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BIOTECHNOLOGY AND THE CHANGING PUBLIC/PRIVATE SECTOR BALANCE: DEVELOPMENTS IN RICE AND COCOA

by

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RÉSUMÉ

Ce document analyse les impacts potentiels de l'évolution du rapport entre secteurs public et privé en ce qui concerne le développement et la diffusion de la biotechnologie dans l'agriculture des pays en développement. Il étudie particulièrement l'incidence de la biotechnologie sur deux importantes cultures des pays en développement : le riz et le cacao.

Les différences qui caractérisent la recherche sur ces deux cultures tant au niveau national qu'international sur le plan des ressources financières et scientifiques consacrées à la recherche et dans les secteurs public et privé concernés sont soulignées. L'étude insiste sur la nécessité de l'intervention gouvernementale pour définir les priorités nationales en matière de recherche et mettre en place des cadres institutionnels nouveaux — incluant une collaboration entre secteurs public et privé — dans les cas où les fonds publics réservés à la recherche ont été réduits ou sont devenus de plus en plus rares.

SUMMARY

This study examines the potential impact of changes in the public/private sector balance for biotechnology development and diffusion in developing country agriculture. It focuses on biotechnology related to two important developing country crops: rice and cocoa.

The study highlights the differences in the ways in which research on the two crops is organised, at both national and international level, in the financial and scientific resources devoted to research and in the public and private actors involved. It stresses the need for government intervention in setting national research priorities and for innovative institutional arrangements — including public/private sector collaboration — in situations where public research funding has been reduced or is increasingly scarce.

PREFACE

This study is part of a research project on "Technological Change in Developing Country Agriculture: Implications of the Changing Public/Private Sector Balance". The project has been undertaken in the context of the Development Centre's 1990-92 research programme on "Developing Country Agriculture and International Economic Trends", headed by Ian Goldin.

The Centre's research on agriculture incorporates several components: a conceptual component to provide analytical guidance for the broader issues; a global general equilibrium model to analyse the overall trends and policy consequences; a component to analyse the links between economic reform and technological change in agriculture; and a series of country case studies to look more closely at the economic reform options for individual representative countries.

The work on technology seeks to determine whether the structural adjustment and liberalisation process — and, by implication, changes in the public/private sector balance — is enhancing or impairing the economic and institutional conditions conducive to technological innovation and greater productivity. In order to examine this hitherto unresearched issue, an eclectic approach has been adopted and a number of different types of study commissioned. These include: a conceptual study of the interaction between changes in economic policies and agricultural productivity; two commodity studies — rice and cocoa; a study of biotechnology research developments with respect to those two commodities; a case study of agricultural research institutions in Brazil; a study of seeds supply and diffusion in three African countries. These provide different perspectives and angles on the relation between economic reform and technological change in agriculture.

This study on biotechnology developments related to rice and cocoa, by Carliene Brenner, complements the commodity studies mentioned above. It examines rice and cocoa research "at the frontier" and highlights the differences between the approaches to research and to the resources available for research on the two crops.

The study finds that the significant changes occurring in the organisation of research lie not so much in the changing public/private sector balance as in the extent of public/private interaction and collaboration. With or without structural adjustment, there are strong arguments in favour of government intervention in assigning national research priorities and of a strong public sector role in conducting the long-term basic research — for example on the preservation of genetic resources — in which the private sector sees few prospects for short-term profit.

The lessons to be drawn from the project and the policy implications will be brought together in a synthesis volume to be published in the Development Centre Studies series.

Louis Emmerij
President of the OECD Development Centre
June 1992

INTRODUCTION

This study is part of a larger research project entitled "Biotechnology and Developing Country Agriculture: Implications of the Changing Public/Private Sector Balance", which examines the interactions between the structural adjustment process — including, presumably, changes in the public/private sector balance — and technological change in developing country agriculture. The study attempts to:

(i) examine the ways in which research is being conducted "at the frontier" and the ways in which the organisation of research may differ from the past;

(ii) discuss a number of developing country preoccupations with respect to the future of agricultural production which stem from the new research configuration; and

(iii) determine how changes in the public/private sector balance, implied by the structural adjustment process, might affect the development and diffusion of new biotechnologies in rice and cocoa.

For the purposes of the study, technology is defined as encompassing all the skills, knowledge and methods, whether embodied in people, procedures, processes or products, which contribute to the transformation of inputs into outputs[(1)]. Technological change, therefore, refers to any improvement in the transformation of inputs into outputs and may relate to minor, incremental modifications or to major breakthroughs or innovations. It also refers to both quantitative and qualitative improvement.

Technological change and diffusion in agriculture, as in industry, is a complex, interactive process, involving different actors and institutions (public and private) in a number of successive activities or phases. These include: (a) research, both basic and applied, which can be intended to enhance knowledge or to contribute to the development of a marketable technology; (b) the incorporation of research output into a tangible technology; and (c) the marketing and, eventually, widespread diffusion of the technology product[(2)].

Historically, agriculture has evolved from a low-productivity, labour-intensive system to a high-productivity, input-, science- and knowledge-intensive system of production. The simplified schema below illustrates four progressive stages of technological change in agriculture and the principal innovations and inputs which have characterised them.

Phase 1: Nature + biological cycles + improved plant breeding and animal husbandry practices + organic fertilizers

Phase 2: Mechanisation:
Improved seeds, plants and animals + land and water resources management + farm machinery

Phase 3: Biochemical (Green Revolution):
New varieties (high-yielding, hybrid) + irrigation + intensive application of plant growth and protection chemicals

Phase 4: Biotechnology:
"Designer" seeds, plants, animals, food + information technology +/- chemical protection + new industrial uses of biomass.

For purposes of illustration, these stages are shown as separate and distinct. In practice, they inevitably overlap. In general, technological change is a continuous, cumulative process and innovation introduced in one phase are not necessarily replaced or discarded in the following.

As technolgoical progress has gradually prevailed over the structural constraints imposed by nature, the links between agriculture and the non-agricultural sectors of the economy have been intensified. Particularly in industrialised countries, the production of food is increasingly dependent on upstream and downstream linkages and the food industry now has important links with the seeds, plant and animal protection (chemicals and pharmaceuticals) industries.

Mastery of increasingly complex, science-based technologies has become a key instrument in the competitive strategies of firms and governments to maintain or increase their shares in markets which, increasingly, have global dimensions. This applies, notably, with respect to biotechnology. Green Revolution technolgoies were developed essentially as "public goods", in public research institutions. In contrast, the new biotechnologies in food and agriculture are, to a significant extent, being developed and "appropriated" outside the established agricultural research system, by private firms and by scientists not necessarily fomerly concerned with agriculture.

This study focuses essentially on the research phase of the technolgy generation and diffusion cycle because it is at this phase in particular that changes in the public/private sector balance are perceived to constitute a rupture with the past. Although it is not always possible to make a distinction between research and development, the study focuses primarily on research "at the frontier" and on developments in biotechnology research rather than on traditional methods of plant breeding. It is important to stress, however, that new biotechnology will complement — but will not supersede — plant breeding.

The analysis is confined to developments with respect to the two commodities which were selected for detailed study as part of the larger project mentioned above: rice and cocoa(3). These two crops are of particular importance to developing countries for different reasons. Rice is the developing world's most important food crop, particularly in Asia, with only a very small share (less than 3 per cent) of total production entering international trade. Cocoa is produced only in developing countries, principally for export rather than for domestic consumption. For some countries — particularly in West Africa — cocoa constitutes their most important source of export revenue. This selection of these two crops therefore permits comparison of developments in biotechnology and of the respective roles of the public and private sectors for both a food and export crop.

In Section I, we discuss very briefly the expansion of agricultural research in general, from the colonial past to the development of international research networks. The ways in which the respective roles of the public/private sectors have evolved — and are evolving — are also outlined.

Section II describes, more specifically, how research on rice and cocoa has been conducted in the past. Section III then analyses current trends in biotechnology research related to rice and cocoa, identifies the leading actors involved in research and examines the ways in which the various actors interact or compete. It also assesses the potential impact of the emerging technologies.

Section IV discusses policy issues of particular concern to developing countries which emerge from the changing pattern of the organisation of research. These include: the hybridization of rice; the substitution of cocoa; and the conservation of genetic resources for rice and cocoa.

Finally, Section V examines the ways in which the changing public/private sector balance implied by the structural adjustment process might affect biotechnology research and technology development in rice and cocoa in the future. It also discusses the policy implications for national governments, bilateral and international aid agencies and the institutes of the CGIAR system.

I. THE EVOLUTION OF AGRICULTURAL RESEARCH[4]

1. The Colonial period

While formal agricultural research systems are relatively recent, informal research and experimentation on plant and animal improvement through selection and improved cultural practices by farmers have contributed to the enhancement of both quantity and quality in agriculture throughout the ages. By the 18th century, countries such as China, Japan and India, were using more advanced agricultural technology than was available in Europe and supporting higher population densities than Europe.

Today's systematic, scientific, national agricultural research systems originated from developments in the early 19th century. By the end of the 19th century, important technological changes had occurred in the increasingly widespread use of chemical fertilizers, combined with the introduction of mechanised farm machinery. As a consequence, most of the countries which had adopted the more technologically advanced agricultural production systems had established institutions whose primary task was to conduct agricultural research. As scientific knowledge assumed growing importance in agricultural experimentation, a division of labour between those primarily engaged in agricultural production and those primarily engaged in agricultural research was created. Early leaders in this transition included Germany, Great Britain, France and the United States, while Japan was one of the first countries in the world to establish a public agricultural research system[5].

The 19th century also witnessed the expansion of British, French, and to a lesser extent, Dutch and Belgian colonies. During the colonial period botanical gardens, experimental stations and model farms were set up in colonies on the African and Asian continents and, to a lesser degree, Latin America and the Caribbean. These institutional innovations have left a lasting imprint on the present structure and organisation of agricultural research. Some 24 botanical gardens and experimental stations were reported to have been set up in sub-Saharan Africa alone. The French Colonial Gardens of Vincennes and the Royal Gardens at Kew became important centres for the storage and international transfer of plant genetic material.

An important feature of these precursors to today's national agricultural research systems is that they were established first and foremost to ensure supplies of tropical cash crops: coffee, tea, oilpalm, cocoa, groundnuts, rubber, sisal, cotton and rice. These were sometimes introduced to countries where they had not previously been cultivated. A second important feature is that these early institutions were not necessarily supported by the government of the colonial power but were in some instances supported by plantation industries, private marketing boards and growers' associations.

In the United States, a comprehensive research and technology development structure was established within the land-grant university system and its accompanying experimental stations in the late 19th century. By the early 20th century, federally-funded agricultural experimental stations covered most states. In the post World War II period, the United States system became a model for national agricultural research systems in many developing countries.

2. Post World War II

Since the second World War national agricultural research systems (NARSs) have expanded both in industrialised countries and, particularly since independence, in many developing countries. Developing countries have either set up or expanded national systems. Financial support or technical assistance through bilateral and international aid agencies, private foundations and former colonial powers has played a key role in the strengthening of NARSs. Table 1 indicates annual growth rates in public agricultural research expenditures and personnel between 1961 and 1985.

