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PUBLIC AND PRIVATE BREEDING: A COLLECTIVE RESPONSIBILITY FOR A CONTINUUM

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ABSTRACT

Plant breeding and breeding research are treated as a collective responsibility of public organisations and private enterprise. Tasks and responsibilities are described and the necessity for a division of tasks and cooperation between public and private sectors is indicated. The crucial importance of a two-way continuum between research and target groups is stressed. In order to formulate the correct research policy and to attain a continuous development of cooperation, the interaction between public and private breeding should be stimulated and organised. It is concluded that the optimal approach to plant breeding in public and private organisations is a joint approach with separate tasks.

KEYWORDS

Research policy, division of tasks, interaction, co-operation.

INTRODUCTION

Governments have the responsibility to provide conditions under which the needs of the people may be satisfied and their interests cared for. Carrying out these responsibilities is generally the task of public institutions and private enterprise.

Agriculture plays a crucial role in meeting human needs. This industry is organised into relatively small-scale units which are generally private enterprises.

Plant breeding is a powerful instrument for shaping, directing, and optimising agriculture. Breeding has gradually developed from an art into an integrating science. In breeding research the knowledge from basic sciences is integrated into a system for developing more suitable genotypes. As a consequence, the research is broad and complex, multidisciplinary and not autonomous.

Using this framework for discussion on public and private breeding I would like to look at the situation of a relatively small country where primary production is extensive, the important role of plant breeding is predominantly government funded, and the development of private breeding is relatively recent. I will present some thoughts about responsibilities, coordination, and efficiency which are based mainly on experiences in another small country with limited funds.

THE TASK AND RESPONSIBILITY OF PLANT BREEDING

Plant breeders manipulate genetic information to develop genotypes which best serve the interest of the grower, the trade, the processing industry, the consumer, and the environment. This responsibility goes far beyond the increase of yield — it requires complex research.

Plant breeders also have a long term responsibility to continually integrate and exploit relevant developments in the basic sciences. This integrating function surpasses the capacity and responsibility of individual breeders, be they employed in private or public organisations.

Breeders face many different crops and many very different problems; their task is so extensive that it must be approached from different angles. It is most important to develop effective cooperation between potential partners when funds are restricted.

Regional plant breeding activities are essential in each country because a well-developed, modern, and active breeding industry is of national interest, and genotype x environment interactions are highly variable. In addition, breeding is clearly a field of research which attracts interest from invested capital, not only for the range and diversity of improvements that can be realised, but above all because improvements are generally heritable and therefore permanent.

The crucial importance of a continuum

As plant breeding and plant breeding research develop further and international cooperation increases, the division of tasks and a continuum assumes great importance. It is thought a governmental responsibility to provide the correct conditions for development.

The correct training of breeders and research workers at different levels is critical to a developing breeding industry. It is important that this includes university training of people who are not just specialists but can overlook the whole field so that they may evaluate developments in basic disciplines for integration.

Breeding research covers fundamental risk-bearing research on the one extreme and routine application of known techniques on the other. Fundamental risk-bearing research and the more basic aspects of applied research are the responsibility of public institutes, as they are usually unattractive to private enterprise. Examples of such research are the genetic and biochemical nature of disease and pest resistance, especially durable resistance; the physiology of adaptation to stress; the introduction of alien genetic material and the study of breeding barriers; and the application of molecular and cell biology. Such research should result in exploitable knowledge, methods, or half-way breeding material.

To provide the climate for private enterprise to invest in plant breeding, governments can provide the legal protection of plant breeders' rights. This may also include the infrastructure and organisation of variety research in order to establish whether a cultivar is new, distinct, uniform, and stable.

Cultivar evaluation is preferably carried out by or under the guidance of a public institute because evaluation must be strictly objective and independent. Public institutes must also take responsibility for conveying the resulting information to the users of cultivars.

Gene banks play a basic role in safe-guarding the future food supply. The establishment and maintenance of these facilities for future plant breeding are another public responsibility.

In an ever developing society, governments have to cope with new problems all the time. To be efficient it is important to stimulate private enterprise and delegate the execution of tasks as soon as, and wherever this is possible. In plant breeding this view results in the following division of tasks.

Public institutions may concentrate on:

- the education of breeders and other research workers
- the fundamental aspects of research, i.e. the risk-bearing aspects of integrating relevant developments in basic disciplines
- the development of breeding methods and of half-way breeding material
- the evaluation and stimulation of new research fields
- the protection of plant breeders' rights
- the evaluation of new cultivars
- the foundation of gene banks
- the execution of breeding where private enterprise is as yet inadequate.

