment and support of the government, to which an international center like IDRC responded. Second, the existence of a strong local demand for sorghum and especially products derived from local sorghum as opposed to imports. Contrary to the experience of other countries, in the late 1970’s and early 1980’s the shift from a traditional to an urban and cash based economy in Botswana did not lead to a shift away from traditional grains to maize, rice, and wheat. Third, the existence of strong institutions which facilitate the development and testing of new technologies. In the case of Botswana this was the case with the Rural Industries Innovation Centre (RIIC), a private non-profit company, governed by a Board of Directors chaired by the Minister of Commerce and Industry, and funded with German aid.

The Potential of the Starch Industry for Rural Industrialization and Poverty Allevation

In the context of economic development, there is an increasing need to promote activities and policies which generate and diversify income in rural areas. Policies that are designed to benefit rural producers often focus on high potential areas and miss those rural households who may not cultivate the crops most suited to intensive agriculture. This is certainly the case in Viet Nam, where farmers in the North Mountains and Central Coast have not directly benefited from policies that have targeted rice production. The hypothesis of this research activity is that the starch industry, based on cassava, sweet potato, and canna starch, is a potential avenue in generating income for that segment of the rural poor in Viet Nam who cannot benefit from intensive rice cultivation or cash crops such as coffee. This is predicated on the strength of links between the production of cassava in poor areas and the local processing of starch for industry to meet an increasing domestic demand for starch-related food (MSG, maltose, glucose, and noodles, e.g.) and industrial (textiles, pharmaceutical, and paper, e.g.) products. This could serve initially to reduce Viet Nam's reliance on imported starch; that is, as an import substitution strategy. Moreover, further development of the cassava sector and starch industry could position Viet Nam as an exporter.

The research activity is conducted within the framework of the Small Grants Fund of the Global Collaborative Post-Production Research Network funded by IDRC and is a joint collaboration between IFPRI, CIAT, and the Postharvest Technology Research Institute in Viet Nam. The project started in 1998 and is now toward conclusion. The preliminary results point to validation of the research hypotheses, namely that starch processing is a rural industrialization strategy benefiting the poor and with potential aggregate income growth.

The study (IFPRI-CIAT-PHTI, forthcoming 1998) shows that in the case of cassava, about 25 percent of total production is destined to starch processing, a share increasing from a marginal value only 10 years ago. The employment effect of starch processing is relevant, with 20,000 rural households employed in processing. Most of these are small households and derive about 50 percent of their income from agriculture. Their total average income including the part originated by starch processing is $300 per capita, which is about 80 percent higher than the average rural income per capita in Viet Nam.

The potential for starch processing is very high. Both domestic demand and foreign demand are growing. Domestic demand is expected to grow at over 10 percent per year. The growth prospects are however limited by serious constraints related to sustainability and quality. Most of small scale industry is seriously contributing to water pollution. That has already set in motion community responses in terms of improved sewage systems, but it might require both improved technology and improved production and institutional innovations to ensure that the benefits to individual smallholder households are not creating negative externalities on the communities. Second, the potential for exports is linked to quality improvements that allow capturing higher prices in international markets and sustaining a continuous high demand for raw materials. This implies a systemic approach that promotes yield improvement in production, more efficient storage methods, innovation in processing technology, quality control, and marketing opportunity analysis. The roles for national and international postharvest technology is key to ensure that the growth potential continues to benefit smallholder farmers and rural households in a sustainable way. Moreover, this type of research might have important implications for other countries where the transition from food to industrial uses of roots and tubers has just started. By looking at the production-consumption continuum, a strong rural industry based on agro-food enterprises could be established, while contributing to poverty alleviation, improvement of food quality, and sustainable use of resources.

4.4 POLICIES AND INSTITUTIONS

In the previous categories, research tended to innovate postharvest activities by improving products or developing new technologies. Research in Utilization and Marketing goes beyond technology development to include marketing strategies and market development. But apart from concrete technologies and marketing mechanisms, the institutional setup in which production and processing take place, and the policies which regulate and promote postharvest activities can also have a significant impact on growers, processors, and merchants.