In the past two decades, developing countries have significantly increased their share in global agricultural research capacity. The number of researchers in developing countries grew at more than four times the annual rate for the industrialised countries. As a result, the total number of researchers in developing countries increased from 33 per cent in 1961-65 to 58 per cent of total researchers in 1981-85.

During the same period, global spending on agricultural research increased by a factor of 2.6. The share of expenditure of developing countries grew from 33 per cent in 1961-65 to 43 per cent in 1981-85. This is nevertheless considerably less than the share of agricultural researchers noted above (58 per cent).

Among developing countries in regional terms Asia and the Pacific (excluding China) accounted for the major share of both numbers of agricultural researchers (17 per cent) and research expenditures (14 per cent), followed by Latin America and the Caribbean (7 and 8 per cent respectively), West Asia and North Africa (7 and 5 per cent), and, lastly, sub-Saharan Africa (4 and 5 per cent).

China accounts for 24 per cent of total developing country agricultural researchers and 11 per cent of total developing country agricultural research expenditure.

A very important feature of the expansion of agricultural research globally has been the creation of the International Agricultural Research Centres (IARCs) of what has become known as the CGIAR (Coordinating Group for International Agricultural Research). The two earliest centres, the International Rice Research Institute (IRRI) in the Philippines set up in 1962 and the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) (1963), played a crucial role in the development of the "Green Revolution" high-yielding varieties of rice and wheat.

The CGIAR, which now co-ordinates the activities of 13 IARCs, 10 of which are located in developing countries, is financed by national governments, private foundations and international organisations, including the World Bank, where it has its headquarters. Annual core expenditures for the CGIAR were around $280 million in 1990. Though this represents an insignificant share of global public expenditures for agricultural research (around 1.8 per cent in 1981-85), the IARCs have had an important influence on the way agricultural research is conducted in the NARs in developing countries. Although their "top-down" or "big-science" approach to agricultural research has been criticised(6), they have provided valuable technical, scientific and moral support to NARs and, perhaps even more important, have been a key source of improved germplasm made available to developing countries. Since the advent of the IARCs, research on a number of commodities of key importance to developing countries has taken on a truly international dimension.

3. Evolving public and private sector roles

A limited number of efforts have been made in recent years to develop quantitative indicators of agricultural research(7) both nationally and internationally, but these have for the most part concerned public institutions only. Very little detailed information is as yet available on private sector research, except for the United States(8).

From the data available on the United States, a relatively long-term trend emerges of growing private sector involvement in some areas of research and with respect to certain crops formerly dominated by the public sector. Thus, in crop breeding and management, and plant protection and nutrition, private sector expenditures currently exceed those of the public sector. Although considered subject to substantial error, the consensus of estimates indicates a large increase in the ratio of private to total research, from about 50 per cent in 1961 to about 60 per cent in 1985. Pray and Neumeyer estimate private sector agricultural research expenditures in 1984 at $695 million for pesticides (33 per cent of the total), $389 million for plant breeding (18 per cent) and $150 million (7 per cent) for biotechnology(9). Little data on private sector agricultural research is available for other industrialised countries.

With respect to developing countries, producers' associations were important during the colonial period in promoting research on export crops such as tea and tobacco in Africa and Asia. They have remained important in some countries, as in Zimbabwe with respect to maize. In other countries, for example in Brazil, as illustrated by Wilkinson and Sorj(10), the co-operative movement has been an important private actor in agricultural research.

Recent, pioneering work to assess the level and scope of private sector research has been conducted on Latin America, Asia and sub-Saharan Africa(11). Interest in the role of the private sector in developing countries has been stimulated for a number of reasons. Firstly, current economic policies in general and structural adjustment policies in particular, advocate a freer role for market forces and a less interventionist stand on the part of government in all economic activities. Secondly, the private sector is assuming a more active role in research, both basic and applied, related to the development of new biotechnology in agriculture and this in turn is expected to have important repercussions for technology development and transfer in developing countries. Thirdly, a more active role for the private sector is closely linked to international pressures to strengthen intellectual property rights protection related to plants.

Agricultural research can be directed towards the development of many different types of technology, including:

(i) mechanical: tractors, harvesters, and other farm equipment;

(ii) processing

(iii) chemical: growth regulators, fertilizers, fungicides, insecticides and herbicides;

(iv) managerial: crop and livestock management techniques, computerised managerial practices;

(v) biological: crop cultivars, animal breeds, hormones, vaccines and micro-organisms.

To date, most private sector research has been concentrated on developing mechanical and chemical technology where patents are readily available and research output easily appropriated. Where private firms have conducted biological research in developing countries, this has sometimes involved plant breeding and the development of new plant varieties. More often it has involved adaptive research, for example the adaptation of imported seed to local agro-climatic conditions.

Pray and others have outlined theoretical determinants of private sector agricultural research in developing countries, linked to profit maximising behaviour. These are listed in Table 2.

The various public and private sector actors involved in agricultural research have also been outlined by Echeverría (see Table 3). Involvement may mean actually carrying out the research or simply funding it.

The distinction between public and private sectors is not always clearcut. An institution may be classified as public or private according to: ownership and control; sources of financing; economic behaviour; and, particularly, whether it is profit-making or not. Recent trends in investment in research at the frontier suggest that the public/private sector distinction is becoming increasingly blurred as, in many public institutions, private sector input in decision making or in funding is more and more prevalent. In addition, changes in economic policy in many countries have put pressure on public institutions to be at least partially self-financing, which implies they are obliged to seek private sector financing.

Similarly, in terms of the criteria listed above, many non-governmental organisations (NGOs) may be private but at the same time rely principally on public (national, bilateral or multilateral) funding. Foundations such as Rockefeller, Ford and many local research foundations can be defined as private in terms of ownership and control but as they are free of the need to be profit-making, may behave like public sector institutions.

Biotechnology has attracted new actors to agricultural research, and new forms of public/private sector interaction are emerging in biotechnology research. One significant development has been the creation of the "new biotechnology firm"[(12)] which carries out both basic research and development. The new biotechnology firms of the 1970s, which proliferated first in the United States and then in Europe, were often founded by former academics and many did not survive. The survivors have been financed in a variety of ways: venture capital; public stock offerings; by multinational corporations (MNCs); and joint ventures, contracts and/or licensing arrangements. Some, particularly in Europe, have been set up with government financial support.

In addition to the new biotechnology firms, MNCs in the seeds, agricultural, pharmaceuticals and food-processing industries in the United States, Japan and Europe, have invested large sums in setting up in-house research facilities for biotechnology research[(13)]. They have also commissioned research or bought equity participation in new biotechnology firms, or have entered into contractual arrangements with public research institutions or universities.

Growing interaction between the private and public sectors and, more particularly, growing private sector investment in basic university-based research is another important trend. At a time of budget stringency and efforts to reduce public spending, university-industry interaction in biotechnology-related research is being actively encouraged in many industrialised countries. Governments have provided incentives to biotechnology firms to locate near university sites or in nearby science parks or to invest in university research programmes in which the firms can participate actively. Some universities have set up, or partly financed, university-based companies which act as consultants or carry out commissioned research.

Public/private sector interaction is also being encouraged in developing-country universities and public research institutions as a result of structural adjustment and pressures to privatise.

The potential impact of a growing share of private investment in university-based research on the free flow of scientific information, on conflicts of interest among university scientists working in biotechnology disciplines and on the setting of research priorities, is a subject of continuing debate. In addition to these concerns, however, the growing importance of new private actors in biotechnology research and plant breeding raises questions about the future directions of such research and the public good nature of research results.

II. ORGANISATION OF RICE AND COCOA RESEARCH: PAST AND EMERGING PATTERNS

Rice is grown in both temperate and tropical conditions and is the most important food crop in many Asian countries. Cocoa is grown only in the tropics in Central and South America, in Africa (particularly West Africa) and in Southeast Asia. It is worth noting that, while cocoa is insignificant in terms of volume produced compared to rice, a much greater share of total cocoa production (more than 70 per cent) enters world trade than of total rice production (around 3 per cent). While export volume represents only about one-eighth that of rice, total cocoa exports, even at today's extremely low prices, represent almost half the value of total rice exports.

1. Rice

Compared to other commodities, rice has accounted for an important share in research expenditures in a large number of developing country NARSs, particularly in Asia, but also in some African countries and in South and Central America. Unless research is carried out in specialised commodity institutions, data on the levels of expenditure for individual commodities within NARSs are difficult to obtain. In many institutions, rice may be only one of the crops on which research is carried out in a national food crops research institute. Judd *et al.*[(14)] have estimated that, for 26 large developing countries in Africa, Asia and Latin America, research on rice accounted for 0.25 per cent of the value of the product on average during the 1972-79 period. This compared, among cereal grains, with 0.51 per cent for wheat and 0.23 per cent for maize.

In addition to national institutions in developing countries, other public sector institutions which are prominent either in conducting or financing research on rice include the French Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and, more specifically, its Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) at Montpellier. IRAT's recent efforts have concentrated on upland and flooded rice, two types of rice production systems which have benefited little from research. CIRAD, and another French institution, ORSTOM, collaborate with developing countries in the context of bilateral aid. CIRAD/IRAT also collaborates with the IARCs which are conducting rice research. IRAT is also a member of a recently-created rice research group which has been set up among European rice-producing countries (including France, Greece, Italy, Spain, Portugal, Romania, Russia) under the auspices of FAO. In recent years, CIRAD has attempted to reduce the concentration in former French colonies in Africa and is extending its efforts in rice to Brazil, and in Southeast Asia.

It is worth noting that, through its CIRAD and ORSTOM operations, France spent a total of around $100 million on tropical agricultural research in 1985, a figure amounting to nearly one-half of the total CGIAR budget for that year[(15)].

At the international level, the most important public institution conducting rice research in the post-war period has been the International Rice Research Centre (IRRI), set up in the Philippines in 1962. However, IRRI is now not the only IARC to conduct research on rice. Others include: the West African Rice Development Association (WARDA) in Côte d'Ivoire, the International Centre for Tropical Agriculture (CIAT) in Colombia and the International Institute of Tropical Agriculture (IITA) in Nigeria. The expenditures of these institutions (that is, core + special projects expenditures), in 1989, were:

IRRI	$33.9 million
CIAT	$32.6
IITA	$32.1
WARDA	$ 6.3

Source: Guido Gryseels and Jock R. Anderson, International Agricultural Research, in: "Agricultural Research Policy: International Quantitative Perspectives", 1991

It is to be recalled that IRRI's and WARDA's mandates concern rice exclusively. CIAT and IITA expenditures are distributed among a number of different crops.

