Breeder Demand for and Utilisation of Wheat Genetic Resources in Australia

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ABSTRACT

As part of an ACIAR-funded project on genetic diversity in wheat in Australia and China, Australian wheat breeders were surveyed to assess the importance of genetic diversity to breeders. This paper reports the findings of that survey, and identifies the key issues that concern wheat breeders. The issues addressed include the breeders' attitude to diversity and the diversity available in their current gene pool. The sources of materials that breeders use to maintain and/or increase diversity in their programs are identified, and ways in which diversity influences breeding decisions are also examined. More importantly from the policy view point, survey responses identify changes over time in the environment in which breeders operate that affect the extent to which they can enhance diversity. The impact of funding constraints, in particular, is shown to influence the extent to which breeders can utilise genetic diversity. The paper raises some important issues for the future genetic diversity of Australia's wheat industry, and the extent to which economic problems related to genetic diversity may arise in the future.

Key Words: genetic/diversity/wheat/breeder/survey

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1. Introduction

The Australian Centre for International Agricultural Research (ACIAR) has provided funding for a project on genetic diversity in wheat in Australia and China, coordinated through the International Maize and Wheat Improvement Center (CIMMYT), in Mexico.

As part of that project, information on the role of genetic diversity in wheat breeding programs in Australia was sought. In particular, we are interested in the importance placed by breeders on genetic diversity and the extent to which there are policy-related factors that inhibit or assist the process of broadening that diversity. In other studies that we are undertaking as part of the overall project, we intend to explore (1) appropriate measures of diversity for economic analysis; and (2) using those measures, the diversity among cultivars in both farmers' fields and at aggregated levels. Measures of diversity, for example, include indicators of spatial and temporal diversity. Conceptually, the spatial and temporal distribution of cultivars across the wheat-producing areas of Australia represent the simultaneous outcome of the supply of genetic diversity in the nation's wheat breeding programs and the derived demand for diversity.

This survey provides some indication of breeders' perceptions of the supply of genetic diversity and the factors that shift or influence the supply. Since the determination of which genetic resources are utilised in the varieties available for cultivation originates largely with breeders, their role in affecting varietal supply is a key element in explaining past and present trends in observed diversity outcomes. A clearer understanding of breeders' methods for priority setting, their perceived constraints, and their understanding of their operating environment is therefore quite important. Farmers demand cultivars for yield or other attributes such as quality or disease resistance, but the outcome of their choices in the aggregate, as constrained by the supply that is available to them, determines the pattern of spatial and temporal diversity.

Previous work on the genetic diversity of Australian wheat by States is summarized in Brennan and Fox (1998), with a particular focus on the contribution of CIMMYT germplasm. Using coefficients of parentage weighted by area shares, Brennan and Fox found some concern for a narrowing in the genetic diversity grown in some eastern Australian states. As has been argued by Souza *et al.* (1994) and Smale and McBride (1996), when farmers choose to grow large areas using only a few varieties, the decline in diversity that results expresses the factors that influence farmer demand more than the decisions of wheat breeders. In general, based on average diversity and weighted diversity measures of Souza *et al*., the diversity among wheat varieties grown in Australia remained high from 1973 to 1993.

Other surveys of breeder utilisation of genetic resources in crop breeding programs include the studies by Duvick (1984) and Rejesus *et al*. (1996). Based on his analysis of survey results for cotton, soybean, wheat, sorghum, and maize, Duvick concluded that although the genetic base of US field crop production was not as narrow in 1981 as in 1970, crop area was concentrated in a relatively small number of favored cultivars. Duvick argued, however, that the genetic base of elite germplasm is wider and provides more useful diversity than is often assumed. Among modern varieties, varietal replacement creates a genetic diversity in time that substitutes for the genetic diversity in space found where farmers cultivate more heterogeneous landrace populations.

Genetic reserves held by crop breeders are also significant. Data from an international survey of wheat breeders conducted by CIMMYT in 1995 (summarised in Rejesus *et al*. 1996) show that the crossing blocks in developing countries contained larger sections of landrace materials and lines from CIMMYT International Nurseries than those of high-income countries. As a result, their parent material may be more genetically diverse in terms of types and geographical origin.