Farmers do not produce in a vacuum; they are linked to other economic sectors. Many times they depend on smooth interactions with buyers or processors to be able to sell their products. Since more farmers are producing for domestic and international markets rather than for subsistence, their integration into input, credit, factor and product markets critically influences their ability to benefit from market interactions. One way to reduce marketing risk, often combined with input supply, is through contract farming. Studies of contract farming schemes have identifies several guidelines for successful institutional setups which allow farmers to benefit from the arrangement. Moreover, the policy and institutional environment are also essential for the fulfillment of the benefits of production and post-production technology. Both unfavorable policies and inappropriate institutions can negate these benefits . The following sections will give some examples of the role of policy and institutions in limiting or enhancing postharvest technology.

Policy Constraints to Export Growth

The success of Viet Nam agricultural and rice exports in particular since 1989 is remarkable. A country for many years beset with persistent food shortages has embarked upon a high growth path that made it the second largest rice exporter after Thailand. The analysis by IFPRI (see IFPRI 1996, Goletti, Minot, and Berry 1997, Goletti and Rich 1998) indicated that the country has the potential of being the largest rice exporter, thus contributing to overall growth and poverty reduction. This potential, however, is constrained by a still rather underdeveloped marketing system, characterized by a multitude of small efficient marketing agents and a few inefficient state enterprises. The access of small and medium enterprises to credit and information - two of the most crucial resources to compete successfully in world markets—is limited. A restrictive has imposed barriers to entry of the private sector to external trade and both the physical and institutional infrastructure constrain the development of an effective and modern marketing system, rather than the lack of appropriate postharvest technologies.

A study on “Rice market monitoring and policy options” was conducted by IFPRI during 1995-96 period. The project aimed at building an understanding of the operations of the rice market both within Viet Nam and in terms of the export market. Little research was done on the rice market of Viet Nam prior to the IFPRI study and the Government was eager to examine policy options related to issues like decentralization, infrastructure, marketing costs, deregulation, credit, technology, stocks, price stabilization, and input markets. The objective was to assist the Government in making the transition from direct quantitative or fiscal interventions in the rice market to a more market-oriented profile.

Essentially the study undertook a “structure, conduct, and performance” analysis of the rice market and used this to inform the policy process in two ways. The first was to array the data collected in an extensive survey in a manner that described the current marketing channels, their costs, and constraints. The second was to utilize these primary data and other survey data to construct a spatial equilibrium model to examine many options for changing policies to improve the functioning of the rice market and generate improved economic welfare. Linking the spatial equilibrium model with income distribution analysis based upon national household surveys allowed IFPRI to satisfy policymakers that relaxing rice export quotas and internal trade restrictions on rice would not adversely impact on regional disparities and food security, and have a beneficial effects on farm prices and poverty. These were major concerns of policymakers prior to the project. The research on these and other policy options gave a degree of confidence to policymakers that relaxing the control would be in Viet Nam national interest. They made these decisions earlier than would have been the case without the IFPRI research (see Ryan 1998). The impact of these research has been evaluated within an innovative framework that attributes the benefit of the policy and institutional research to the saving in time that the information provided to implement policy changes contributing to higher income. (see Ryan 1998). The benefit-cost ratio of the research was conservatively estimated to be 56 for an initial investment of less than $1 million if only the welfare gains to Viet Nam are taken into account. Inclusion of these benefits to the rest of the world would raise the benefit-cost ratio to 91.

Contract Farming

Among postharvest policies and institutions, contract farming[5] is probably the one which has received the most attention from researchers in recent years. For smallholder sectors facing missing or incomplete markets for inputs, outputs or factors, vertical integration is often a means to overcome market imperfections. Contract farming is a way to link the growing and processing and/or export stages along the production chain and thus lower transactions costs.

In contract farming schemes, “contract farmers sell their crops under contract to private or public enterprises for processing or export in return for various price guarantees, inputs and services” (Glover, 1990:303). Processing or exporting companies lower their risk by securing a steady and timely supply of the crop, often at a fixed price. Even cooperative processors are increasingly

[5] In this text, the term contract farming refers to both contracts between farmers and private companies, and between farmers and public or parastatal enterprises, which are sometimes called outgrower schemes.

making use of contracts to ensure a steady and reliable flow of raw materials. Farmers still face the same production risk from climatic changes etc. as when producing independently, but they are able to reduce marketing and price risks. Another reason small farmers enter into such contracts is to gain access to markets where otherwise transaction costs would be too high (Delgado, 1998), such as international or specialty markets.