Gryseels and Anderson(16) have estimated the "commodity" orientation of the CGIAR core operating expenditures. The total share of cereals in those expenditures, which represented 57.9 per cent of expenditures in 1971-75 had declined to 38.7 per cent by 1986-88. Among the cereal grains, rice remains by far the most important, although its share of expenditures has declined from 21.5 to 17.2 per cent (compared to 9.1 per cent for wheat, barley and triticale, 7.3 per cent for maize, and 5.0 per cent for sorghum and millet). Regional allocations for research activities on rice indicate that Asia and the Pacific account for the largest share (63 per cent); followed by sub-Saharan Africa (28 per cent); Latin America and the Caribbean (8 per cent) and West Asia and North Africa (0 per cent).

Among private institutions, the Rockefeller Foundation has played a role of great importance, not only through substantial financial contributions to rice research in both national and international programmes, but also in influencing the directions rice research has taken. This role will be expanded upon in the section on biotechnology in rice.

- *Rice research prior to World War II*

Rice has a long research tradition, particularly in Asia. The first rice experimental station was created in Burma in 1907. By the early 20th century, systematic rice breeding work was also under way in Indonesia, what is now Bangladesh, and in Korea. Rice-breeding work began in India in 1929, although the Central Rice Research Institute (CRRI) was not established until 1946(17).

An important feature of rice research — and production — prior to World War II was the superiority of Japan which, by 1900, had achieved yields of 2.8 mt/ha. After two centuries of isolation from the rest of the world, Japan began to modernise at the beginning of the Meiji period (1868-1911). As its economy was essentially agriculture-based, it was decided that productivity must be boosted in agriculture in order to finance industrialisation. At first, this objective was pursued through importing mechanical agricultural technology from the West but this was inappropriate for Japanese small-scale production conditions(18).

When it became clear that importing technology was not resulting in the productivity gains anticipated, policies were redirected towards the development of indigenous knowledge and towards the biological improvement of varieties. Initially, research was essentially adaptive. Drawing on the best seed varieties developed by veteran (*rōnō*) farmers which were "on the shelf" but had not been widely diffused due to the restrictive character of society in the Tokugawa period, research consisted mainly in the screening and adaptation of these varieties. As fertilizer was readily available from Japan's rapidly-growing industry, the *rōnō* varieties selected were characterised by high fertilizer-responsiveness, did not lodge easily and were less susceptible to disease at higher levels of nitrogen application.

It was not until this indigenous source of technology had been exhausted and yields began to decline that more effort was directed towards basic research. In 1904, the National Agricultural Experimental Station launched the first rice breeding project to develop new seed varieties by crossbreeding and in 1905 a project was launched to improve rice varieties by pure line selection. The establishment in 1927 of a co-ordinated, national rice-breeding programme (through the Assigned Experiment System for rice) led to the first of a number of successful *Norin* varieties, launched in 1931. The *Norin* varieties successively replaced older varieties in the latter half of the 1930s.

As indicated above, one important objective of Japanese rice research has been the development of varieties responsive to fertilizer. Japanese varieties were directly transferred to Korea, at the time a Japanese colony, because the climate is similar to that of Japan. A South Korean branch of the Japanese National Agricultural Experimental Station was established in 1935 to assist in the selection of fertilizer-responsive, high-yielding varieties.

It was more difficult, however, to transfer improved varieties developed in Japan to the sub-tropical climate of Taiwan. Yields of the *japonica* varieties first tested in Taiwan in the early 1900s were lower than those of most of the native varieties. In 1926, the Japanese varieties adapted to Taiwan's conditions through crosses with native Taiwan varieties, were officially designated as *ponlai* (which means heavenly rice). An important feature of the *ponlai* varieties is early maturity.

Elsewhere in Asia, particularly in tropical South and Southeast Asia, rice yields remained low, in part because research effort was focused more on export crops (sugar, rubber, tea and cotton) than on cereal grains. Furthermore, population density was lower in tropical Asia than in Japan and so it was possible to increase production by extending the land under cultivation.

Nevertheless, some progress in tropical rice research was achieved. Knowledge of breeding techniques advanced considerably and statistical procedures were developed in the 1930s which improved the accuracy and reliability of varietal screening. This concerned India and Indonesia in particular.

- *Post World War II*

Since the second World War, the most significant development has been the introduction of the Green Revolution technology "package", intended above all to increase productivity. While IRRI played a crucial role in the development of the new technology, it was able to draw on research which had been conducted elsewhere, particularly in Taiwan and China[19].

In China, efforts to intensify cropping through emphasis on water control and on early-maturing varieties continued after the new government came to power in 1949. The objective of the new Chinese government was to maximize output per hectare per year in the knowledge that little new land was available for extending cultivation. At the same time, there was a clear constraint on liquid capital for the purchase of inputs, but little constraint on labour supply.

The first semi-dwarf Chinese variety (*Guang-chang-ai*), released in 1959, was the first short-statured, high-yielding *indica* variety successfully developed by crossbreeding. One of the parents of this particular variety has become the major dwarfing source of most of the important varieties bred in China.

In Taiwan, despite the rapid dissemination of the *ponlai japonica* rice varieties, at the end of World War II more than 40 per cent of the rice growing area in Taiwan was still planted to *indica* varieties. Hybridization among native and between native and other *indica* varieties began in the early 1950s. The first of the crossbred semidwarf *indicas* in Asia, *Taichung Native 1*, was developed in 1960. The new semidwarf varieties represented a very important technological change in tropical rice production. They offered the possibility, under ideal production conditions, of yield potential comparable to the yields achieved as a result of more than 50 years of steady progress in the temperate zone.

Taichung Native 1 and several of the leading *ponlai* varieties, were widely disseminated to other countries in tropical Asia and Africa in the early 1960s. Perhaps the most important contribution of the Taiwan semidwarf *indicas* was that they were the source of the dwarfing gene for the new varieties that were subsequently developed at IRRI and elsewhere in Asia.

IRRI's initial breeding objective was to produce a plant type — both *japonica* and *indica* varieties — that would be resistant to lodging, make efficient use of solar energy and fertilizer, and achieve higher yields. This required: a shorter plant type; a lower grain to straw ratio; reduced photoperiod sensitivity; and shorter growth duration.

In its early years, IRRI concentrated its research on relatively favourable environments, and certainly on those with relatively plentiful water supply or irrigation. This early emphasis has since been modified to some extent and more effort is now devoted to all the different ecosystems: rainfed lowland; upland (annual and perennial); deepwater; and tidal.

One of the most significant developments in rice breeding in the 1970s was the commercial development of F1 hybrids in China. Following the initiation of a hybrid rice breeding programme in Hunan Province in 1964, the first successful demonstrations of hybrid rice took place in 1974. Since then the area planted to hybrid rice has increased rapidly, now representing about 55 per cent of China's total rice acreage. Since 1966 the Chinese have successfully experimented with haploid breeding through "anther culture", a means of achieving stability in the varietal characteristics or homozygosity in one generation instead of six or seven.

2. Cocoa

- *Public institutions*

One of the most important characteristics of cocoa is flavour and while it may to some extent be conferred by the genetic composition of the plant, cocoa flavour is very much influenced by the processes of fermentation and drying of the cocoa bean. To date, an important share of the total cocoa research effort has been devoted to processing. However, for the purposes of this study, we concentrate principally on research related to plant improvement.

According to Bloomfield and Lass(20), the first government-sponsored research station for cocoa was set up in the state of Bahia, Brazil, in 1923. Prior to that, the work of individual scientists had been supported by colonial administrations in Sri Lanka, Trinidad and Suriname.

Cocoa research began in an organised way during the colonial period in the West Indies (Trinidad) and in Africa. The West Africa Cocoa Research Institute (WACRI), for example, was set up in the colonial period to co-ordinate cocoa research work in Ghana and Nigeria. Following independence, the research substation at Tafo became the Cocoa Research Institute of Ghana, while the substation at Ibadan became the Cocoa Research Institute of Nigeria(21).

In the francophone areas of West Africa, the Institut Français du Café et du Cacao carried out a similar function, but was not disbanded at independence. The institute is now renamed Institut de Recherches du Café et du Cacao (IRCC). This institute constitutes one of the departments of CIRAD. IRCC is largely financed by the French government and within its overall budget, around 60 per cent of its resources are devoted to coffee and around 40 per cent to cocoa. As with other French institutions — and public institutions in other countries — the objective is to decrease the share of government financing and seek funding from external sources, either from public or private sector donors. It is intended that eventually 60 per cent of resources will be provided by government subsidy and 40 per cent by outside resources.

While during colonial times, the former French cocoa research institute concentrated its efforts exclusively in its own colonies, effort has been made in recent years to extend the number of countries in which IRCC works. Thus, at present, it has projects in the field in Guyana, Côte d'Ivoire, Vanuatu, Cameroon, Indonesia, Malaysia, Philippines and Venezuela.

At present IRCC collaborates almost exclusively with public sector institutions but is not adverse to collaborating with industry. In fact, its laboratories in Montpellier do work more closely with industry. In Vanuata, it is working in collaboration with the Commonwealth Development Corporation (CDC).

In research projects in developing countries, IRCC contributes 50 per cent of the funding, while the receiving country is expected to provide 50 per cent. IRCC collaborates with governments but assists in arranging a financial package which may be contributed by public, private, bilateral or international institutions. The research conducted by IRCC in developing countries is essentially in the nature of applied research and covers plant breeding and selection, crop management and plant protection.

Cocoa research is also sponsored, directly or indirectly, through bilateral aid programmes. This is the case with the British aid agency, the Overseas Development Administration (ODA), which is contributing £7.5 million financial and technical assistance over four years to the Ghana Cocoa Research Institute and the Cocoa Marketing Board. The technical assistance component covers the provision of personnel at the Ghana Cocoa Research Institute as well as the training of Ghanaians in the United Kingdom. ODA is also supplying equipment for the rehabilitation of laboratories in line with the priorities of the research programme. Changes which ODA is encouraging in the GCRI include a shift from the present scientific disciplinary approach to one which concentrates on specific problem areas. It is also in favour of less emphasis on a science-driven approach and more emphasis on a "bottom-up" approach which more directly involves the farmer. A Farming Systems Unit has been set up for this purpose. ODA also supports CDC in commercially-oriented plantation research in Southeast Asia.

Again in the context of bilateral aid, USAID provides limited financing for cocoa research, mainly in Central America.

Among the international institutions, the EEC is financing research projects related to cocoa through its Science and Technology for Development programme.

Among producer countries, Brazil established a strong cocoa research programme under the Commissão Executiva do Plano da Lavoura Cacaueira (CEPLAC). Until 1981, CEPLAC was funded by a levy of 10 per cent on exports of cocoa beans and products. After that time, it became government-funded but its funding has recently been drastically reduced as part of Brazil's structural adjustment policies. CEPLAC has recently been integrated into the Ministry of Agriculture. Initially, in addition to conducting research, CEPLAC was responsible for extension work, with providing credit to cocoa producers, and developing the production and related infrastructure. Its activities are at present greatly curtailed and are concentrated essentially on attempting to control the outbreak of witches' broom disease in Bahia.

In Southeast Asia, Malaysia and Indonesia also have cocoa research programmes which are a part of their national agricultural research programmes.

