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Plant Breeding [and Discussion]

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Plant breeding

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This paper discusses the question: what genetic contributions to efficiency of crop plant production may be expected in the next decade or two? Two aspects of efficiency are recognized. General efficiency, reflected in the yield of a standard product, is essentially a matter of conversion of carbon dioxide and radiant energy to a desired product with minimal waste or loss. Minimal waste is achieved by optimal use of the environment and by optimization of plant structure and physiological response. The best opportunities for enhanced yields lie in improved partition of assimilate rather than in enhanced net assimilation. Minimal waste is primarily a matter of disease resistance; field (or horizontal) resistance is likely to become ever more widely used. Control of harvest and storage losses offers little opportunity to the plant breeder. Specific efficiency is reflected in quality and is concerned with altered chemical composition, often, and increasingly, of a fairly well-defined nature. There seems to be a clear trend towards breeding for quality factors. The conclusion is that the 1980s will see further yield advances, together with great improvements in specific efficiency. Thereafter we may well be, in advanced agricultures, approaching plateaux in the yield performance of many crops. If so, the levels of the plateaux will be determined by the degree of success achieved by plant breeding, interacting with such factors of the environment as are accessible to control by good husbandry.

1. Introduction

Biological performance in general rests on the genotype–environment–phenotype triangl The farmer is concerned to produce the best phenotype he can – usually the most profitable by managing the environment to the advantage of the chosen genotype. Agricultural research observes the same distinction. Plant and animal breeding are the genotypic components, husbandry research the environmental. Genotype and environment interact in the sense that optimal performance – the best possible phenotype – results from mutually adapted genotype and environment: a nineteenth-century barley variety would not stand up to twentieth-century fertility, nor would a blackface sheep do in the wet tropics. Major advances in agricultural productivity are therefore generally made, not by changing one component alone, but rather by changing genotype and environment simultaneously. The point has been well and often made in relation to the 'green revolution' which is essentially a set of variety-fertilizer packages; neither variety nor fertilizer alone suffices.

This paper is concerned with the genotypic component of crop plant efficiency, correlated husbandry changes being assumed. It looks to the 1980s but must, inevitably, rest largely upon recent trends and achievements. I shall not question the assumption that ever-increasing agricultural productivity is a desirable social objective though I am aware that some aspects of it can be questioned. Current local surpluses notwithstanding, it seems to me very probable that we shall need all the food we can produce a few decades hence.

I make a broad distinction between general efficiency (roughly, yield) and specific efficiency (roughly, quality) though it turns out that the distinction is sometimes rather arbitrary. It is perhaps worth adding that the plant breeder and crop husbandman can pursue efficiency wholeheartedly and are encouraged, indeed generally compelled, by economic factors to do so. The animal breeder and animal husbandman are in a somewhat different situation, as the preceding contribution to this discussion shows (Donald 1973). Society at large is more conscious of its animals than of its crops; no one objects to 'factory farming' of potatoes.

Literature references to a survey such as this presents difficulties. Detailed references would be impractically numerous. I have therefore chosen to refer for the most part to recent authoritative reviews which cover much of the field, notably: Eastin, Haskins, Sullivan & van Bavel (1969), Lupton, Jenkins & Johnson (1972) and Wareing & Cooper (1971).

2. General efficiency

The criterion of general efficiency is yield of a standard product, quality being disregarded for the moment. For the plant breeder the question is: what genotypic factors control the efficiency of conversion of carbon dioxide, water and minerals to the desired product with minimum waste or loss? The following discussion is based on figure 1.

