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BIOTECHNOLOGY AND THE IMPROVEMENT AND INDUSTRIALIZATION OF COCOA: ANTECEDENTS, CONSEQUENCES, AND IMPLICATIONS

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BIOTECHNOLOGY AND THE IMPROVEMENT AND INDUSTRIALIZATION OF COCOA: ANTECEDENTS, CONSEQUENCES, AND IMPLICATIONS

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ABSTRACT Cocoa is representative of major Third World agricultural export crops that are facing declining prospects due to stagnant per capita consumption, overproduction, low prices, and declining export revenues. Biotechnology will affect cocoa production distribution in two major respects. First, biotechnology will be applied to cocoa production and promises to increase output, and hence overcapacity and overproduction, very substantially over time. This research, however, will help to sustain the cocoa production industry in the face of bleak prospects. Second, and contradictory to the first, biotechnology will be applied to substitute for cocoa beans and intermediates in chocolate production and other areas of food manufacturing. Both aspects of cocoa biotechnology portend further deterioration in the role of cocoa in providing income and export revenues to Third World countries. These impacts will be most adverse for African producer countries, due to their widespread poverty, lack of alterative primary export commodities, low agricultural and biotechnology research capacity, and other factors. The prospective impacts of biotechnology on cocoa production raise complex social and ethical issues about the future role of research on and the role of primary agroexport commodities in Third World development.

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INTRODUCTION

Biotechnology is now conventionally regarded as portending a "second green revolution."[1] Moreover, it is widely suggested that biotechnology may make possible a technical revolution in agriculture that can be more benign socially and environmentally than was the experience of the green revolution of the late 1960s and 1970s. There is a strong element of truth to both assertions, as far as they go.

Advances in the technology of recombinant DNA, in our understanding of protein synthesis, gene regulation, and so on, and in the techiques of tissue culture and regeneration of whole plants from culture are bringing us closer to the day when biotechnology may make possible major improvements in agronomically-important polygenic traits such as photosynthetic efficiency. These advances will ultimately enable significant increases in crop productivity and output on a world scale, though almost certainly at a slower pace than was widely forecast a decade ago.

In addition, the various techniques commonly thought of as belonging to biotechnology potentially enable agricultural researchers to deal directly with a set of concerns related to the fact that classic green revolution technical packages were of limited applicability in the Third World (being confined mainly to favored agroecological zones in which conditions were favorable for irrigated rice and wheat production). Unlike green revolution technology, which was largely focused on a small handful of cereal grains, biotechnology is equally if not more applicable to the crops, such as roots, tubers, tropical

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1. This sentiment was particularly prominent during the early and mid-1980s (e.g., BOSTID, 1982) when agricultural biotechnology was accompanied by widespread "hype" (Buttel et al., 1985; Kenney and Buttel, 1985; Buttel, 1988). There has been growing recognition, however, that biotechnology was oversold during its early years and that its major applications lie well in the future (see, for example, Buttel, 1989). See Sasson (1988) for a comprehensive overview of the applications of biotechnology in the developing world and NRC (1986) for a discussion of biotechnology in plant improvement.

vegetables and pulses, commonly grown by peasant smallholders. Biotechnology also carries the promise of making it possible to develop cultivars (with traits such as cold, heat, salt, and aluminum tolerance) and other inputs that are far more applicable to marginal agroecological zones and to the technical conditions faced by marginal cultivators than were those of the classic green revolution phase. These prospects suggest that the application of biotechnology to the development of new agricultural systems and inputs may enable international agricultural institutions to avoid the weak underbelly of the green revolution: its tendency to excerbate socioeconomic inequality, particularly when superimposed on socially unequal landholding systems and inegalitarian social structures in general (Lipton with Longhurst, 1989). Further, there is considerable legitimate enthusiasm about the potential of biotechnology to lead to farming systems that depend to a lesser degree on purchased inputs, especially chemical fertilizers and petrochemically-based pesticides, than was the case with the classic green revolution "packages" relating to wheat and rice (Gould, 1988; Wolf, 1986).[2]

The confluence of these hopeful prospects - of increased agricultural productivity, but with a minimum of social disclocation and environmental disruption - would indeed make agricultural biotechnology a most welcome intervention. Accordingly, there has been a strong tendency for observers of biotechnology to focus on these new tools through this "green revolution lens" - i.e., in terms of the means and goals of the green revolution, with respect to the controversies generated by the green revolution (e.g., Pearce, 1980; Anderson et al., 1988; Lipton with Longhurst, 1989), and with respect to the

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2. It is important to stress, however, that biotechnology is also being applied to crop improvement in forms, such as the development of herbicide-tolerant crop varieties, that will have the opposite tendency: of rationalizing or reinforcing the use of purchased petrochemical inputs (Goldberg et al., 1990).

conditions that prevailed at the time the green revolution was being nurtured in the laboratories and field plots of CIMMYT and IRRI.