Private companies may concentrate on:

- the applied research directly related to the development, production, maintenance, and marketing of cultivars
- the execution of some of the above public tasks under the responsibility of the government.

This division of effort may lead to a profitable specialisation of research groups each acquiring appropriate skills and concentrating on different aspects of the plant breeding continuum. In this view, public institutes are instruments of policy making. It is their responsibility to challenge private breeders by demonstrating new developments and by continuous open discussion of research programmes, based on the conviction that public and private sectors are partners in a cooperative process.

In general, the actual division of tasks depends on the state of development of plant breeding in a country and on the development of the private breeding companies. The marginal area between public and private is continuously moving: where private enterprise further develops it should take over more tasks of the public area, and public institutes should concentrate more on basic and new research. Overlap of activities results in competition between public and private and that is undesirable because it discourages cooperation.

It is the government's responsibility to coordinate the division of tasks and cooperation and to attune the public activity to the private enterprise. It is therefore crucial to create and maintain a two-way continuum in information: in one way a stream of new knowledge which originates from the fundamental research, is integrated in breeding and then applied in practice; in the reciprocal way a stream

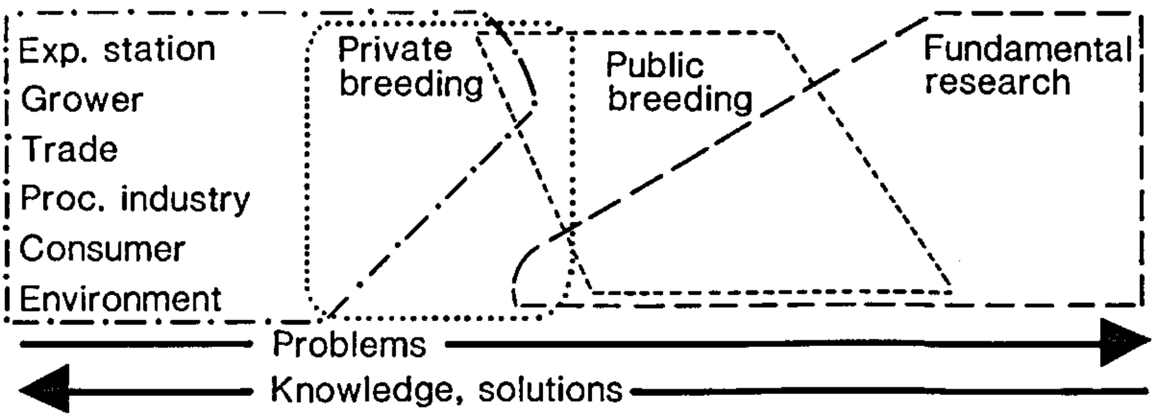

Figure 1. Partners in cooperation and division of tasks, the basis of a two-way continuum. Overlapping areas indicate direct interactions.

of problems is defined in practice for which solutions are sought in (fundamental) research (Fig. 1). Such a continuum protects against ill-balanced and disturbing developments.

In this view, public breeding — in cooperation with private breeding — acts as a bridge between the two extremes: the fundamental research and the application of knowledge in practice. This function can only be carried out in the correct way through well-developed contacts with all sectors of the agricultural industry.

A public breeder's research policy

A breeder's research policy is to a large extent determined by current and anticipated problems in agriculture. Growers form the main target group of public breeding. Private breeding companies are an essential intermediary between public research and growers.

In public breeding research institutes, setting priorities in a research programme is a problem of balancing a complex set of factors. Social as well as scientific developments should be taken into account.

Social developments that influence the breeder's programme are:

- changes in the development of different branches of industry
- developments in the relevance of crops and problems, their current and potential economic and social importance, the international market position, development in production costs, production systems and production periods
- development in the capabilities and interest of private breeding companies
- consumer's interest in quality and food safety
- the need for product diversification
- concern for the environment, e.g. the effect of heritable resistance to chemical pesticides
- genetic erosion
- problems of developing countries.

Scientific developments influencing a breeder's programme include:

- development of knowledge on host-parasite and other intimate partner relationships
- possibilities of computer-aided simulation techniques
- developments in biochemistry and physiology
- developments in molecular and cell biology.

In general, the degree of knowledge is increasing and a more fundamental approach to breeding research is necessary. Continuous changes in its environment mean a public institute needs a receptive, flexible and self-critical attitude to realise the importance of a continuous test of its programme. The programme should continually change and reflect, or rather anticipate changes in practice.

A research project is started, changed, or stopped after considering the:

- expected perspective of (further) breeding research
- relative potential of achieving improvements by research other than breeding
- costs of a project
- the expected gain in knowledge from the project.