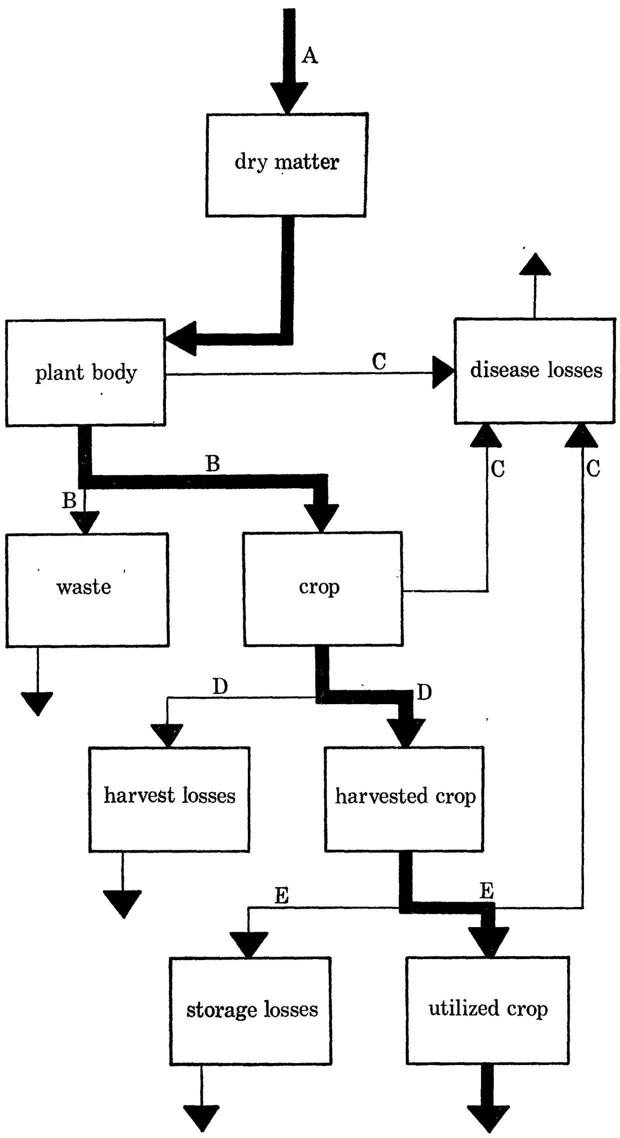

Figure 1. The fate of dry matter in crop production.

(*a*) *Dry-matter production*

If one examines a wide range of genotypes of any one crop in one place, it usually turns out that some are ill adapted and grow poorly without being obviously diseased. There must, therefore, be a genetic component of adaptation to new environments in terms of dry-matter production. Comparisons among a set of adapted strains, however, would reveal much smaller differences. Given adapted strains, husbandry seems, in a sense, much more important; timeliness of operations to use the whole season, weed control and the use of fertilizers all have their principal effects on gross growth or dry-matter production. Nevertheless, there are genetic effects, evident for example, in the breeding of non-bolting sugar beet which can be sown early in the season and in the trend towards breeding cereals with erect leaves to produce a more efficient canopy (maize, Pendleton, Smith, Winter & Johnson (1968); wheat, Bingham (1972); rice, Chandler (1969); cereals in general, C. M. Donald (1968)). Variation in photosynthetic activity is known to exist in a number of crops but is generally unrelated to yielding ability (Thorne 1971). Presumably, a source–sink relation, such that excess photosynthetic goes into unwanted structures or compensatory respiration or both, is limiting.

It is perhaps in the forages in which most of the over-ground plant parts constitute the crops that differences in total dry-matter yield would be expected to be most important. In practice, there is morphological variation among adapted cultivars of grasses thought to be big enough to make it worthwhile to breed for efficient plant structure adapted to cutting régimes, but it is not evident that large gains can be expected and, in any case, environment rather than genotype in practice limits grass production. Forage yields of 18 to 20 t/ha have frequently been achieved experimentally with short-term maximum gains in the most favourable season as high as 400 kg/ha day (equivalent to conversion of 7.9 % of incoming radiant energy) (Cooper 1972; see also Alberda 1971, Cooper & Breese 1971).