When most people ponder agricultural research they think mainly about the development of new varieties or strains of crop plants and animals or of new chemicals or biologicals that can be transferred to farmers in order to increase the efficiency of their operations. Similarly, biotechnology is often conceived of mainly though its applications to food crops, the increased output from which would help to feed the malnourished masses of the developing countries. Biotechnology is thought of mainly in terms of developing new agricultural production systems and inputs, analagous to modern varieties of wheat or rice during the 1960s and 1970s. These images of agricultural research in general and biotechnology research in particular will likely prove to be inaccurate, however, because they involve only one major form of biotechnology, what we call "intervention."[3] Intervention involves research aimed at modifying the "natural" production process of agriculture by adding new components, generally in the form of purchased off-farm inputs, such as improved seeds, new biocide chemicals, and so on. "Interventionism" involves agriculture remaining as a natural production process, even as new technology is developed to refine and transform the production process. It is biotechnology as interventionism that holds promise as a means of increasing agricultural output in more socially equal and environmentally benign ways than was the track record of the classic phase (from the mid-1960s through the 1970s) of the green revolution.[4]

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3. This notion is borrowed from Goodman et al. (1987), though we use the concept of "intervention" in preference to theirs of "appropriation."

4. Note, however, that the promise of biotechnology in permitting output increase in a relatively socially equal and environmentally benign way is based on the technical options these technologies can make possible, and involves no such prediction to this effect. There are, in fact, a number of factors -

There is, however, a second fundamental form of agricultural research, which can be referred to as "substitution." "Substitutionism" involves agricultural production being displaced as a natural production process by an industrial process, which is typically located distant from agricultural or rural areas, generally in an advanced industrial country. Substitutionism is by no means new or unique to biotechnology. Major historical examples of substitution include synthetic fibers for cotton and wool, synthetic artificial dyes for indigo, oleomargarine for butter, "nondairy creamers" for cream, and synthetic for natural steroids (Goodman et al., 1987).[5] There was, in fact, some limited substitution for cocoa before the biotechnology era - chiefly the substitution of lauric-type hard butters (made from coconut, palm-kernel, and soybean oils) for cocoa butter in chocolate production. Substitution was estimated to have displaced about 200,000 tons per year in cocoa-bean equivalent, or a little more than 10 percent of global cocoa production, in the early 1980s (UNCTAD, 1984:26-27). Biotechnology, however, has greatly expanded the range of opportunities for substitution (particularly for sugar, high-value vegetable oils, and high-value medicinals, flavorings, fragrances, cosmetics, and the like) and promises to propel substitutionism to the forefront of agricultural research (van den Doel and Junne, 1986).

In this paper we will focus on the case of cocoa (or "cacao," is it is commonly referred to in the developing world),[6] for several reasons. First,

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private-sector and developed-country dominance in biotechnology, the tendency for current research to stress the most commercially-attractive crops and technical options, and so on - that suggest that new biotechnology products are unlikely to realize this potential.

5. See van den Doel and Junne (1986), Fowler et al. (1988), Hobbelink (1991), Sasson (1988), and Wilkinson (1987) for further discussions of biotechnology substitution processes.

6. In so doing, however, we follow common (though inaccurate) usage. Strictly speaking, cacao should be the preferred terminology for the tree, its beans,

cocoa is a good example of a major Third World industrial-export crop - and thus is a good example of a crop that was self-consciously excluded from the mandate (of focusing on food crops for domestic consumption) of the International Agricultural Research Centers (IARCs), the flagship institutions of the "first green revolution." Cocoa is the fifth most important Third World agricultural export commodity, behind coffee, sugar, natural rubber, and cotton. While biotechnology will not have a dramatic impact on cocoa production for several years, cocoa is a good example of how the expanded scope of biotechnology methods relative to those of the green revolution will affect industrial-export crops. Second, due to the long-lived perennial nature of the cocoa tree, cocoa has a low elasticity of supply, and because of stagnant per capita consumption in the industrial world it has a low elasticity of demand.[7] Thus, major improvements in cocoa (of an "interventionist" nature) would undoubtedly compound the already severe problems of instability and tendency to global overproduction. Third, as will be suggested later, the ultimate impact of biotechnology on cocoa over the long term may well be to create industrial substitutes for cocoa intermediates, especially cocoa butter, which will lead to an irreversible decline in export revenues for several countries that currently depend heavily on this crop for foreign exchange and state revenues. In other words, unlike the "green revolution," the "biorevolution" may disproportionately "revolutionize" the production and processing of nonfood crops, and do so ultimately by removing them from the sphere of agricultural production entirely.

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and its butter intermediate. Cocoa should be used to refer to solids derived from beans (cocoa cake or its pulverized form, powder).

7. The low price elasticities of supply and demand for cocoa have been recognized for quite some time, and were the case even before stagnation in consumption was apparent (Yeung and Singh, 1976).

Cocoa is thus an interesting crop with which to explore issues of technology choice engendered by the growing availability of the multivalent techniques of biotechnology. Among the major producers of cocoa for export are several African countries that are heavily dependent on export earnings from this crop and that will still face bleak development prospects even if cocoa production is not disrupted or displaced by biotechnology intervention and substitution processes (OTA, 1988). But as we will stress later, however, the social and ethical issues that may come from substitution for agricultural sources of cocoa are not a simple function of decreased export earnings.

