High Lysine Corn – What Lies Ahead?[1]

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ABSTRACT

This paper reviews the worldwide impact, now and in the future, of the 1963 discovery by Purdue researchers that the protein of the opaque-2 mutant contained more lysine and tryptophan than normal corn protein. Agricultural breeding, growing, harvesting, storage and distribution aspects are delineated and economics reviewed. Physical and chemical differences are discussed in relation to the foregoing aspects and implications concerning processing. Present and future roles of high lysine corn in human nutrition, particularly in lesser developed countries are discussed. Potential impact on the animal feeding industry is considered.

Discovery of the potential nutritional value of the opaque-2 gene by Edwin Mertz and Oliver Nelson of Purdue University in 1963 was the direct result of an effort to find a corn variety which would offer better protein quality to the malnourished in corn-eating areas of the developing nations. Hence, its discovery was motivated by human nutritional needs. The reason that it may become a factor in animal feeds results from its unique qualities which are attractive for feeding certain farm animals.

The story of the discovery of the opaque-2 gene has been told and retold (1-4). Its development into a commercial crop in Colombia and in the USA has been recorded (5-8). Its nutritional qualities have been studied by numerous investigators and their results recorded (9-12). To discuss what lies ahead requires that we have some understanding of (a) background of development into a commercial crop; (b) agronomic aspects of seeds and crops; (c) the composition of high lysine corn as compared with normal corn and its relation to nutritional qualities, processing and its use in products; (d) uses in foods; (e) economics of uses in animal feeding; (f) factors which appear likely to motivate consumption of high lysine corn in different parts of the world.
Discussion of what lies ahead logically will follow the same pattern.

BACKGROUND OF DEVELOPMENT INTO A COMMERCIAL CROP

In the 50's, the United Nations and other groups were striving to highlight the major nutritional deficiencies of the diets of large segments of the populations of the developing nations, and particularly those in the tropical belt around the world. They stressed the need for improvement in diets as a major step toward increasing the capacity of those peoples for improving their economic status. An increasing awareness of the importance of protein quantity and quality in diets was emerging then. It became apparent that protein deficiency was far more widespread than caloric deficiency. Supplies of animal-based foods were inadequate and were too expensive for those who most needed proteins. All of the widely consumed cereal grains lacked sufficient amounts of some of the essential amino acids. One approach was to change the protein genetically so as to obtain a more balanced amino acid profile. Corn, deficient in lysine and tryptophan, was a staple food in many countries. Improvements of its protein quality could offer hope for millions of people.

After analyzing hundreds of corn varieties in mutant types from samples obtained from all over the world, Drs. Mertz and Nelson discovered one which had almost an ideal amino acid profile. By cross-breeding this mutant with local varieties they were able to grow experimental quantities of high lysine corn at Purdue. Seed from this corn was planted at a number of locations to obtain stocks for further agronomic development. Notable among these was the work of the Rockerfeller Foundation in Colombia (13).

AGRONOMIC ASPECTS

Opaque-2 modified hybrids seem to germinate less readily than normal hybrids. Repeated growing tests indicate that this poses no problem since the high lysine corn can be harvested at about the same time after planting as normal hybrids. Planting and cultivating practices do not differ. However, care must be exercised to provide reasonable isolation of the two types of corn when they grow in the same field. This can be done either by physical separation or by delaying planting of the high lysine corn sufficiently to assure that normal corn in the area will have pollinated by the time the high lysine corn silks. Moisture levels at harvest are higher than those of normal hybrids but the opaque-2 corn dries faster. All methods of harvesting from husking the ear to the most modern picker-shellers have been used effectively. There has been no evidence of significant rot, and no unusual problems as fungus in storage have been observed.

There is, and will probably remain, a yield difference between the two types of corn. After enough cycles of genetic manipulation have been accomplished involving back-crosses of the opaque-2 gene into the hybrid to establish the hybrid identity, the volume of corn produced per acre is about the same. This was established in practical tests conducted by Funk Bros. Seed Co. on over 50 farms in the USA in the 1969 growing season. However, the bulk

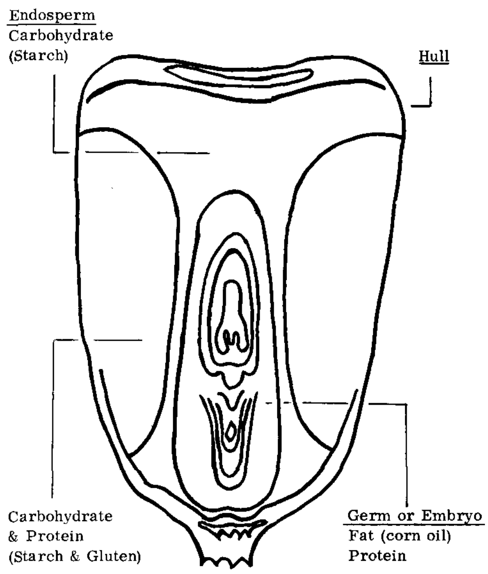

FIG. 1. Cross section of corn kernel.