To summarize, it seems that once adapted varieties are available, large gains from breeding for enhanced dry-matter production are not to be expected; an adapted crop exploits the available environment rather effectively. This is clearly in accord with de Wit's (1968) generalization that adapted temperate crops can accumulate a working maximum of about 200 kg/ha day of dry matter, equivalent to about 20 to 25 t/ha season. Further, in crops in which only a part of the dry matter is harvested, source–sink relations – yet very poorly understood – often limit yield (Bingham 1972; Heslop-Harrison 1969; Thorne 1971; Watson 1971). This conclusion might need modification if means could be found of converting the photosynthetic systems of temperate crops to the more efficient system (with low photorespiration and low carbon dioxide compensation concentration) found in certain grasses and amaranths of warm countries (Stoy 1969). No means of doing this is yet apparent but an elegant means of selection is available (Moss, quoted in Stoy 1969).

(*b*) *Partition of assimilate*

Any crop plant requires a skeleton to bear the essential foliage and the product. Diversion of assimilate to the desired sink, whether grain or tuber, and reduction of foliage, stems and other unwanted structures to the necessary minimum has been a highly significant feature in the evolution of all crops (except for some forages). The process continues, even in advanced crops, today and there is no doubt yet scope for great changes. The following figures from Watson (1971) are indicative (useful as a percentage of total dry matter): winter wheat 34, spring wheat 36, barley 51, potatoes 84, sugar beet 63. A few examples from many must suffice.

In potatoes, reduction of haulm growth was a major feature of adaptation of the crop to different latitudes (and therefore day lengths); in the light of the figure just quoted, it is not clear how much further this can go. In European cereals, tiller number and straw length have been greatly reduced during this century and will doubtless go further; C. M. Donald (1968) has even suggested non-tillering cereals. Bingham (1971) argues that the best opportunities for cereal breeding lie mainly in improved partition brought about by more efficient plant structure; specifically, his new cereals would have reduced tillering, less stem, prolonged ear growth, more persistent upper leaves, erect leaves, increased grain numbers and, perhaps, awns. Borlaug's Mexican wheats, the foundation of the 'green revolution', carry the principle of reduction of plant size to the tropics. Sorghum in the U.S.A. and the new rices from the Philippines (Chandler 1969) are also short-strawed though, with different systems of cultivation, not sparsely tillering.

As mentioned above, dwarf cereals show a profound interaction with husbandry; they permit high fertility and demand good weed control. Among fruits (e.g. apples and bananas) and rubber, dwarf mutants are available or are being sought or induced and have the attraction of improving wind resistance and permitting large populations. The most extreme foliar reduction yet sought seems to be in the leafless (though stipulate) peas of Snoad & Davies (1972).

A rather special case of an assimilate partition problem is provided by the need in some crops to produce an article of standard size (e.g. potatoes, fruit); units outside the acceptable range may be waste or nearly so.

What are the prospects? For the whole-plant-forages, presumably little or none (though non-flowering grasses would be attractive). But for many other crops the potential must be, I think, considerable, despite the changes that have already occurred; many are surely larger, more leafy and less efficient than they need be.

(*c*) *Diseases*

Breeding for disease resistance has been a major – perhaps the biggest single – feature of plant breeding during the past 50 years. Losses caused by disease are notoriously difficult to estimate but no one would disagree that they are, in total, great. As an example, Crowdy (1971) puts U.K. grain losses in barley and wheat at about 8 Mt/year (equivalent to over 2 t/ha or one-third of the potential crop).