- *Private sector actors*

In Europe and the United States, the cocoa consumer industries provide funds for cocoa research. In the United Kingdom, the chocolate industry association, called the Biscuit, Cake, Chocolate and Confectionery Alliance (BCCCA), contributes to the Cocoa Research Fund which finances research in the United Kingdom or in producer countries. The major share of these funds contributes to cocoa research in Ghana and to the Imperial College of Tropical Agriculture in Trinidad. At present the contribution of BCCCA cocoa-related research is around £400 000 annually.

In the United States, the American Cocoa Research Institute (ACRI) serves as the research arm for the Chocolate Manufacturers' Association (CMA). Members of CMA/ACRI provide financial support for the research programme which covers five broad areas: biotechnology, cacao research, cocoa processing and evaluation, health and safety. The funding level for all five areas is at currently around $750 000 per year. The emphasis given by the Institute in recent years to biotechnology and to yield-enhancement has shifted to integrated pest management and plant resistance.

ACRI also supports research projects in developing countries of Central and South America, particularly at CATIE (the Centro Agronomico Tropical de Investigacion y Ensenanza) in Costa Rica, Ecuador and Brazil.

Cocoa research is also carried out by the major chocolate manufacturing firms: Nestlé, Hershey, Mars, Cadbury Schweppes, Suchard. However, data on the share of their R&D budgets actually spent on research related to improvement of the cocoa plant, or on their support of research conducted in public institutions, is difficult to establish.

In Malaysia, the major plantation companies (United Plantations, Sime Darby, Golden Hope, Guthrie) are all conducting research on cocoa, which constitutes a much less important aspect of their business than does palm oil or rubber. Research efforts have been concentrated on improved planting material, particularly clones, and on quality improvement, whether through agronomic research or processing techniques. The plantation companies collaborate to some extent in fixing research priorities and in sharing the results, although this is clearly not the case in the development of competing techniques. The private sector is also represented on the body which determines national cocoa research priorities.

- *Principal areas of research*

Progress has been achieved in both the quantitative and qualitative aspects of cocoa research, by both the public and private sectors. Improved planting material, in the form of hybrids and clones, has made much higher yields possible. Progress has also been made in control of some of the principal cocoa pests or diseases, principally by chemical means, although increasing attention is now being paid (for example in Malaysia) to integrated pest management. Research has also resulted in quality improvement in terms of flavour, particularly in Malaysia, through improved drying and fermentation techniques.

However, research on the physiology of the cocoa plant and its genetic characteristics is much less advanced than research on other export crops such as palm oil, rubber and tea or than research on rice. Furthermore, little progress has been made in resolving the problem of incorporating resistance to the numerous pests and diseases which cause very substantial losses in cocoa production.

When comparing the organisation of cocoa research to that of rice, it is striking to note, firstly, the low level of scientific and financial resources devoted to cocoa. Secondly, there has been no systematic setting of objectives and priorities, nor co-ordination of research effort in the case of cocoa. Finally, there has been no sustained international effort, or international collaboration in national research efforts with respect to cocoa.

III. BIOTECHNOLOGY RESEARCH IN RICE AND COCOA[22]

1. Rice

- *The Rockefeller Foundation International Program on Rice Biotechnology*

The Rockefeller Foundation, a private, non-profit organisation, is continuing its long-standing commitment to rice improvement through an international programme to promote the application of new biotechnologies to rice. In 1982, when the agriculture programme of the Rockefeller Foundation was reorganised, the application of molecular biology to plant breeding in developing countries became one of its foremost objectives. In determining the essential criteria for its biotechnology programme, the Foundation sought: to identify an important need that was not yet being addressed; to ensure a high degree of synergy among the various activities to be supported; and to pursue a strategy which would permit eventual Foundation disengagement. After examining several options, it was decided to focus on a single crop and to develop a fully-integrated programme ranging from fundamental research to the application of new techniques in breeding, and to include socio-economic evaluation.

Rice was the crop finally selected, not only for its importance to developing countries in terms of production and consumption, but also because projections indicate that in many countries, growth in demand for rice will exceed supply in the short to medium term. Furthermore, mature rice research and breeding programmes exist both at the IARCs and in a number of developing countries and it is argued by some that these breeding programmes are reaching a point of diminishing returns in terms of further improvement to be achieved by conventional methods.

It was also found that rice was at the time a neglected crop in biotechnology research. In 1983, when the Rockefeller Foundation was in the process of defining its programme, not a single research programme could be found in the United States or Europe which was studying the molecular genetics of rice, although a few modest research efforts on rice tissue culture were under way. Even in Japan surprisingly little research was being devoted to the molecular genetics of rice although, as discussed below, the situation there has since changed.

The broad aims of the Rockefeller Foundation's International Program on Rice Biotechnology are: firstly, to ensure that new techniques for crop genetic improvement based on advances in molecular and cellular biology are developed for rice; secondly, to facilitate the transfer of these biotechnologies to rice breeding programmes in developing countries in order to produce improved varieties that address priority needs; and thirdly, to assist in building the scientific research capacity necessary for continued development and application of new genetic improvement techniques for rice in selected developing countries.

The programme is based on priorities for international research on rice improvement which were established through a method developed by Herdt and Riely[23]. Basically this is a modified cost-benefit approach which comprises quantitative estimation of the expected benefits to society of resolving the major challenges confronting rice production. The benefits are then assessed in terms of their contributions to environmental and equity goals. For each challenge, the likely effectiveness of biotechnological, as compared to conventional approaches, are evaluated.

Table 4 shows the order of priorities which emerged from this method. The biotechnology research areas on which the programme is concentrating its efforts include:

Wide hybridization
Genetic maps and markers
Protoplast regeneration
Genetic transformation
Cloning and characterising useful genes

Between 1985 and 1990 the Rockefeller Foundation devoted $34 million and half its Agricultural Sciences Department's staff resources to its Rice Biotechnology Program. Almost two-thirds of the total have been devoted to biotechnology research and around a quarter has been devoted to capacity-building in developing countries. This includes the provision of fellowships to 100 scientists from developing countries to conduct advanced biotechnology research. A further small share has been devoted to economic analysis of the impact of technological change in rice in several Asian countries and to determining priorities for rice biotechnology in those countries. A number of projects related to biosafety issues for developing countries are also financed.

The Program constitutes a major international network of: researchers in universities in the United States, France, the United Kingdom, Belgium, the Netherlands and Japan; public research institutions in France, Germany, Australia, China and Korea; and two of the IARCs, IRRI and CIAT. Regular annual meetings are held where members of the research network are able to meet, exchange experiences and report on progress. In addition, a newsletter entitled "Rice Biotechnology Quarterly" is published.

The Rockefeller Foundation imposes very clear conditions with respect to intellectual property rights protection related to the research output of the Program. While some universities or researchers in industrialised countries may wish to patent research results, all research results generated by the programme must be made available to developing countries without any restriction.

- *Other private sector actors*

Until recently, it was assumed that private sector firms were conducting very little rice research, except with respect to agricultural chemicals and agricultural machinery, which are not the subject of this study. That situation is now changing. Firstly, with new biotechnology, if firms develop a new technique it may be possible to introduce that technique in any number of crops. Secondly, the development of hybrid rice opens new possibilities for the private seeds sector. Pray has listed 14 private firms conducting rice breeding in Japan, India, Philippines, the United States, Spain and Italy (see table 5).

Pray has also listed farmers' organisations conducting rice research in Japan, the United States, Uruguay, Colombia, Brazil, Venezuela and Peru.

To our knowledge, no systematic survey has been conducted of private firms conducting biotechnology research related to rice. Japan Tobacco and Plant Genetic Systems of Belgium signed an agreement to develop and commercialise hybrid rice in April 1990, with Japan Tobacco purchasing $6 million of PGS stock. The object of this collaboration is to apply to rice a genetic technique already patented by PGS. Research will be conducted mainly in Ghent but testing will be done in Japan, with a view to producing a hybrid with improved taste and texture as well as improved agronomic qualities.

PGS, in collaboration with Professor Robert Goldberg of the University of California at Los Angeles (UCLA), have succeeded in isolating a promoter that permits the expression of a gene only during the development of a plant's male reproductive organs (anthers). This anther-specific promoter has been used to express a gene which confers male sterility in the plant. Through the promoter, a protein encoded by the gene is expressed only during the critical few days when pollen would normally develop in a plant, thus suppressing its production. After rendering the plant male sterile, the protein then disappears, allowing the plant to continue its normal development.

It is hoped to apply the PGS male-sterility technique to rice. The advantage of the new technique is that it would drastically reduce the length of the breeding cycle for hybrid rice and obviate the need for the manual hybridization methods used at present which, in addition to being extremely labour-intensive and time-consuming, do not necessarily ensure consistent quality.

In the United States, a number of new biotechnology firms are conducting biotechnology research related to rice. These include Crop Genetics International (CGI) which is developing biopesticides delivered through endophyte technology. A plant-dwelling endophytic bacterium Cxc, which naturally occurs in bermudagrass, modified with recombinant DNA techniques, is used as the delivery system for introducing pest resistance in plants. "*InCide*", as the product is called, is at present being field-tested in the United States and France for resistance to the American corn borer in maize. Field trials will be conducted for another year or two before the product is released on the United States market and then in Europe. CGI has assembled a number of other endophytic bacteria for use in developing *InCide* biopesticide products on a wide range of crops. It has also identified genes which encode other biopesticidal activity.

The company is now conducting field tests of the vaccine on rice at its research farm in Ingleside, Maryland. CGI hopes to market its rice biopesticide in Japan.

The Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF) has recently launched a public/private sector rice genome project. The first stage in the gene-mapping, the identification of genetic markets, has already begun in Japan, with some 350 RFLPs isolated. The project aims to map 2000 RFLPs and create a high-resolution physical map of the genome within 7 years. It also aims to involve major Japanese corporations and MAFF in collaborative research.

- *The public sector*

As indicated in the section above on the Rockefeller Foundation Rice Biotechnology Program, a number of universities are engaged in biotechnology research on rice. A growing number of developing countries are developing biotechnology research capabilities, either in new biotechnology institutions, within their NARs or in the framework of science and technology programmes. However, the extent to which biotechnology research is directed specifically towards rice is difficult to determine.

Among the IARCs, IRRI has for several years been conducting a hybrid rice programme. A new biotechnology laboratory was recently set up which supports both inbred and hybrid rice-breeding programmes. IRRI collaborates with Cornell University in rice genetic mapping research as well as in the Rockefeller Biotechnology Program.

Another institution which could play a growing role in biotechnology research for developing countries in the future is the International Centre for Genetic Engineering and Biotechnology (ICGEB). At the initiative of UNIDO, ICGEB was established in 1988 at two sites: Trieste and New Delhi. Research on plant biotechnology is undertaken in New Delhi, along with work on malaria and human virology. These three themes were chosen for their relevance to the 45 member countries which form the ICGEB biotechnology network.