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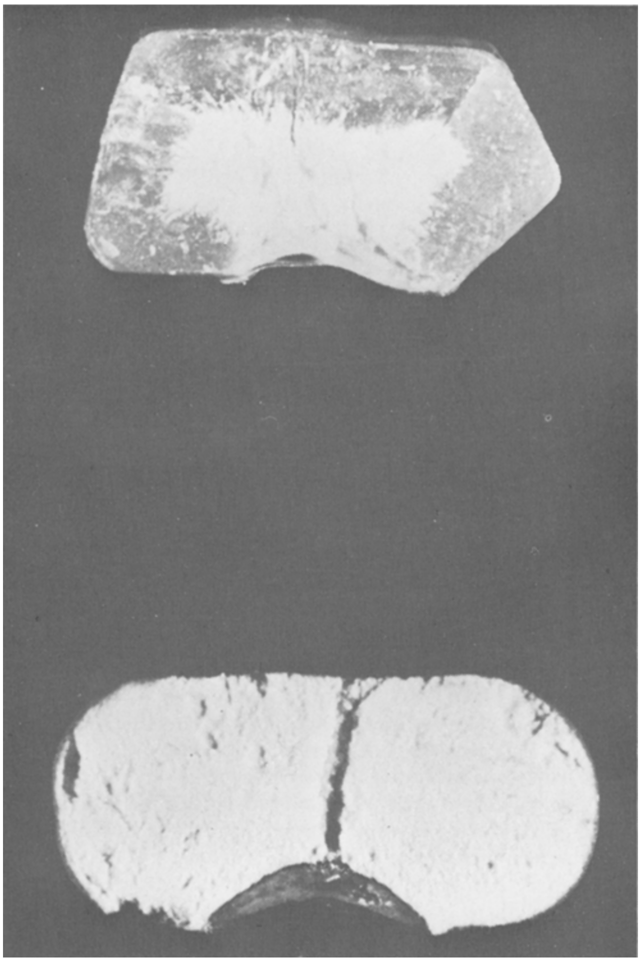


FIG. 2. Photograph of cross sections of normal and high lysine corns.

density of opaque-2 corn is lower-52 to 53 lb per bushel vs. 56 lb per bushel for normal hybrids. This means a yield penalty of 5% to 7% and a consequent higher price.

In those countries having a commodity distribution system for corn, a further price penalty can be expected. The special handling required, including isolation in the field, in transportation and in storage, coupled with the probable need for contracting quantities required with farmers and distributors, can add another 15 cents to 25 cents per bushel until the quantity grown becomes great enough to establish high lysine corn as a commodity. In countries having no commodity distribution system, the penalty will be lower.

COMPOSITION

Figure 1 shows the major portions of the corn kernel: hull, endosperm and germ (or embryo). The hull is chiefly

TABLE I

Approximate Composition of Corn

Components	Normal corn, %	High lysine corn, %
Moisture	10.6	13.8
Protein	9.4	10.5
Fat	4.3	5.3
Carbohydrate	72.8	67.0
Fiber	1.6	2.2
Ash	1.2	1.4

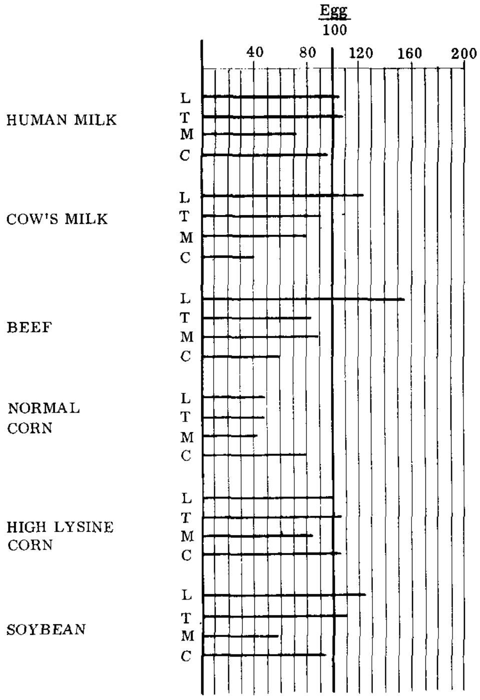


FIG. 3. Relationship of limiting amino acids in common foods. L, lysine, T, tryptophan, M, methionine; C, cystine.

indigestible fiber. The endosperm contains most of the carbohydrate in the kernel and much of the protein; the germ is chiefly protein and fat. The carbohydrate is starch and the fat is corn oil.