In the following section, the survey of Australian wheat breeders is described, and the results of the survey are then presented in section 3. Some implications of the findings are then drawn out in the final section of the paper. To assist readers understand the issues more clearly, a glossary of technical terms and acronyms used in the paper is presented in Appendix A.

2. Survey of Australian Breeding Programs

A survey questionnaire was sent to each of the 14 Australian wheat breeders, in both the public and private sector. All but one of those breeders directly releases varieties for commercial use by farmers. A copy of the questionnaire is attached (Appendix B). A total of 18 separate questions were asked, divided into issues of:

(a) Attitude to diversity;
(b) Diversity in current gene pool;
(c) Sources of materials to maintain and/or increase diversity;
(d) How diversity influences breeding decisions;
(e) Impact of changes over time on diversity; and
(f) Impact of funding constraints on diversity.

Before being mailed to the respondents, the survey form was pilot-tested to ensure the questionnaire was clearly worded and unambiguous. That process led to responses generally being complete and appropriate, although some comments that were included in the "Any other comments" section were re-allocated to an earlier section of the questionnaire when processing the responses.

The survey was carried out in the period August to October 1998. Overall, the final response rate was 86%, with 12 completed responses being received from the 14 distributed.

3. Results of Survey

3.1 Attitudes to Diversity

Breeders were asked if they believed that a lack of genetic diversity available to their program was constraining their progress in breeding. There was a range of responses, from a definite "No" from six breeders to "Yes, for some specific characters". Rather than the *availability* of diversity, breeders felt the constraints on their breeding progress were due to the lack of *means to use* effectively the genetic diversity available. Thus, some breeders suggested that there was generally adequate diversity available when they sought it our specifically, but that they were unable to exploit that diversity fully because of limited funding.

When they were asked to rate the extent to which progress towards specific goals was constrained by a lack of available diversity (Table 1), the breeders gave generally consistent replies.

- With respect to yield, breeders reported a wide range of views as to whether lack of diversity was constraining progress, although very few considered it a primary constraint to yield progress.
- In terms of rust resistance, breeders were unanimous in their opinion that a lack of genetic diversity was not limiting progress. An interesting finding, though, was that breeders expressed less concern about diversity in their own program than about diversity available outside the program. This finding reflects the view that while they use the main known rust resistances, the number of effective resistances available worldwide is a matter for some concern.
- For other biotic and abiotic stresses, breeders ranked the extent to which lack of diversity was constraining progress as medium or high.
- Diversity in quality was generally ranked low or zero as a constraint.

Table 1: Breeder Ratings on Obstacles Presented by Lack of Available Diversity *

(H: high; M: medium; L: low; 0: zero)

	In your collection				**Within Australia**				**Worldwide**			
	H	**M**	**L**	**0**	**H**	**M**	**L**	**0**	**H**	**M**	**L**	**0**
Yield	1	4	5	2	2	4	4	2	2	4	2	4
Rust resistance	0	0	9	3	0	2	8	2	0	4	4	4
Other biotic resistance	2	5	3	2	2	6	2	2	1	6	1	4
Abiotic stress	1	5	3	3	1	6	2	3	1	6	0	5
Quality	0	2	6	4	0	3	5	4	0	2	4	6

* Out of total response of 12 breeders

There was no evidence of regional differences in the responses, at least partly because the small number of respondents made such trends difficult to identify.

In additional comments, breeders reiterated that the constraints are mainly due to a lack of knowledge of sources of specific, economically important genes, or to the breeders' inability to select effectively for all the important characters simultaneously, rather than a lack of availability *per se*. Consistent with that view, two breeders reported that available diversity was not constraining progress in any aspect at any level.

3.2 Diversity in Current Gene Pool

3.2.1 Diversity in current program

Breeders were asked to describe the diversity of their current gene pool. Two breeders described it as "High," one as "Low," and all others rated their genetic diversity in their current gene pool as "Medium" or "Medium-High." One of the "High" ratings came from the one germplasm development commercial breeder responding to the survey. Overwhelmingly, then, breeders of commercial varieties consider that they maintain a moderate level of diversity in their own programs.