There are three kinds of diseases; those that kill, those that reduce the photosynthetic apparatus and those that damage the crop product. There is an enormous diversity of pathogens, including mammals, birds, insects, nematodes, fungi, bacteria and viruses. Plant breeding has had at least some success against all categories of disease and pathogen but also many failures. The most conspicuous failures have occurred when race-specific major genes were used to counter airborne fungi such as rusts, mildews and potato blight. Varieties carrying one or more race-specific resistances commonly succumb, and do so sooner rather than later, to newly evolved strains of these genetically versatile fungi. Potato breeders have realized for some years that non-specific 'field resistance' ('horizontal resistance' of Van der Plank 1963) was necessary and that the race-specific *R*-genes were little more than a nuisance. Cereal breeding is now tending in the same direction and the time is probably not far off when 'vertical resistance' against many airborne fungi will have been largely superseded. This trend seems perfectly clear. For the rest, generalization is difficult. Sometimes (as against many soil borne fungi and nematodes and against viruses) specific resistance genes are available and valuable; sometimes (as with potato leaf roll virus) they are not available, but then horizontal resistance can usually be constructed. A mixture of vertical and horizontal resistances according to circumstances seems to be indicated (Lupton 1967; Day 1968).

There are so many diseases that high resistance to everything in any one variety is statistically infeasible. Rather we shall see an increased emphasis on avoidance of extreme susceptibility coupled with a continuation of the present situation: a mixture of different kinds of resistance used jointly with sensible use of chemical controls and suitable husbandry where appropriate (cf. de Wit 1968). Diseases usually have to be lived with but there is every reason to expect that plant breeding can reduce still further the losses they cause.

(*d*) *Harvest losses*

In this category I include losses which are not due to disease. Causes are various and, though there is a genotypic component, bad luck with weather or imperfect (or ill-managed) machines are probably more important. The cereal breeder can no doubt reduce still further losses due to lodging and shedding but there is not much the potato breeder can do about imperfect lifting, cutting and bruising. In short, reduction of harvest losses will be more a matter of management than of breeding. This is conspicuously true of one of the biggest harvest losses of all – of grass fouled and trampled by the grazing animal.

(*e*) *Storage losses*

As with harvest losses, reduction of this category of loss is much more a matter of management than of variety. Initial condition of the stored material and control of the storage environment are all-important. Potatoes perhaps provide a partial exception in that some varieties, for various reasons, store better than others.

To summarize, it seems to me that greatest opportunities for plant breeding to enhance general efficiency will lie in future, as they do now, in partition of assimilates and in disease resistance. In terms of the reference letters used in figure 1, B, C > A > D, E.

3. Limits of yield

Estimates of potential maximum yields for a number of crops in northern Europe have been given by de Wit (1968). Gross photosynthesis in a closed canopy yields about 300 kg/ha day of dry matter from which remains about 200 kg/ha day, after losses in respiration and roots have been deducted. With a season of 150 days, but less than a full canopy in spring, gross dry-matter yields of 20–25 t/ha season are indicated and have in fact been achieved. A surprising range of crops produce at about this level, given good soil and good husbandry. Unless a fundamental improvement in the efficiency of photosynthesis can be achieved (see § 2*a* above) which seems unlikely, crop yields will be limited by the efficiency of partition of this level of total assimilate. For grasses (cut rather than grazed) 20 t/ha of dry matter seems feasible and is already being approached by a minority of efficient producers. For cereals, de Wit suggests about 10 t/ha of grain and for potatoes about 90 t/ha of tubers or roughly twice present 'good yields'. There would therefore seem to be room for more than a doubling of present average yields. But this neglects the fact that soils and seasons are often imperfect. It seems to me inconceivable that average yields should ever approach the maximum even if excellent individual performances were to do so. This conclusion is supported by the observation that average yields for several crops are quite closely correlated with total seasonal incident light energy (Alberda 1971). Something less than a doubling of average yields of crops seems to me to be a reasonable expectation on the basis that the best will remain roughly twice the average. This will be achieved by a combination of improved husbandry and better varieties and we could be well on the way to this situation by the end of the century.

The preceding argument would be invalidated if my assumption of maximal crop yields of 20 to 25 t/ha season were wrong. These figures are empirical and they represent approximately 2% conversion of incident radiation. Theoretically, about 9% conversion should be possible and short-term gains of 4% have been recorded (Penman 1968). One can only note the discrepancy and wonder whether physiological theory is in need of revision or whether the empirical estimates suffer from yet unrevealed defects. But even the latter still leave plenty of room for future improvement.