A comparison of normal and high lysine corns, Figure 2, shows that normal corn has a relatively large, horny endosperm as indicated by the cross section inside the hull. High lysine corn is more chalky and softer than normal corn. High lysine corn has a larger germ as will be seen by comparing the darkened sections at the bottom of the two kernels.

A comparison of the composition of samples of normal corn and high lysine corn, Table I, shows differences in all of the components. While protein content is a little higher, carbohydrate content is lower. The larger germ yields some additional oil.

Interest chiefly centers around the improved protein quality. Assuming egg has the correct distribution of amino acids for human nutrition and assigning 100 as the level of each amino acid in egg, Figure 3 shows how human breast milk, cow's milk, beef, normal corn and soybeans compare with egg for each of the four limiting amino acids. It is evident that cow's milk and beef are rich in lysine but slightly lacking in methionine and deficient in cystine. Normal corn is deficient in all of these essential amino acids. Comparatively, high lysine corn appears to have a nearly ideal distribution of these amino acids.

The real test of any nutrient is its usefulness to human beings. Helen Clark (14), at Purdue University found that the protein and essential amino acid requirements of five young adults were satisfied when they received between 250 and 300 g of high lysine corn daily. One large man required 350 g. However, from other work it is known that 600 g of normal corn would not have been similarly sufficient.

In studies with children in Guatemala, Ricardo Bressani (15) found that the quality of high lysine corn protein was about 90% of that of skim milk.

Much more rigorous tests of the value of high lysine corn were conducted by Arturo Pradilla (16) of the Universidad del Valle in Cali, Colombia. He gave high lysine corn as the only source of protein to children severely ill with kwashiorkor. The children were selected as severely malnourished but without tuberculosis, chronic infections or basic metabolic problems. In four months' time these children made remarkable recoveries. They became alert and tempermentally better adjusted, their emaciated limbs filled out, skin lesions and hair dullness disappeared, and all evidences of kwashiorkor disappeared.

In 1969, studies sponsored by CPC International Inc. were conducted by N.S. Scrimshaw and associates (17) at the Massachusetts Institute of Technology in Cambridge, Massachusetts, to determine the nutritional value of high lysine corn protein. The reference protein in these tests was hen's egg protein and the subjects were healthy, young American adults. Eight male MIT students participated in the study and continued their normal daily activities throughout the experimental period. The test protein was utilized in two forms—whole ground corn meal and degerminated corn meal obtained from corn grown by Maizena, S.A., in the Cauca Valley, Colombia. The daily diet was controlled so as to maintain each individual's caloric needs while the level of protein was kept at less than requirements so as to assure its maximum utilization. The results (Table II) indicate that the digestibility of the proteins in both whole and degerminated high lysine corn is high, the nutritive value compares favorably with various sources of high quality animal protein, and the nutritive quality of high lysine corn appears to be as good as or better than the reported biological value of cow's milk protein. In these tests the biological values of whole and degerminated high lysine corn proteins were almost identical.

Turning now to processing, high lysine corn offers little interest to corn wet millers. They process corn to separate the starch from the gluten and oil from the germ. Starch and oil are the more valuable fractions. Gluten and fiber are sold to animal feed mixers. The lower starch content of high lysine corn more than offsets any advantage of a slightly higher oil content. The higher solubility of the gluten fraction means more protein is solubilized in the steepwater, increasing costs of recovery.

The change in character of the endosperm will pose problems to dry millers who generally want to maximize the output of larger grits. The more floury nature of high lysine corn endosperm will shift the output toward smaller particle sizes with more flour and less grits.

Distillers will find their economics shifted toward higher raw material costs because of the lower carbohydrate content of high lysine corn.