As many countries seek market-oriented growth strategies for their smallholder agricultural sectors, contract farming is often a popular strategy. A considerable amount of literature has been written on the subject, especially related to Africa. Researchers have investigated the impact these contracts have on farmers and regional economies. Many furthermore identify factors that increase the chances that a contract farming scheme will be successful. These experiences and recommendations can be valuable information for governments or companies who want to set up such a scheme.

Since contract farming is a relationship characterized by a considerable power differential, the terms of the contract, as well as the socio-economic environment of the scheme fundamentally influence the scheme's viability. Especially in cases where the contracting company has monopsony power, guidelines which increase the ability of farmers to benefit from such schemes are extremely valuable. Of course much such information is location and case specific, but some generalized lessons have more widespread applicability.

Overall, contract farming seems to have a positive effects on small farmers' incomes (Porter and Phillips-Howard, 1997; Glover, 1990; Watts et al., 1988). In a comparative study of contract farming in Africa, Watts et al. found changes between a slight increase of 10 to 15 percent, and drastic increases of 100 percent. The most dramatic income growth was in the case of french bean growers in central Kenya who produce for export to Europe. The impact on equity tends to be less positive, both at inter- and intra-household levels.

Especially in the case of perennial tree crops with long gestation periods and high inputs costs, the poorest farmers are often unable to participate without additional assistance, for example through credit programs. Intra-household distribution frequently becomes an issue when husbands enter into a contractual agreement, while the farming activity is in fact the woman's responsibility. Since women tend to spend a larger proportion of their income on child care, who receives the payment for the crops can have an important effect on family welfare.

Glover (1990) identifies several key factors which influence the viability of contract farming schemes. The first factor is related to the nature of the crop. Contract farming has advantages over independent smallholder or plantation production with wage labor when a crop has high and relatively skilled labor requirements.

A second factor is related to prices and pricing policies. Large and lucrative markets for the product obviously increase the viability of a scheme by allowing for profits for both processors and growers. Furthermore land tenure needs to be well defined; otherwise farmers' bargaining positions tends to be weak. Macroeconomic and macro-institutional policies are a fourth factor which includes both overall economic and political stability, and continuity and effective organization of services such as input supply, credit and payments. Another important factor is the design of payments systems is important; it needs to be transparent, and minimize intra-household conflict.

Monopoly and monopsony power both influence the viability of a contract farming scheme. While monopoly power enables the processing firm to make higher profits which may be shared with growers, monopsony power is often detrimental as it restricts the sellers' bargaining power. Barriers to entry and exit can threaten the success of a scheme. Barriers to entry restrict participation in the scheme, sometimes excluding the poorest farmers, and thus limiting the scheme's effect on poverty. Barriers to exit lower a farmer's bargaining power, which tends to reduce growers' participation in profits.

Farmer participation in management is another factor which contributes to good performance. The existence of a farmer organization with some influence on decisions tends to improve communication with the company and lower conflict. The last factor is income and crop diversification. Schemes where farmers do not depend solely on income from contract farming, but have some alternative income sources, and/or grow some food on part of their land perform better.

In an evaluation of contract farming schemes in Africa, Porter and Phillips-Howard (1997) furthermore stress the importance of scheme staffing and farmer-company relations. This point is related to Glover's point about farmer organization and participation in management. According to the authors, local staff is extremely important in facilitating communication between company and farmers, and in mediating when there are conflicts. If policy makers have access to information on factors like these which determine the effect of contract farming schemes on participating farmers, they are better able to design contracts in such a way that they maximize their contribution to economic development.

Watts et al. study under what conditions contract farming contributes to local and regional development. They find that contract farming has considerable potential for employment creation. In Malawi, 80 percent of contracted tea growers, and in Ivory Coast 89 percent of oil palm producers hired wage labor. This increase in rural employment has slowed rural-urban migration. The authors found the effect of contract farming on non-farm employment more difficult to evaluate, although where contract farming was associated with a local processing industry, this effect was also positive.