In this paper we will begin with an overview of major trends in Third World development that bear on the prospects for the application of biotechnology to crops such as cocoa. We will then provide some basic background information on global production and consumption of cocoa and on the emergent technologies for improving cocoa production and substituting for agriculturally-produced cocoa. Finally, we will discuss some of the possible implications of these technologies for world nations that currently depend heavily on exports of this crop.

GLOBAL TRENDS RELATING TO PRIMARY EXPORTS AND ECONOMIC DEVELOPMENT

Ever since David Ricardo and the diffusion of his notion of comparative advantage, observers of quite varied theoretical and ideological stripes have recognized the importance of exports - particularly primary exports - to what we now call Third World development. Most major theories of economic development stress, either positively or pejoratively, the role that primary exports play in shaping the development paths of low-income countries.

The development experiences of the past decade or two have done little to alter this view. It has been widely held that the late 1970s and early 1980s were an era of capital mobility from the developed industrial countries to the Third World, in which low-wage Third World labor was utilized in routine assembly operations in order to produce cheap goods that were exported back to the West. The East and Southest Asian "Gang of Four" (Korea, Taiwan, Singapore, and Hong Kong), widely regarded as paragons of successful Third World development, premised their development paths since the 1960s solidly on being export platforms (albeit for manufactured, rather than primary, exports). Most other low-income countries that enjoyed sustained expansion during the 1980s, especially those elsewhere in Southeast Asia, were export-platform economies as well, for both raw materials and, to a lesser extent, for manufactured goods. Even for less fortunate countries, particularly low-income cuntries experiencing "debt stress," externally-imposed "structural adjustment" programs invariably place great emphasis on increasing foreign exchange earnings through commodity exports - in this case, almost always primary exports.

Against this conventional wisdom on the role that commodity exports can or must play in the Third World development process, there are growing signs that technical and socioeconomic changes in the world economy may progressively lessen the potentials for exporting. Gerd Junne (1988), for example, has noted that the "big-three" "high-technologies" of the late twentieth century - microelectronics, biotechnology, and new materials - all portend the "dematerialization" of production in the world economy in the future. By dematerialization, Junne means the "tendency to produce the same use value with a continuously decreasing physical input" (1988:194). Microelectronics, for example, involves miniaturization (and less raw material input), production processes that minimize scrap and defective items, and improvements in production logistics that minimize inventories and the factory space to store them. New materials technology likewise makes possible stronger, lighter, more abrasion-resistant materials that are easier to recycle and require less physical input, less energy to operate, and less frequent replacement. Most importantly for Third World commodity exporters, many of the most important areas of research and development (R&D) in new materials are those that make possible the substitution of locally-available raw materials in the North (e.g., quartz sand for optical fibers) for imported raw materials (e.g., copper for electrical wires). Finally, biotechnology makes possible industrial production processes under normal temperatures and pressures (which are less energy intensive) and can help to recover useful raw materials from waste and increase the possibilitities of recycling. In addition, as we will stress below, biotechnology can make possible substitution for high-value agriculturally-produced raw materials and useful substances. The nature of each of these new high-technologies suggests that the future will be one of reduced per capita consumption of raw materials. For the industrial countries where the lion's share of manufacturing continues to be located, there will be less need for commodity imports from the developing world, and for the Third World as a whole there will likely be fewer degrees of freedom for export-led development plans.

These technological trends would appear to be buttressed by several parallel political and economic trends. First and foremost is the possibility that the world economy of the future will continue to exhibit slow economic expansion relative to the track record of the 1960s that is still regarded as "normal." Further, the composition of growth and accumulation seems to be shifting inexorably toward services, rather than material production. The unresolved debt problems of most Third World countries, and the consequent need to pare hard-currency imports, continue to dampen their potential as export markets for fellow developing nations. Finally, as suggested by Gilpin (1987), there is a distinct possibility that the stagnation of the world's developed-industrial economies may lead to a new wave of protectionism, initiated by countries (e.g., the U.S.) or groups of countries (e.g., the EEC) that are faring poorly in the world economy of the late twentieth century. Each of these trends, if realized, would be adverse for Third World commodity exports.

It should thus be recognized that the possibility of biotechnology leading to substitution processes that displace agriculturally-produced cocoa is by no means an isolated phenomenon. Further, the possibility of declining primary export markets for Third World countries is not merely an outcome engendered by the specificities of biotechnology. Biotechnology merely reinforces larger trends that all point in the direction of dematerialization of production.