The foregoing analysis of the impact of high lysine corn on the three major industrial processor groups shows that there will be little enthusiasm among these groups for high lysine corn. Evidently, food uses are most likely to come from dry milling fractions and they will have to bring a premium over their normal corn counterparts. This poses a real challenge to food processors to find ways to take advantage of the nutritional qualities of high lysine corn protein while paying a premium both for the raw material and the higher proportionate costs of processing which must be borne by the finer fractions.

USES IN FOODS

In the major corn-eating countries in the developing nations, e.g., Mexico, Central America, Colombia, Peru, Brazil and Venezuela in Latin America and Kenya and South Africa in Africa, a major part of the corn is consumed directly on the farms. Often these families are among the most impoverished and malnourished who, with little or no money to spend, are forced to live on what they can grow on small plots of ground which are often low in soil nutrients. Clearly, for these people high lysine corn can be a boon.

TABLE II

Summary of Mean Values for the Digestibility and Nutritional Quality of High Lysine Corn Protein for Young Adult Men[a]

Protein source	Digestibility	Biological value	NPU[b]
Whole corn	92 ± 6	79 ± 10	73 ± 12
Degerminated corn	95 ± 5	82 ± 9	78 ± 10
Hen's egg	96 ± 8	95 ± 7	92 ± 12

[a]Mean values $\pm$ standard deviation for eight subjects.
[b]Net protein utilization.

Unfortunately, the farmer has habitually planted some of the kernels from his most recent crop to start his new crop. Now, he must purchase or be given seed to start high lysine corn growing. Since he is of a superstitious nature because of low educational level, it will be difficult to convince him that he should do something which might result in loss or reduction of his crop, and he, therefore, may reject the opportunity to make a significant improvement in his family's nutrition. This problem can be attacked best by local governments.

With the rapid growth in urban populations, feeding peoples in the medium to lower economic levels becomes a bigger problem. Many of these people have recently migrated from farms and small towns to the large urban centers. Again, their identification with corn as a staple food is strong. Products emphasizing corn can find wide acceptance, provided people like them and they are low enough in cost. High lysine corn as a substitute for normal corn offers the nutritional advantages so important in helping to overcome malnutrition among these groups.

Typical are tortillas in Mexico and Central America, arepas in Venezuela and Colombia, and fuba and cus cus in Brazil. These products alone account for from 25% to 80% of the corn consumed by human beings in these countries. The minor differences in composition between normal corn and high lysine corn can pose problems in achieving the same texture, taste and appearance in widely known products. The only commercial products which have been introduced in markets anywhere, to our knowledge, are the weaning food (Duryea) in Cali, Colombia, and a precooked arepa mix (Ricarepa) in a limited test market in Bucaramanga, Colombia, both by Maizena, S.A., a unit of CPC International Inc. Doubtless many other products will follow as high lysine corn and processing knowledge become more widely available.

USES IN ANIMAL FEEDING

Numerous investigators have tested high lysine corn as a feed material for farm animals. Because their digestive systems allow cattle to generate their required amino acids from a variety of feedstuffs, high lysine corn offers no special attractiveness. There is no known recorded evidence of experiments with high lysine corn in feeding cattle.

In poultry, Beeson (18) of Purdue University has shown that "in growing chicks from 1 to 21 days of age there was no significant difference in growth rate or feed conversion when opaque-2 corn was substituted for normal corn when the protein levels were equalized with soybean meal. However, when a deficiency of methionine was corrected, opaque-2 corn produced significantly better gains and feed conversion than normal corn at sub-optimal levels of protein. These data suggest that opaque-2 corn may produce a more beneficial effect in older chicks or laying hens which have a lower protein requirement." This conclusion was essentially confirmed by Cromwell et al. (19) at Purdue University. Others (20-24) have carried out tests under carefully controlled conditions, but there is no known recorded evidence of practical farm tests with high lysine corn as a major component in poultry feeds.

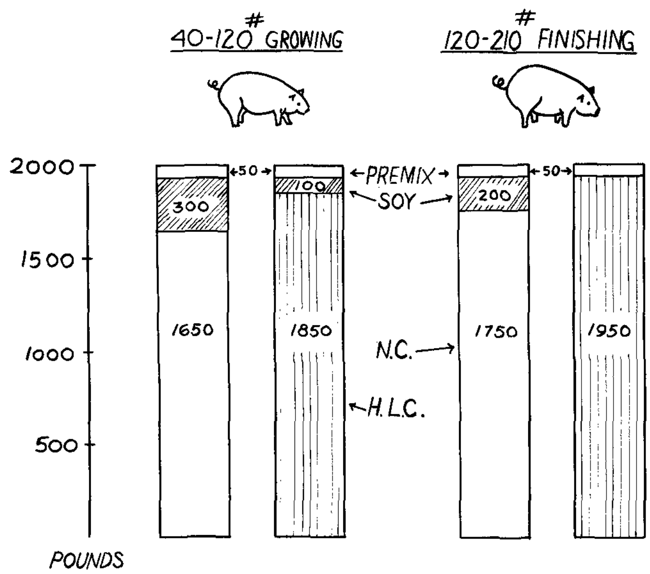


FIG. 4. Swine feeding program - normal corn vs. high lysine corn. Feed ratios used in practical farm feeding trials.