With respect to effects on regional development and multipliers, Watts et al. point out that linkages to other sectors tend to take a long time to fully establish themselves. In general, highly centralized management systems tend to have few linkages to the local economy, so some degree of decentralization is desirable. From their examples they conclude that contract farming tends to have a positive effect on the number of farmers as a percent of the regional population. Apart from employment generation and higher farmer incomes, contract farming also generates some regional reinvestment of scheme surplus, and contributes to improvements in infrastructure.

As to the effect of contract farming on food security, Watts et al. note that while food production was often negatively affected, this need not be deleterious if sufficient food is available for purchase. In some cases, such as on oil palm projects in southern Ghana, there were local food shortages and considerable volatility in food prices. These effects can be minimized if sufficient land is available for food crops, if credit and other scheme inputs can be used for food production, and if farmers are allowed flexibility in crop selection and intercropping. Furthermore, scheme transport can be used to make food available locally.

In a 1994 article, Glover finds that there are several ways in which contract farming has an effect on food security. Positive effects arise from the additional income created through contract farming, and from multiplier effects, extension services, input and service provision etc. The household member who receives the payments for the crop has an important effect on its use; where money paid to women has a better chance of being used for food. Negative effects stem from the displacement of alternative crops, which can be overcome by leaving cropping decisions to farmers.

Through vertical integration, small farmers can benefit from advances in processing technology. One example is in palm oil production. In Malaysia, the world's largest producer and exporter of palm oil, large numbers of small farmers grow oil palms under contract. Oil palm fruit are very perishable and need to be processed quickly after harvest, which makes them a typical candidate for contract farming. Technological advances in processing allow to refine palm oil, which used to have a very distinctive color and flavor, until it is bland and colorless. These technical advances allow palm oil to compete with a wide variety of vegetable oil, for example in margarine and shortening production. The resulting strong demand for palm oil has translated into growing incomes for large numbers of Malaysian smallholders. The extent to which farmers receive a share of the benefits from further advances in processing technology depends on their bargaining power, and on the policies regulating contracts between growers and processors

The Mexican government is currently attempting to encourage private investment in rural agricultural processing. One of its projects is an oil palm scheme, where small oil palm growers produce for privately owned processing plants. In designing an institutional setup to link growers and processors, Mexican authorities can take advantage of the literature on contract farming. They are thus allowing farmers to decide how much of their land to devote of oil palm, with the option of adding oil palm acreage later on. Small grants help farmers with initial investment costs and gestation lags.

The contract between growers and processors will be somewhat unusual: while most contracts are for only one year, Mexican investors prefer long term contracts. This is related to the fact that oil palms are perennial tree crops, and reflects a desire to ensure a steady supply of raw materials for the plant. Furthermore, since farmers in the area have a history of activism and organization, investors are considering a setup where farmers would be shareholders in the processing plants. This would give them a voice in management, ensure profit sharing, and hopefully reduce antagonism and conflict between growers and investors (Wolff, 1998). Research on contract design and factors affecting scheme viability thus allows to design sustainable institutional setups which can contribute to regional development and growth.

4.5 SUMMARY

These examples give an idea of the wide range of topics which are part of postharvest research, and of their impact on income and employment creation, equity, and human health and nutrition. The table below summarizes these impact studies, and presents their results in a manner which facilitates comparison. Not all studies include internal rates of return; where they are missing, some other measure or indication of impact is provided. As mentioned before, not all benefits are easily quantified, and therefore tend to be left out of quantitative analysis. This should be born in mind when examining the economic returns on the investments. Moreover, the impact literature on postharvest research, while growing, is still small relatively to similar studies in production research. The examples provided in this chapter are only part of an initial effort to collect information on impact of postharvest research and their review does not pretend to be exhaustive.

The impact studies reported, however, point to important benefits of postharvest research in terms of most indicators relevant to the goals of food security, poverty alleviation, and sustainable use of resources, particularly in developing countries. Where an internal rate of return is provided, it tends to be high and positive. Even though the small number of studies provided here does not allow drawing reliable estimates of average rates of returns, it was shown that the internal rates of return range between 13 and 14,000 percent. In their very extensive study of return to agricultural R&D in general, Alston et al. 1998 find an average rate of return between fifty and sixty percent, which would roughly indicate that returns to postharvest research may be as high as returns to all agricultural research. Thus, it appears there is no justification for the comparatively small amount of funding postharvest research receives at the level of the international agricultural research system when compared to production research.