THE BOTANY AND WORLD ECONOMY OF COCOA

Theobroma cacao L. is a small tree indigenous to the Amazon Basin region of Latin America and to Chiapas, Mexico (Fowler et al., 1988). In its natural habitat cocoa grows under dense shade, and where rainfall is heavy and well distributed and where temperatures are relatively uniform. While cocoa can be cultivated under a variety of conditions in the tropics, successful cocoa production has a fairly specific set of environmental requirements, e.g., annual rainfall of 1500-2000 mm, with a dry season of no more than 3 months with less than 100 mm per month; temperatures varying between 30 to 32^{o} mean maximim and 18 to 21^{o} mean minimum; and an absolute minimum of 10^{o}. There must also be no persistent strong winds. Relatively deep, fertile soils with a pH of around 6.5 are optimum, though production under less than optimal conditions can be undertaken with fertilization.[8]

Cocoa is by origin an understory plant, and traditionally cocoa has been cultivated under shade, e.g., by forest thinning, planting of special shade trees (such as Gliricida sepium), or as an intercrop with coconuts. Young cocoa plants must be protected by shade, but under certain favorable conditions of climate and soil cocoa can be grown without shade. Cocoa trees are typically planted 3 to 4 meters apart, or at a density of about 1,100 per ha. During the establishment period weed control is very important, and is often done through herbicide applications, though mature stands with a thick canopy inhibit weed growth. After the canopy forms (in 2 to 4 years) pruning is needed to make the trees accessible for harvesting and pesticide applications. Especially if shade trees must be planted (at about the same density as cocoa), establishment of cocoa is very labor intensive. In general, cocoa is a sensitive crop that requires careful management - including but not limited to making judgments about the amount of shade required under varying conditions of climate and soil, the timing and extent of pruning, weed control and fertilization, replanting and rehabilitation of stands, and many other areas of cutlural practice.

An individual cocoa tree in fertile soil can often live for a century or more and yield well throughout its life. Under most cultivated conditions, however, most cocoa trees will not survive that long due to pests, diseases, and damage, and cocoa trees are most productive from between 15 and 25 years of age. It is generally estimated that the "economic life" of a field of cocoa

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8. This section relies heavily on Lass and Wood (1985), which remains one of the most useful and comprehensive summaries of technical problems and research opportunities in cocoa.

trees is about 40 years, after which time replaning or extensive rehabilitation is required.

One of the dominant features of global cocoa production is that cultivated trees tend to have a narrow genetic base. Most current varieties descend from a few collected 40 to 50 years ago. Cocoa is generally regarded as having a high degree of genetic vulnerability with respect to insect pests and pathogens. Approximately half of the world's cocoa crop is lost annually to disease and insects (Fowler et al., 1988).

Cocoa seeds develop inside a pod with a thick husk. Pods do not open or fall off when ripe, and seed dissemination thus depends on an animal opening the pod and discarding the seed after having consumed the pulp that surrounds the seed. Seeds germinate soon after removal. Under cultivated conditions cocoa pods are harvested at intervals (normally 1 to 4 weeks) and are opened within a few days of harvest. The wet beans are then fermented (for 1 to 6 days, depending upon the type of cocoa produced), which is essential to produce the chocolate flavor, and then are dried to 6 to 7 percent moisture. Cocoa butter and other intermediates, which are extracted from the processed cocoa bean, mostly in the industrial countries, are used to make chocolate and other foods containing cocoa or chocolate, and are essential ingredients in many pharmaceutical and cosmetic products.

Cocoa has been cultivated for over a millenium in parts of Latin America, and more recently in the Caribbean. By the late nineteenth century cocoa had been introduced to the West African mainland, where cultivation spread rapidly, particularly in the Gold Coast (now Ghana). Cocoa played an extremely significant role in the development of West Africa, having replaced gold and slaves as the commodity through which the Gold Coast was integrated through exports into the larger world economy (Mikell, 1989:xi). The rise of cocoa led to the development, albeit in a truncated form, of the capitalist economy that still prevails there. West Africa, especially the Gold Coast and Nigeria, soon began to dominate world production. The Gold Coast was the world's largest producer of cocoa by 1911. Today about 60 percent of world cocoa production is still accounted for by African countries, though this percentage has declined sharply from the 70-plus percent share of world production Africa enjoyed in the early 1960s. Ghana's share, however, has declined steeply, from about 36 percent of global production in the early 1960s to about 12 percent in the early 1980s; Nigeria's track record has been comparable, though not as dramatic (having registered a decline from 18 to 11 percent over the same time period). The Ivory Coast has now become Africa's, and the world's, largest cocoa producer.

Cocao is grown within 20^{o} of the equator, and is produced almost exclusively by developing countries in the tropics, mostly outside its center of origin. Eight countries (Ivory Coast, Brazil, Ghana, Nigeria, Malaysia, Cameroon, Ecuador, and Indonesia) currently account for 85 percent of world cocoa production.

Cocoa has traditionally been regarded as an export crop that lends itself well to smallholder peasant cultivation because it is labor-intensive, grows particularly well in multiple cropping regimes with crops such as coconut, is appropriate to African land tenure systems, can be grown under conditions of a substantial dry season, and can be cultivated without extensive use of purchased inputs (Lass and Wood, 1985). About half of world production is undertaken on small landholdings, particularly in West Africa. The role of plantations in cocoa production, however, has increased considerably in recent years as new Asian producers such as Malaysia[9] have entered the world market,

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and as some traditional producers such as Brazil have increased their share of global production. The shift toward plantations has also been hastened by the investment demands involved in establishing cocoa, by the increasing complexity of managing cocoa production, and by the trend to the use of expensive purchased inputs in response to increasingly severe disease and pest problems. West African smallholder production of cocoa has declined (mainly in Ghana and Nigeria) for a variety of reasons, among them growing pest and disease problems, the aging of stands, the lack of replanting and rehabilitation, and political-economic instability. Also, due to cocoa swollen shoot virus and capsids, the standard rehabilitation technique used in South America (the "Turrialba method") cannot be employed in West Africa.