Plant research is focused mainly on rice. Research priorities reflect ICGEB's emphasis on the application of molecular biology to practical problems: plant gene expression, plant transformation, transgenic enhancement of herbicide tolerance and insect resistance, acceleration of plant breeding through gene tagging and DNA fingerprinting of rice insect populations. The New Delhi Centre receives funding from the governments of Italy and India, from the Rockefeller Foundation, WHO and also from industrial sources. The facilities of the Centre are available for basic research, contract research and teaching, with strong interactions with scientists from developing countries. The linkage between ICGEB and industry was a primary objective of the original UNIDO proposals. Teaching of developing-country scientists is also a high priority of the Centre, with emphasis on in-service training.

2. Cocoa

- *Recent developments*

Compared to the comprehensive, systematic international efforts being carried out with respect to biotechnology in rice, efforts related to cocoa are both modest and dispersed. In the private sector, the Big 5 in chocolate manufacturing are all carrying out research related to cocoa but data on levels of expenditure and detailed information on areas of research, is not readily available. However, it is clear that the research efforts of the private sector are, in general, concentrated on cocoa drying and fermentation, on the processing of cocoa and its by-products and on chocolate manufacturing processes. Efforts are also under way on research on cocoa butter substitutes from other fats and oils. Relatively little of total R&D budgets is devoted to cocoa plant improvement.

One of the exceptions is Nestlé which, through its Research Companies (or RECOs) is involved in plant research in a number of countries including: Sweden, Spain, Ecuador, Malaysia, Cote d'Ivoire and France. Among these, Francereco concentrates exclusively on plant biotechnology. Francereco has a research staff of about 50, four of whom (including one Mexican) work on cocoa.

Nestlé is one of the world's largest cocoa-product manufacturers, accounting for around 10 to 12 per cent of total imports or some 650 000 tons. Like the other major cocoa-importing companies, in addition to conducting its own research Nestlé contributes (both in the United States and in Europe) to the funding of cocoa research in public institutions. In France, Nestlé contributes to research carried out by the IRCC. As pointed out by Nestlé, IRCC is not competent to set priorities with respect to the quality aspects of cocoa sought by individual firms and so this type of research is left to the companies, or to industry-sponsored research.

Francereco has recently moved into new premises where it is conducting pre-competitive research on cocoa, in three principal areas: using RFLP (restriction fragment length polymorphisms) and RAPD (random amplification of polymorphic DNA) techniques, identification of desirable plant characteristics; the development of new techniques for the conservation of genetic resources (for example, the freezing of embryos); a method for clonal propagation.

Although detailed information is not available, Nestlé also conducts or sponsors research by public institutions in some of the developing countries in which it has set up production facilities. One example is the financing of germplasm expeditions in Mexico.

In the United Kingdom, Cadbury-Schweppes has a budget in the order of between £3 and £4 million a year for the development of Cadbury products and processes. Cadbury's processing has been designed for the particular characteristics of Ghana cocoa, of which it imports 100 000 tons a year.

Part of the chocolate industry's contribution to cocoa research is used to support biotechnology research in public research institutions in the United Kingdom and the United States. In the United Kingdom, biotechnology research related to cocoa is carried out at the Scottish Crop Research Institute, Reading and Liverpool universities, Imperial College, and University College of Wales. High-tech areas on which work is currently concentrated include a recent breakthrough in RAPD techniques at the Scottish Crops Research Institute. This technique will make it possible to establish genetic linkage maps linking particular diseases to particular genes.

In the United States, ACRI has set up a Cocoa Molecular Biology Program at Penn State University. This programme has been set up as a foundation, with an investment of $1.5 million, which allows for annual expenditure of around $100 000. Some additional financing for collaborative projects involving developing country scientists is obtained from, for example, USAID. Nine people are currently employed on the programme, including four Ph.D's, four Ph.D. students and one M.Sc.

The major areas of research of the Penn State programme are: genetic transformation of the cocoa tree; the study of cocoa butter biosynthesis — especially fatty acid desaturation; and study of witches' broom disease. It is hoped eventually to be able to engineer the tree for resistance to cocoa swollen shoot virus (aimed at Ghana and Togo) and to produce a cocoa butter which remains solid regardless of climate (aimed at Brazil). The genetic transformation research is carried out with the assistance of a Ghanaian biochemist and with a grant from USAID. Work to develop probes for fungal diseases being carried out by Penn State scientists in collaboration with scientists at CATIE in Costa Rica also benefits from USAID financial support.

The most notable achievement thus far of the Penn State University programme is the claimed success in developing an axillary bud in-vitro propagation procedure for micropropagation. Efforts to replicate the experiment, made at the tissue culture laboratory of United Plantations in Malaysia have, however, not been successful.

Preliminary results in some areas of biotechnology research have been very encouraging. Providing sustained research effort is maintained, it is anticipated that within the next five years, biotechnology methods will be available for: the propagation of selected clones; germplasm identification through molecular fingerprinting; and germplasm preservation and exchange.

Unlike the situation with respect to rice, there is no corresponding co-ordinated effort to map the cocoa genome. Dr. Paul Fritz, at Penn State University, is exploring the possibility of setting up an international scientific network to work on the coca genome. This would permit greater concentration of effort and closer interaction between Penn State and European and developing country institutions and scientists conducting research in this area.

An important aspect of the agreement between Penn State University and ACRI to set up the research foundation is that publication of research results should in no way be inhibited. This proviso would of course not necessarily apply to specific projects carried out at the University funded by individual firms.

- bilateral aid

Although our research had not sought, specifically, to determine whether bilateral aid is provided for biotechnology research related to cocoa, examples did emerge during interviews. ODA, in addition to the financial and technical assistance to the Ghana Cocoa Research Institute and Cocoa Marketing Board mentioned earlier, is providing assistance for the development of DNA probes and RFLP markers intended to contribute to better understanding and prevention of fungal and viral diseases. Research in these areas is conducted in collaboration with the John Innes Institute at

Norwich University in the United Kingdom. USAID is sponsoring research on the development of rDNA probes for the prevention of fungal diseases in Costa Rica and is also financing developing country scientists at Penn State University.

3. The potential impact of biotechnology in rice and cocoa

To a very large extent, the thrust of rice biotechnology research is a reflection of systematic analysis of the ways in which biotechnology could contribute to the resolution of the major constraints facing rice production in the different regions of the world where rice is a major food crop. As indicated earlier, the major constraints to rice production have been assessed (both in terms of the monetary value of production foregone and as a share of the quantity of production foregone) as has the potential effectiveness of biotechnology compared to conventional techniques in eliminating or reducing those constraints.

With respect to cocoa, no similar systematic approach to biotechnology research has been made. A comprehensive review of priority areas for cocoa research by conventional methods was prepared by a group of experts in 1985 and published by the World Bank(24) but this did not lead to a coherent, co-ordinated research effort.

Projections regarding rice production and consumption suggest that increases in rice production required to feed growing populations in the next decade and beyond will have to depend almost entirely on higher productivity and on growth rates in yields even higher than those experienced during the Green Revolution period. Much of the rice breeding of the 1980s was devoted to maintaining yield potential which has not increased significantly since the first high-yielding varieties were introduced in the 1960s. There is therefore a pressing need to increase productivity through technology development and biotechnology is perceived as providing a useful tool towards that end.

The major immediate problems associated with cocoa are not those of under-production but of over-production and of historically low prices. From a quantitative point of view, considerable scope remains for increasing productivity with existing techniques and better crop-management practices. Existing production units can also be rehabilitated with qualitatively superior planting material, particularly clones which have demonstrated superior agronomic characteristics.

Pests and diseases cause high losses to cocoa production and, in some regions, the control of pests and diseases is a major preoccupation. The development and application of biotechnology as a diagnostic tool could make an invaluable contribution to the early identification and characteristics of diseases affecting cocoa.

Despite the hopes raised, the impact of new biotechnologies on crop yields in general is not clear. The biotechnologies currently being developed may contribute indirectly to higher productivity through combating stress factors, although it is possible that stress-resistance will be accompanied by some yield loss. Raising yields *per se* will require complex multiple-gene transfer technologies which have not yet been developed.

Biotechnology does offer high potential for quality improvement or for tailoring raw materials production to very specific consumer, processing or industrial requirements. While quality modification is not a priority in the rice biotechnology research described above, flavour and texture are important attributes in some rice-consuming countries. Improved cocoa butter content and/or quality is a major objective of cocoa biotechnology research. As cocoa butter is the most highly-valued component of the cocoa bean, this could lead to greater product differentiation and a premium price paid for cocoa beans with superior or modified cocoa-butter content. As it is not expected that demand for cocoa will expand appreciably in the near future, quality is likely to become an increasingly important factor in competitiveness.

While it is considered that cocoa flavour is very much determined by the drying and fermentation process, flavour may also be influenced by genetic composition. However, biotechnology research in this area could not be expected to yield results in the short term unless the cloning of high-quality genotypes becomes possible or if genotypes already recognised as of premium quality can be made more disease-tolerant.

One area where the impact of biotechnology may be important is in addressing environmental concerns. Biopesticides have important potential for reducing pollution problems caused by the intensive use of chemicals, although it is not yet clear how effective they will be. Nor is it yet clear how the costs of seeds or planting material incorporating biopesticides will compare to those of purchasing chemical pesticides. Concerns regarding the intensive or indiscriminate use of chemicals apply more to rice production than to cocoa production as the majority of cocoa producers are smallholders who use few chemical inputs.

A second area where biotechnology could clearly make an important contribution is in the characterisation and conservation of plant genetic resources.

Despite the potential positive impact of biotechnology in contributing to the resolution of particular production constraints and in quality improvement, demand for the new technologies remains uncertain as does their competitiveness against alternative techniques. The Green Revolution technological package was introduced at a time when there was considerable pent-up derived demand by farmers. It is not at all clear that such derived demand exists for the new biotechnologies, particularly with respect to cocoa, where there are problems of over-supply and low world prices.

As with earlier technologies, biopesticides, disease-resistance and other plant biotechnology products will be mainly embodied in germplasm and will therefore pose no novel problem for adoption by farmers. However, it is not clear that the early plant biotechnologies will offer profit incentives to farmers. It can therefore be argued that it may be necessary to offer incentives to biotechnology and farm supplies industries in order to promote diffusion of the new technologies at the farm level.

IV. POLICY ISSUES FOR DEVELOPING COUNTRIES

1. The hybridization of rice

Despite research efforts in both developed and developing countries, and at IRRI, hybrid rice has been extensively cultivated only in China. The pace of development of this technology outside China has been slower than anticipated for a number of reasons: limited availability and/or non-adaptability of breeding materials developed in China; low frequency of maintainers among elite lines adapted to tropical conditions; and lack of fertility restorers among *japonica* rice varieties[(25)]. Lack of suitable male sterile lines has also delayed the development of hybrid rice seed production.

Research conducted at IRRI over the past ten years has tackled many of the technical problems and some heterotic rice hybrids have been identified and are being tested in national co-ordinated trials in the Philippines, India, Vietnam and Malaysia. Hybrid seed production, at present yielding 1-2 tons per hectare of seed, is now being developed. The seed production technology still needs to be evaluated in on-farm trials and its economic viability assessed. IRAT, at Montpellier, has also developed rice hybrids which are currently being tested in the Camargue region of France. The cost of hybrid seed production is at present prohibitive in many countries and it is unlikely that costs can be reduced appreciably without the incorporation of new biotechnology methods in hybrid development.

