to find if this value is consistent. Preliminary observations on four varieties do not confirm it: only one increased in lysine content and then only by a small amount. However, further investigation is necessary.

Conclusion

The composition of cereal grains has had relatively little attention so far from plant breeders. There appears to be scope for improvement in the quantity and quality of the proteins and in the quantities of some other components, notably oil and fibre. Changes in starch composition are also evidently possible. The indications are that searches for plant material with special qualities are likely to be worth while. Two problems face the breeders. First, they must decide whether it is worth embarking on long-term research programmes to improve particular aspects of quality. Second, they must ensure that varieties which have valuable quality characters reap an adequate economic return for those who grow them. Co-operation between breeders and nutritionists should assist in the solution of both these problems.

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Practical problems concerning the marketing of cereals with improved protein value

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The marketing of new cereal varieties with improved protein value only might today meet with several practical problems. I intend to discuss some of these problems here, mainly those arising in the industrialized countries in connexion especially with a possible utilization of their cereal production for reducing the shortage of food in the developing world.

https://doi.org/10.1079/PNS19700008 Published online by Cambridge University Press

As a source of protein, cereals are outstanding in importance for a large minority of the world's population, as is evident from Table 1 (after Borgström, 1967). In spite of this, no cereal variety has, as yet, been introduced only on the basis of its improved

Table 1. *World protein production (metric tons* $\times 10^6$*)—yearly average* (1963–4) (From Borgström, 1967)

Protein source	Total production	Available for human consumption
Plant:		
Cereals	100·5	60·3
Oilseeds	24·4	8·0
Legumes	7·0	6·0
Starchy tubers and roots	8·5	4·0
Fruits and vegetables	6·0	5·0
Total	146·4	83·3
Animal:		
Milk	12·3	8·1
Meat	9·6	9·0
Poultry	2·3	2·1
Eggs	1·9	1·6
Fish and shellfish	5·2	2·9
Total	31·3	23·7
Total, plant and animal	177·7	107·0

protein value for direct human consumption. On the other hand, varieties of wheat with high protein content and barley with low protein content have long been accepted, as they meet requirements of the flour-milling and brewing industries respectively. In these cases, however, the nutritional value of the cereals, or of the cereal proteins, has hardly been considered, the main goal being certain specific properties of the cereals during baking and malting.

The food customs, as a rule conservative in nature, of different human populations may constitute an important obstacle to attempts to alleviate malnutrition (Harper, 1961). The improvement of the proteins in conventional foods therefore has an indisputable advantage in comparison with the development and introduction of new, unfamiliar protein products. The advantage of improving the proteins of the existing cereals thus needs no further comment.

Today, developments in several cereals show that it is possible to produce varieties with improved protein content and protein value. Examples may be quoted from maize (Mertz, Bates & Nelson, 1964), barley (Munck, Karlsson & Hagberg, 1969), wheat (Johnson, Mattern, Whited & Schmidt, 1969) and rice (Swaminathan, Austin, Kaul & Naik, 1969).

Improved cereals for food and feed—the problems of unequal distribution

Notwithstanding promising plant-breeding results with respect to improved protein value, large segments of the human population will continue to suffer from inadequate protein supply if rapid utilization of such new varieties is detained for sociological, political or economic reasons.

The nutritional value of cereal products is, of course, dependent on the entire production chain. In the handling and processing of protein-improved cereals, the quality has to be considered at every stage of this chain, or that gained by breeding might easily dwindle or be lost completely. This might call for modifications and improvements of the production chain, and the introduction of protein-improved cereals might give rise to rather complex problems. In developing countries such problems will be accentuated and even more complex, as the introduction of improved cereals is likely to have to be combined with quite fundamental education in the fields of nutrition and agriculture. One of the problems is that in order to maintain such improved varieties, and to prevent their breakdown by mixing and intercrossing, comparatively sophisticated control methods have to be available and systematically employed. It is therefore reasonable to assume that the successful introduction of improved cereal varieties will take a longer time in developing than in developed countries, and that the gains that will accrue from this introduction will be delayed, even though there is an awareness of the gravity of the situation.