4. Specific efficiency

Under this heading I refer to quality factors, using the word 'quality' rather narrowly to exclude that which is better referred to as 'condition' and to exclude also variation in the amount of a chemically well-defined product for which the crop (e.g. sugar, rubber) is grown. Used thus, specific efficiency is concerned with the chemical (and to some extent the physical) constitution of the product in relation to a defined use. A working classification on which to pin the discussion is as follows:

treatment	product
(A) crop processed	(1) industrial (2) food
(B) crop not processed	(1) food (2) feed

Examples of the four categories are:

A1: rubber, sugar cane, sugar beet, the vegetable oils (e.g. palm oil and rapeseed oil), insecticides (e.g. pyrethrum), fibres (e.g. cotton) and tobacco.

A2: bread wheat, malting barleys for beer, malting barleys for whisky, processing potatoes, wine grapes, stimulant beverages (e.g. tea, coffee, cocoa).

B1: fruits, vegetables, potatoes (unprocessed), grains directly consumed (e.g. some maize, rice).

B2: grasses, legumes, brassicas, feed grains and green-fodder versions of other crops (e.g. rye, maize).

Broadly, specific efficiency is of great (and rising) significance in A2 and B1, of variable importance in A1 and of least importance in B2. The criteria of quality in A2 and B1 are largely organoleptic but there is often an approach to chemical or physical definition as in the bread wheats, malting barleys and processing potatoes. Definition is normally in fairly loose chemical, physical or technological terms (e.g. 'high nitrogen', 'high specific gravity') rather than precise chemical terms but the approach may sometimes be quite close (as in barleys for malt whisky manufacture with high amylose:amylopectin ratios or processing potatoes with low reducing sugar contents). Given that an increasing proportion of our food in prosperous north temperate societies will be processed (which seems certain) and that consumers will become ever more critical about the quality of the unprocessed fraction (a questionable assumption, perhaps, if 'quality' be distinguished from 'condition'), it seems inevitable that the demands upon the plant breeder for specific efficiency will increase. Technological needs that can be defined in exact chemical terms will be so defined; thus organoleptic or empirical technological definitions will decline in importance, to be replaced by exact chemical assay. Of great practical importance in this context is the availability of rapid methods of estimation. The development of high lysine maize for human food (Riley 1970), high lysine barleys (Munck 1972) and high diastase barleys for grain whisky distilling have been (and are being) greatly facilitated by modern analytical techniques.

A word of caution is, however, needed here. The plant breeder, working on at least some of the crops destined for processing, needs to be aware of technological possibilities that may tend to negate his efforts; the crop may come into competition with a new industrial product or quality demands may change. Thus natural rubber and vegetable fibres are both in increasing competition with the products of the chemical industry; the synthesis of the essential flavours of tea, coffee, cocoa (even whisky) is not inconceivable. As to changing quality demands, bad wine, it is said, can often be improved, beer brewing practices can be adjusted, too-sweet potato crisps can be vacuum-fried, low protein content in wheat partly compensated by the Chorley Wood process. The soya bean in the U.S.A. is changing from being primarily an oil-seed (with a protein by-product) to a source of vegetable protein with which to construct synthetic meats. Forecasts of ever increasing demands upon the plant breeder for specific efficiency need therefore to be viewed with some caution. The demands will be there but they may change rather quickly. Minor technological changes have shorter time scales than plant breeding.