It should be stressed that while cocoa still remains a viable smallholder commodity in many areas of West Africa, the history of cocoa cultivation there has hardly been benign. Historically, the experience of cocoa in the Gold Coast was fairly typical. Cocoa cultivation was introduced through British colonial rule and by metropolitan companies, and in some areas peasants were prevented, sometimes forcibly, from engaging in subsistence production of food crops. At the turn of the century many Gold Coast peasants were relucant to produce cocoa, and during the early years production was undertaken mainly by the traditional rural elite (elders and chiefs) on lands appropriated from peasants. Only later, as opportunities for self-provisioning declined, did smallholder peasants enter into cocoa cultivation. The benefits of cocoa cultivation have gone disproportionately to the urban merchant elite and rural "middlemen," rather to the direct producers.

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9. Malaysian production of cocoa increased dramatically from the mid-1970s to the mid-1980s, reportedly about 10-fold. Malaysian cocoa plantations currently enjoy the highest per acre production levels in the world, at about 0.5 to 0.6 tons per acre in established stands (Fowler et al., 1988).

Ghanaian cocoa producers still are stratified into large and small operations. Today much of the labor involved in cocoa production is poorly-remunerated wage labor on large (but mainly nonplantation) farms, and accordingly the cocoa belt has been subject for decades to social unrest, peasant political mobilization, and attempts to form cocoa producer cooperatives in order to counter the power of merchants, financiers, and the state. The Ghanaian state, particularly that of the colonial Gold Coast, has historically relied so heavily on revenues from direct or indirect taxation of cocoa such that the countryside has long been politicized over issues relating to extraction of surplus from rural workers to the urban centers.[10] The politics of cocoa and rural exploitation played a role in the movement for independence from the British, and control over cocoa was pivotal in leading to the 1966 coup. Cocoa producers have clashed with essentially all heads of state in Ghana since independence. The world cocoa market has long been volatile, with world market downturns leading to repeated cycles of high unemployment and forced rural-to-urban migration (and international migration). Traditionally, and increasingly so today, smallholder cocoa cultivation is undertaken by rural women, both as rural entrepreneurs and unremunerated household laborers. The Ghanaian cocoa economy, however, by increasing the opportunities for male entrepreneurship, contributed to the decline of the traditional matrilineal household structure, with the consequence that males increased their control over the labor and property of females and, in general, contributed to a decline in the socioeconomic status of women (Mikell, 1989; Beckman, 1981).

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10. The pattern and consequences of the penetration of cocoa production in Nigeria were relatively similar to the pattern in the Gold Coast (Forrest, 1981).

More recently, during the late 1970s and 1980s, Ghanaian cocoa production has declined, being both caused by and the consequence of what Mikell (1989) has referred to as widespread "rural chaos" in the country. In her view, cocoa, rather than providing an engine for national development, has led to political instability and economic stagnation. While this judgment is arguably too harsh, the fact remains that cocoa production has been a mixed blessing in West Africa.

Cocoa is the classic example of a major agricultural commodity produced in the tropics, that is largely processed and consumed in the advanced industrial world, and that has exhibited overproduction, stagnation in demand, and extreme price instability. Over the 20 years from the early 1960s to the early 1980s global output increased by only about 30 percent, mainly due to stagnant or declining per capita consumption in advanced countries. But, stimulated by the rising price of cocoa during the mid-1970s, cocoa production has increased sharply over the past decade. Prices have plummeted in response, from approximately $2.50/lb. in 1977 to $.50/lb. by late 1989, and by the end of the 1980s carryover stocks were approaching one-half of annual global consumption (Commodity Research Bureau, 1990). Prices, and thus Third World export revenues, have been volatile owing to the low elasticities of supply and demand and other factors.

The majority of beans are ground in the advanced countries (67 percent in the early 1980s, compared to 85 percent in the early 1960s; UNCTAD, 1984). Most Third World production is exported in raw (bean) form, though Third World production of intermediates (butter, paste, and powder) has increased modestly since the 1960s. Most producing countries, save for a few Latin American countries where chocolate is consumed locally, do not convert cocoa into manufactured chocolate products. Likewise, most cocoa imports of the developed industrial countries are in the form of beans or intermediates (butter, paste, and powder) rather than manufactured chocolate. South-south trade in beans or semi-processed products does exist, mainly within geographical areas (e.g., within Latin America), but it is a small proportion of world totals.

BIOTECHNOLOGY, AGRICULTURAL RESEARCH, AND COCOA

As noted earlier, biotechnology R&D on agricultural commodities takes two different forms: intervention and substitution. In this section of the paper we will provide an overview of these two aspects of biotechnology research on cocoa. Table 1, taken from Hobbelink (1991:87-88) provides a summary of these major research efforts.