As happened earlier with maize, the successful development and diffusion of rice hybrids would provide incentives for the development of a private seeds industry which, in most countries, does not yet exist for rice. Indeed, in some developing countries the private seeds sector remains undeveloped for all crops. There does seem to be an ineluctable progression towards the introduction of hybrid plants, whether in cereal grains, fruit and vegetables or flowers. This is largely because hybrids have the advantage of conferring built-in "patent" protection for the plant breeder or inventor, even in the absence of a formal system of intellectual property rights protection as farmers cannot plant a second time without considerable loss in yield and are therefore obliged to purchase new seed for each planting. In this way, private firms can recuperate the costs of research and development.

Lessons from other crops[(26)] suggest a pattern in the growth of a private seeds industry in developing countries. This is linked to the launching of successful improved varieties for which there is a sudden upsurge in demand, which the public institutions conducting research and producing and marketing seed, cannot fulfil. It is at this point that opportunities are opened for small, private firms to enter the market, at first by simply reproducing seed.

For the farmer, the transition to using hybrid rice would inevitably imply higher costs for seed purchases. It may also be necessary to purchase additional inputs of fertilizer or other agricultural chemicals if maximum yields are to be achieved with hybrid seed. Unless the new seed provides yields which are sufficiently high to compensate for the additional costs, and the additional rice produced can be sold at profitable prices, the farmer may not be induced to substitute existing seed technology with the new technological "package".

The development of a private seeds sector is linked not only to demand for hybrids on the part of producers, but to other factors also. These include incentives or disincentives to firms such as: adequate profit margins for seeds sales; the size of the actual or potential market for hybrids; regulatory processes related to research authorisation, the importation of germplasm, varietal certification, etc. And, increasingly, it must be anticipated that the development of a private seeds sector will be linked to assurances of protection of intellectual property rights in one form or another.

It is argued that the development and diffusion of hybrid rice is the only available solution to the problem of stagnating yields in rice production. In a growing number of developing countries, a private seeds industry for crops other than rice is already in place. In these countries, the rapid development of a private rice seed sector could therefore be anticipated. However, it is important that governments should be aware of some of the implications of "privatisation". Experience suggests that in building their markets in developing countries, private seeds firms concentrate their efforts in the most productive regions, among the more prosperous farmers. The widespread introduction of hybrid rice could therefore result in greater disparity than exists at present among different agro-ecological regions and among different countries in terms of productivity in rice. It may also result in wider disparity, at least in the short term, among different groups of rice producers.

2. The substitution of cocoa

Another issue of concern to developing countries, often cited in biotechnology literature, is that new biotechnologies will make it possible to produce substitutes for tropical products — including cocoa — in temperate climates or under industrial conditions. The example of the substitution of cane sugar by high-fructose corn syrup (HFCS) and other non-sucrose sweeteners is very often used as an illustration.

The substitution of cocoa butter by other non-cocoa fats is not new. Cocoa butter equivalents (CBEs) and cocoa butter substitutes (CBSs) have been available for many years. However, they are currently produced by conventional fat chemistry methods and could not be defined as new biotechnology products. CBSs range from relatively expensive products based on shea and illipe fats, which are very similar to cocoa butter, to cheaper products based on palm oil and palm kernel oil fractions. These are less similar to cocoa butter and are at present used only in a limited way as cake and biscuit coatings, etc.

Data on levels of production of CBSs and on their costs compared to cocoa butter are difficult to obtain. Data on Malaysian exports of palm kernel stearin show, firstly, that exports have increased rapidly between 1983 and 1990, from 1 345 to 32 762 tonnes. Secondly, they show that prices for Malaysian palm kernel stearin have been declining since 1987. Thirdly, they show that the price of the highest-quality stearin exported in 1988 was around one-third the price of Malaysian cocoa butter exported, and that of a slightly lower quality one-quarter the price of cocoa butter[27].

A very limited number of European firms supply the major chocolate producers with CBSs. At present, these firms are working on very narrow profit margins because the price of cocoa butter is very low. Prices of CBSs based on palm oil are lower than those based on shea or illipe, which are often mixed with palm oil or palm kernel products. It is probable that fewer CBSs are being used currently than when cocoa prices were higher and that cocoa prices would need to increase substantially in order to stimulate demand for CBSs.

It appears that multinational corporations (MNCs) are conducting biotechnology research which would permit cocoa butter substitution. One firm suggested that this research was considered as a defensive strategy against the event of a rupture in supplies of cocoa through a natural disaster, uncontrolled outbreak of disease or pest infestation, political upheaval, etc. In Japan, biotechnology methods based on enzyme technology are being used. At present these possibilities are not being exploited for both economic and non-economic reasons. On the one hand, cocoa butter prices are very low. On the other, public acceptance has become a major constraint in the food industries and MNCs are reluctant to incorporate biotechnology in food products.

The substitution of cocoa butter is technically feasible and is already taking place although, as has been suggested, there is little interest in increasing the level of substitution while cocoa prices are at their present level. Moreover, within the European countries of the EEC, the substitution of cocoa butter in chocolate products is strictly regulated and limited to 5 per cent. Interviews with company representatives and cocoa experts suggest that, in the future and outside the EEC, levels of cocoa butter substitution may increasingly be linked to brand names and to standards of quality in chocolate products. While, at the lower end of the price and quality range, somewhat higher levels of substitution may be permitted, this would not be the case in the high quality, prestige segment of the chocolate market.

Biotechnology is expected to have considerable impact in the fats and oils sector in the near future and this is likely to increase competition between individual crops and between temperate (sunflower, soybean, rapeseed) and tropical (oil palm, coconut) sources of oils and fats. For countries such as Malaysia which is both a cocoa producer and a producer and exporter of CBSs from palm oil and palm kernel, the threat of substitution of cocoa is balanced by alternative market opportunities, provided Malaysian CBSs remain competitive. However, for those producing countries which are heavily dependent on cocoa exports, increased substitution of cocoa butter in the future would pose more of a threat.

3. Conservation of genetic resources

A third concern of developing countries is that of the conservation of genetic resources. The question of biological diversity, the erosion of plant genetic resources and of species, and environmental sustainability is very much at the forefront in international negotiations. Concern regarding diminishing plant genetic diversity, threatened by population pressure, climatic change and the widespread adoption of genetically-uniform high-yielding varieties, is both recent and pressing. Biotechnology could, in principle, make a positive contribution to the characterisation, storage and preservation of plant genetic resources. Advances in biotechnology are also stimulating interest in exotic germplasm.

The protection of genetic resources for rice and cocoa presents very contrasting pictures. The International Board for Plant Genetic Resources (IBPGR) created in 1974 as one of the IARCs, is the agency responsible for promoting the collection, conservation, evaluation, utilization and exchange of plant genetic resources[28]. The Board is not primarily a technical assistance or funding agency. Its work is conceptual rather than operational and has been evolving toward intellectual leadership in genetic research, the development of documentation and transfer methods, and the training of plant geneticists and technicians in advanced methods.

The Board has set four criteria for determining when to encourage the conservation of a plant species: the degree of risk and genetic loss; current and potential economic and social importance of the species; plant-breeding requirements; and the size and scope of existing collections.

The global mandate for conserving the genetic resources of rice varieties lies with IRRI, while West African rices now fall within WARDA's mandate. In 1977, at a time when few national gene banks existed, IRRI sponsored a first workshop on genetic conservation in rice. In addition to the work of screening, conserving and evaluating its own accessions, the IRRI International Rice Germplasm Centre (IRGC) has gradually built up a collaborative network with national genebanks.

Although there is growing interest in the wild relatives of rice as rich sources of useful genes, they are difficult to find, difficult to conserve and not as well represented in germplasm collections as traditional varieties and improved lines. During 1990 collaborative collecting activities were carried out in a number of Asian countries, including Myanmar (Burma) and Papua New Guinea, where little wild rice had previously been collected.

The IRRI International Rice Germplasm Centre (IRGC) distributes germplasm on request, free of charge. In 1990, more than 50 000 packets of seed were sent to researchers and evaluators, in response to requests from 266 scientists in 40 countries. The base germplasm collection maintained at IRGC is at present duplicated and stored at the USDA/ARS National Seed Storage Laboratory in Fort Collins, Colorado, United States.

In contrast to rice, there is no single institution which has a global mandate to protect cocoa genetic resources. IPBGR has acknowledged two primary collections of cocoa germplasm: the Cocoa Research Unit (CRU) in Trinidad and CATIE in Costa Rica.

The former is a department of the Faculty of Agriculture at the University of the West Indies which has been in existence since 1928. Collection of cocoa genetic resources began in the 1930s and the collection now includes close to 2 000 accessions from all over the world. Formerly scattered over four different sites, the collection has recently been re-established in one site, now known as the International Cocoa Genebank, Trinidad (ICG,T).

The CRU is financially supported from a number of different public and private sources which include: the Government of Trinidad and Tobago, the Government of Jamaica, the United Kingdom Biscuit, Cake, Chocolate and Confectionery Alliance, the International Office of Cocoa, Chocolate and Sugar Confectionery (an industry body), the European Development Fund of the EEC, and IPBGR. However, funding has been irregular and unassured.

At CATIE at Turrialba in Costa Rica, the collection includes more than 400 clones drawn from cocoa cultivated in the country and imported clones, some of which were obtained from Trinidad. IPBGR has recommended that the Costa Rica collection should be duplicated in Trinidad and vice versa. The gene bank at CATIE has received intermittent funding from the United States Chocolate and Confectionary Industry. Germplasm from the collections in Costa Rica and Trinidad is freely available to plant breeders throughout the world.

Cocoa germplasm collections exist in a number of developing countries in Latin America, Africa and Asia but most are small. Brazil has the largest collection in the world and the process of plant collection is still under way. Brazil, as some other countries, is reluctant to make germplasm material freely available to potential competitors. Collection, maintenance and characterisation of germplasm are expensive and financing is either stagnant or declining. Charging for the exchange of germplasm would be one way of earning revenue to continue the work of conservation.

Permanent funding for the protection of cocoa genetic resources has proven difficult to date, both nationally and internationally. The cost of a viable programme to ensure research and management of the collection at the CRU and to upgrade it to the standard required of an international centre has been assessed at around $700 000 annually. A number of efforts have been made to ensure permanent funding by approaching producers, the chocolate industry, the Government of Trinidad and Tobago and bilateral and international donors. To date these efforts have borne little fruit.

V. STRUCTURAL ADJUSTMENT AND BIOTECHNOLOGY IN RICE AND COCOA

For the purposes of this study, it has been assumed that the structural adjustment process implies a modification of the public/private sector balance which will affect technology generation and diffusion. It has also been assumed that modification of the public/private sector balance will have negative as well as positive impact, at least in the short term, particularly in situations where government intervention in the economy is strong, where the public sector has played a predominant role and where markets are undeveloped.

