GENETIC IMPROVEMENT OF SEED PROTEINS

Genetic Improvement of Seed Proteins

PROCEEDINGS OF A WORKSHOP

Washington, D.C.
March 18–20, 1974

BOARD ON AGRICULTURE AND
RENEWABLE RESOURCES
Commission on Natural Resources
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

The workshop reported herein was held under the sponsorship of the Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council, on March 18–20, 1974, in the Lecture Room at the National Academy of Sciences in Washington, D.C.

The purpose of the workshop was to present and consider current information on genetic improvement in quality and quantity of seed protein in relation to human nutrition. The opportunities for utilizing environmental and physiological variables, e.g., O_2 and CO_2, were considered.

Experts from a diversity of related scientific fields, including plant physiology, plant breeding, molecular biology, biochemical genetics, and mammalian nutrition, focused on the basic cellular and biochemical mechanisms that are involved in plant protein synthesis. Applicability of genetic engineering to plant breeding research was explored.

The organizers are grateful to the specialists who appeared on the program and to the participants in the discussions.

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Introduction

As biologists, geneticists, physiologists, plant breeders, we are aware of the important role of seed proteins in the world struggle against malnutrition, so I need not dwell on this fact, nor is it the intent of this workshop to dwell on the malnutrition problem as such. I do submit that against this backdrop of malnutrition our deliberations will be most timely and appropriate.

Scientists, several of whom are here as participants, are concerned by mounting evidence that genetic manipulation of seed protein by plant breeders may be seriously impeded by gaps in our knowledge of protein metabolism and, perhaps, by lack of effective communication between the biological disciplines involved.

These disciplines, particularly molecular biology and molecular genetics, need to focus on the problem. In this meeting, leading plant breeders, molecular biologists, geneticists, biochemists, and physiologists will examine plant protein metabolism in depth and, it is hoped, formulate some innovative approaches to acceleration of favorable modification of storage proteins in the food species of plants.

If the food species of plants are to be improved nutritionally, the job will ultimately fall to the plant breeder. The plant breeders have already responded to pressure for more and better plant protein with some notable successes.

This is a new kind of activity for the plant breeder. It is a difficult one, because guidelines are frequently absent or, at best, indistinct. It has been suggested that some breeders have a euphoric attitude about protein improvement. The implication is that they may be unaware of the serious biological constraints on plant protein manipulation.

The plant breeder attacks the problem by measuring protein, the end product of a long and complex chain of metabolic events. The breeder does this, for the most part, because he must do it. This is the method that is readily available to him. Is this what he should be doing? I suspect that in some cases, it may not be.

Some of the questions that must be answered are these:

What are the points in protein metabolism that offer the best opportunity for effecting useful changes in the amount or composition of seed proteins?

What are the most serious constraints imposed by biological or physiological phenomena in protein metabolism that breeders know little about? More important, what are the opportunities provided by these phenomena?

Can the molecular biologist or the molecular geneticist help the breeder? If so, when and how?

Where are the gaps in our knowledge of protein metabolism that will most seriously impede breeding progress?

What key cellular biochemical mechanisms are involved? At what point in the chain of metabolic events do they function?

Are there tests for protein precursors, or enzymes, or for key proteins themselves that would be useful selection tools in the hands of the plant breeders? Breeders may suggest that there are few such useful tests available to them at this time. The physiologists, on the other hand, may suggest that some potentially useful tests are now available but are not being used by the breeders. If this is so, why?

Are there cooperative investigations that should be instituted to provide such information?

The National Academy of Sciences has provided the forum. Communications across the disciplines represented here may be difficult because we speak somewhat different languages, but such communications must occur.

I

SEED PROTEIN USE, DEVELOPMENT, AND MODIFICATION

AARON M. ALTSCHUL

The Protein–Calorie Trade-off

The purpose of this presentation is to examine the relationships between protein supply and total food supply with a view to providing an orientation for the ensuing discussions on the biological aspects of protein synthesis in cereals.

The basic question that must be faced is whether or not there is a protein problem, for if there is no protein problem, then there is no point in worrying about more or less protein in cereals. Perhaps a more pertinent question is whether one can talk about either a protein problem or food problem as two separate problems. As the analysis proceeds, it will turn out that the protein problem and the food problem are two aspects of the same problem: Neither can be discussed without reference to the other.

Historically, the protein problem had its origins in medical considerations. Kwashiorkor was discovered and identified as a disease of extreme protein deprivation. It occurred in children of poor people in poor countries whose diet contained predominantly cereals with no animal or legume protein or, worse yet, whose diets contained large proportions of roots such as cassava. It was quite clear that the observed clinical cases represented the tip of the iceberg, and that, for each child seen in a hospital, there were tens or hundreds or thousands of children whose growth was stunted by inadequate protein in their food.

