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Cacao & Biotechnology
A Report on Work in Progress

ISSUE: Cacao and Biotechnology
CROP: Theobroma Cacao
COUNTRIES AFFECTED: All cacao producing countries of the Third World--especially Ivory Coast, Ghana, Brazil, Cameroon, Nigeria, Malaysia and Ecuador.
IMPACT: Development of high-yielding cacao varieties could lead to overproduction and jeopardize price and stability of cacao-producing countries while shifting production from small-scale producers to large-scale plantations; the use of biotechnology to convert low-priced oils into cacao butter could drastically reduce the demand and price for cacao beans.
COMPANIES INVOLVED: U.S. Chocolate Manufacturer's Association (15 U.S.-based companies) and the American Cocoa Research Institute, Hershey Foods, DNA Plant Technology, Genencor, CPC International, Ajinomoto (Japan), Fuji Oil (Japan), Cadbury-Schweppes (United Kingdom)
WHEN: Work on all areas is now in progress.

Introduction

Cacao is the second most important agricultural commodity from tropical regions in the international trade market. According to FAO statistics, approximately 1.7 million metric tons of cacao beans are produced annually. Worldwide, annual exports of cacao beans are valued at $2.6 billion. Cacao butter, extracted from the processed cacao bean, is used to make chocolate and is an important ingredient in pharmaceutical and cosmetic products.

Cacao is grown in a narrow tropical strip between 20 degrees north and south of the equator. Just seven countries -- Ivory Coast, Ghana, Brazil, Cameroon, Nigeria, Malaysia and Ecuador -- account for 80 percent of world production (see map). Half of the world's cacao crop is produced on small land holdings. Africa accounts for 57% of world

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production, Central and South America account for 34%, and East Asia accounts for 9%.[1]

The cacao plant, Theobroma cacao, is indigenous to the Amazon Basin region of South America, although one sub-species, Lacandonense, is found in the high forest of Chiapas, Mexico.

The genetic base of cultivated cacao is extremely narrow. Virtually all of the commercial cacao produced today is derived from a few varieties collected 40-50 years ago.[2] As a result, cacao is extremely vulnerable genetically--approximately half of the annual crop is lost to disease or insects.[3]

Various techniques of biotechnology are being applied to Theobroma cacao in the U.S., Europe and Japan. This RAFI Communique will examine three major focuses of that research (outlined below) and the potential impact on cacao-producing nations of the Third World.

1) The use of both tissue culture and genetic engineering to create higher-quality cacao beans and cacao butter, higher-yielding plants, and greater insect and disease resistance.

2) The use of enzymatic processes (protein engineering) to convert cheap oils such as palm or soybean oil into high-quality cacao butter.

3) Cacao butter biosynthesis -- The use of cell culture to create cacao butter in the laboratory.

Biotechnology Research to Improve Cacao Varieties

In mid-1986, a (US) $1.5 million endowed research program to support the study of the molecular biology of Theobroma cacao was established at Pennsylvania State University (Penn State) by two industry-supported groups, the American Cocoa Research Institute and the Chocolate Manufacturers Association of the United States. The research being conducted at Penn State University is the largest research effort[4] focusing on cacao and biotechnology in the United States.

The goal of Penn State's research on biotechnology and cacao is "to stabilize the export crop for manufacturing countries." A university publication describing the cacao research program explains: "The political instability of many of the cocoa-producing countries adds to the precarious position of the chocolate industry, which is wholly dependent

on this one crop."[5]

Under the direction of Dr. Paul J. Fritz, the Penn State program is using biotechnology techniques to develop high-yielding, high-quality cacao plants. The researchers aim to develop varieties which have more cacao pods on each tree, more beans in each pod, larger beans of uniform quality, and trees resistant to drought, cold, fungi, viruses and pesticides.