1. The potential contribution of biotechnology to rice and cocoa production

Biotechnology could, within a time frame of 5-15 years, make an important contribution to both rice and cocoa production. In the case of rice, it could improve resistance to some of the pests and diseases which result in production losses. It could also lead to the development of lower-cost hybrid varieties, as well as a reduction in the length of the breeding cycle for new varieties. As hybrids produce yields of 15-20 per cent higher than the best semidwarf varieties, biotechnology could facilitate the breakthrough required to raise yields, which are at present stagnating or even declining in many rice-producing areas.

Rice research "at the frontier" is conducted with clear objectives in view and is co-ordinated at international level, involving a large network of scientists. One important aspect of the research effort is the importance attached to building biotechnology capacity in, and transferring the new technologies to, developing countries.

In cocoa production too, biotechnology could make an important contribution within five years or so. The most immediately promising developments concern: diagnostic probes; propagation of selected clones; and germplasm identification, preservation and exchange. The early diagnosis of disease could offset the very high production losses incurred in cocoa through diseases and pests. A proven procedure for the clonal propagation of cocoa would open the way to the easy reproduction and transportation of improved planting material. Finally, biotechnology tools could greatly facilitate characterisation of the genetic composition of cocoa as well as the conservation of germplasm.

In contrast to the case of rice, cocoa research at the frontier lacks clearly defined objectives and international co-ordination. There is therefore a strong need to use the limited financial and human resources available for research as effectively as possible. The question of building cocoa biotechnology capability in developing countries is more problematic than in the case of rice, for the reasons discussed in the paragraphs below.

2. Public and private sector roles in technology development and diffusion

- *Research: basic and applied*

Public institutions, both NARs and IARCs play an important role in rice research. In many developing countries in Asia, Latin America, and to a lesser extent Africa, rice research and plant breeding capability are well developed. While little biotechnology research is as yet conducted within the NARs, those with established research and plant-breeding programmes are well placed to exploit new biotechnologies as complementary tools.

While, as indicated earlier, four of the IARCs are conducting rice research, only IRRI has an established rice biotechnology programme. IRRI, as well as some of the NARSs, work in collaboration with the Rockefeller rice biotechnology programme or are part of the Rockefeller programme network.

At present, the Rockefeller Foundation is a key actor in rice biotechnology. However, although no specific date has been fixed it is intended that, as the particular research problems are resolved, and when the necessary research capacity has been transferred to developing countries, the Rockefeller programme will gradually be phased out.

A few commercial firms in the United States, Europe and Japan are known to be involved in rice biotechnology research and particularly in the application of biotechnology methods to the development of hybrids. A growing number of seed firms and co-operatives are becoming involved in rice breeding, but are probably undertaking applied or adaptive, rather than basic research.

The applied research side of IRRI activities includes a hybridization and seed production programme. In addition, IRRI plays a key role in the co-ordinated international efforts to conserve rice genetic resources.

In the past, the major share of cocoa research has been financed and conducted in public institutions in the producer countries, with some financial contribution from the cocoa-consuming industries. This balance is now shifting to some extent. On the one hand, as a consequence of structural adjustment the budgets of research institutions in developing countries have become much more stringent, if not actually reduced. On the other, in addition to its own in-house research, the cocoa-consuming industries are financing cocoa biotechnology research in universities in the United States and the United Kingdom. Industry is also sponsoring the research of individual scientists in cocoa-producing countries and contributes to efforts to conserve cocoa genetic resources in Costa Rica and Trinidad.

Private plantation companies are playing an increasingly prominent role in cocoa research in Malaysia and, to a lesser extent, in Indonesia. To date, research effort has been devoted mainly to quality improvement and, particularly, to cocoa processing, but has also included the development of improved planting material in the form of hybrids and clones. For the major Malaysian plantation companies, palm oil rather than cocoa is their most important crop in terms of both volume and value.

Some of the companies have set up tissue culture laboratories for research on palm oil. If a proven procedure for micropropagation of cocoa became available, they would be well placed to exploit the technology, provided it could be purchased or licensed.

- Technology development and diffusion

While the emphasis in this study has been essentially on the research phase of technology development and diffusion, it is nevertheless appropriate to discuss the roles of the public and private sectors in the diffusion of the product or technology which incorporates the results of research.

The roles of the public and private sectors in the diffusion or marketing of cocoa and rice technology have both similarities and differences. For rice, private sector marketing activities have concerned, first and foremost, purchased inputs such as fertilizers, pesticides and herbicides, as well as agricultural machinery. Similarly, for cocoa, the private sector has provided chemical inputs, but as yet little mechanisation is used in cocoa production.

Private, commercial firms have to date played a much less important role in the marketing of technology in the form of improved seed or planting material for both rice and cocoa. This situation is changing at least in Malaysia, where plantation companies are now marketing planting material or seeds for cocoa. The situation would be expected to change considerably in the event of technical and economic breakthroughs in producing hybrid rice.

Changes in the respective roles of the public and private sectors in rice and cocoa research are occurring. They are not, however, directly linked to structural adjustment but are more the result of a general trend of restricted public funds for research and of increased public/private sector collaboration and interaction in research. For both products, public/private sector collaboration is an important component of the overall research effort. The key role played by the Rockefeller Foundation — a non-profit but private organisation — in rice biotechnology research has already been emphasised. In addition, new actors — private firms — are becoming involved in rice research in industrialised countries. A major share of cocoa biotechnology research is carried out in public research institutions, in both producer and consumer countries, but is largely financed by the cocoa-consuming industries. This public/private sector interaction is contributing to a further blurring of the distinction between the public and private sectors and their respective roles.

3. Implications of an enhanced private sector role

Major changes in the public/private sector balance are already on the horizon with respect to rice as a result of efforts to develop hybrids. With or without structural adjustment policies, the successful introduction of hybrids would open the way for the development of a private seeds sector and the pace of development would be expected to vary according to: the institutional and regulatory framework with a given country; prior existence of a private seeds sector, even in the "infant" stage; the size or potential size of the market for hybrids; prospects for profitability, etc.

The situation with respect to cocoa is likely to be more closely linked to prices on the world market. While it can be argued that low prices would result in inducing lower-cost production practices, the link between the adoption of new technology and prices is probably neither clear nor uniform. Equally, it can be argued that if prices descend below a certain level — which may be dangerously close — cocoa may become unprofitable compared with other crops, or farmers may no longer be able to meet the costs of pest and disease control or of maintenance of their plantations.

- Impact on research

Structural adjustment implies, if not a reduction in public investment in agricultural research, at least a reallocation of scarce resources. This may lead in some cases to a more responsive and productive agricultural research system but, as suggested in recent Development Centre research[(29)], it may also result in the termination of long-term research programmes or other discontinuities. With respect to rice, in the event of the development of a private seeds sector, the question remains whether commercial firms would carry out research, other than minor adaptive research, and what would determine research priorities. If research were undertaken, it would probably be targeted to the most productive regions where demand for hybrids would be highest. This may mean neglect of research in the more difficult agro-ecological regions, where the poorest producers are located.

The major share of R&D of the major chocolate manufacturing firms is devoted to proprietary processing and other technologies rather than to research on cocoa production. Cocoa butter substitution and cocoa butter quality are areas in which research is expected to continue. The principal preoccupations of industry are to ensure supply and quality. Whether or not industry support for biotechnology research in public institutions can be expected to increase in the future will probably depend on assessment of research progress and on the state of the cocoa market.

The private plantation sector has been playing an increasingly important role in research in Malaysia and, to a lesser extent, in Indonesia. Stronger involvement of the plantation sector in research on higher-yielding hybrids or clones and in tissue culture could probably only be anticipated if cocoa prices improve.

It seems unlikely, however, that the major private sector firms would invest more, either in-house or through external financing, in the basic research for which there is a pressing need in the case of cocoa. Furthermore, none of the IARCs carries out cocoa research and the scientific and financial resources of the cocoa research foundations created by the chocolate industry are very modest compared to the resources devoted to rice.

- Impact on technology development and diffusion

An expanded role of the private sector in rice seeds production and marketing could be expected to have both a positive and a negative impact. On the positive side, it should imply more efficient production, price competition and more consistent quality in seeds, as well as more effective extension and technical services to farmers, accompanied by efforts to promote the diffusion of hybrids. On the more negative side, it may imply a concentration of effort in favour of the most productive regions and most prosperous farmers, and a lack of flexibility in providing for the diverse needs of different farming systems and poor farmers.

Under present market conditions, the future role of the private plantation sector in cocoa technology development and diffusion is difficult to foresee. The major problems associated with cocoa production tend to be overproduction rather than underproduction, and heavy crop losses. These are more strongly linked to the need for cocoa to compete with other, more profitable crops, than to private/public sector issues.

Another question raised by an enhanced private sector role is that of complementarities and interaction between the public and private sectors. Traditionally, the fruits of agricultural research effort in public institutions and in the IARCs have been perceived as "public goods" made freely available on request both to other public institutions and to commercial firms.

In cocoa-producing countries, public/private sector interaction has been an important feature of research in at least Brazil and Malaysia. In the former case, it was a levy on cocoa exporters which financed cocoa research. This levy was abolished, however, in the context of the present government's adjustment and liberalisation policies. As illustrated in Bloomfield and Lass[30], this has had a dramatic effect on CEPLAC's research effort which has been severely curtailed. In Malaysia, interaction has taken a different form and consists essentially in a freely available supply of improved planting material from MARDI and public/private collaboration in the setting of national cocoa research priorities.

An additional question raised by stronger involvement of the private sector in cocoa technology development and diffusion in the future, which is particularly relevant to Malaysia, is whether it will necessarily lead to greater emphasis on economies of scale and, consequently, to a strong shift towards large-scale production. If so, this trend may affect other producer countries where, for the most part, smallholder cocoa production predominates.

There appear to be two conflicting trends associated with enhancement of the role of the private sector in technology development and diffusion. One is the clear — almost universal — trend towards the increased financing of research by the private sector in public research institutions which, traditionally, have subscribed to the notion of the free circulation of scientific information and the public good nature of research. The other is the trend towards appropriation of the results of research resulting from pressure to introduce and enforce intellectual property rights protection. In agriculture, intellectual property rights have been protected through the introduction of Plant Breeders' Rights or, more simply, through the widespread introduction of hybrid varieties. Few developing countries have yet introduced formal intellectual property rights protection systems.

Increasingly, technology diffusion or transfer — particularly if foreign firms are involved — will be linked to the issue of intellectual property rights. With respect to rice, although details of the arrangement are not available, it has been suggested that exclusive licensing arrangements between China and Cargill for hybrid breeding material have considerably retarded IRRI's hybrid rice programme[31].

The question of collaboration with the private sector raises questions both for national institutions in developing countries and for the IARCs. The IARCs are in the process of confronting the problem of how to fulfil their public good role and continue their close collaboration and technology transfer role in developing countries and, at the same time, benefit from the advances made in biotechnology research by private firms which may be subject to patent protection.