As to category A 1, industrial crops, considerations of specific efficiency in some seem almost irrelevant: sugar is sugar and rubber rubber. The product is chemically defined from the start and the plant breeder is concerned only to promote yield and to try to minimize unwanted minor constituents, for example bad latex colours in rubber and gummy carbohydrates in sugar cane that interfere with crystallization. Palm-oil seems to be excellently adapted to its chosen industrial uses and there is no sign that the plant breeder will be called upon to change its composition. By contrast, rape seed oil is nutritionally unsatisfactory and a fairly fundamental alteration of fatty acid composition (mainly elimination of erucic acid) is in hand (Röbbelen 1972). Tobacco quality is defined by a truly fantastic array of organoleptic factors upon which chemistry has made little or no impression (Akehurst 1968), while quality in the fibres is defined in empirical physico-technological terms. The only possible conclusion seems to be that, in these crops, specific efficiency varies in importance from nil to critical. If the situation changes in future it will presumably be towards closer and chemically more exact definition of what is needed.

Finally, category B 2, unprocessed feedingstuffs, seems to me to present a different picture from the other three. Sheer yield of digestible dry matter dominates. For ruminants, the nature of the nitrogen content matters little or not at all (and can be supplemented by urea anyway); for non-ruminants, high energy feeds are supplemented by industrial protein and other nutrient materials. Regardless of the system of animal production, the art of the husbandman or feed-compounder repairs what deficiencies there may be in the basic materials. Suggestions that breeders of animal fodders should pay attention to protein or mineral content or to amino acid constitution seem to me to be ill conceived. Minerals can readily be provided. Proteins and amino acids are available from industrial sources and must tend, with time, to become cheaper (Pyke 1971; Raymond 1972).

One significant exception to the generalization that specific composition of animal feeds matters little concerns toxic substances. Some legumes, brassicas and grains (*Triticale*) contain various toxins which must either be eliminated or at least reduced to an acceptable level. Another exception may or may not be of general significance. Lechtenberg *et al.* (1972) have shown that the bm_3 mutant of maize yields a forage that has lower lignin content, higher digestibility and higher acceptability to stock than that of normal maize. A direct relation between the three characters is expected. Analogous mutants in other forages, if they can be found or made, might open the way to a general improvement in the specific efficiency of forages by way of lower fibre content and improved animal intake. Specific mutants such as bm_3 apart, low fibre content (reflected in high digestibility) has always been a prime concern of the forage breeder but it does look as though a qualitative advance may be feasible in some crops.

To summarize, it seems that specific efficiency, reflected in defined alteration of chemical composition, will increasingly be demanded of crops destined for human consumption, whether processed or not; will sometimes be demanded of industrial crops; and will rarely be demanded of animal feedingstuffs, where sheer yield of digestible matter dominates. Among crops destined for processing, the demands on the breeder may sometimes shift rather rapidly in response to technological change.

5. Techniques

This paper is concerned with the objectives of plant breeding rather than with the methods. Underlying all plant breeding is a great deal of hard work. Heritabilities of economic character are rarely high, large populations are needed, selection is rather inefficient and success comes, for good statistical reasons, but rarely. The basic routine of generating large segregating populations and selecting desired genotypes from their descendants is unchanging. This routine is, however, complemented and facilitated by an ever-growing array of techniques, drawn largely from genetics, of great diversity, even of elegance. To these must be added the ever more refined analytical methods to which reference was made in § 4.

Wide hybridization has been a significant episode in the evolution of many crop plants; for example, bread wheat, oats, swedes and some bananas are allopolyploids. Conscious exploitation of wide hybrids, either as sources of disease resistance by backcrossing (as in wheats, potatoes and tobacco) or as new crops *per se* (as in *Triticale*, some grasses and brassicas) is a commonplace of contemporary plant breeding. During the past 50 years sugar cane has been reconstructed on an interspecific hybrid base.

Chromosome pairing control, elucidated in wheat and inferred in other crops, offers methods of exploiting recombination between genomes on a scale hitherto unimaginable (Riley 1970).