Interactions between public and private breeding

To have a vigorous public research programme information about developments in agriculture and other sectors of society should be available. This information can only partly be gathered from literature. Both a broad knowledge of the industry and direct communication with the target groups is needed. To this end, public institutes need an organisation which guarantees their programme is continuously and critically discussed by a wide range of interested parties. A system of a board and advisory committees for each area of research is suggested. In each group room is given for the direct influence of the private sector and a full evaluation of views, opinions, and interests should take place before deciding on research priorities.

Once a decision has been made and a project is running, periodic discussions between research workers and private breeders on progress, the value of the material developed, and the moment of transfer to the private companies are very useful. Extension meetings also play an important role. It should be stressed that all these discussions allow the public institute to influence developments and programmes of private breeding companies. In this way a situation is created for a flexible development of the division of tasks, a cooperation based on mutual trust and interest, and shared responsibilities.

A crucial aspect of the division of tasks is the moment when a breeding project is transferred from a public institute to private breeders. The products of public research may be knowledge and/or new material. In the Netherlands new knowledge and methods are published and are free of change. If material is produced this may in some cases be in the form of cultivars (in asexually propagated plants) but it is mostly half-way breeding material. Cultivars are distributed by plant propagators who pay the public institute a license fee. Half-way breeding material is released to the registered Dutch breeding companies. This release of breeding material logically results from continuous discussion on a research project. A hearing is organised to discuss the release procedure and the price of the material and the board of the institute eventually decides on the release. The price of the material is based on the costs of the project, the prospects of the material, and the feasibility of the price. In general the aim is to recover 10-15% of the financial input involved in developing the released material.

A very direct influence on a public research programme can be exercised by the private sector through contract research. This interaction may increase the national research capacity by efficient use of the existing infrastructure. It can stimulate cooperation between research organisations, strengthen multidisciplinary research and it may even lead to new structures for making policy. In order to prevent disturbance of a public research programme and to restrict potential conflicts of interest, regulation is needed regarding organisation, financial and legal aspects as well as regulation regarding openness of information. Contract research projects must be compatible with the policy of the institute and must not disturb its infrastructure (management, assistance, equipment). Such projects must not be at the cost of the running programme and the normal responsibility of the institute.

Another possibility for the private sector of making use of the existing infra-structure is the creation of funds to stimulate certain research fields at public institutes. Recently this was done in the Netherlands with the integration of developments of molecular and cell biology into breeding research. This approach gives public institutes extra room for the exploration of new research areas without too much risk to the existing programme.

Separate or joint approach

Part of a government's responsibility regarding agricultural production is to see to it that plant breeding is efficient. It should also provide the correct conditions for development. But in the absence of any private enterprise in some areas of plant breeding, the initiative must be taken by public institutes.

Once private breeding companies exist, public institutes should aim for maximum development. Then, as the private companies are evolving, the division of tasks, as discussed above, may be revised. This will lead to specialisation and increased efficiency.

In the above view, public and private breeding each have their specific place and task in the necessary continuum, i.e. a joint approach with separate tasks. Generally, a public institute should concentrate on those aspects of breeding and research that cannot (yet) be taken care of by private enterprise, i.e. the more experimental and unexplored areas of research, and the removal of bottlenecks in breeding. Further activities should be delegated.

Other approaches may lead to competition between public and private breeding which could impede the necessary development of private companies (especially when private breeding is still in its infancy). Non-cooperative approaches will only accentuate the different priorities of public and private enterprise and further distract public institutes from the continually required new research. If public institutes fail on the latter point, private companies may have to seek information elsewhere.

The desired continuum should also include an organisation which controls the health, identity, and vitality of plant material supplied to the grower. Monopolies and their unfavourable consequences should be prevented. Within certain limits sound competition between private breeding companies may be a major factor for progress.

In order to have maximal productivity the joint approach — which prevents overlap and competition, is stimulating and thus makes one plus one more than two — is preferred. Flexibility, thorough discussion and broader criticism should be strived after. One of the advantages of a small country, i.e. the relative ease of organising interaction and coordination, should be exploited.

A recent example of the need for cooperation in breeding research is the integration of some developments in molecular and cell biology. At first not many plant breeders were aware of the relevance of the new possibilities and only some took the initiative of critically evaluating them in relation to plant breeding objectives. On the other hand most molecular biologists have insufficient insight in plant breeding and problems involved in the science. In this situation coordination is indispensable.

CONCLUSION

Plant breeding, a broad and complex multidisciplinary field of research with a great potential for optimising agriculture, must be approached from different angles. If public and private activities are both carried out the partners should, for efficiency, divide tasks and cooperate. Public activities are preferably concentrated on education, fundamental research, protection of breeders' rights, and cultivar evaluation. Private enterprise may cover all applied research related to the development, production, maintenance, and marketing of cultivars.

