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SECTION II

SELECTION OF ALTERNATIVE STRATEGIES FOR MEETING PROTEIN NEEDS

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GENETIC IMPROVEMENT OF CEREAL GRAINS

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My talk concerns the genetic manipulation for improvement of cereal grains. First, I would like to make some comments on overall, increased food production of the last few years. I am referring to what has been commonly called by the press "The Green Revolution" in food production, especially in Asia. Although it might be more *à propós* to speak about changes in production patterns in the Western Hemisphere, I think the two cases that I have selected will amply illustrate the magnitude of these changes more easily than if I tried to speak about progress in a vast number of countries. In India and Pakistan, there are 700 million people. Tackling the complexities of expanding food production in this kind of situation is similar in magnitude to dealing with the food production problems for a population equal to all the Americas, plus a good share of Africa.

Yet India and Pakistan, where the problem is the greatest, are two relatively small countries. What has happened in these nations in the last four years?I should like to consider the case of wheat, and restrict it for the moment to India. Using as a benchmark the all-time high of 1965, a very favorable year, India produced approximately 12 million metric tons. During the harvest just finished, India has produced 23 million metric tons. It is very significant that this rise in wheat production was achieved largely through increase of yield per acre. This is particularly important considering there is very little additional land that can be brought under the plow. In a similar way increase in crop yields must be the pattern of attack for most of the densely populated countries of the world, where new arable land is almost non-existent.

Indirect Effects of the Green Revolution

Beyond increased food production, what else does this change portend? I have restricted these comments to wheat. It started somewhat later in rice but I have no doubt that in the next four years—if we have peace—there will be a similar expansion in production in that crop. Maize has also made considerable progress in the past four years. So, for the time being, there has been a significant increase in food production in this very densely populated part of the world. We have been able to buy a little time—one, two or three decades—providing we continue to work at this problem from all angles and receive continued support from the concerned governments. If we do not, food production will not stay ahead of population growth. Within three decades, I hope that man will have regained his senses and adjusted his population growth—so that the absolute essentials for a decent life will be available to all born into this world. By producing additional amounts of wheat I think something very significant has happened to the total economy. I would like to emphasize the fact that in a country such as India, Pakistan, and most of the near Middle East and South East Asian countries, a vast segment—80%—of the total population, live on the land, mostly supported by a subsistence agriculture but they have very little to sell. They actually live outside the economy of their country. However, when one gets a sudden increase in grain production from 12 to 23 million tons, many of these small farmers will participate in the economy. They have something to sell—a state of affairs which never existed previously.

A whole series of changes is set in motion at the village level. The peasants buy things they never had before—simple machines, more fertilizer, more pumps, more motors and casings—and most of these things are built in India. They start buying consumer goods. If you are the head of the household, you might buy a Singer sewing machine in order to provide better clothes for the family, or a transistor radio. The latter allows the Government to broadcast educational programs to all backward villages hitherto completely isolated. The most important factor of all is that hope has replaced despair. Although you can't use a yardstick to measure hope, in terms of what it means in indirect benefits, there is no question but what this psychological change has had wide repercussions.

There are certain disadvantages, however, of which we must be aware. The cereal grains are displacing some of the natural sources of plant protein on which millions of people living in the near Middle East subsist. This is a most undesirable state of affairs and must be corrected. I am sure that Dr. Roberts will show us how this problem must be approached. Cereal grains are displacing such important protein crops as chick beans, pigeon peas, beans and lentils which play a significant role in the diet of these people. We must now also strive to rapidly increase yields of grain legumes.