The realization of the crucial role of protein in the lives of vulnerable groups such as children and pregnant and lactating women led such

United Nations organizations as UNICEF to ship milk all over the world and to attempt to develop alternative cheaper sources of protein products suitable for these groups. It led the U.S. Agency for International Development (AID) and the U.S. Department of Agriculture to develop and ship huge amounts of a mixture called CSM, which was predominantly corn and soybean flour. It led AID to initiate large-scale demonstrations of fortification of cereals with amino acids in Tunisia, Thailand, and Guatemala; these projects are in progress. It led AID, in another effort, to try to stimulate the food industry to introduce protein into common foods in a way that would provide additional protein from hitherto untapped resources. And it stimulated people (e.g., Mertz and Nelson, this volume) to look for varieties of cereals with higher protein value.

But, obviously, it is not possible to divorce protein considerations from the rest of the food issues. What was originally called kwashiorkor is more properly termed protein–calorie malnutrition. It was asked whether shipments of protein foods alone would solve the medical problems. The medical analysis was unequal to the task of quantifying the problem. It was large, it was severe, but hard numbers were not available.

The logical approach toward quantification is to determine, it seems, what the human needs for protein are; compare these to available supplies; and ascertain the relationship between protein utilization and total calorie intake. This is an ongoing effort; periodically, expert committees of UN agencies and like committees in several nations have met to codify the state of knowledge in this area.

It is clear that protein requirements cannot be determined or presented in isolation and that any figures for protein requirements must presume an adequate supply of calories and other nutrients. Moreover, since proteins are sources of amino acids, protein requirements cannot be described without specifying the type of protein: digestibility, percentage of essential amino acids as part of total amino acids, and pattern of essential amino acids as related to requirements. It is in infancy that the human being is most sensitive to protein requirements, needing more protein per unit of weight than at any other age, a greater proportion of essential amino acids as part of the total amino acids, and the widest spread among the essential amino acids.

In the last several decades there have been a number of revisions of the amino acid requirements. The trend has been downward; the requirements are now lower than had earlier been thought (FAO/WHO Report, 1973).

What can one do with this kind of information? It is possible to say that the average person who receives these amounts of protein along with adequate amounts of other nutrients will get enough protein to avoid showing evidence of protein deficiency. They can identify people whose protein intake is grossly deficient. They can be used in designing diets for people in well-defined clinical situations such as parenteral feeding. And they can, in a general way, predict how much protein is required, given adequate availability of other nutrients, to feed human beings under rigidly controlled conditions, approaching the feeding of animals in pens.

What is not provided by these kinds of data? They do not deal with those issues in which human requirements differ from those of animals. The question of optimum nutrition is not as easily defined as it relates to humans because it is part of a quality of life that includes many other aspects of life including sensory needs, performance, happiness, emotional stability, and length of useful life. More important, these data do not predict what people will do when faced with choices brought about either by restricted food supply or by increasing purchasing power.

When this kind of consideration is applied to public policy, it leads to ambiguities. The same information can be used to support the allegation that there is adequate protein or to substantiate the charge that for certain groups there is a protein deficiency. The same information can allow some to conclude that there is a protein problem and others to conclude that there is a general food problem, that *more of the same kind of food* is needed rather than particular emphasis on protein foods. Thus, the nutrition community is divided on this issue, and this diminishes interest in the protein supply question as a specific issue (Altschul, 1974a,b,c).

Further examination of the concept that postulates *more of the same kind of food* shows that of the choices made when people become poorer or richer, this is less likely than others (see Figure 1). When people become poorer or when the ratio of resources to population in a nation decreases, *the same amount of food of a different kind* or *less food of a different kind* are more likely alternatives. And when a person's income increases or the ratio of resources to population in a nation increases, the most likely alternative is *more food of a different kind*. These come about because protein foods are more expensive than calorie foods. As resources decrease, the expensive foods suffer first; and as resources increase, more expensive (and tastier) foods enter into the mix of the diet.