Agronomic and Breeding Research

Cocoa, like many other agriculturally-produced raw materials crops cultivated by smallholders, has not been the object of sustained, high-quality "agronomic" (or "interventionist") research. Such agro-export crops were explicitly omitted from the mandates of the world's premier international agricultural research institutions, the IARCs. Most of the agronomic research on cocoa has been undertaken by the major Third World producing countries. As with Third World agricultural research in general (see de Janvry and Dethier, 1985), cocoa research has been plagued by budget instability, and by corresponding problems in undertaking the long-term research necessary for a crop with a developmental cycle in excess of 50 years. Research on cocoa improvement would have been far less than its currrently modest levels had it not been for the strong personal commitments and persistence of particular individuals such as P. Alvim of CEPLAC in Brazil. It should be stressed, however, that there has long been research in the advanced countries relating to industrial processing of cocoa. Most of this research has been undertaken in corporate laboratories or through corporate sponsorship, either by individual companies or consortia such as the American Cocoa Research Institute and the Chocolate Manufactuers of America, in public agricultural research institutions such as Pennsylvania State University (see, for example, Dimick, 1986) and Cornell University (see, for example, Kinsella, 1984; Kanner et al., 1987).

As noted earlier, cocoa production has increasingly suffered from the crop's narrow genetic base, and from corresponding problems with diseases and insect pests. This has been caused by, among other factors, the lack of plant breeding research, which in turn is due to the weak institutional and funding structure of cocoa research in general. In addition, the long-lived perennial nature of cocoa - in which cocoa plants require 2 to 4 years to flower and fruit and 15 years to reach maximum production, and in which at any given time there is enormous investment in established stands - has been another disincentive to active research on and transfer of new varieties.

Several of the techniques of modern biotechnology are now being employed to both improving cocoa production and substituting for agricultural sources of cocoa intermediates. Using improved selection methods, researchers are attempting to develop new cocoa varieties with superior yield characteristics (more pods per tree, more beans in each pod, larger beans of uniform quality) and with resistance to drought, cold, fungi, viruses, and pesticides. It is widely held that cocoa breeding could dramatically increase cocoa yields. As an example, current Malaysian yields, on the order of 0.5 to 0.6 tons per acre, are greatly in excess of those that prevail in most producing countries (which average roughly 0.2 tons per acre).[11] Further, breeders believe it is possible to develop new varieties with per acre bean yields of 1.5 or more tons per acre, which suggests the awesome output potential - and also the potential for overproduction - that might be achieved through more research. Traditionally, however, release and diffusion of superior cocoa varieties have been limited by the perennial nature of the crop and by the costs involved in obtaining planting materials and etablishing stands.

Current research on the improvement of cocoa has been made more attractive by the availability of micropropagation techniques, which enables researchers to regenerate large numbers of superior, genetically-identical cocoa plants in the laboratory. This promises to be a vast improvement on traditional means of seed propagation.

In addition to research on improving the yield and disease resistance of cocoa plants, there is now R&D devoted to altering the genetic composition of cocoa plants in order to produce beans with more desirable characteristics for processing and manufacturing (Battey et al., 1989). One such research goal is to increase the fat content of cocoa seeds, and thus the yield of cocoa butter (Dimick, 1986). Another priority is on "engineering" (through recombinant DNA) cocoa varieties to contain a gene coding for thaumatin (a secondary metabolite of an African shrub that is "super-sweet"). If successful, cocoa beans could be processed into a sweet, but sugar-free chocolate.

Before leaving the topic of R&D on cocoa, it should be noted that research goals made possible by biotechnology by no means exhaust the desirable foci of research on this crop. The interrelated problems of genetic uniformity and vulnerability to pests, insects, and fungi suggest that broadening the

11. Current yield disparities are not entirely due to genetic variation in yield potential, however, since cultural practices and effective pest and pathogen control are essential in determining output levels.

genetic base of the crop, particularly with pest and disease control in mind, along with agroecological research to achieve greater biocontrol of pests and diseases, is an urgent priority. Research advances of this sort will be most appropriate to the technical conditions faced by smallholder producers of cocoa. Indeed, one of the implications of biotechnology for cocoa research is that these modern techniques will be very likely be pursued at the expense of needed research relating to better utilization of cocoa genetic resources and agrocological knowledge in crop improvement and reduction of pre-and postharvest losses.

Substitution Research

As noted earlier, cocoa production has long been subject to wide price fluctuations on world markets. Further, as African countries remain the major suppliers, and have had a long history of political unrest in the cocoa belt, chocolate manufacturers have long been preoccupied with the insecurity of supply. A number of biotechology processes, however, are now being actively explored for their potential in substituting for agricultural production of cocoa.