Table 4.2–Impact of Postharvest Research

Category	Project	IRR (%)	Other Measure of Impact
Product Quality	Reduction of Hydrogen Cyanide Contents in Cassava	13 - 26	Reduced suffering and improved quality of life
	Micronutrient Enhancement to Fight Malnutrition (Turkey)	44 - 68	
	Flavr Savr Tomatoes		
Harvest and Storage	Grain Storage	16 - 43	
	Biological control of storage pests	68	
	Storage and Handling of Tropical Fruit	64	
	LGB control		The benefits in just two countries (Ghana and Tanzania) outweigh all the research expenditures over the last 15 years.
Utilization and Marketing	Dried Cassava Chips as Animal Feed		US$ 22 million additional income created in Colombia 1984 – 1991; increased income in northeastern Brazil
	Lowering Beef Processing Costs through Improved Packaging		Total surplus gain of US$ 845.6 million from lower processing costs and prices, and increased production
	Sorghum milling	20	The actual return are much higher than the reported figure since the evaluation was conducted only after 4 years its initial inception.
	Starch from roots and tubers and rural industrialization (Viet Nam)		US$22 contributed by starch industry. More than 20,000 rural households employed and self-employed by the sector. Their income is 80 higher than the average rural household. Growth prospects of the sector over 10 percent per year.
Policies and Institutions	Policy constraints on marketing	14,000	Rural growth, benefit to the rural poor.
	Contract Farming		Effects on income, food security and employment; Guidelines for contracts which ensure viability and profitability for growers

Source: Authors.

5. CONCLUSIONS

Until recently, postharvest research has received limited attention within the CGIAR system. This has changed somewhat since the 1996 TAC report, which argued that postharvest research should play a more important part at the international research centers. As mentioned in the introduction, several trends contribute to the increasing importance of postharvest activities.

Perhaps the most important of these trends is urbanization. As an increasing share of the population, including poor and marginal sectors, lives in cities, access to cheap, affordable and nutritious food becomes a priority. The low labor productivity of rural areas is a major cause of rural-urban migration. Agricultural growth is often insufficient to provide productive employment for a large rural population. Postharvest activities such as storage, transportation, processing, and marketing are alternative income sources, often representing opportunities to increase value added in rural areas through small rural agroenterprises.

Growing international trade provides both opportunities and challenges for agricultural development. To be able to participate in export markets, producers need well-organized postharvest chains, access to market information, and technology that will allow them to be price and quality competitive. Even competing with imports increasingly requires sophisticated marketing strategies. In many countries, improving infrastructure opens up new markets and opportunities for the postharvest area.

As income levels in many developing countries rise, the composition of people’s diets changes: fresh fruits and vegetables, meat, and vegetable oil consumption increase. These all products which require efficient storage, marketing and processing. Scientific progress is increasing the scope for improving storability of products, germplasm enhancement with micronutrients and vitamins, and processing of agricultural commodities. Finally, growing concern for the environment implies both opportunities and challenges, for example in alternative storage pest management, or in environmentally friendly packaging materials.

These trends contribute to the increasing importance of postharvest activities in the food sector of developing countries. Should the CGIAR system revise its present priorities and devote more attention to postharvest research? The answer is yes, for the following reasons. First, postharvest research has demonstrated **high rates of return**. Second, while much research with such high rates of return is carried out by the private sector, many types of postharvest research have **international public good characteristics**. Therefore the private sector will not engage in those activities, and it is up to governments and particularly international organizations to supply them. Finally, postharvest research contributes to the CGIAR goals of increasing income growth and reducing **poverty**, **enhancing food security**, and promoting **sustainable resource use**. Each of these reasons will be described in more detail below.

- **High internal rates of return**. The previous chapter has evaluated the impact of several postharvest research projects. The rates of return on postharvest research are on average comparable to rates of return from production research, and thus make an about equal contribution to income growth for every dollar spent on research. Furthermore many improvements, for example in human health, have important non-monetary value which is excluded from internal rate of return calculations. The economic impact of postharvest research investments is encouraging, and does not warrant a continued discrimination against such activities in funding allocations.