There are serious protein deficiencies in the developing nations in contrast to the more affluent countries. If we look at total protein production and consumption as it relates to human diet in the world, approximately 70% of the total comes from plant proteins and only 30% from animal proteins. The cereal grains constitute 50% of total production. Relative costs of food in different countries must also

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be taken into account when we look at this problem of nutrition. Here in the United States, where there is an abundance of food, only 17% of the total take-home pay goes into expenditure for groceries. Contrast this to even advanced countries in Western Europe, where approximately 40% of the total take-home pay is spent on food. Compare this to the situation in India and Pakistan, where perhaps 70% of the pay goes to pay for food. Thus, when something goes wrong, you are even shorter of what you actually need. The percentage of income required for food will undoubtedly influence the kind of food you are going to consume. It is very difficult to justify the conversion of cereal grains into animal products in a country already short of food. Even under ideal conditions of management and modern technology, it takes approximately 3 lbs. of grain to produce 1 lb. of chicken meat, 4½ lbs. of grain to produce 1 lb. of pork and 6½ lbs. of grain to produce 1 lb. of prime beef. So it is readily apparent why—in most of these developing countries—there is a serious scarcity of animal protein which would otherwise bring about some semblance of a balanced diet. This is in dire contrast to the more privileged people of this country with their easy access to animal protein.

Improvement of Cereal Protein Quality and Quantity

Therefore, most people of the developing countries rely heavily upon cereals as their principal source of protein. We must take a look at the limitations of these cereal proteins. In the first place, all of them are short in one or more of the essential amino acids when they constitute a large part of the total diet and protein intake. Lysine—an essential amino acid—of course is limiting in all the major cereal grains. The second most limiting amino acid will vary with the different cereal grains. Nonetheless, we can start out with lysine. How can we do something about improving the nutrient value of our cereal proteins? There are three general approaches: (1) We can breed new varieties of grain with improved balance of essential amino acids. This is a relatively new approach which has been developed only in the last seven years. I call this "genetic engineering." (2) Using genetic engineering, we can also develop varieties that are higher in total protein production by manipulation of genes. And (3) we can develop improved cultural practices with any conventional variety—or better yet, with the improved varieties that have built-in genetic improvements for amino acid balance, through such manipulations as proper application of chemical nitrogenous fertilizers—or by growing cereals and certain legume crops in rotation, and in this way increase the total percentage of proteins.

These three avenues are open to us in trying to do something about the protein problem through the cultivation of plants. This genetic breeding or genetic engineering or manipulation of genes came into being as a means of improving amino acid balance as recent as 1964 with the discovery of the potential importance of the Opaque-2 gene in maize. I would like to point out that the Opaque-2 gene in maize, used as a genetic marker, was discovered and described in the 1920's by Jones and Singleton in Connecticut. But no consideration was given at that time to the significance of its other potentialities. It was not until 1964, at Purdue that Mertz, Nelson and Bates discovered that this Opaque-2 gene also provided higher than normal levels of lysine. It turned out also to have much higher levels of tryptophane—the second most limiting amino acid in maize. Normal maize has about 2% lysine in the endosperm protein; the opaque-2 gene maize has about 3.39%. This is a very significant increase. It is not only evident from chemical analysis but by biological value, which also falls in the same pattern. When rats were fed first at Purdue and then at many other institutions on Opaque-2, and the growth rate compared to that with normal maize—they were of very different orders. The same was true when weanling pigs were fed similar diets, where the main—or only—source of protein was that provided by Opaque-2 and normal maize. They grew at a much more rapid rate. This work was done at Purdue, at Columbia, in South America, and in Guatemala.

Then the final "clincher" came, when it was discovered that when children suffering from kwashiorkor were fed Opaque-2 by Dr. Pradilla and his group at the Zambali Medical School in Cali, Colombia, they responded beautifully.

There were many original shortcomings in the Opaque-2. First of all, this was a very poor corn as a basic type from the farmer's point of view. If one is going to use these genes, one has to incorporate them into the background of a whole series of outstanding corn varieties or hybrids that are adapted to different regions. This takes time. It takes a whole series of crosses and back-crosses. One has to be able to follow these in segregating populations so as not to lose the gene. As long as one is dealing with the original Opaque-2, it is self-evident because this is a soft endosperm or soft kernel type and one can spot this easily in the different kernels that are present in an ear of corn. But soft kernel texture is undesirable.