3.2.2 Entries in Crossing Block

As an indication of the size of the breeding programs, breeders were asked to estimate the total number of entries in their "crossing block"; that is, the potential parental lines in the most recent season. The size of the breeding program, as defined this way, does not necessarily carry implications for diversity levels. The mean for all breeders was 231 lines, although the numbers ranged from 40 to 550. The response given by the germplasm development breeder was particularly high because that program is based mainly on extensive backcrossing. About 30% of breeders had 50 lines or fewer in the crossing block, with a similar proportion having 400 or more.

3.2.3 Types of materials in crossing block

Breeders were then asked to specify by source the percentages of entries in the crossing block, on average over the past five years. The results are summarised in Table 2. Since the main sources of materials used for crossing are the breeders' own programs, they are for the most part working with adapted materials. When looking outside their programs, Australian breeders generally rely very little on landraces in their programs, preferring to use more adapted materials from either other Australian programs or international centres such as CIMMYT and ICARDA. Other national programs were used less frequently. Specialised programs use lower levels of material from other Australian programs, because materials from other Australian programs are less relevant to the specific goals such as durum breeding. Breeders also turn to materials such as the *Triticum tauschii* derivatives and synthetic hexaploids, and specialised germplasm for specific attributes from a variety of sources.

Table 2: Types of Materials in Crossing Block (%)

	Unweighted mean	**Weighted mean***	**Minimum**	**Maximum**
Landraces	**2**	**3**	0	10
Lines from own program	**43**	**35**	20	80
Lines from other Australian programs	**19**	**18**	2	35
Lines from overseas national programs	**8**	**10**	0	20
Lines from CIMMYT or ICARDA	**17**	**19**	2	50
Other (mainly specialised germplasm)	**10**	**15**	0	50

* Weighted by number of entries in crossing block

These results are similar to those reported in Rejesus *et al*. (1996). In that study, respondents from all regions of the world appeared to give top priority to the advanced lines of their own programs. For the high-income countries, the Former Soviet Union and Eastern Europe, the second most important materials entered in crossing blocks are nationally released varieties, followed by advanced lines from other countries. In the crossing blocks of wheat breeders working in developing countries, CIMMYT lines and released varieties are the second most heavily used type of germplasm.

3.3 Sources of Materials to Maintain/Enhance Diversity

3.3.1 Introduction of new materials to program

To assess the rate at which breeders routinely seek to introduce sources of genetic diversity from outside their program, the survey asked what percentage of the materials in their crossing block was new each year. On average, breeders introduced 25% new materials each year (29% when weighted by number of lines in the crossing block) (Table 3). That percentage was higher for breeders emphasising germplasm development or specialised programs rather than the commercial release of mainstream varieties. From these responses, it appears that breeders of commercial varieties prefer to work with a known population and to introduce new materials strategically.

Table 3: Percentage of New Materials in Crossing Block Each Year

	Unweighted mean	Weighted mean	Minimum	Maximum
% new materials each year	**25**	**29**	7	70

The mean value of the replacement rate found here is lower than that reported for high-income countries (59%) by Rejesus *et al*. (1996), although the sample sizes in both cases are small (38 for high-income countries in the Rejesus *et al*. study).

3.3.2 Types of materials introduced to increase genetic diversity

Breeders have looked to a range of sources for new materials and have introduced various types of materials over the past five years to increase the genetic diversity in their program (Table 4). The two main sources of materials have been lines from CIMMYT or ICARDA international nurseries (40%) and varieties or advanced lines from other Australian breeding programs (29%). Other significant types of materials have been varieties or advanced lines from overseas national programs (14%) and specialised materials from various public and private sources (18%). The very low level of use of landraces (2%) again demonstrates that breeders are tending to use more adapted materials for introducing diversity. These results are again similar to those reported in Rejesus *et al*. (1996). In that study, only 7% of all parent materials used in crossing in high-income countries were wild relatives or landraces. By contrast, breeders in developing countries reported that 14% of parent materials used in the pursuit of yield, biotic resistance, abiotic resistance or quality goals were wild relatives or landraces.