- **International public good character**. Should postharvest research be carried out by the private or by the public sector? The answer is that in fact part of the research in postharvest activities should be, and is carried out by the private sector. Thus CIP has stopped investing in potato processing because private companies can easily appropriate the gains from this type of research.

  The CGIAR system should mainly come into play when postharvest research has the character of an international public good, which means that private investors would not provide sufficient funding because they cannot appropriate the research gains. When research has public good character, but is only relevant for a reduced geographical area, it should be undertaken by national research organizations. Only when a public good has widespread international applicability should it be part of the CGIAR effort.

  Examples of such international public goods in the postharvest area abound. CIAT's cassava project is an example where a methodology for rural enterprise development was applied in several Latin American countries, and is being adapted for other regions as well. IRRI's simple rice drying technology has been copied and modified by small manufacturers. R&D costs for such technology cannot be easily recuperated by the private sector, and public investment is needed as a catalyst for private innovation. Public goods are underfunded by the private sector, and are thus candidates for public or multilateral funding. IFPRI's research on policies and institutions is amenable to application in a variety of countries that experience similar constraints to the development of postharvest systems. However, the private funding of this type of research is marginal.

- **Effect on poverty**. Postharvest research contributes to reducing poverty by enhancing income earning opportunities for poor people, and by providing time-saving processed foods to the urban poor. One of CIAT's foci is the research on the establishment and strengthening of small-scale rural agroindustries and complementary support services. This provides income opportunities for smallholders and for landless laborers, which tend to be among the poorest strata in developing countries.
  Participatory research methods for identifying markets, developing postharvest technology options and selecting appropriate organizational schemes for small rural enterprises are products that are non-location specific. Cross-case and cross-country analysis of experiences, lessons learned and best practices are in high demand by development practitioners at the local level.
  Reduced wastage during storage reduces food and income losses for farmers. In the case of tropical fruit, improved storage technology opens up new markets for products from developing countries and thus creates income opportunities and reduces poverty. In addition, processed convenience foods reduce the amount of time the poor, and especially urban women, have to spend preparing meals. Improved processing that leads to more convenient foods thus frees up time for other activities such as wage work, contributing to poverty reduction.
- **Effect on food security and health**. Postharvest research contributes to food security and health in several ways. Improved storage technologies, such as biological pest control or controlled atmosphere storage reduce postharvest food losses. Reducing losses increases the amount of food available for consumption. The project dealing with biological control of

the larger grain borer reduces losses in on-farm storage for smallholders, and thus enhances food security.

The reduction of cyanide potential in cassava is an example where postharvest research had a important effect on food safety, since a significant proportion of the African population suffers from cyanide-related diseases. Micronutrient-enhanced staple crops will contribute to the fight against malnutrition while saving resources for other health-related programs.

- **Effect on sustainable use of resources.** Postharvest research contributes to sustainability by finding alternatives to chemicals which have polluting effects on the environment, and are hazardous for human health. Thus alternative pest control mechanisms for grain storage reduce the need for pesticides, which reduces pollution, minimizes accidents with pollutants, and also lowers pesticide residues in food consumed by humans.

The reduction of postharvest food losses in itself contributes to sustainability. Reducing waste of already produced food is more sustainable than increasing production to compensate for postharvest losses. Increasing production leads to more intensive farming or to an expansion of the area under cultivation, both of which may have negative effects on the environment especially when poor rural households tend to farm in fragile ecosystems or marginal land.

Natural resource management research that seeks to reduce environmental degradation of soil and water resources and conserve biodiversity, benefits from close links to research on market. Value adding opportunities that enhance the value of key commodities would also increase income generation for improving welfare and providing farmers with the financial resources for investment in resource enhancing technologies.

As the significant contribution of postharvest research to CGIAR goals such as poverty reduction, food security and sustainability becomes clear, and in the light of high rates of return, the very skewed allocation of funds to production versus postharvest topics cannot be justified. Since so far, relatively little has been invested in postharvest research, there is potential for large impacts as constraints and bottlenecks are removed. It would thus be desirable to re-examine current funding priorities and to allocate a larger proportion of resources to the postharvest area.

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