Most investigation has been conducted with swine because the amino acid profile of high lysine corn is nearly ideal and because of the high consumption of corn by swine. Beeson et al. (25) at Purdue University predicted in 1966 that "use of opaque-2 corn in a growing-finishing swine feeding program could result in a feed savings of \$1.95 per pig (\$1.95/200 lb of gain)." Hodson (26) of Iowa State University predicted in 1969 that "high lysine corn may cut the cost of raising hogs by \$1 to \$2 a head and cut supplemented high protein ration requirements in half." Many other investigators have studied the value of high lysine corn in swine feeding (27-35).

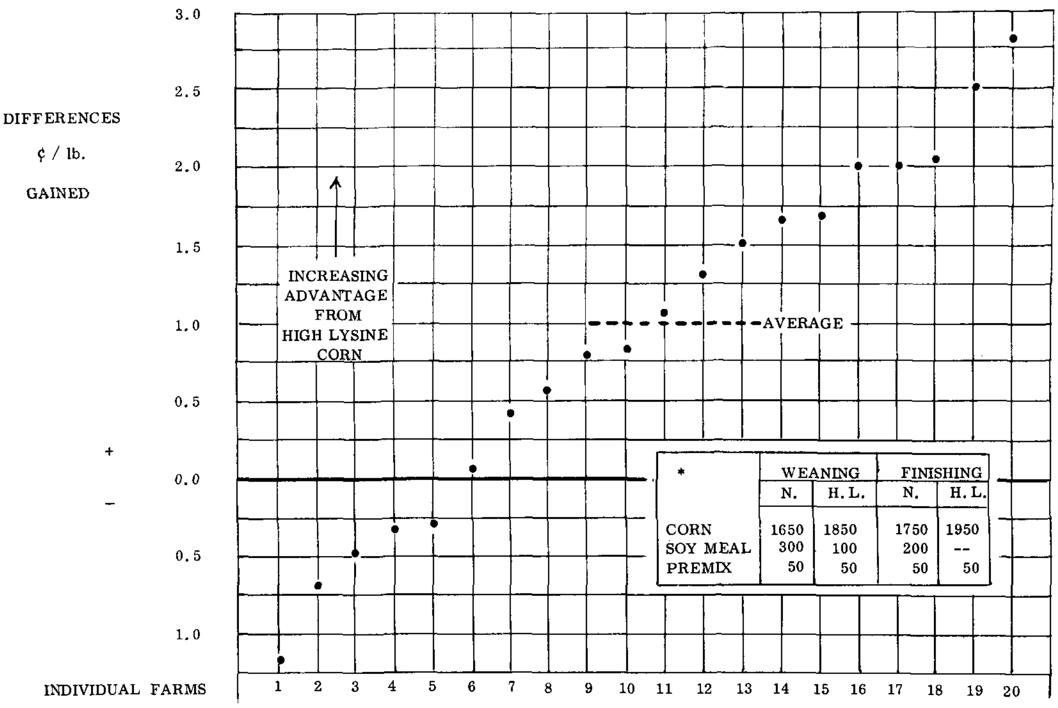
Earlier this year Funk Bros. Seed Co. conducted tests with farmers in an 11 state area of the Midwest. These farmers grew normal corn and high lysine corn during the 1969 growing season. They fed rations, Figure 4, to litter mates, one half on normal corn and one half on high lysine corn. These tests progressed through finishing the swine for market. The results (Fig. 5) from 20 farmers show a wide disparity among farmers but seem to indicate a conclusive advantage for high lysine corn. The range of feed cost gains was from 1.16 cents per pound of weight gain in favor of normal corn to 2.86 cents per pound of weight gain in favor of high lysine corn. The arithmetic average of differences showed a 1 cent per pound of weight gain in favor of high lysine corn. The average gain seems to confirm the earlier predictions of university investigators.