Cacao is a perennial crop, and it normally requires two to four years for a new variety to flower and fruit. Once researchers succeed in developing superior, high-yielding cacao varieties, the key to widespread use and adoption of these varieties depends on a technique called "micropropagation." Micropropagation of superior cacao varieties would enable scientists to regenerate virtually unlimited numbers of genetically-identical cacao plants in the laboratory at a much more rapid rate than traditional breeding techniques or seed propagation. The same technique has been applied to tobacco, tomatoes, bananas, oil palms and other plantation crops. Researchers have attempted rapid micropropagation of cacao for many years, but without success.

The inability to achieve rapid micropropagation of cacao is the major stumbling block to the speedy release of high-yielding, disease resistant cacao varieties. Dr. Paul Fritz of Penn State University predicts that scientists will succeed in micropropagation of cacao in the near future. According to Fritz, "It won't be very long until we'll have that [micropropagation] solved--there are too many people working on that who are interested in seeing it happen."[6]

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Using genetic engineering, scientists will someday be able to form new cacao plants tailored to meet the specific needs of industry. Penn State researchers, for example, have the long-term goal of altering the composition of cacao butter. Increasing the fat content of the cocoa seed by just 1 percent, for example, could result in millions of dollars of savings to chocolate manufacturers (because of the increased yield of cacao butter).[7] Another long-term project is to engineer a cacao variety containing a gene for thaumatin, a super-sweet protein which is derived from an African shrub. The end result would be a sugarless, but sweet-tasting, chocolate product--eliminating the need to add sugar in the manufacture of chocolate. According to cacao researcher Dr. Paul Fritz, although such projects seem far-fetched now, "I think that within a few years we could be testing these things experimentally."[8]

In order to accomplish these and other goals of genetic engineering, scientists must first identify and isolate specific genes, and then try to understand their characteristics, functions and how they are regulated. To this end, Penn State University researchers are now establishing the world's first "cacao gene library" by splicing DNA (the gene carrying material) into bacteria and preserving it in freezers. According to Dr. Fritz, "DNA thus preserved is indefinitely stable and is a source of cacao genes much as a library is a source of books."[9] The cacao genes now being "catalogued" at Penn State University are the raw materials for the future of genetic engineering and cacao.

* * * *

DNA Plant Technology Corporation (Cinnaminson, New Jersey, USA) is a agricultural biotechnology company that specializes in developing plant-based products for industry. In a joint venture with the largest U.S. chocolate manufacturer, Hershey Foods, DNA Plant Technology is using tissue culture and cellular genetics to develop new and improved cacao varieties. The company will not discuss details of their research, but, according to Hershey Foods, new cacao varieties have not yet been field tested.[10]

In addition to research efforts in the United States, European-based chocolate manufacturers are also applying techniques of biotechnology to Theobroma cacao. Cadbury-Schweppes, for example, has a major biotechnology research project underway at Lord Zuckerman Research Centre in association with the University of Reading, England.[11]

What Impact on Cacao Producers?

Worldwide, the average yield of cacao producers is 350 to 400 lbs. of beans per acre. Penn State researchers hope to develop new varieties which will yield at least 1,000 lbs. per acre.[12] But even higher yields are possible. According to Dr. Russell E. Larson, Science Advisor of the American Cocoa Research Association, intensive cropping systems combined with new varieties developed via biotechnology will make it possible to obtain yields of up to 3000 lbs. of beans per acre or more--an increase of 750% above today's average yield.[13]

Scientists and companies working on cacao biotechnology are quick to point out that their research will ultimately benefit the producers of cacao in the Third World by increasing yields and farmers' income. On the surface, this appears plausible. But it is likely that the benefits of advanced technologies and high-yielding cacao varieties will be skewed towards the large-scale cacao growers. As a

result, cacao production will shift from small-scale producers to large-scale cacao plantations. Small-scale cacao producers in Africa, where the majority of the world's cacao is now produced, will be at a particular disadvantage. According to Dr. Larson:

> Probably 50% or more of the cacao in the world is produced on small holdings. For economic reasons, it is not feasible for these growers to apply some of the advanced technologies such as adequate fertiliers usage and spray chemicals to control pests...Brazil and Malaysia have a higher proportion of large size plantations and are able to apply advanced technologies quickly. It is probable that African growers will be hard-pressed to achieve the high production levels of Brazil and Malaysia in the near future.[14]

The application of new biotechnologies to cacao will thus facilitate a fundamental shift in the world production of cacao from small-scale producers to large-scale plantations. Future cacao production will likely be concentrated in Brazil and Malaysia, where advanced technologies and large-scale plantations are now in place.