Table 4: Types of Materials Used to Increase Genetic Diversity (%)

	Mean	Minimum	Maximum
Landraces	**2**	0	10
Lines from other Australian programs	**29**	0	70
Lines from overseas national programs	**14**	0	35
Lines from CIMMYT or ICARDA	**40**	12	80
Other (mainly specialised germplasm)	**15**	0	50

3.3.3 Sources of materials used to increase genetic diversity
Breeders use a wide range of sources for their materials in order to broaden the genetic base of their programs. The main sources listed (in order of number of times mentioned) were:

1. International nurseries, especially from CIMMYT (also from ICARDA);
2. Exotic (non-commercial) lines from germplasm development programs, such as those conducted by NSW Agriculture, Agriculture Victoria, CSIRO, and the University of Sydney;
3. Australian Winter Cereals Collection, Tamworth;
4. Lines from other national programs, especially USA, Canada, Europe;
5. Other lines from other Australian breeding programs;
6. Other lines from CIMMYT, such as synthetic wheats;
7. Overseas private company sources.

3.3.4 Use of material from Australian Winter Cereals Collection
All breeders reported that they had used the Australian Winter Cereals Collection (AWCC) in the past five years. The average number of requests reported per breeder in that period was 24, or approximately 5 per year[1].

The breeders generally judged the material they obtained as “useful,” “very useful,” or “essential” in enabling them to expand the range of genetic materials they require. The AWCC is commonly used as a means of obtaining specific germplasm with targeted attributes in order to broaden the genetic base of the breeding programs.

3.4 How Diversity Influences Breeding Decisions

3.4.1 Effect on crosses made
All breeders indicated that genetic diversity influences their decisions on the type of materials used in their crosses. Most crosses are based on adapted germplasm, which leads more directly to varieties for release. However, most breeders indicated that they use some (often relatively small) proportion of their crosses with more diverse material in wider crosses to add variability for grain yield, quality and stress tolerances to their programs.

3.4.2 Effect on crossing techniques used
All but one of the breeders indicated that the need to introduce genetic diversity affects, at least in part, the crossing techniques used. Almost all breeders specifically mentioned that they were more likely to use back-crossing when working with exotic or poorly adapted material in order to increase the gene frequency of the adapted parent (and hence increase the probability of commercial acceptability). Some breeders mentioned other crossing methods used with these materials, including bi-parental and triple crosses, and particular crossing strategies they us for back-crossing more exotic materials.

[1] Separate information provided by M. Mackay, Curator AWCC, indicates that over the period 1993 to 1998 between 22 and 44 requests for materials were received from Australian wheat breeders each year. On average, 12 items were sought in each request. These requests from wheat breeders represented approximately 25% of the total requests to the AWCC in that time.

3.4.3 Effect on selections made

Most breeders indicated that the selections they make in their programs are affected by their concern for genetic diversity. Where backcrossing is used, some breeders suggested that they need to take fewer selections, while for others where more distantly-related material is used, more selections may be necessary to get useable types. In general, the heritability and ease of selection (which is of course related to parental material used) affects selection methods and approaches, with more cycles of crossing/selection needed for the more diverse material. Approximately one quarter of the breeders reported that all crosses were treated equally in terms of selections, although one then noted that that is probably not a good strategy.

3.4.4 Effect on varieties released

A small majority of breeders indicated that genetic diversity does influence their decisions on which varieties to release, as they want a range of maturities, stress tolerances and quality types in their mix of varieties available. However, several breeders replied that it does not influence those decisions, or that it would only do so if there were a yield advantage. It appears that breeders generally strive to release varieties with a range of genetic backgrounds, but if they find that an advanced line has some yield or quality improvement they will release it, regardless of how close it may be genetically to other existing varieties.

3.4.5 Determinants of genetic materials used in program

Breeders gave a wide range of responses when asked what factors influence decisions they make on the genetic materials to use in their programs. Broadly, though, they indicated that they consider the limitations of their current germplasm, the need to maintain variability for important characters in their program, the availability of suitable material, and an assessment of the needs of the industry in terms of quality, yield, resistances, and market types. The funding constraints and the immediate expectations of funding bodies and growers were also listed as factors that influence the choice of genetic materials in the program, since these create pressures to make fewer wide crosses and focus on the main shorter-term aims.