These opaque kernels also have low density. With the same number of grains per ear, therefore, they will have less yield—generally 8-10%—even up to 14%—less grain. In an unimproved state, therefore, Opaque 2 maize would be completely unacceptable to the ordinary farmer, especially the small traditional farmer. Furtheremore, the soft kernel texture makes it more vulnerable to damage by insects, both in storage and in the field before harvest. Many of these soft kernels are also damaged by fungi before the ear matures. Thus, there are considerable handicaps in trying to use this gene to improve the nutritional value of maize. Beyond this, the kernels are much less attractive and have different milling characteristics and different dough handling properties, all affecting their possible acceptance by the farmer. If you plan to use this as an industrial material, you must overcome this objection, too.

Present Status of High Lysine Varietal Development

What is the current status of developing varieties and hybrids that will be acceptable for commercial use in the case of Opaque-2 derivatives? Many varieties and hybrids are being converted to Opaque-2 types. The disadvantages which I have previously mentioned have held back their full acceptance in most cases up to now. Nevertheless, in Brazil–and especially in Colombia–commercial acreages of opaque types are being grown by farmers–and this involves considerable acreages in some places. In these cases, farmers have an integrated corn or maize-hog production and use it to offset high feed costs. This is especially important where one does not have high protein food supplements, such as soybean meal, etc. There are certain contract growers in Colombia and Brazil who are growing Opaque-2 maize derivatives or hybrids for food-fabricating companies producing specialty foods, baby foods, etc. None of these new varieties, however, has of yet come into general use on widescale farming or in the area where my organization is particularly interested, *viz.*, with the small subsistence farmer. It is here that one can make the greatest contribution to improving the nutrition of the underprivileged people, for they buy only the minimum. It is hard to get extra food supplements or food concentrates into the stomachs of these low income rural people. You might achieve this by supplementation and of course you must in hospitals, schools, and–insofar as is possible–in urban populations; but when dealing with rural people, it would be far better if one could incorporate these benefits into the seed and let the farmer grow them. Once he buys the seed–or once he has been given the seed–he can continuously resow this each year and benefit from it.

The future looks promising. In the past year or two there has been more and more hope that the Opaque-2 maize derivatives or hybrids will find widescale acceptance. The reason for optimism is that there are now several known genes that will correct the softness of the kernel. By doing this, one can maintain the high lysine and high tryptophane value of the original transfer from the Opaque-2 type. In order to accomplish this, however, highly competent analytical procedures in the chemical laboratory are vital in order to check that the gene for high-lysine and high-tryptophane hasn't been lost in the process of incorporating the genes for hard texture, thereby masking the soft appearance of the original opaque genes, which was evident by visual examination.

Our group at the International Center for Maize and Wheat Improvement in Mexico under the direction of Doctors Sprague, Johnson, Vassal, Villegas and others–all working together as a team–feel that there is a good chance that within two years' time large commercial quantities of seed–not only of high nutritional value–Opaque-2 derivatives–but with high grain yield, hard kernel texture and built in broad adaptation, will be available. Adaptation is very important. It will be very costly and difficult to incorporate these genes into 1,000 different varieties of corn. And corn (I use corn and maize synonymously)–in contrast to certain other crops where you can build-in wide adaptation to elevations, temperatures, latitudes rather easily–unfortunately does not lend itself by ordinary breeding techniques to this sort of adaptation. It seems that now, however, Dr. Sprague and his group have produced some very promising lines possessing this breadth of adaptation for growing up and down mountains and, hopefully, also across fairly wide latitudes–and they will have these factors combined with high nutrient value. If this seed is succesful, then it simplifies seed production and seed distribution. The prospects are bright for this to happen soon.