The need for more protein for human consumption, and the role of the industrialized countries as importers of protein foods and feed, have not yet been fully accepted among economists in these countries as the serious problems that they are threatening the future of mankind. This has had some rather unusual consequences, as usually in the industrialized countries more cereals are produced than are actually used. As the surplus cannot profitably be disposed of on the world market, the overproduction is not accepted as a goal—steps are even taken to curtail production. The reply by the Swedish Department of Technical and Humanitarian Assistance of the Swedish International Development Authority to the United Nations questionnaire (arising from the United Nations (1968) report) titled *Increasing the Production and Use of Edible Protein* may be quoted to illustrate the situation in industrialized countries; 'Sweden is a highly developed country and suffers from no lack of adequate food resources, even though some types of food are imported. On the whole, there are no activities within the country to increase the contribution from conventional agriculture—on the contrary this contribution is gradually being diminished.' The main reason for this attitude is the fixation to the world-market price as a guidance to sound economy. To be able to discuss to any extent the world-market price and prime costs, however, the efficiency of agriculture must be studied from an international point of view with respect to all hidden costs, such as erosion of land, human maintenance, development, etc.

In the developing world, cereals are normally the staple food, serving as the main source of calories and proteins. Yet the production is on the whole far less than required, because of inhomogeneities in factors due to seasonal-dependent access, deterioriation losses, social differentiations, etc. In general, developing countries also have a low capacity to buy, and this together with a local overproduction in industrialized countries restricts the will to produce more cereals for international trade. And yet the Advisory Committee on the Application of Science and Technology to Development reported to the Economic and Social Council of the United Nations (1968) as follows: 'For a growing number of the developing countries food imports from industrialized countries are essential; without such imports, they experience further deterioration in the health and well-being of large segments of their populations. This dependence of the developing world on food shipments from industrialized countries is increasing steadily and seems likely to continue.' Incentives for producing high-quality protein cereals in industrialized countries therefore have to be sought after. One such incentive is readily available—the profitable production of meat. Much of the cereal production is now used as feed grain in industrialized countries. Because of the profit involved in animal production, the nutritional value of these cereals is becoming increasingly important and special attention is focused today on the usually too low protein content and value. For example, Sweden is now planning to increase the relative national production of proteins for feed, mainly because of the large surplus production of cereals, which today have to be disposed of on the world market through a national subsidy programme. An improvement of the protein content and protein quality would increase the amount of cereals that could be used within the country as feed. This would both diminish the export of low-protein cereal attended with heavy losses, and the importation of supplementary protein products such as soya and fish meal. From a restricted Swedish point of view, this is certainly sound economy, but unfortunately it does not involve considerations of the international shortage of protein for human consumption.

And last but not least, if the demand for protein in one area is to initiate production in another it is essential that efficient transport systems and adequate storage facilities are available, as well as systems which guarantee the individual farmer reasonable economic remuneration for growing high-quality varieties.

Protection of quality—damage during harvesting, storing, drying and processing

Yearly investigations in Sweden have shown that on an average about 50% of the annual harvest of wheat is, from a technological point of view, damaged and classified as feed grain (Olered, 1966). A similar investigation of barley and oats was initiated in 1968 (T. Hummel-Gumaelius, 1969, unpublished results). The results from the 1st year of investigation are not yet fully treated, but they indicate a large variation in quality in spite of the favourable harvesting conditions in 1968. It was found that the water content of harvest averaged about 18%; 5·5 months later 50% of the bulks still held more than 16% water: this should be weighed against the fact that storage is not considered to be safe until the water content is less than 13–14%.

From India, tremendous damage to cereals during storage and distribution has been reported; moreover, such cereals are consumed by human beings in large quantities (Tainsh, 1967). It is therefore probably quite safe to assume that damaged grain, which in industrialized countries should be classified as feed grain, in the developing world often enters into the human diet. If so, this may lead to an increased need for supplementary protein, partly as a result of decreased protein quality of the grain and partly as a result of toxic effects owing to toxins produced by micro-organisms, and which have been shown to interfere with protein utilization (Madhavan, 1965; Munck, 1967).

In order to obtain high-quality cereals, damage must be reduced by improving harvesting, drying, storing and other processing techniques (Munck, 1964). It is futile to breed for improved protein if this is destroyed at later stages of handling and processing. The introduction of the combine has, for example, generally resulted in a later harvest, which increases the risk of damage in humid regions. In Scandinavia, therefore, research is going on to improve, above all, harvesting and drying techniques. One approach is to harvest the cereals with a mechanical picker and dry whole ears at high temperatures, and thresh at the end of the drying procedure. This technique is still in the experimental stage, but it has several advantages compared with the older method. One advantage is the more rapid drying, which decreases the risk of damage of the cereals resulting from storage of overmoist seeds before drying (Munck & Mossberg, 1967).