3.5 Impact of Changes over Time on Diversity

Breeders were asked whether there had been changes over the past 15-20 years in the environment in which they operated that had influenced the extent to which diversity was incorporated into their programs. Breeders responded in a number of ways. Only one breeder reported no influential changes on the way in which diversity is incorporated in the breeding program. Others listed a number of changes in their programs, without relating them directly to diversity. However, the majority of respondents described a range of changes in either the extent to which diversity is available or the way in which they incorporate diversity over that period.

Factors influencing the extent to which diversity is incorporated in the breeding programs included:

(a) Changes in market quality parameters;
(b) Changes in funding levels and arrangements;
(c) Changes in disease spectrum;
(d) Changes in the quarantine system;
(e) Changes in availability of exotic breeding materials;
(f) Technological changes

(a) Impact of changes in market quality parameters
Quality objectives have become more prominent in breeding programs over the past 15-20 years, as markets have become more discerning in the wheat qualities they demand. Because many lines are now rejected for reasons of unsuitable quality, some breeders say that they are more constrained in the choice of parents. Many breeders now look for sources of a particular quality trait and limit their use of lines that exhibit poor attributes for that trait.

On the other hand, the increase in the quality types that are now acceptable to the market means that wheat varieties can be released in several different quality categories. This change has allowed breeders to make broader crosses than if there were only one or two narrowly defined quality types. The result is a set of varieties that are widely diverse in maturity types, dough qualities and end uses, but that are not necessarily genetically diverse. The overall impact of the market quality parameters on genetic diversity is therefore ambiguous.

(b) Impact of changes in funding levels and arrangements
Modifications in the nature of funding for breeding programs have also taken place over the past 10 years or so. It has changed from a situation of core funding from (generally) State governments to levy-based funding through the Grains Research and Development Corporation. Breeders reported that the funding structure has consequently become more skewed towards short-term outcomes. The funding structure does not encourage wide crosses and crosses for parent building because crosses such as these aimed at genetic diversity, while critical to long-term progress, are long-term and unpredictable. This has led some of the breeders to emphasise back-crossing for the addition of specific characters and to focus less on crosses aimed at expanding genetic diversity.

On the other hand, one breeder with a specialised program reported that funding had become greater and more flexible in recent years, allowing the opportunity to pursue small projects outside the main breeding program. This was not a common response.

(c) Impact of changes in disease spectrum
Wheat diseases have had an ambiguous impact on genetic diversity over the past 15-20 years. In that time, some wheat diseases have spread through changes in agronomic practices such as stubble retention and reduced tillage. These modifications in farm management have required that resistance to additional diseases be incorporated into new varieties. At the same time, the introduction of new diseases such as stripe rust in the late 1970s has reduced diversity due to the need to incorporate genes with resistance to stripe rust into new varieties. The use of the few available resistance genes initially limited the materials that could be used in some programs until effective and broad-based resistance was in place.

On the other hand, the achievement of a relatively stable situation over the same period for stem and leaf rust (and more recently for stripe rust) has permitted additional breeding objectives to be addressed. A larger amount of resources were thus made available to incorporate additional diversity for other characters. In addition, the increased threat of exotic diseases such as Karnal bunt and Russian Wheat Aphid has influenced breeders to identify materials containing resistance for these diseases in sources that have not previously been used in the breeding programs.

(d) Impact of quarantine system
Breeders also expressed concern that the rate of movement of material through quarantine was constraining the rate at which diversity could be incorporated. Proposals to have more than

one generation in quarantine were put forth, since it can take as many as 18 months between the arrival of the seed in Australia and its availability to the breeder.

Recently, the Australian Quarantine Inspection Service (AQIS) introduced "cost recovery" for the quarantine aspects of importing germplasm into Australia. Breeders introducing germplasm into Australia are now faced with having to pay higher direct costs than in the past. Given budget constraints, these costs are becoming increasingly significant, and some breeders reported that they have had to reduce the number of lines they import for testing. This could have important impacts on the genetic diversity of Australian crops in the future.