Tissue and cell culture studies offer techniques for producing haploids or dihaploids on a scale previously inaccessible and hence of expediting breeding programmes; they also open the way to *in vitro* hybridization of somatic cells (achieved in *Nicotiana* by Carlson, Smith & Dearing 1972) and hence, perhaps, of making crosses which might not otherwise have been possible. That otherwise 'impossible' crosses can be so made, however, has yet to be demonstrated.

Polyploidy, induced by chemical means, has not fulfilled earlier hopes of providing dramatic one-step improvement. But it has had some economic success in a few crops (sugar beet, red clover and some ornamentals) and is routinely used in many preliminary breeding operations.

New population structures have been suggested by the undoubted economic success of 'hybrid' maize. Hybrid onions, sprouts and tomatoes followed and hybrid wheats and barleys are projected. The potential of hybrid small grains is uncertain but at least it has to be investigated (Svensson 1972). A major genetic problem in this context – that of heterosis and over-dominance – is yet unresolved. It may turn out that 'hybrids' are never necessary for the highest levels of performance (even in maize). The economic potential of heterogeneous populations – thought by some to be considerable – is yet another unresolved problem.

Composite crosses, as an approach to the conservation and exploitation of wide genetic viability, ought, in principle, to have genetic potential which has yet hardly been explored. They are in use in barley, potatoes, sugar cane and rubber in various forms and in various places.

Biometrical genetics, dealing as it does with the quantitative characters which are the chief concern of the plant breeder, ought to exert a guiding influence on breeding plans. It is just beginning to do so, having long had an important impact on animal improvement schemes.

Biochemical genetics took about 30 years to move from *Neurospora* to plant breeding. Several examples cited in this paper (e.g. high amylose and high diastase barley, high lysine and low lignin maize, low erucic acid rape seed) all depend, at least in part, on mutations of defined biochemical effect. No doubt future demands for specific efficiency will call forth many more. (It is worth recalling that tobacco is tolerable to smoke because of a demethylating mutation.) There is, however, one specialized kind of plant breeding in which biochemical genetics has had a rather longer history, namely the breeding of micro-organisms for the production of specific metabolites such as vaccines, antibiotics and amino acids (Meynell 1970).

Mutagenesis became something of a bandwaggon but, despite the gimmickry, has a real, and probably increasing, place in plant breeding. Given effective screening methods and biochemically reasonable objectives, mutation induction, whether by physical or chemical methods, has a considerable contribution to make. Disease resistances, biochemical attributes, and useful morphological and physiological mutants have all been induced in various crops.

To summarize, most plant breeding is, of its nature, just routine hard work and will no doubt remain so. But the breeder of today has at his disposal a great, and increasing, array of sophisticated and elegant techniques that either facilitate routine methods or sometimes make possible that which could not otherwise be done at all; he would seem to be fairly well equipped to meet the demands of the 1980s.

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Discussion

A. Hagberg (*Svalöf, Sweden*). I thank you very much for the kind words of welcome. I certainly have enjoyed very much this opportunity to attend this meeting and I am especially grateful to Dr Simmonds for his clear presentation of a plant breeders view on crop production in the 1980s. I agree with most of his statements but not all. Evidently the efficiency of the plants to produce the desired crop of maximum yield with maximum of security and with the optimal composition is of fundamental importance to the future of mankind. The increase of yield will go on – in most conditions we have not yet reached the plateau. In some countries we have a surplus of cereals some of the years. From the global point of view these surplus quantities are rather marginal although they can cause great difficulties for the individual countries. I can understand Dr Boerma's point that each developing country has to create its own potential for food production. They should not stay dependent on import of cereals from the developed part of the world. On the other hand, the suggestions put forward in the discussions here to create some kind of food bank of cereals as a reserve based on the surplus quantities should be taken seriously as we otherwise may run into severe lack of cereals in individual years. The rich countries should feel it a duty to handle such a world food bank as a reserve to avoid starvation by loss of crops.