To have a continuous development of this system of division of tasks and attunement of activities, interactions between public and private sectors are to be stimulated and organised. A two-way continuum in information (problems v. knowledge) should be strived after. Reciprocal, open criticism and confrontation of views should be encouraged. The research programme and further activities of public institutes must aim at stimulating an optimal development of private enterprise.

The above means that public and private sectors should have a joint approach with separate tasks. Overlap and competition between public and private activities should be prevented.

Small countries may be big in taking advantage of an intimate public-private cooperation, avoiding waste of resources, and expressing the collective responsibility for a continuum.

SYMPOSIUM DISCUSSION

Dr A. Rathjen, University of Adelaide

I would like to take issue with the fundamental parts of the address. It seems to me that the fundamental problem is that you said the private breeders are an essential intermediary. I disagree. Public institutions have suffered for a very long time from government funding cuts. One of the underlying problems throughout this conference is the various cuts — at PBI, DSIR, universities. One of the things that we have to be very careful about indeed is that our public institutions survive. They do have to produce things which are useful to consumers. Private breeders moving into the profitable area of plant breeding is very damaging to public institutions and I submit that really the very expensive part of breeding is done at public institutions. There are only three important bodies, the consumers, the producers and the plant breeders. I don't see the need for private industry in the area.

Hogenboom

I was talking about the responsibilties of target groups and government as seen from the point of view of responsibility. And when you have the responsibility of making sure everything goes well with the population then I think it is not too difficult to give private breeders a very important intermediate function. It is not impossible for me to see that public institutes may no longer be needed after 20 or 30 years. That depends on the capacity of private breeding companies. Some of them are doing very well and are doing their own rather basic research. I think for at least basic sciences there will always be a place for government institutes to do the basic developing new research. But we can not deny that private enterprise has a very nice field of activity in doing applied research and selling varieties.

Rathjen

In the ideal world it would work but the governments do not really see themselves as having any responsibilities. They do in the social areas but not in long term development.

Hogenboom

I think the important thing is to have communication and movement, everything else will develop according to the type of society you are in.

Sir James Stewart, N.Z. Wheat Board

Is there any government pressure on you in the Netherlands to commercialise your operations?

Hogenboom

Yes, there is pressure, even more pressure than here. We have two pressures, first commercialise and the second is go into the direction of more fundamental research. This is acting like scissors because the two pressures are opposing or accumulating. It is not bad to be under pressure.

DEVELOPMENT OF HIGH AMYLOSE MAIZE PRODUCTION IN AUSTRALIA

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ABSTRACT

A high amylose open pollinated maize cultivar was developed by seven cycles of mass selection (seed parent only) to test the feasibility of high amylose starch manufacture and use in Australia. High amylose starch has been successfully produced since 1981, and a substantial local demand for the product has been identified.

A breeding plan to meet current and long term needs for cultivars with genetic diversity and higher productivity is outlined. This plan provides for continuous population improvement of two divergent parent populations for the purpose of producing an inter-population hybrid high amylose cultivar.

KEYWORDS

Amylose-extender locus, mass selection, starch production, synthetic.

INTRODUCTION

Amylose is the linear polysaccharide component of normal maize starch. The linear (amylose) and branched (amylopectin) molecular forms of starch have very different physical properties, and starches composed of only one component have many specialised uses in both food and non-food industries for which the natural mixed starch is unsuited. The high energy cost of fractionation makes separation of amylose and amylopectin from mixed starch sources non-commercial. In maize, separation can be achieved, in part, by use of gene mutants. Waxy maize, based on homozygosity for a recessive allele (*wx*) at the waxy locus, has been developed and widely used as a source of pure amylopectin starch. Recessive alleles at the loci su_1, su_2, *du*, and *ae* modify starch composition in the opposite direction, i.e. toward a high amylose content. Amylomaize cultivars, homozygous for allele *ae* at the amylose-extender locus, and with an amylose content of about 60%, have been developed and grown on a small scale in USA (about 6400 ha in 1975; Creech and Alexander, 1978) as a source of high amylose starch.

In this report we desribe our efforts to develop high amylose maize production in Australia. This development has progressed from a small feasibility study in 1980/81 to a contract production area of about 4000 ha in 1984/85. High amylose maize production is likely to continue as a high value component (in terms of returns per hectare) of the Australian maize industry. This development is not a major innovation, but is presented as an instance in which industry motivation required plant breeding innovation, namely the development of an appropriate high amylose cultivar at a low research and development cost.