(e) Impact of changes in availability of exotic breeding materials

The recent development of new synthetic hexaploids (based on *Triticum tauschii*), and their availability through CIMMYT and ICARDA, in particular, has provided Australian breeders with access to a wide range of new diverse materials. These synthetic hexaploids were mentioned by many breeders as sources of new diversity available to them, often through materials introduced through the AWCC.

Breeders also mentioned that in recent years, germplasm enhancement programs have been established by various organisations in Australia. These programs have become significant sources of diversity for particular characteristics. At least one breeding program has established its own separate germplasm enhancement program to develop high-yielding, high-protein parents and increased genetic diversity for use in the breeding program.

Finally, the increased interest in durum wheats (and other tetraploids) in recent years has increased the amount of genetic information available about durums. These developments have greatly benefited the diversity of the durum breeding program.

(f) Impact of technological changes

Breeders mentioned several aspects of technological change in the past 15-20 years that had an impact on genetic diversity. For example, improved communication methods such as Internet access have made the exchange of information faster, so that breeders can be in contact with more people to know what genetic diversity is available.

In addition, methods used to incorporate diversity have changed with the development of molecular markers and double-haploid techniques. These techniques have facilitated the incorporation of particular characters more readily into the breeding materials. However, the other side of the coin is that the use of double haploids and marker-assisted selection leads to fewer wide crosses, with more emphasis on targeted, short-term outcomes. Concern was expressed that the increased use of these techniques may lead to a reduction in diversity in the future.

One breeder reported that improved analytical techniques have led to increased precision in defining and understanding genotype x environment interactions. This precision permits a better understanding of the different aspects of genetic diversity and a more informed process of breeding progress.

3.6 Impact of Funding Constraints on Diversity

3.6.1 Extent of funding constraints

Breeders gave two different responses regarding the impact on diversity of funding constraints in recent years. One-third of breeders responded that funding was not constraining their programs at present, while one specialised program reported that funding had in fact increased substantially in recent years. On the other hand, the majority of breeders indicated that funding available to them constrained the extent to which they could introduce and use diversity in their programs. A typical response was "Our program is shrinking, and we are forced to concentrate on our core business of releasing varieties, so we do not breed for some types we would otherwise aim to do." Given reductions in real levels of funding for breeding, they have had to establish priorities for the types of diversity and for how much new diversity to introduce and incorporate into the program each year.

3.6.2 Uses of additional funding

Respondents were asked to rank the areas into which they would put any additional funding obtained for their program. The responses are summarised in Table 5. The results were extremely variable, with all areas except "Genetic diversity for quality" ranked first by at least one breeder, and all areas also ranked low (rank of seven or lower) by at least one breeder. Overall, "Improved selection methods (including DNA markers, etc)" was ranked highest, closely followed by "Genetic diversity for other biotic resistance." "Genetic diversity for abiotic stresses" split the respondents into two groups, with 50% giving it a ranking of 1 or 2, while another 42% gave a ranking of 8 or 9. For most other options the range of responses was less dispersed. The one option consistently ranked low was "Genetic diversity for quality." Reasons given indicate the belief that there is already adequate genetic variation in quality. Moreover, tighter specifications for quality demanded by the market limit the broad incorporation of characteristics currently not present in marketed varieties.

Table 5: Ranking of Areas for Additional Funding
(1 Highest, 10 Lowest)

	Responses			**Overall ranking**
	Mean	**Min.**	**Max.**	
Genetic diversity for yield	4.2	1	8	**3**
Genetic diversity for rust resistance	5.8	1	9	**7**
Genetic diversity for other biotic resistance	3.3	1	7	**2**
Genetic diversity for abiotic stress	4.6	1	9	**5**
Genetic diversity for quality	6.2	3	9	**8**
Novel sources of diversity	5.4	1	9	**6**
Improved selection methods	3.0	1	7	**1**
Increased emphasis on quality	4.3	1	8	**4**
Increased attention to niche markets	6.4	1	10	**9**
Other (specify)	9.4	3	10	**10**

Breeders' interpretation of the issues listed may have partly been responsible for the widespread range of responses. Some breeders indicated that they do not aim for genetic diversity for yield *per se*. Rather, diversity for yield and adaptation contains a large element of responses to biotic and abiotic stresses, and breeders address those objectives by aiming for diversity in the response to stresses directly. For others, these issues were combined into "diversity for yield." An important issue for some was that the genetics might be unknown for some stresses or that resistance/tolerance to some stresses such as frost may not be readily available.