One such process is the application of tissue culture techniques to produce cocoa butter (Kinsella, 1984; Kanner et al., 1987). Industrial cell and tissue culture is now already routine in the production of high-value secondary metabolite substances such as shikonin and vanilla. Not only could industrial cell and tissue culture production of cocoa butter reduce dependence on unstable raw material suppliers, but it could also make possible more uniform cocoa butter that is directly tailored to the needs of industry. It is generally thought, however, that large-scale industrial cell and tissue culture production of cocoa is far on the horizon or may never be practical on a large scale, for two main reasons. First, the raw cocoa product is currently quite inexpensive on world markets (Foster et al., 1988).[12] Late 1980s data suggest that tissue-culture-produced cocoa butter costs about $100 per lb., compared to $4/lb. from beans. Plant breeding improvements in cocoa, made possible through micropropagation and "genetic engineering," along with current trends toward declining prices and continued growth of carryover stocks, would make it even less likely that cultured cocoa butter would be economical.[13] Second, the tissue culture process must be very exacting. The unique fatty acid composition of cocoa butter, which is largely responsible for its valuable properties (e.g., melting point, mouth feel), is very difficult to replicate in the correct proportions in tissue culture (see Institute of Food Technologists, 1989).

Perhaps more promising is the application of biotechnology processes to converting low-cost oils, such as olive, sunflower, or palm oil, into a cocoa substitutes through enzymatic processes, or "protein engineering."[14] Enzyme technology is a refinement of fermentation technology whereby the enzyme which undertakes a particular chemical conversion is identified and extracted from the cell. Biotechnology promises to extend the scope of protein engineering by creating novel enzymes not found in nature that can catalyze specific organic reactions in a wider range of feedstocks. Two large Japanese companies

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12. Some firms such as Cadbury-Schweppes, however, are employing tissue culture techniques to develop synthetic cocoa flavorings from low-quality beans.

13. The increased role of biotechnology in improvement of the cocoa plant can be illustrated by the trend toward the major annual periodical in the field, the proceedings of the International Cocoa Research Conference, to have been substantially given over to reporting biotechnology results by 1988 (see, for example, Adu-Ampomah et al., 1988a, 1988b).

14. For example, in the mid-1980s cocoa butter was 20-fold more expensive per pound than was plam oil (Slater, 1988).

(Ajinomoto and Fuji Oil) have led the way in this area of R&D, and already hold or license patents on enzymatic processes for conversion of cheap oils into cocoa butter. Patent applications have also been filed (by Genencor [USA]) on an enzymatic process and a specific enzyme for coverting palm oil into cocoa butter. Industrial substitution processes such as these are made especially attractive by the current worldwide market glut in palm oil and other edible oils.

Another potential promising process is a based on the modification (through nuclear hybridization and spheroplast fusion) and selection of fatty-acid-producing mutants of yeast and other microorganisms that can produce an end-product resembling the composition of cocoa butter (see, for example Verwoert et al, 1989; Ykema et al., 1989). A patent on such a yeast-based process is held by CPC International (USA), and Wessanen, a Dutch subsidiary of UK-based Berisford, has filed for patents on a related process in the Netherlands.

The enzyme and microorganisms-based technologies for producing fats with properties similar to cocoa butter appear to be the most promising substitutionist technologies at this time. It should be stressed, however, that these substitutes are, in principle, less attractive than cocoa butter produced through industrial cell and tissue culture because the former would be an "imitation" product - and thus less useful in marketing - while the latter would be "the real thing."[15]

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15. Substitutes produced through protein engineering may also prove to be plagued by the legacy of many deaths having resulted from a batch of L-triptophan produced through an enzymatic process by a Japanese firm. It remains unclear, however, whether these deaths resulted from a problem intrinsic to protein engineering or whether they were caused by inadequate purification procedures.

It has arguably been the case that the most important factor discouraging even more widespread R&D on cocoa substitution has been the global price decline for cocoa beans and intermediates that has continued essentially unabated since the late 1970s. However, comparable declines in the costs of edible oils, from which cocoa substitutes and other substitution products can be manufactured through biotechnology, have helped to sustain interest in this area of R&D. Accordingly, the major firms showing interest in cocoa substitution R&D are no longer the major chocolate manufacturers (e.g., Hershey, Nestle, Mars); increasingly, the edible oils industry is dominating this area of R&D, suggesting the key role that the declining prices of these oils are playing in driving substitution R&D.

SOCIAL IMPLICATIONS OF COCOA R&D TRENDS

The evolving, mostly biotechnology-related, trends in cocoa R&D just discussed have a number of straightforward, though contradictory, social implications. Among the social implications of the emerging milieu of cocoa R&D are the following:

1. Agronomic research on cocoa ("interventionism") promises to increase the level, and perhaps the stability, of cocoa supply, and thus to create a long-term oversupply problem and falling prices. The countries and cultivators that are most likely to be affected are African countries and their smallholder producers.

2. These new "agronomic" or "interventionist" research thrusts suggest the likelihood of increased capital-intensity and management complexity of cocoa production. Thus, plantation producers, especially in Malaysia and Brazil, will be the major beneficiaries. Again, in this respect African countries and their smallholder producers will be the losers.

3. For the major West African producing countries, which in general rely heavily on cocoa export revenues, the loss of this source of foreign exchange and state revenues will be devastating. With the possible exception of Nigeria, given its higher per capita income and the possibility that it can benefit from a secular increase in oil prices, the loss of cocoa export markets and revenues will further cripple their already-bleak development prospects.