Malaysia is already the fastest growing cacao producer in the world. Malaysian cacao production increased tenfold between 1974 and 1984, and an estimated 625,000 acres of cacao will be in production by the year 2000. Malaysian cacao plantations already report the world's highest cacao yields--1000 to 1200 lbs. per acre for established plantings.[15]

Cacao Butter Substitutes -- Biotechnology and Oil Conversion

Another major impact on the future of cacao producing countries involves the use of biotechnology to convert cheap oils into cacao butter. According to Bioprocessing Technology, April, 1987:

> New technologies have potential to overturn oils and fats markets by reducing reliance on high-priced imports such as cacao butter. Discontented with the need to import, companies will produce similar oils from domestic sources, in the process even creating oils not found in nature.

Several companies in the United States and Japan are pursuing this goal. A major Japanese food company, Ajinomoto (Tokyo, Japan) has licensed a patented enzymatic process developed by a researcher at the University of Tokyo. The main use of this process is "synthesis of high value oils

such as cacao butter substitutes from lower value oils."[16] Fuji Oil Co., Ltd. (Osaka, Japan) has also patented a process to develop cacao butter substitutes from olive, safflower or palm oil.[17].

Genencor (South San Francisco, California, USA) has filed patents on another process which creates enzymes for use in upgrading oils and fats. According to the company, enzymes could be used to convert cheap palm oil into expensive cacao butter.[18] According to Henry Edmunds, Manager of Product Commercialization at Genencor, "We don't have anything commercially available yet--but it's certainly a realistic goal."[19] The company predicts that their fat-producing enzymes may be on the market within two to five years.[20] Genencor is jointly owned by Genentech (South San Francisco, California, USA), Corning Glass Works (Corning, New York, USA), A.E. Staley (Decatur, Illinois, USA) and Kodak (Rochester, New York, USA).

CPC International (Union, New Jersey, USA) holds a patent on a microbial process which involves the cultivation of yeasts with fatty acids. The end product is oil that mimics the composition of cacao butter. According to early reports, "Whether or not these oils can produce chocolate that would meet with consumer acceptance remains to be seen, but lab results indicate yes."[21]

The use of biotechnology to develop cacao butter substitutes from lower quality oils illustrates the enormous impact that biotechnology may have in altering or disrupting traditional markets for agricultural products produced in the Third World. If a process to synthesize cacao butter using protein engineering is commercially successful, the worldwide glut of cheap palm oil and other edible oils would undoubtedly replace a large share of the cacao butter market.

Production of Cacao Butter via Cell Culture

There has been a great deal of speculation about the possibility of someday producing cacao butter on a commerical scale using cell culture technology. The use of plant cells for the production of desirable products (flavors, fragrances, nutrients, pigments, etc.) is already being used to produce high-value products such as shikonin (a dye and pharmaceutical) and vanilla (see RAFI Communique, January, 1987). For chocolate manufacturers and other major buyers of cacao beans, the advantages of producing cacao butter via cell culture are obvious. Product quality could be uniform and tailored to the needs of industry, and supplies would be reliable--without regard to price, weather, season, or politics.