Hence, medical considerations alone or nutritional considerations alone are insufficient to provide a basis for public policy. Cost and

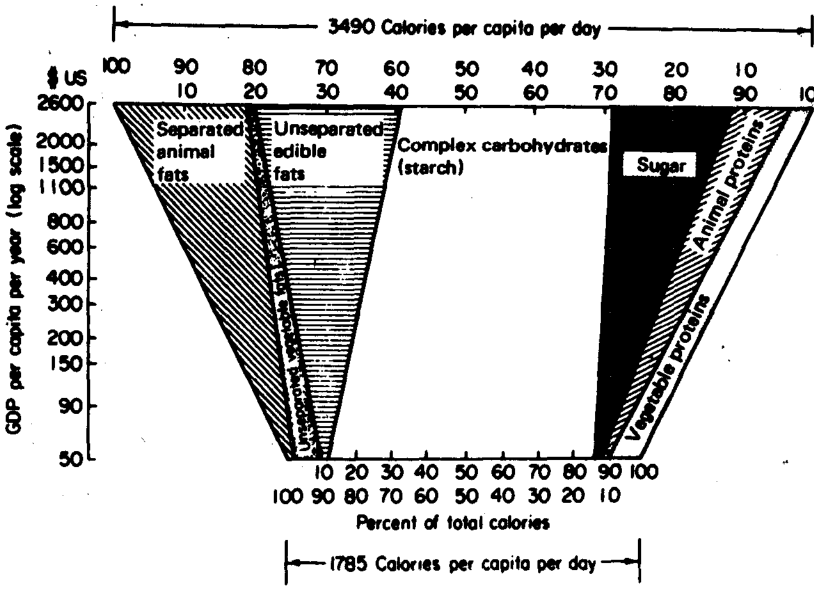

FIGURE 1 Effect of income on energy intake and distribution of major sources of food energy. The total calories and proportion of calories derived from each food type are shown according to country income for 1962. The ranges in total calorie intake represent the lowest and highest values recorded. Figures are based on national food balance sheets. (Reprinted with permission from Altschul, 1974a.)

esthetic considerations are equally important; actually, they usually override medical or nutritional considerations.

We can illustrate these points by considering two cases:

1. Where there is a threat to the current level of food supply in any given country
2. Where income is increasing in a specific country

In the first case, the threat could arise from increased population, or changing conditions of energy constraints, or a combination of the two. We must remember that the two major constraints on total food production are availability of land and energy. The Green Revolution made it possible to apply more fossil energy to optimize photosynthetic energy. With the sharp increase in energy costs, some areas may not be able to continue the generous energy inputs that are required to maintain the gains of the Green Revolution. The other case, the one where income is increasing, constitutes a pressure for foods of higher esthetic quality, particularly meat.

Case No. 1 When there is a threat to the current level of food supply, maintenance of total calorie supply is the first interest. One could almost say that everything is sacrificed to maintain calorie intake to avoid starvation. And since calories cost less than protein, poverty favors less and poorer protein. For example, increased demand for calories favors cereals over legumes since the yield of calories per acre is greater for cereals than for legumes. An increased demand for calories favors both of them over animal protein since this is the most expensive of all kinds of protein. Moreover, even greater poverty favors starchy roots over cereals, and these contain very little protein.

Let us take the case of India, for example. The Green Revolution was quite successful there. For the decade of the 1960's, calorie availability per capita remained constant despite the increase in population, and so did the protein content per capita (Figures 2 and 3). There was, however, a major rearrangement: The percentage of

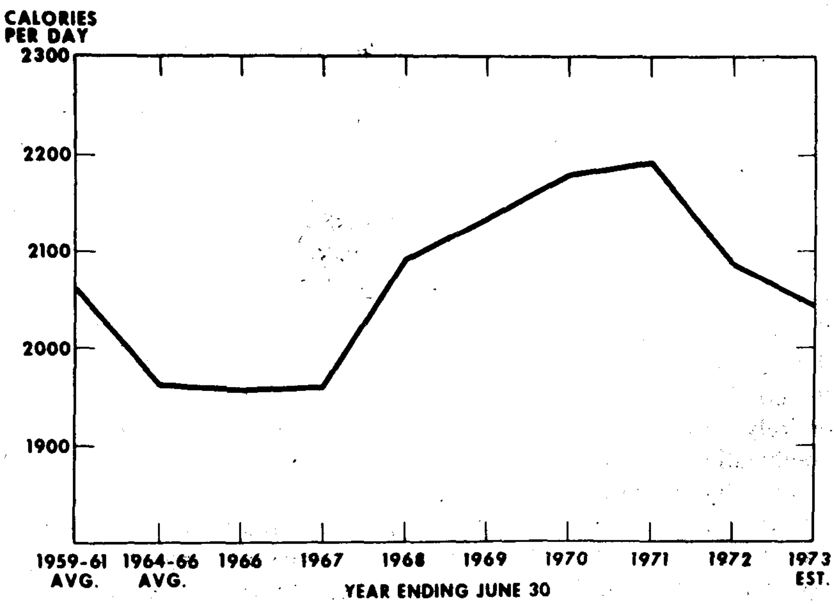

FIGURE 2 India: Per capita availability of energy 1960–1973. (Reprinted with permission from Schertz, 1973.)