Several questions have been raised on the quality of crops. The most important question in this connexion is whether or not it is possible to improve protein quality in cereals. Dr Boerma mentioned that at least 70% of all world supply of protein is produced as cereal protein. This

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means over 100 million tonnes of protein annually the quality of which is low mainly because of low lysine content. I certainly do not agree with Dr Simmonds in his statement that there is no need for breeding for protein quality in cereals when we can supplement with pure lysine. A simple calculation of the cost of supplementation compared to the cost of breeding is very convincing. If the genes for high lysine and improved protein quality now found in maize, barley, wheat, rice, etc., can be transferred into well-adapted, high-yielding genotypes a world cereal crop of high protein quality could be available to mankind with a protein quantity three to four times as high as all animal proteins together. And this is in crops people are used to grow, used to handle and used to consume. I think personally the discovery of high lysine cereal (first in maize) is the greatest discovery in the 1960s and it will lead to high protein quality cereals all over the world during 1980s.

At Svalöv we are dealing mainly with barley and wheat from this point of view and we already have good evidence that high lysine barley is a reality and will be marketed within a few years. These varieties have the same high grain yield as do the best conventional types; they have about 35% higher lysine yield, and their protein and especially their lysine has a much improved availability or digestability compared with the conventional barley varieties.

Still better response to selection may be obtained if the breeder concentrates his efforts to a specific protein. Thus, selection for low α-amylase activity on moisture treatment at ripening of rye, wheat and barley has resulted in varieties with improved sprouting resistance. This is especially important with rye. A new rye variety named *Otello* is giving the farmers about a 10-day longer period to find a suitable day for harvest without damage by sprouting. Rape is another very interesting crop which may be either a protein crop and/or an oil crop. Protein composition is from some aspects very good in rape seed, but the content of glucosinolates have to be reduced considerably. In our laboratory at Svalöv Egon Josefsson has proved this to be possible by efficient selection. Furthermore, the quality of the oil of rape is rather poor from a nutritional as well as from a technological point of view. However, this is also improved by plant breeding. Thus, we will at least in the Scandinavian countries in the 1980s have two kinds of rape: one oil crop rape with high quality fat and one protein crop rape yielding high quality protein.

Plant breeders have just started tackling the quality problems by breeding. In most crops the variation in chemical and biochemical systems is unexploited and we can expect great progress as soon as the breeding goal is defined and an efficient biochemical or chemical screening technique is developed. The best example of this trend in breeding towards high quality may be the development of the modern sugar beet crop.

An interesting question is whether the market in our neighboring countries e.g. the common market countries (E.E.C.) will be ready to receive high-quality varieties. The tendency at present seems to be that in those countries within the E.E.C. where the market is developed towards quality production, the stimulation system is breaking down to the level of the market in the poorest developed member country. This must be a great danger to the E.E.C. in competition with other production centres.

The breeders are used to plan for 15 to 20 years ahead because 15 years is the time very often required to obtain a practical result – a new variety – in a breeding project. Most often it is not possible to have the breeding goal defined and presented to the breeder. Very often the breeder has to take the initiative and to use his imagination and also start background research to find out what is biologically the most realistic goal. Such background research is very usefully coordinated along complex production chains leading to food for human consumption. These chains will have or will not have animals involved but they are all based on crop production.

The important information we have today about plant breeding is that the plants can be genetically changed to improved quality. We are just at the beginning of this process with new biochemical selection techniques now available. This means that rapid progress is possible in this initial stage.

The plant breeders problem is to define realistic goals – biologically and economically – for plant breeding and to find a simple and efficient screening procedure. Most often the genetic variability is present or can be created; it is not the bottleneck in most cases.

Advanced plant breeding is now a complex team work of research. However, the Plant Breeders Right Convention means a support to breeding based on marketing of varieties. Unfortunately, there is a tendency towards increased commercial interest, which means a decrease in flow of information and exchange of ideas and material. This is a hindrance to progress which I personally consider unfortunate.

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