Possibilities of Improvement of Nutritional Value of Other Cereals

What are the possibilities on other fronts, for example, improving other cereals? In 1967, a similar gene (from the standpoint of its effect) was found in barley. It has been called "hy-proly." This was found in an indigenous Ethiopian variety–a natural mutant. Swedish research workers, especially Arerberg, Karlsen and Munk are incorporating this into improved barley varieties with the objective of using these as a more efficient source of feed for producing animal proteins. We at the International Center are interested and are developing a program for incorporating this gene into high-yielding barley varieties for use in the low-rainfall areas of North Africa and the Near and Middle East, where barley is used as a food. In this vast region, it is grown in areas of lower annual rainfall than wheat usually requires.

We have worked for six years on a man-made cereal which, however, has yet to attain any commercial importance, called "Triticale." Triticale is derived from a cross between wheat and rye. It was first described as a naturally-occurring hybrid–amphiploid–in approximately 1888. But it was not until about the mid-1930's–when the technique for doubling chromosome numbers came into being–with the use of the plant alkaloid, colchicine–that it was possible to make many of these combinations of wheat and rye, and to double their chromosome number so that they would be partially fertile. Researchers in Europe and Japan have spent a lifetime working with these plants–among them Muntzing of Sweden, Sanchez-Monge of Spain, as well as Hungarian, Russian, and Japanese workers. We became interested in the possibilites of using this wheat-rye combination as a prime source for protein in order to attack the world nutritional problem and formed a joint venture with the University of Manitoba where new efforts had been earlier initiated. This cooperative program has made great progress. Originally, we were stymied from every side by plants being partially sterile. They produced big ears or heads but had few seeds. This has now been overcome.

We have improved the architecture of the plant so that it will respond better to improved cultural practices, improved use of fertilizer, and in the process, increased the yield of grain. It is still not as high in grain yield as our best-yielding wheat. One of the curious things we have found in the past two years in working with Dr. Fred Elliott of Michigan State, who has used the meadow vole as test organism), is that some of the triticale lines have unusually good protein efficiency ratings—the full equivalent and perhaps considerably better than Opaque-2 maize! This discovery carries a lot of import. It hasn't been checked out with higher animals yet, except for preliminary experiments with chicks. Within the next few months, however, hopefully, feeding experiments of the new, man-made cereal can be conducted on pigs and as soon as it can be justified—on underprivileged children who suffer from serious protein malnutrition.

This wheat-rye combination offers a new possibility. Here is an entirely manmade cereal. If we can overcome one defect that still remains—grain plumpness—then there is an excellent possibility that this cereal can compete successfully with any of the other small-grain cereals such as wheat, barley and oats and serve a very useful purpose in areas where small grains are the basic source of plant protein.

What about wheat and rice? They are the two most important grains. Up to now—as far as the change in amino acid patterns goes—we haven't done too well with them. Hopefully, progress will be made shortly by increasing total levels of grain protein in both of these crops. The genes are known; and some varieties have already been produced which will yield 1-2% more total grain protein than the progenitors from which they were formed. There is plenty of opportunity to improve further on this while we continue our search for genes which might improve amino acid patterns. Genes have been found for both wheat and rice, but they have not been easy to use, up to the present time. Hopefully, more efficient ones will subsequently be discovered.

Summary

Considerable progress has been made in expanding cereal grain production in the last four years. But it is modest indeed, as compared to total needs. We must remember that—according to the Food and Agriculture Organization and also to the World Health Organization—that half of the world's people are still undernourished, badly nourished or malnourised. This is not a very pleasant picture! We cannot allow this situation to continue any longer and maintain our food supplies solely on a par with current population growth. The solution to the problem will probably require an expansion of 30% in cereal grain production. This could be done very rapidly—if it were a question solely of producing it any old place in the world. All you would need to do, is to turn loose the American farmer and give him the necessary incentive—the same with the Canadian, Australian, Argentinian and Soviet farmer. But this wouldn't solve the problem of malnutrition and undernutrition in the developing nations, because they wouldn't have the necessary money to buy the additional 30% of cereal grain needed. And even if their governments were in a position to do so the people who sorely need it have such low incomes that they couldn't purchase the grain from their own government! Poverty and malnutrition are intimately linked. At the same time, therefore, we have to work at putting money into the pockets of the rural people of the developing nations (who represent nearly 80% of the total population) in order that they have the wherewithal to buy goods. This is the procedure which has been successful up to now. We must proceed to push this economic help even faster than ever. There is no room for complacency, because of the monster lurking in the wings—population growth!