4. The low-income countries of West Africa, however, have tended to suffer from distorted development paths relating to their dependence on exports of primary products. The bleak prospects for cocoa exports and revenues over the next several decades suggest that they should consider alternatives to the "export trap," in both cocoa and other primary commodities.

5. Low-income countries, either singly or preferably in a consortium, will need to consider doing their own biotechnology R&D in order to anticipate, and possibly preempt, industrial-country R&D that threatens their role in the global cocoa market. They have begun to do so in terms of cocoa improvement, but as with most Third World countries they have failed to invest in industrial biotechnology. The latter will be essential in enabling these countries to most effectively exploit their primary resources, particularly their diversity of genetic resources. Cocoa-producing countries may also be able to compete effectively with foreign firms in producing cocoa substitutes.

6. Cocoa production is by no means unique in its being subject to disruptions relating to new biotechnology R&D. Substitution, in particular, has been a long-term trend relating to agriculturally-produced industrial raw materials (Goodman et al., 1987). Biotechnology merely increases the opportuntities for profitable pursuit of substitution processes. Several other crops - the most important of which globally is sugar - have already been profoundly affected by

traditional and new biotechnology-related substitution. The future holds more of the same.

7. Developing countries will need to respond to the threat of substitution for their primary products in several ways. First, biotechnology, buttressed by the dematerialization implications of the other "high-technologies," implies that developing countries need to face up to the fact that primary exports will not be an effective engine for development. Second, however, low-income countries will need to invest in biotechnology R&D in order to capture the benefits of these new technologies and minimize the disruptions that will inevitably result as dematerialization of the world economy continues.

Biotechnology-based improvement of cocoa and biotechnology substitution for primary tropical export commodities such as cocoa thus raise some profound social and ethical issues. On one hand, biotechnology, as applied to improvement of the cocoa plant, can assist in maintaining the viability of producing the raw commodity and in sustaining the livelihoods of hundreds of thousands of rural workers in the Third World. On the other hand, cocoa improvement, to the degree it increases productive capacity and overproduction and simultaneously shores up an agro-export production system with little likelihood of generating above-poverty incomes, will condemn most persons involvement in direct cultivation of cocoa to low levels of living if not abject poverty. Industrial substitutionism will not only exacerbate the adverse impacts on direct producers; it will mean lower third World export volumes and revenues for developing-country states. Yet industrial biotechnology techniques, if effectively developed in Third World contexts, may hold very considerable promise for Third World countries in capitalizing on their biodiversity. The issues involved, in other words, are by no means straightforward. However they should be, or will be, resolved, it is abundantly clear that biotechnology will affect all countries of the world, including those that have very limited access to the technology.

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Table 1. Biotechnology Research on Cocoa

Research by	Type of research	Comments
Penn State Univ. (USA)	Tissue culture for HYVs, increasing fat content, incorporating 'sweetness genes'. Also rDNA work on cocoa tree	$1.5 million budget, co-funded by industry (ACRI and US Chocolate Manufacturers Association)
DNAP (USA)	Tissue culture for new varieties	Joint venture research with Hershey Foods. EPO patent application filed for cocoa TC technique
Cadbury-Schweppes (UK/USA)	Tissue culture and rDNA. Also work on improving fermentation of cheap cocoa	With University of Reading (UK). Tissue culture research has reportedly stopped recently
Ajinomoto (Japan)	CBS from cheap oils	Licensed patent from Tokyo University
Fuji Oil (Japan)	CBS from olive, safflower or palm-oil	Processes patented. Company claims the CBS has good properties for chocolate
CPC Int'l (USA)	CBS from yeasts	Process patented
Genencor (USA)	Enzyme techniques to convert palm-oil in cocoa butter	Patent application for process filed
Cornell Univ. (USA)	Cell culture to produce CBS	Research started in 1987
Nestlé (CH)	Enzyme techniques to improve fermentation of cheap cocoa	Focus on cheap cocoa from Malaysia
Mars (UK/USA)	Enzyme techniques to improve taste of Malay cocoa, including fermentation techniques	Joint research with Malaysian government
KAO Corp. (Japan)	rDNA enzymes to produce CBS	Two patent applications at EPO
Unilever (UK)	Enzyme technology to convert several oils and fats into CBSs	Unilever currently controls 50% of global CBS market
Wessanen (Netherl.)	CBS from mutant yeasts	Dutch patent application for new techniques. Company claims that new method is fast and economical
Station des Cultures Fruitières (Belgium)	Tissue culture of cocoa	100% of regeneration rate is claimed
USDA/ARS (USA)	CBS from cottonseed and olive oil	
IAEA/FAO (Austria)	Tissue culture of cocoa	
University of Lille (France)	Growth regulators and tissue culture on cocoa tree	
Univ. of Manchester (UK)	Protoplast isolation and fusion	
Univ. of Liverpool (UK)	Protoplast isolation	

SOURCE: Hollelink (1991:87-88).