Given that some breeders expressed a concern that the use of genetic markers and marker-assisted selection may result in a reduction in overall diversity, the fact that the top-ranking option was improved selection methods (including DNA markers, etc) could highlight some concerns for diversity in the future.

3.7 Other Comments

Some of the breeders responding to the survey questionnaire provided additional comments on the overall issue of genetic diversity.

(a) One breeder argued that germplasm resources need to be properly funded and maintained, and must be accessible. That entails keeping the germplasm resources in the public sector, which is both more efficient and, furthermore, is an audited system. There are great dangers in entering into commercial breeding agreements that restrict access to germplasm for anyone.

(b) A breeder noted that the Australian wheat industry is based on a narrow range of "families" of varieties, notably WW15, Gabo, Dirk, MEC3 and Pavon. This narrow base could lead to genetic vulnerability.

(c) Another breeder noted that there is a need for more research to examine the genetic resources already held in collections, since there are still many lines with potential useful genes that to date have not been identified in screening and testing.

(d) Different breeding programs would expect to have different responses to the issue of genetic diversity, because each program has its own emphasis on the stresses for which it selects and the characters needed. The structure of the programs (size of populations, selection pressures) are likely to reflect differences in responses to the questions.

4. Implications of Findings

Overall in the survey, Australian wheat breeders expressed cautious optimism in their approach to genetic diversity. Breeders were generally satisfied that they had a reasonable, though not high, amount of diversity in their program. Few considered that their progress with the major breeding objectives was highly constrained by the lack of available genetic diversity. Cautious optimism also characterizes Duvick's conclusions for the US in 1984, although the breeders surveyed internationally in 1995 by Rejesus, Smale, and van Ginkel appeared more skeptical. The concern expressed by breeders in the international survey probably reflected in large part the change in the global political climate, and the fear that variety protection laws would reduce the access to materials. Australian wheat breeders are less reliant on other countries for the diversity in their materials.

All breeders introduce new genetic materials into their programs regularly, on average about one-quarter of their crossing block each year. That demonstrates a continuing new search for useful materials in their programs. While many of those new lines were obtained from other Australian breeding programs, the principal sources of new materials were CIMMYT and/or ICARDA nurseries. The importance of the international agricultural research system to the Australian wheat industry, identified in Brennan and Fox (1995), is clearly continuing strongly. The consistent use of other lines from CIMMYT (including synthetic wheats) and lines from other national breeding programs in addition to the international nurseries underscores the importance to Australia of international linkages in wheat breeding.

A key component of the availability and distribution of germplasm for Australian wheat breeders is the Australian Winter Cereals Collection at Tamworth. All breeders reported using the AWCC as a source of materials, and the assessment of the materials they obtained was very positive. It clearly plays a key role in allowing the Australian breeding programs to expand their genetic base. In addition to its role as a repository and gene bank for the Australian industry, the AWCC plays a key role in the introduction of materials from overseas and in undertaking some of the quarantine requirements for that material. There appear to be considerable economies of scale associated with a central agency such as AWCC taking a leading role in introducing international nurseries, for example.

Breeders reported that the genetic diversity of the materials they worked with influenced many activities in their programs. The crosses they make, the crossing techniques they use, the selections they make and the decisions on varieties they release are all influenced, to a greater or lesser extent, by consideration of genetic diversity. When asked to list the major determinants of the genetic materials they used, breeders generally listed the needs of the industry and the need to release varieties to ensure the viability of the program before they mentioned broadening genetic diversity.

A common view was that the current funding arrangements and industry pressures were forcing them to concentrate more (and more than they felt was desirable) on the short-term goal of releasing new varieties. While they recognise that that is the aim of their program, they argue that there should be greater resources devoted to exploring wider crosses and more diverse genetic material to ensure that the flow of new improved varieties can continue into the future.