Considerable research has focused on the production of cacao butter from cultured cells--with extremely limited success to date. Dr. John Kinsella of Cornell University (Ithaca, New York, USA), with support from Hershey Foods, spent several years trying to produce cacao butter in the laboratory using tissue culture techniques. According to Kinsella, "In terms of production, we're a long way off."[22] Thus far, the composition of cultured cells (triglycerides and fatty acids) is significantly different from that of cacao butter.[23]

Other cacao experts agree that large-scale production of cacao butter via cell culture is currently an unrealistic goal. According to Dr. Fritz of Penn State University, "Forget it. It won't work. You just can't get the right fatty acids--and it isn't efficient or economical."[24] Cacao butter can be produced in the laboratory for about $100/lb. compared to $4/lb from beans. Studies conducted by DNA Plant Technology Corporation reveal that a product must cost at least $80/gram or higher to merit research on its production via cell culture. "In the case of cacao, it's so cheap we simply can't compete with the natural plant," remarks Maro R. Sondahl of DNA Plant Technology.[25]

If researchers are successful in developing high-yielding cacao varieties in the the near future, it is likely that the price of cacao beans will go down--further reducing the incentive to engage in the production of cacao butter via cell culture.

Conclusion

The application of plant biotechnologies to Theobroma cacao will have a profound impact on the future of cacao production in the Third World. Tissue culture and genetic engineering offer the potential to form new cacao varieties which are specifically tailored to meet the needs of industry.

The development of high-yielding varieties will likely lead to overproduction, declining prices and economic instability in cacao-producing countries. Advanced technologies and high-yielding cacao varieties will facilitate a shift in the world production of cacao from small-scale producers to large-scale plantations.

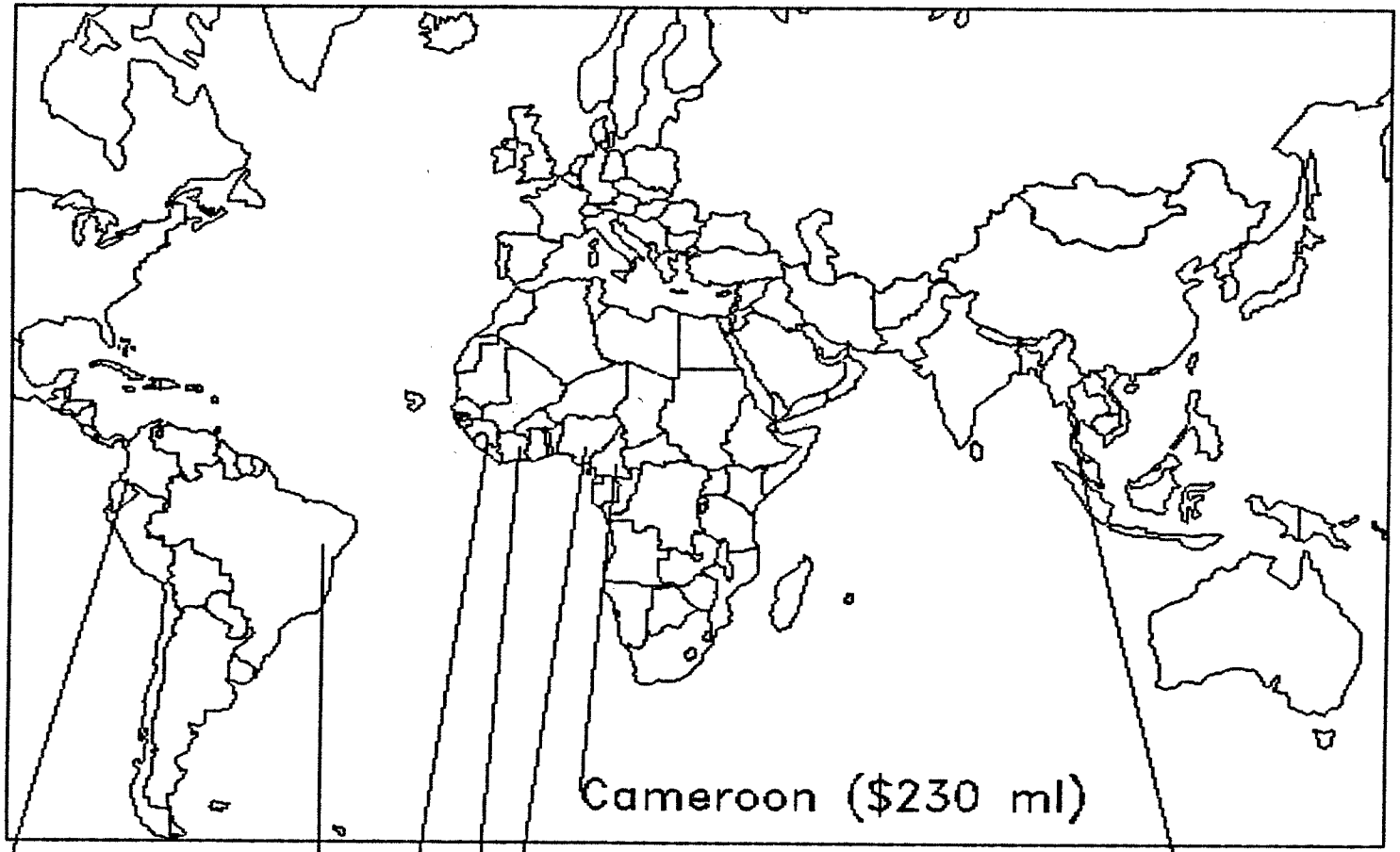
If a process to synthesize cacao butter using protein engineering becomes commercially available, cheap palm oil and other edible oils will undoubtedly capture a large share of the cacao butter market.