THE NEED FOR A HIGH AMYLOSE STARCH SOURCE

The project to breed a high amylose maize cultivar and produce high amylose starch was developed informally, beginning in about 1974, in anticipation that a local market could be found for this starch form. There was no industry demand and little known usage of imported high amylose maize starch before our first commercial production in Australia in 1981.

Industry reasons for embarking on this project were:

- High amylose starch was an obvious and complementary addition to Corn Products — Fielders existing production of normal corn starch, waxy starch, and modified waxy starch.
- Genetically modified starch forms, from waxy and amylomaize, could provide a hedge against any future Food and Drug Administration (USA) and National Health and Medical Research Council (Australia) regulations restricting the use of chemically-modified starch in human foods.
- Between 1965 and 1980 many new food and non-food uses of high amylose starch were devised and patented (Young, 1984; Table 1) and it seemed likely that a broad Australian industry demand for high amylose starch could be developed. Local production of high amylose maize and high amylose starch was needed to test this proposition.

Table 1. Development of new applications of high amylose starch (Young, 1984).

Year	Patent descriptions for new uses: Non food	Food
1961	Amylose yarn	
	Paint thickener	
	Cigar binder	
	Water soluble film	
	Foundry core binder	Extruded confectionery products
	Cement binder	
	Low moisture film	
	Corrugating adhesive	Coating canned fruit
	Multiply packaging	Cooked food thickener
	Encapsulating agent	Transparent dried fruit coating
1970	Paper reinforcing	Confectionery - creme centres
	Surgical thread, bandages	Bread quality, antistaling
	Meat packaging film	Confectionery, gums and jellys
	Biodegradable film	Gelatin replacement
	Hydrogels for slow release drugs	Tomato paste texturising
	Textile printing, and marking ink	Deep fried food coating
	Glass fibre sizing and reinforcement	Coating french fried potato
	Tablet manufacture	Edible foams
	Air freshener gels	Low calorie bread
		Pudding thickener
		Crisp pastry dough
		Pizza pastry dough additive
1980	Slow release herbicide packaging	Canned fruit thickener
		Extrusion products

THE PLANT BREEDING RESPONSE TO INDUSTRY NEEDS

Usually there are at least two sources of cultivars for local production of a new crop. In the present study these were:

- Introduction of amylose-extender maize inbred lines from USA for production of a high amylose hybrid — a reasonable plant breeding and genetics research effort was allocated to high amylose development in USA between 1946 and 1970. A number of public, amylose-extender inbred lines, usually the backcross derived versions of popular normal maize inbreds, were developed at the University of Missouri, and at Purdue University, Indiana, (Henderson, 1980).
- Rapidly developing an amylose-extender maize population.

The latter option was chosen, for the following reasons:

- The commercial uncertainty of a local high amylose maize industry did not permit an allocation of resources for an inbred maintenance, hybrid seed production, and testing programme.
- A high amylose synthetic cultivar could be developed rapidly (three plant generations) from available stocks, and this avoided the time lag involved in procurement, quarantine, propagation, seed increase, and hybrid seed production based on introduced amylose-extender inbred lines from USA.
- A synthetic variety, though expected to have a lower yield potential than a hybrid, was appropriate for testing the feasibility of local production and end use of high amylose maize starch.
- A synthetic variety avoided the need for detailed, accurate forecasting of future seed requirements, because low cost seed can be retained to satisfy the needs for any future level of grain production. (It was this aspect of our planning that permitted a rapid expansion of the area sown in the 1982/83 and 1983/84 growing seasons).
- A broadly-based synthetic cultivar might enable high amylose maize to be grown in a wide range of environments, thus providing flexibility for securing contract acreages.

DEVELOPMENT OF SU AMYLOMAIZE HIGH AMYLOSE MAIZE SYNTHETIC

A synthetic variety with allele frequency, q (*ae*; amylose-extender greater than 0.97 was developed by the breeding plan described in Fig. 1. The SU Amylomaize cultivar was developed by hybridisation, random mating,

Figure 1. Breeding plan for development of the high amylose maize population, SU Amylomaize.:

Time period	Breeding procedure	
1974	Hybridisation	*ae/ae* ♀♀ x *Ae/Ae* ♂♂ MG Co-op/W22 FR Synthetic
1975-1976	Random mating 3 cycles	*Ae/ae* population selection of *ae* phenotype kernels
1977-1985	Mass Selection (seed parent only) 7 cycles 500 selected ears/cycle 1.25% retention	SU Amylomaize p(*Ae*) = 0.03; q(*ae*) = 0.97 selection for yield/plant stalk strength earlier maturity kernel phenotype ear height husk leaf extension

and mass selection (seed parent only) in sequential steps between 1974 and 1985. In this cultivar, the major source of variability for characters other than endosperm type was the FR synthetic. This synthetic population was developed earlier by intercrossing inbred lines 13B, 21H, 23TR, 25TR, H548. These inbreds were developed from Australian open pollinated maize varieties, and four had been used in double cross maize hybrids. The FR synthetic is a relatively late maturing variety, broadly adapted to the coastal production areas of the New South Wales north coast and southeast Queensland, and is characterised by gene frequencies p(Rf1) = 0.9 and q(rf1) = 0.1 at the Rf1 locus (restoration of fertility to Texas cytoplasm maize), and p(Pwr) = 0.62 and q(Pww) = 0.38 at the *P* locus (pericarp and cob colour).