In other areas, where the harvesting period in general is drier, other types of damage predominate; for example, improper storage leaves cereal bulks open to rainfall, insects and rodents.

Processing, such as bread-making or toasting, also damages the cereal proteins (Munck, 1968), although this damage is mostly not so obvious as those just mentioned, and comparatively easy to detect.

Protein content and protein quality—criteria of high-quality cereals

If varieties characterized only by improved protein quality and quantity are to be generally accepted and grown, they must attract some kind of price differentiation independent of the purpose for which these varieties are intended. There is little doubt that this is the most efficient method of stimulating an interest in high-quality cereals. In order to carry out this price differentiation, protein quality must be defined in some way and the necessary control system must be available.

Protein quality cannot yet be described by pure chemical criteria. This means that all new, improved selections should be checked at an early stage in feeding experiments. Suitable experimental feeding techniques with mice and rats are available (Eggum, Madsen, Petersen, Munck & Modeweg-Hansen, 1969; Munck, 1968). During a later stage of testing, experiments with large animals including nutritional and economic aspects of improvement are needed. However, it is necessary for plant-breeding work, as well as for classification of the cereals on the commercial level, to have much more rapid methods, and that necessarily implies chemical methods. It is now quite clear that the Kjeldahl nitrogen method is inadequate, because the nitrogen content does not reflect protein quality, which is a function of amino acid composition.

An adequate method should have broad applicability, be simple and inexpensive; and, in view of the comprehensive damage to cereal proteins during handling, storing and processing, it would also be of great advantage if the method could distinguish between different degrees of damage to the proteins, e.g. by detecting the presence of free ϵ-amino groups of lysine.

These requirements seem to be met by the so-called dye-binding method, which since about 1950 has been utilized to estimate crude protein content in several vegetable and animal products. The principle of this method is that an acidic dye is coupled with the basic groups of the proteins in the sample in question. The dye–protein complex is precipitated under standardized conditions in a solution of dye, the decolorization of which is measured after filtration or centrifugation. The dye-binding capacity (DBC) has been found to be strongly correlated with the nitrogen content in products such as milk (Ashworth & Chaudry, 1962) and flour (Udy, 1954, 1956). In other products also the correlation is generally good, as long as the material is of the same type and origin and treated in the same manner. Samples which do not fit the correlation have been found, however, in most products (Bunyan, 1959; Fajersson, 1966; Mossberg, 1966). These results can regularly be explained by divergent content of basic groups of the samples in relation to the nitrogen content. The basic groups are mainly represented by guanidine- (arg), imidazole- (hist), ε-amino- (lys) and α-amino groups of the proteins (Fraenkel-Conrat & Cooper, 1944).

The DBC method has been further developed at the Plant Breeding Institute of Weibullsholm in collaboration with the Swedish Seed Association (Mossberg, 1965, 1966, 1969; Munck, 1968). Fig. 1 shows the correlation between DBC and nitrogen content for some different cereals. It is clear from the figure that each cereal has its own regression and relation between DBC and nitrogen content. It is also clear, as seen from Fig. 2, that this difference can be explained on the basis of the different content of basic amino acids in the different cereals. These two figures,