Prepared by Hope Shand, RAFI.

FOOTNOTES

[1]"Cocoa Raw Product-Production and Problems" by Russell E. Larson, in Proceedings of the Symposium Cacao Biotechnology, Penn State [2]University, 1986, p. 7.
[2]"Cocoa Germplasm-Some Novel Approaches to its Conservation" by Withers, Yidana and Atkinson in Cacao Biotechnology, Penn State [3]University, 1986, p. 97.
[3]"Cracking the Cocoa Bean" by Tracy Walmer, Penn State Agriculture, [4]Fall, 1986, p. 14.
[4]Personal communication with Dr. Paul S. Dimick, Penn State Univer-[5]sity.
[5]"Cracking the Cocoa Bean", Penn State Agriculture, Fall, 1986, p.15.
[6]Personal communication with Dr. Paul Fritz.
[7]"Cracking the Cacao Bean", Penn State Agriculture, Fall, 1986, p.14.
[8]"Biotechnology-Applications to the Cacao Plant" by Fritz, Fanji and [9]Stetler in Cacao Biotechnology, 1986, p.136.
[9]Ibid., p. 122.
[10]Personal communication with Dr. Douglas Lehrian, Manager of Ingredients [11]Research, Hershey Foods.
[11]Personal communication with Cadbury-Schweppes, USA. Cacao biotech-[12]nology research in Europe is not included in this Communique.
[12]"Cracking the Cocoa Bean" in Penn State Agriculture, Fall, 1986, p. 14.
[13]"Cocoa Raw Product-Production and Problems" by Russell E. Larson, [14]in Cacao Biotechnology, 1986, p. 13-14.
[14]Ibid, p. 17.
[15]Ibid., p. 7 and South Magazine, "Beans Means Better Genes", [16]September, 1986, p. 104.
[16]Bioprocessing Technology, April, 1987, p. 1.
[17]Bioprocessing Technology, February, 1985, p. 4.
[18]Bioprocessing Technology, October, 1986, p.1.
[19]Personal communication with Henry Edmunds, Genencor.
[20]Ibid., and Business Week, "Toughening Up Enzymes for the Factory [21]Floor", October 20, 1986, p. 91.
[21]Bioprocessing Technology, February, 1985, p. 4.
[22]Personal communication with Dr. John Kinsella.
[23]"Producing Cocoa Butter from Cultured Cells", by John E. Kinsella, in [24]New York's Food & Life Sciences, Vol. 15, No. 2, 1984.
[24]Personal communication with Dr. Paul Fritz.
[25]Personal communication with Dr. Maro Sondahl of DNA Plant Technology.

VALUE OF CACAO BEAN EXPORTS FOR SEVEN MAJOR PRODUCERS



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