A feature of the breeding plan in Fig. 1 is the choice of mass selection (seed parent only) for continuous improvement of SU Amylomaize. A number of effective directional selection procedures for improvement of maize populations have been well documented (Hallauer and Miranda, 1981). Mass selection (seed parent only) was chosen because:

- Mass selection is an inexpensive breeding procedure. Commercial uncertainty of a high amylose maize industry at the inception of this programme precluded an allocation of funds for high amylose maize improvement. However, using mass selection, a low cost, feasible scheme combining a cycle of selection with annual replacement of breeder seed was developed.
- Mass selection permitted individual plant selection at low cost for simultaneous improvement of ear size, ear height, maturity, husk cover and tightness, stalk strength, and amylose-extender kernel phenotype. Selection for this array of characters was necessary because the hybrids made to initiate the synthetic population were the rather wide cross of USA corn belt germplasm with Australian maize.

Low cost mass selection (seed parent only) integrated with breeder seed replacement has been carried out for seven cycles. In each cycle, the number of selected ears required was set at 500, to provide sufficient breeder seed and to permit selection at moderate truncation levels for each of the plant characters listed above; the total population size was not predetermined. Selection was by phenotypic evaluation of individual plants in an isolated foundation seed production area of about three hectares. Usually the required number of ears was obtained from an area of about one hectare. On this basis the retention fraction was about 500/40,000 or 1.25%. The truncation level achieved for individual characters was not recorded, but an approximate value can be estimated by assuming equal selection intensity for each of the six characters. Then, the truncation level for individual characters is given by $0.0125^{1/6} = 0.48$. This is equivalent to a selection intensity of 0.81 (Falconer, 1981).

In the SU Amylomaize programme, residual plants after mass selection are bulk harvested as a foundation seed lot. Annual replacement of breeder seed, designed to maintain the *ae* allele frequency at greater than 0.95, is integrated with mass selection. In each generation, the amylose extender phenotype kernals from the 500 selected seed ears are composited to obtain the planting seed for a one hectare field that is the population for the next cycle of mass selection and for breeder seed production.

As a check on the maintenance procedure, the relative frequency of alleles *Ae* (normal endosperm) and *ae* (amylose-extender) has been calculated from the proportion of heterozygous (*Ae/ae*) plants detected among the selected group of ears in each generation of mass selection. These data are given in Table 2, and show that this method of producing breeder seed has been effective in keeping the frequency of the *ae* allele high.

Table 2. Estimated allele frequencies at the *Ae* (Amylose-extender) locus in selected populations, and an unselected population, of SU Amylomaize.

Population	Year grown	Allele frequencies *Ae*	Allele frequencies *ae*
C0	1978	0.03	0.97
C3	1982	0.02	0.98
C4	1983	0.02	0.99
C5	1984	0.01	0.99
C5[1] Commercial	1984	0.06	0.94
C6	1985	0.03	0.97

[1] Commercial field planted with C4 breeder seed.

One observation suggests that annual replacement of breeder seed will continue to be good policy. The allele frequencies in a commercial production field in 1984 were calculated from the proportion of *Ae/ae* plants to be p(*Ae*) = 0.06 and q(*ae*) = 0.94. These estimates compare with the allele frequencies in the preceding population (i.e. C4-1983) of p(*Ae*) = 0.01 and q(*ae*) = 0.99. The amylose content of amylomaize is only slightly reduced by normal allele contamination up to 10-15%, but it is still desirable for the *ae* allele frequency to be maintained at greater than 0.95 in foundation seed.

The quality of the high amylose starch produced from SU Amylomaize has been checked by measurement of amylose content, and by some physical tests. The apparent amylose content of 14 samples from the 1982 growing season was measured at Corn Products/Moffett Research and Development Centre, Illinois. Apparent amylose values ranged from 53.3 to 69.0%, and the mean value was 61.7%. These values indicate acceptable quality because high amylose starch is acceptable for most applications if the apparent amylose value is greater than 50%.