- *Impact on the adoption of new technology by farmers*

The time-frames for the "useable technology" phase of biotechnology in rice and cocoa do not in principle differ appreciably. It is possible that rice hybrids produced with the aid of new biotechnology methods will be diffused by the turn of the century. For cocoa, significant developments could occur by then, provided sufficient resources are devoted to research and that demand for the new technology exists.

It is important to keep in mind that plant biotechnology will usually be incorporated in seed and planting material. It will therefore present no novel problem for introduction by farmers. The ways in which structural adjustment — and the implied change in public/private sector balance — is likely to affect the adoption of new technology at the farm level depend on the ways in which the adjustment process affects the pattern of incentives and constraints to producers. These incentives and constraints include: price levels and price fluctuations, both for output at the farmgate and for inputs and technology (seed and planting material, fertilizer, chemicals, machinery). They also include subsidies for improved seed or planting material and fertilizer and, finally, availability of and access to credit and agricultural services.

Development Centre research on the supply of improved seeds of crops other than rice and cocoa, in three African countries[32], suggests that under structural adjustment farmers are generally receiving a higher share of world market prices for their output than before. At the same time, prices of inputs tend to be higher and subsidies for seed or planting material and fertilizer to be reduced.

For farmers, the adoption of new biotechnology — as other technology — will depend on price and profitability. In addition, new technology would also need to provide clear advantages over existing, whether in terms of higher productivity, higher quality or other desirable characteristics, for example, possibilities for integration in farming systems.

It is not possible to predict ways in which adjustment policies will affect patterns of incentives to producers with respect to new biotechnology. Price, productivity and quality advantages in rice and cocoa incorporating biotechnology are not yet clear.

One development which might be anticipated with respect to the diffusion of biotechnology related to cocoa — particularly in the event of an extension of larger-scale production — is that of contract farming. Biotechnology will facilitate the "tailoring" of agricultural raw materials to very precise industrial requirements. For the large chocolate manufacturing firms currently involved in biotechnology research contract farming would be a way of ensuring that farmers are using planting material of consistent quality, or displaying very specific agronomic or flavour characteristics.

4. Policy implications

Changes are occurring in the organisation of research on rice and cocoa at the frontier. The significance of these changes may lie not so much in the changing public/private sector balance as in the extent of public/private interaction and collaboration.

Rice research benefits, first and foremost, from the lead taken by the Rockefeller Foundation in the setting up of an international rice biotechnology research network. It also benefits by being able to draw on the accumulation of knowledge in mature national systems of rice research, on IRRI and on ICGEB which represents an institutional innovation for agricultural research.

New biotechnology firms in industrialised countries have, in the last few years, become involved in rice research with a view to introducing in rice proprietary techniques developed initially with other crops in mind. Private sector involvement is likely to expand if an economically viable system for producing hybrids becomes available.

The situation with respect to cocoa research at the frontier differs from that of rice in a number of important respects. Commercial firms are both conducting in-house biotechnology research and sponsoring research in public institutions. At the same time, research capability within national public institutions — particularly with respect to biotechnology — is not as developed in cocoa-producing countries as in rice-producing countries. In most countries, there are added problems of maintaining research budgets and of maintaining the viability of cocoa production under structural adjustment. Furthermore, there is no vigorous international cocoa research network which might counterbalance as well as complement the essentially commercial priorities of the large chocolate manufacturing firms.

Our findings suggest that with or without structural adjustment, there remains strong justification for government intervention and for a strong public sector role in agricultural research, technology development and diffusion. There will thus be a continued need for government intervention in awarding national research priorities, particularly in a more competitive, liberalised agricultural sector. The public sector will also be required to carry out long-term basic research in which the private sector would see few prospects for profit, in the preservation of genetic resources and to cater for the very wide diversity of needs of different producers.

Attitudes and approaches to the role of public research institutions are changing, although whether this is directly attributable to structural adjustment *per se* or to a more general movement towards reduced government spending and an enhanced role for the private sector is unclear. New forms of collaboration and interaction between the public and private sectors are emerging which may lead to greater convergence and blurring of the public/private sector dichotomy.

While we have argued in favour of a continuing important role for public sector institutions, it is clear that there is also a growing need for innovative institutional arrangements and collaboration in the face of stringent public budgets for research. The Rockefeller Foundation rice biotechnology network provides a useful illustration of such arrangements and it is to be hoped that ICGBE will be successful in its role of promoting the development of biotechnology capabilities and in transferring the fruits of biotechnology to developing countries.

One area which transcends national interests and which extends beyond the public/private discussion is that of the conservation of genetic resources. As we have seen in the case of rice, an expanding international network to protect and preserve genetic resources is in place. No corresponding international commitment to the conservation of cocoa genetic resources has yet been made.

A policy issue very much at the forefront of international negotiations, which will need to be addressed by national governments, is that of the introduction of intellectual property rights protection for plants. The resolution of this issue will impinge on the ways in which the public and private sectors in developing countries interact, particularly with respect to biotechnology, and on the prospects for technology transfer by foreign firms.

Apart from policy concerns for national governments, this study of rice and cocoa research at the frontier raises questions of broader concern:

— Firstly, could the Rockefeller rice biotechnology network be used as a model for international research efforts directed towards other crops?

— Secondly, should the bilateral and multilateral aid community provide more support for export crops? In the early days of the IARCs, in a world faced with the prospect of food shortages, the emphasis on food crops was appropriate. However, the emphasis has now shifted towards a farming systems approach where both food and cash/export crops may be included. Should the international aid community now revise its aversion to the support of export crops in order to assist in some of the pressing problems facing the future of cocoa?

— Finally, this study and other Development Centre research suggest that structural adjustment does not necessarily assure an enhanced role for the private sector in research, particularly in long-term or basic research. This then raises the question of the trade-offs between the short-term benefits and long-term costs of adjustment and their implications for technologies which will be directed towards sustainability in agricultural production.

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Table 1. **Growth of agricultural research expenditures and personnel:**
Compound annual averages

Region	Agricultural Research Expenditures (millions PPP dollars per year)			Agricultural Research Personnel (full-time equivalents)		
	1961-65	1981-85	Annual average growth rate %	1961-65	1981-85	Annual average growth rate %
Sub-Saharan Africa (43)[a]	149	372	4.7	1 323	4 961	6.8
China	271.4	933.7	6.4	6 966	32 224	8.0
Asia & Pacific excluding China (28)	316.7	1 159.6	6.7	6 641	22 576	6.3
Latin America & Caribbean (38)	229.1	708.8	5.8	2 666	9 000	6.3
West Asia & North Africa (20)	126.9	455.4	6.6	2 157	8 995	7.4
Total developing countries (130)	1 093.6	3 629.8	6.2	19 753	77 737	7.1
Japan	404.5	1 021.6	4.7	12 535	14 779	0.8
Australia & New Zealand	161	313	3.4	2 627	5 902	4.1
North America	994	1 617	3.1	13 940	17 103	1.0
Northern Europe (5)	90	182	3.6	1 519	2 711	2.9
Western Europe (8)	454	1 135	4.7	7 639	11 396	2.0
Southern Europe	88	317	6.6	2 135	4 485	3.8
Total developed countries (22)	2 190.7	4 812.9	4.0	40 395	56 376	1.7
World Total	3 284.3	8 442.7	4.8	60 148	134 113	4.1

a. Number of countries included.
Source: Philip G. Parley, Johannes Roseboom and Jock R. Anderson, "Regional Perspectives on National Agricultural Research", in *Agricultural Research Policy*, 1991, Cambridge University Press.

Table 2. **Factors influencing the level of private agricultural R&D**

Main determinants of private agricultural R&D expenditure	Factors influencing determinants	
	Economic and technical	Government policies
Market factors Expected demand	Income growth Income elasticities Export demand Demand elasticity	Agricultural price policies Import/export policies
Input prices	Level of industrialisation Supply and demand of inputs	Input price controls Credit policies Government supplies Input import policies Industrial policies
Appropriability	Nature of technology Market structure	Public R&D effort Anti-trust policy Parents and plant breeders' rights legislation Enforcement of rights
Technological opportunity	Private local R&D	Public R&D IARC research
	Foreign technological developments	Policies on multinationals Technology import policies
	Quality and cost of scientific inputs	Output of universities Subsidies on R&D costs Imports of R&D equipment

Source: Carl E. Pray and Ruben G. Echeverría, "Private Sector Agricultural Research in Less-Developed Countries", *Agricultural Research Policy*, 1991, Cambridge University Press.

Table 3. **Types of public and private organisations that conduct and/ or fund agricultural research**

<table>
<tr><td>Public sector</td><td colspan="3">Departments of ministries of agriculture, livestock, education, science and technology, and others

National research institutes
National research councils
Universities
Parastatals
International agricultural research centres</td></tr>
<tr><td rowspan="5">Private sector</td><td>Non-commercial</td><td colspan="2">Universities
Private sector targeted aid agencies
Foundations
Voluntary organisations</td></tr>
<tr><td rowspan="4">Commercially oriented</td><td>Input companies</td><td>Seeds
Feeds
Animal health products
Agro-chemicals
Machinery and equipment</td></tr>
<tr><td>Farm sector</td><td>Farmers
Co-operatives and producer associations
Plantations and estates
Other large firms
Commodity institutes</td></tr>
<tr><td>Food sector</td><td>Processing and food sector companies</td></tr>
<tr><td>Technical assistance</td><td>Consultancy and management companies</td></tr>
</table>

Source: Ruben G. Echeverría.

Table 4. **Rank order of priority traits for the Rockefeller Foundation's rice biotechnology programme**

Resistance to tungro virus
Resistance to yellow stemborer
Resistance to gall midge
Cytoplasmic male sterility
Drought tolerance
Resistance to brown planthopper
Submergence tolerance
Greater lodging resistance
Seedling vigour
Resistance to ragged stunt virus
Tolerance to drought at anthesis
Tolerance to waterlogging
Resistance to leaffolder
Resistance to sheath blight
Cold tolerance at seedling
Apomixis
Tolerance of coastal saline/acid sulphate conditions
Resistance to bird damage
Resistance to storage pests
Resistance to bacterial blight
Resistance to blast
Resistance to striped stemborer
Resistance to whitebacked planthopper

Source: Gary H. Toenniessen and Robert Herdt, Agricultural Sciences Division, Rockefeller Foundation, April 1988.

Table 5. **Firms conducting rice breeding**

Country	Company	No. of breeders	Research goals
Japan	Kirin Mitsui Mitsubishi Sumitomo Japan Tobacco	3-4 3-4 1-2 3-4 1	Hybrids Hybrids Hybrids Hybrids NMS[a] hybrids
India	Mahyco Pioneer Proago	hiring 1 1	Hybrids Hybrids Hybrids
Philippines	Cargill	1	Hybrids
US	Ricetec Busch Research Foundation Rice Researchers Incorporated	1 2 2	Hybrids Brewing & quality rice Speciality rices
Spain	Herba		Introduction of long grain varieties
Italy	CIS Forrajjera		Long grain rice

a. NMS stands for nuclear male sterility.

Source: Carl E. Pray.