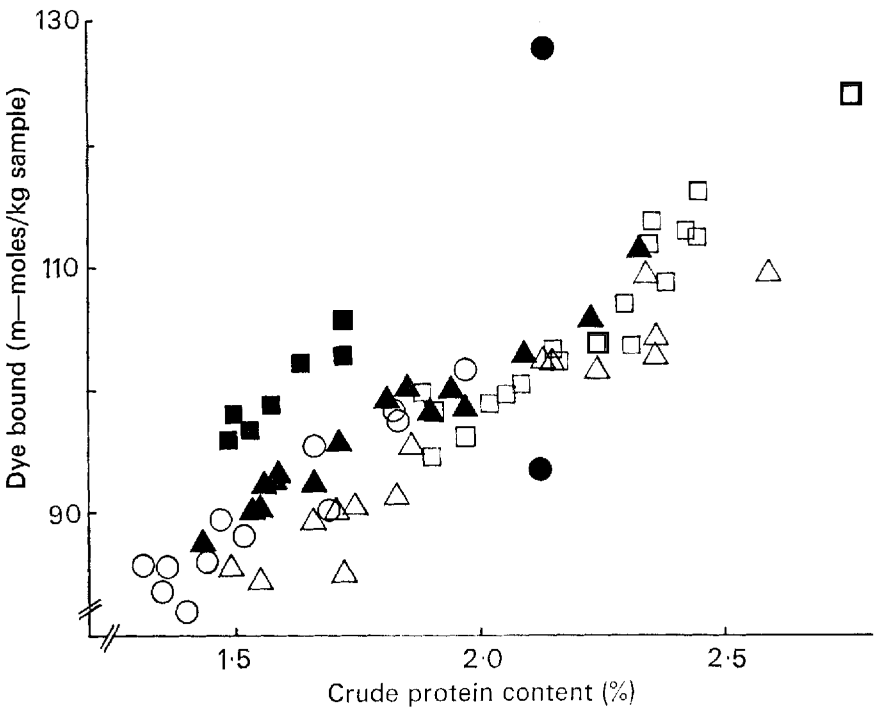

Fig. 1. The correlation in different cereals between nitrogen content and dye-binding capacity: ○, rye; ■, oats; ▲, barley; ●, maize; △, wheat; □, ryewheat. (Values from Mossberg, 1969.)

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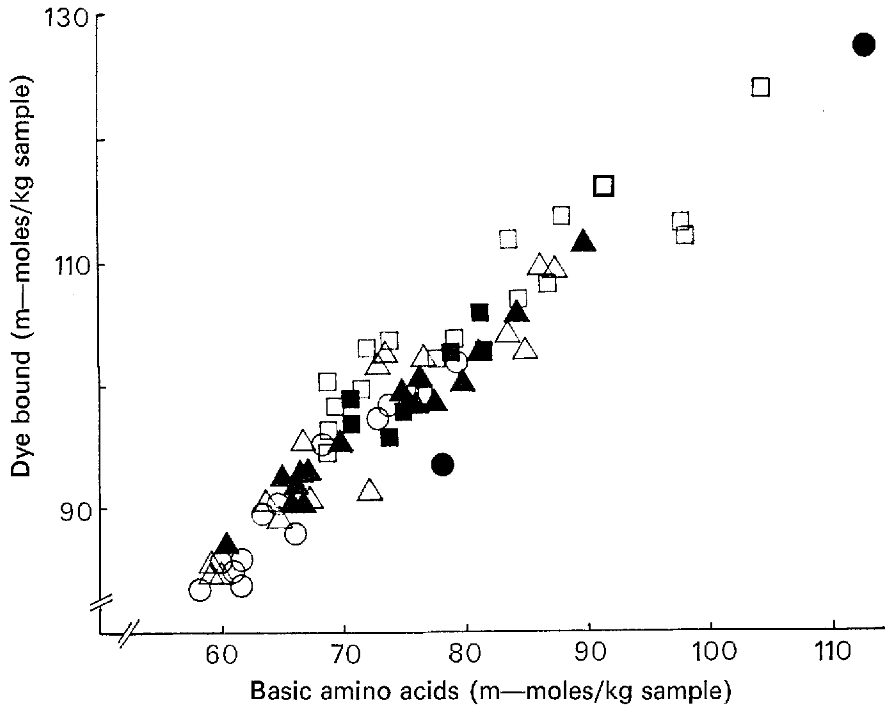

Fig. 2. The correlation in different cereals between content of basic amino acids and dye-binding capacity: ○, rye; ■, oats; ▲, barley; ●, maize; △, wheat; □, ryewheat. (Values from Mossberg, 1969.)

which include one sample of normal maize and one sample of high-lysine maize (opaque-2), also illustrate that the DBC method clearly distinguishes between normal maize and opaque-2 maize.

The DBC method has also been successfully applied to cereals damaged experimentally under controlled conditions, and very good correlations were found between DBC and live-weight gain of mice fed with such barley as the sole source of protein (Mossberg, 1966).