CURRENT GOALS OF HIGH AMYLOSE MAIZE BREEDING

One function of plant breeding is to provide, through forward planning, for the future genotype needs of a crop production system. For high amylose maize the immediate needs are for cultivar diversity and cultivars of increased yield potential.

High amylose maize production in Australia has been developed with a single cultivar. SU Amylomaize has been grown in all production areas from Gippsland (Victoria) to Burdekin R. (North Queensland). It is logical to expect that growers will demand cultivars with regional adaptation, particularly in terms of disease resistance, and a higher potential yield. Response to this pressure will lead to cultivar proliferation and to a level of cultivar diversity.

Achieved yields of SU Amylomaize are low (3 to 4 t/ha) relative to that of normal endosperm single cross maize hybrids (8 to 10 t/ha). This is because:

- SU Amylomaize is a population with a lower potential yield than that of productive hybrids.
- The *ae* (amylose-extender) allele affects starch content and kernel size, as well as the amylose:amylopectin starch ratio.

Typically, homozygous amylose-extender endosperm kernels have reduced 1000 kernel weight and reduced test weight. These effects of the *ae* (amylose-extender) allele were quantitiatively measured by paired observations on kernels of normal and amylose-extender phenotype from ears on plants with heterozygous alleles at the *Ae* locus (Table 3).

In all 38 separate comparisons which provided the data summarised in Table 3, the amylose-extender phenotype class had reduced 1000 kernel weight and reduced kernel density, compared with the normal phenotype class. The mean paired differences were significantly different ($P<0.001$) to zero in all six tests. The effects, averaged over three sources of material, were a 10.5% reduction in 1000 kernel weight and 5.6% reduction in kernel density.

There are two methods of providing cultivar diversity and higher yield potential in high amylose maize. An expedient procedure is the introduction of standard inbred lines of *ae/ae* genetic constitution from USA, for the purposes of local production of single or double cross high amylose hybrids. Inbreds W64A *aeae*, OH43 *aeae*, B37 *aeae*, B73 *aeae*, Mo17 *aeae* and A632 *aeae* have been introduced. With these lines, an array of hybrid high amylose cultivars equivalent in genetic diversity and regional adaptation to the normal endosperm hybrid cultivars currently in use in Australia can be produced. Two reservations on this approach are:

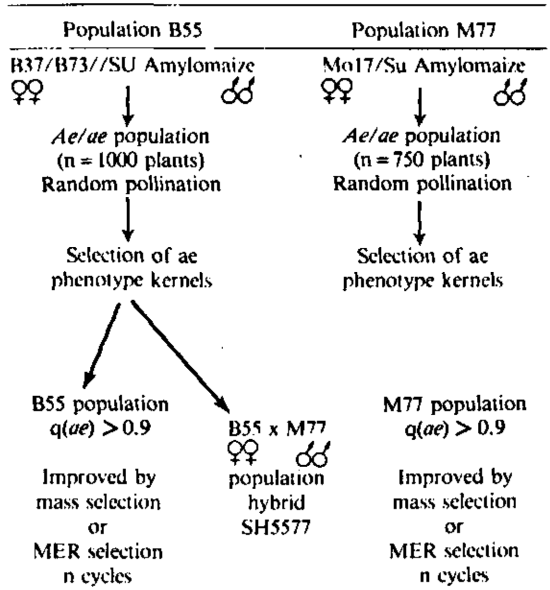
- In some inbred and hybrid backgrounds the *ae* allele is associated with extreme starch per kernel reduction resulting in a collapsed, shrivelled kernel at maturity. Evaluation of hybrid combinatons and selection among hybrids may overcome this defect, but the opportunity for such selection is restricted by the small number of

Table 3. Paired comparisons of normal and amylose-extender endosperm kernels, from *Ae/ae* ears, for kernel weight and density.

Source of *Ae/ae*	Kernel phenotype	Number of ears studied	1000 kernel weight: Group means (g)	1000 kernel weight: Mean difference (g)	Kernel density[1]: Group means (g/100 ml)	Kernel density[1]: Mean difference (g/100 ml)
SU Amylomaize, C6	Normal		324.3		75.8	
		20[2]		+27.5±2.6		+4.2±0.4
	Amylose-extender		296.7		71.6	
B55, syn-1	Normal		317.9		77.4	
		7[3]		−39.4±4.5		+5.4±0.7
	Amylose-extender		278.6		71.9	
M77 syn-2	Normal		357.0		76.9	
		12[4]		+45.4±4.3		+3.9±0.6
	Amylose-extender		311.8		72.9	

[1] Measured as sample weight/dry volume. Values inflated compared with standard test weight, by measurement of dry volume in a narrow diameter graduated cylinder.
[2] Unequal sample sizes in range 137 to 202 kernels.
[3] Unequal sample sizes in range 106 to 417 kernels.
[4] Unequal sample sizes in range 131 to 286 kernels.