But beyond this, there is another great danger lurking on the horizon that threatens our ability to expand food production—the emotional environmentalists are attacking on two different fronts. In the food production front, they are using organic gardening experiments based all too often largely on a few tomato plants grown in the back yard to project ahead how to feed 3.7 billion people! It is questionable whether this experiment is a very good foundation upon which to make such calculations. When they are back home in their privileged countries (such as this one) they have another front—bringing political pressure to bear in order to have legislation passed outlawing the use of chemical fertilizers. If this should come to pass—I will tell you right now—that without the use of chemical fertilizers, we are all—sooner or later—doomed to starvation! The same applies to pesticides, where these lobbies—comprising the emotional environmentalists—I shan't dignify them by calling them ecologists—are already crying doom.

I started out as a forest ecologist and I worked with wildlife, watershed management and forestry, the integrated use of land in its broadest sense. These extremists are not—I assure you—ecologists. They are environmentalists. They are attacking on the pesticides front, attempting to legislate against pesticides that are needed when used wisely—and whose use I certainly advocate to protect our food crops. I am sure that most of you in the medical field are fully aware of the effect that legislation against DDT (already passed in the United States) will likely have on health particularly in relation to malaria. This has been brought under control for the past 25 years in many countries, but still runs rampant in vast areas of the world. We have no satisfactory substitute available for DDT at present. It is one thing to pass legislation here in this country where control measures for malaria may not be needed at the moment. But I have no doubt whatsoever that—soon after banning of DDT is achieved—there will be some arm-twisting brought to bear on the developing nations, saying: "Look! We have corrected the fouling of the environment. Now it is up to you to do likewise." But if they do follow suit, malaria will again ascend to its pre-DDT levels.

Nonetheless, I am very optimistic about the future of man. He has come a long way during the

2,000,000 years since he first stood up on his back legs after he emerged (probably from the bush in East Africa). His progress has been amazing if one looks back at this second on the biological clock to 9,000 years ago—when, after having survived as a hunter, he discovered agriculture and animal husbandry. From that time to this is a short 9,000 years. After agriculture and animal husbandry came into being (which permitted the specialization of labor), we had the beginning of specialties—of pottery makers and metal workers and basket weavers who exchanged their products for food produced by farmers. Villages were born. Then cities. And modern civilization came into being, with its myriad problems which still confront us. Man has indeed come a tremendous distance in this last "biological" second . . .

I think we should all be amazed—and also thankful. We should not be cynical. Even if we haven't—as yet—solved all the problems of the basic social ills that have restricted, so far, an equitable distribution of our social benefits. I think that we can achieve this if we balance population growth so that there is adequate food production, housing, clothing, proper medical care, employment, education for all, and adequate transport. And, of course, we are depleting our non-renewable resources without developing proper substitutes. We have caused a deterioration of the environment through doing an excellent job of fouling up our rivers, streams and lakes and smogging our atmosphere! But I am sure that we are well on our way toward correcting some of these abuses. We can work at this for the next 10 years, but what will it be like—30 years from now—when we have *double* the world population? I am confident that political stability hinges largely upon our ability to provide a decent standard of living to all who are born into this world. Already we have cities—megalopolises—so large that something is always going wrong! I have a firm belief that cities such as Calcutta, Dacca and New York are fast approaching the stage where they are ungovernable by any coneivable system of government. The situation is made even worse by the frightening population explosion. As I said, however, we have come a long way. We can correct all these ills and thus build a better way of life. The choice is ours!