Table 2. *Protein content and percentage of lysine in the protein of CI* 3947 (*Hiproly*) *and of other varieties of barley*
(From Munck, Karlsson & Hagberg, 1969)

Locality	Variety	Protein content (%)	Lysine content (% of protein)
Bozeman, Montana	CI 3947	15·3	4·3
	Hannchen	11·4	3·5
Aberdeen, Idaho	CI 3947	18·4	4·4
	Four samples of commercial varieties	12·3	3·6
Svalöv, 1967	CI 3947	16·9	4·0
	Foma	11·0	3·4
Svalöv, 1968	CI 3947	14·5	4·2
	Three samples of low-protein varieties	10·7	3·9
	Five samples of high-protein varieties	15·0	3·4

The promising results with the DBC method led to its use in a search in the world collection of barley varieties for types with a high content of lysine (Munck *et al.* 1969). In Fig. 3 the relation between DBC and nitrogen content in so-called normal barley and some selections from the world collection is illustrated ($r = 0{\cdot}650$). For three of the samples (all representing the accession no. 3947) the deviation from the regression represented by the normal material is extremely large. These samples, representing the most promising selection so far from the world collection, have a high lysine content in the protein, as well as a high protein content (Table 2). The selection has been made at the Swedish Seed Association by the DBC method in combination with Kjeldahl nitrogen determinations. This 3947-barley is very much like the theoretical high-protein and high-lysine barley discussed by Carpenter & Taylor (1968). Fig. 4 shows the correlation between DBC and the content of basic amino acids of the same material. The correlation is much stronger ($r = 0{\cdot}959$) than that between DBC and nitrogen, showing the dependence of DBC on basic amino acids.

The dye-binding method, therefore, seems to be very well suited for plant-breeding purposes, as well as for processing control, for example when drying cereals at high temperatures. It also shows promise for the classification of cereals as to protein standard in commercial practice.

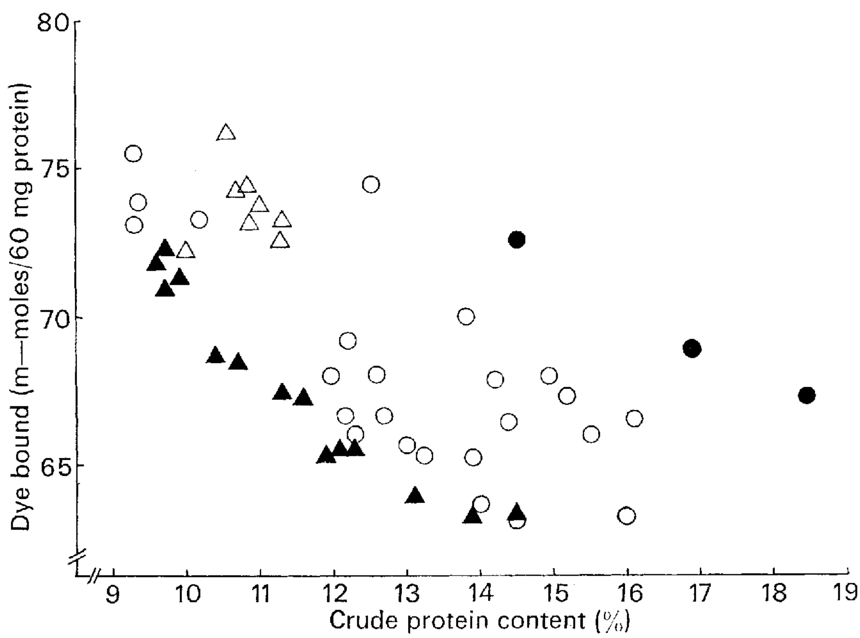

Fig. 3. The correlation in barley between crude protein content and dye bound per 60 mg protein (constant amount of protein weighed in for DBC determinations): ▲, normal material, grown 1964; ○, selections from world collection; △, Foma barley, grown 1967; ●, CI 3947 'high protein and lysine barley' (Hiproly). (Values from Munck, Mossberg & Karlsson, unpublished results, 1969.)