Figure 2. A population improvement — population hybrid breeding plan for high amylose maize



inbreds presently available.

- Amylose-extender inbreds are more difficult to propagate and seed increase than their normal counterparts, and costs of production of hybrid seed, particularly of single cross hybrid seed, may be high.

The second method is based on the opinion that the potential size of the high amylose maize industry and its immediate and long term cultivar needs combine to make a population improvement breeding plan appropriate. Such a breeding plan has been initiated and it is described in Fig. 2. To implement this plan, two maize populations designated B55 and M77, have been created so that the population hybrid, B55/M77, will exhibit heterosis for grain yield. The populations B55 and M77 conform to, and make partial use of the known Reid/Lancaster heterosis pattern that is exploited in modern maize breeding (Chase, 1974; Sprague, 1984). The first interpopulation hybrid, SH5577, was produced by crossing the broadly based syn-2 populations of B55 and M77 in 1984. The respective parental populations have the genetic variability to sustain intra-population selection for kernel type (to increase starch content), disease resistance (particularly for stalk rot and common smut), and individual plant yield. It is proposed to use mass selection for intrapopulation improvement, and to use the improved population in each generation for production of hybrid seed. In this manner any intrapopulation improvement that is reflected in increased hybrid yields is immediately transferred to production. This 'two divergent population to population hybrid' scheme makes limited immediate use of heterosis, but sets up the condition whereby more sophisticated and costly selection schemes, involving testing for progeny performance, (e.g., modified ear row selection, or reciprocal selection,) could be implemented in the future, if needed, and if resources are available. Also, greater genetic divergence of the broadly-based parental populations should result from one backcross of each to their respective recurrent parent lines i.e., in the populations developed from the matings B73/B37 ♀♀ //B55 ♂♂, and Mo17 ♀♀ / M77 ♂♂ respectively.

A feature of this scheme is that there is sacrifice of expression of heterosis for grain yield in favour of provision for:

- Low cost hybrid seed production (because the residual plants from each generation of mass selection can provide ample parental seed at low cost for hybrid seed production.
- Continuous population improvement, initially for plant, kernel, and disease reaction characters but ultimately for yield of grain also. Experimental comparison of alternative cultivars will be needed to determine if this compromise is wise. The scheme provides for limited cultivar diversity, in that SU amylomaize, the divergent populations $(B55)^n$ and $(M77)^n$, the *population hybrid SH 5577, and the* advanced generation of the population hybrid could all be used as cultivars in circumstances deemed appropriate.

DISCUSSION

It is premature to assert that high amylose maize is an established component of the Australian maize industry. However, a capacity to produce and market high amylose starch has been demonstrated, and a substantial local demand for the product has been identified. Progression to this point is an outcome of close industry — plant breeding interaction, to which each has made an identifiable contribution. The recognition that new uses for high amylose starch might translate into a local demand for this product was a pure industry perception. Development of a low cost breeding plan to obtain a local cultivar to test the feasibility of local production and marketing of high amylose starch was an appropriate plant breeding response to the commercial uncertainty of the project at the time. This obviated the need for even moderate research funding, which might or might not have been available between 1974 and 1980.

We have indicated that plant breeding can provide, through forward planning, for future genotype needs of a high amylose maize industry. This does not imply that we predict expansion of the industry, though this would be welcome. Rather, combined industry-plant breeding activities in the near future are directed toward stabilising the industry by:

- Enhancing the profitability of high amylose maize production.
- Broadening the base of local demand for the product.

The first of these goals is in the province of plant breeding, i.e., through the development of cultivars of greater productivity. In the developmental period, industry sources have been willing to compensate for lower yield of amylomaize by raising the commodity price. Growers, manufacturer, and end users could expect to share the benefit if high amylose starch can be produced at a lower unit cost by means of high productivity cultivars. On the second of these goals, local end users are not currently using high amylose starch for the full spectrum of its applications. Industry is active in demonstrating the full array of uses of high amylose starch to potential end users, and in exploring the possibility of export marketing.

The establishment of high amylose starch production in Australia has generated interest in other maize genotypes as natural sources of modified starch. There is speculation that the desirable properties of high amylose maize starch depend in part on an increase in a starch fraction described as 'anomolous amylopectin'. The latter fraction is interpreted (Wolff *et al.*, 1955) to contain amylopectin molecules of greater linearity, and hence a tendency for polymerisation, compared with normal maize amylopectin. Research to produce high amylose maize lines enriched in anomalous amylopectin and to determine if this variation is useful to industry will require future contributions from genetics, plant breeding, and starch chemistry.

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