FACTORS MOTIVATING CONSUMPTION

An analysis of the consumption of corn in the USA indicates that about 80% of the crop is fed to farm animals with the remaining 20% being divided among corn processors, inventory accumulation and exports. A relatively small part of the crop, of the order of 4% to 5%, is used in human foods. Swine consume about 30% of the crop, cattle about 27% and poultry about 25%. As previously stated, high lysine corn will have little impact on cattle feeding. The impact it will have on poultry feeding is not known. Swine, more like human beings, lack ability to synthesize amino acids. Since corn is the primary ingredient in most swine rations, and the amino acid profile of high lysine corn is nearly ideal for swine, it can be expected that swine feeding will be a major factor in determining when and if high lysine corn becomes a crop of significance in the USA.

If we examine some of the major corn-eating countries, we will see quite a different picture. In Colombia, for example, about two thirds of the crop is used in human foods. As one of the major corn-eating countries having a serious protein deficiency among many of its people, Colombia could benefit greatly from the nutritional advantages of high lysine corn protein. The government there has taken a strong position in favor of promoting high lysine corn for human foods as rapidly as possible. It seems likely that the combination of human need and government pressure will be major factors in determining the future course of high lysine corn as a major crop.

People in certain parts of Brazil consume large quantities of corn, while in other parts corn is a relatively small factor in human foods. Even so, over 20% of the crop is consumed by human beings. In contrast to Colombia, corn consump-



*	WEANING		FINISHING	
	N.	H.L.	N.	H.L.
CORN	1650	1850	1750	1950
SOY MEAL	300	100	200	--
PREMIX	50	50	50	50

FIG. 5. Feed savings in swine feeding tests - high lysine vs. normal corn rations.

tion by farm animals is significant with over 60% of the crop going to animal feeding. A sizable proportion of this goes to swine feeding. It seems likely that both swine feeding and human foods can influence a change in the crop to high lysine corn, with the change likely to occur regionally in relation to economic forces concerned with swine feeding in certain areas and human needs in the major corn-eating areas.

One could analyze other major corn-growing countries and a similar pattern would evolve. Generally, as a country becomes more developed economically, its corn consumption becomes more animal-oriented and less human-oriented. This is consistent with the lesser dependence on cereal grain proteins and the greater dependence on animal proteins for food as incomes increase, which follows the pattern of preferences so often demonstrated.

WHAT LIES AHEAD?

If high lysine corn is to become more competitive with present day, high-yielding hybrids, agronomic improvements must come in a number of areas. It seems improbable that opaque-2 modified hybrids can be made to yield more bushels per acre than today's high yielding hybrids. With a 5% to 7% yield penalty on a weight per acre basis, high lysine corn is at a disadvantage. Desirable improvements include a harder and denser kernel more like flint or dent corn to improve yields and to make high lysine corn more attractive to dry millers, higher protein content to utilize better the quality of the protein, a 20% increase in lysine content primarily to improve attractiveness for animal feeding, and higher oil content to increase the economic value of the crops.

Another gene, known as floury-2, imparts a similar effect on protein quality as the opaque-2 gene. It has been studied by several investigators (18,36-38). It may be combined beneficially with the opaque-2 gene in hybrids in the future.

More recently it has been learned that by combining a waxy gene with the opaque-2 gene in hybrids, a corn of nearly normal density results and the protein quality is retained. While this will not necessarily assure equal yields of normal corn and high lysine corn, it may result in a less floury endosperm.

A weakness of all cereal grains is their realively low protein content. While genetic change may make some improvement, it is likely that cereal grains will never compete with oilseeds as protein concentrate sources. On the other hand, isolating and concentrating the protein in high lysine corn while retaining its excellent qualities could open up wide opportunities in competition with oilseed proteins.

Protein-containing residues from industrial processors may retain the beneficial qualities of the high lysine corn protein and increase their attractiveness as feed ingredients. This could only become a factor of importance if the economics of processing high lysine corn are altered significantly by one or more of the improvements previously indicated as desirable.

Governmental actions in developing countries to take more advantage of high lysine corn for human nutrition could alter the normal economic balance and increase the rate of crop growth. This could affect industrial processors earlier than might otherwise occur.

In conclusion, the original purpose of a balanced amino acid corn protein was to improve the quality of food for millions of people suffering from malnutrition who consume corn as a staple diet food. Are we denying many of these people its benefits because we are tied to past practices in creating foods? Only the future will show the extent to which man can rise above the inhibitions imposed by the past on his thinking.

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