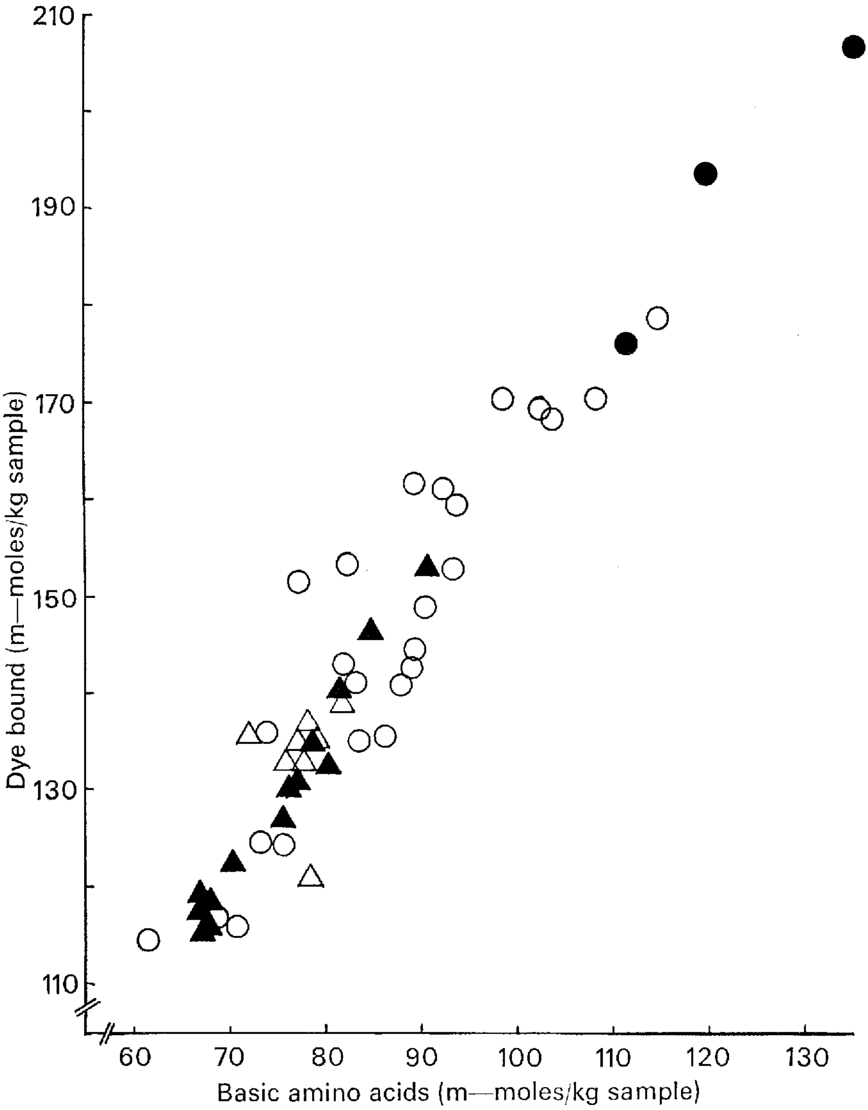

Fig. 4. The correlation in barley between content of basic amino acids and dye bound per kg sample (constant amount of protein weighed in for DBC determinations): ▲, normal material, grown 1964; ○, selections from world collection; △, Foma barley, grown 1967; ●, CI 3947 'high protein and lysine barley' (Hiproly). (Values from Munck, Mossberg & Karlsson, 1969, unpublished results.)

Conclusions

Many industrialized countries might today still have unused agricultural potential at the same time as many developing countries have an inadequate food supply. There seems, however, to be a certain lack of interest in exporting cereals from industrialized countries to developing countries. There seems also to be a certain lack of interest in stimulating the farmers to produce high-protein cereals for human consumption.

It is thus very likely that for the near future the development of improved cereals for feed will be the main stimulus to the improvement of cereal proteins. This is likely to result also in the improvement of cereals for human consumption, as the marketing of improved feed grain will probably result in a price differentiation on the basis of protein standard. Such a differentiation might act as an incentive for the farmer to grow improved varieties which will then be available for animal as well as human consumption. Suitable analytical criteria will necessarily be developed for the production of feed grain and the same methods will be applicable to, and useful for, food grain. Such methods are also imperative for fundamental investigations of the factors that have to be changed and controlled to achieve production of high-quality cereals. The DBC method has up to now been giving promising results, but its application, restrictions and improvements must be further investigated. Such investigations are planned as an inter-Scandinavian research project.

An increase in the world supply of protein can be achieved in several ways, which should complement one another. Large savings are to be expected rapidly when, for example, harvesting, drying and storing techniques are improved. More gradually, an actual increase in the protein quality and protein quantity of our cereals can be achieved by plant breeding.

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