By obtaining information on perceptions regarding diversity, breeding priorities, and constraints directly from the breeders, we have developed a better understanding of the institutional setting in which they operate. It remains uncertain, however, whether there any linkages between the changes over time in breeders' perceptions about diversity, changes in the policy environment, and changes in observed levels of diversity. Using various indices of diversity from data collected on wheat production by variety, varietal releases and introductions in Australia, and varietal pedigrees over recent decades, we will examine changes in measured diversity levels in relation to some of the constraints and changes mentioned by the breeders. These efforts address supply factors that are important, albeit partial, influences on the determination of genetic diversity.

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Appendix A: Glossary of Terms and Abbreviation Used

ACIAR	Australian Centre for International Agricultural Research
AQIS	Australian Quarantine Inspection Service
AWCC	Australian Winter Cereals Collection, Tamworth
CIMMYT	International Maize and Wheat Improvement Center, Mexico
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ICARDA	International Centre for Agricultural Research in the Dry Areas, Syria
Backcrossing	Repeated crossing using the same parent line, to ensure progeny is very similar to one parent.
Crossing block	Set of varieties and lines that are grown for use as parents in breeding program
Triticum tauschii	Primitive relative of wheat (diploid: 7 pairs of chromosomes). Source of useful genes for wheat.
Tetraploids	Relative of bread wheat (tetraploid: 14 pairs of chromosomes)
Synthetic hexaploids	Bread wheat re-constituted from originator species (hexaploid: 21 pairs of chromosomes). Means of incorporating useful genes into bread wheat.
Landrace	Traditional variety selected by farmers and with no scientific breeding
Doubled haploids	Method of producing genetically stable lines from tissue culture
DNA markers	Means of identifying presence of specific genes in a line or variety
Marker-assisted selection	Use of DNA markers in selection within a breeding program
Biotic stress	Stress caused by another organism, such as fungus, virus
Abiotic stress	Stress caused by environment, such as drought, frost

Appendix B: Copy of Survey Questionnaire

Survey on
Importance of Genetic Diversity in Wheat Breeding Programs

1. Attitude to Diversity

1A. Do you believe that a lack of genetic diversity available to your program is constraining your progress in breeding? If YES, explain.

1B. How do rate (High / Medium / Low / Zero) the extent to which progress towards the following goals is constrained by a lack of available genetic diversity:

	In your collection	**Within Australia**	**Worldwide**
Yield			
Rust resistance			
Other biotic resistance			
Abiotic stress			
Quality			

2. Diversity in Current Gene Pool

2A. How would you describe the diversity of your current gene pool? (Circle)

High / Medium / Low

2B. In the most recent season, what was the total number of entries in your crossing block?

2C. On average over the past five years what percent of the entries in your crossing block were:

Type of Entry	**Percent of Material**
Landraces	
Varieties or advanced lines from your own program	
Varieties or advanced lines from other Australian programs	
Varieties or advanced lines from overseas national programs	
Lines from CIMMYT or ICARDA International Nurseries	
Other *(Specify)*	

3. Source of Materials to Maintain and/or Increase Diversity

3A. Do you routinely seek sources of genetic diversity from outside your program? If so, over the past five years, what percentage of materials in your crossing block was new each year, on average?

3B. What materials have you introduced or used in the program with the specific view of increasing the genetic diversity of your program over the past five years?

Type of Entry	**Percent of Material Introduced**
Landraces	
Varieties or advanced lines from other Australian programs	
Varieties or advanced lines from overseas national programs	
Lines from CIMMYT or ICARDA International Nurseries	
Other *(Specify)*	

3C. What are the primary sources of materials used to broaden the genetic base of your program?

3D. How many times have you requested materials from the Australian Winter Cereals Collection in the past five years?

3E. How useful was the material you obtained in enabling you to expand the range of genetic materials you require? Explain.

4. How Diversity Influences Breeding Decisions

4A. Does genetic diversity, other than diversity in disease resistance, influence your decisions regarding:

(a) The type of materials used in the crosses you make? If YES, how?

(b) The crossing techniques you use? If YES, how?

(c) The selections you make? If YES, how?

(d) The varieties you release? If YES, how?

4B. What influences the decisions you make on the genetic materials to use in your program?

5. Impact of Changes over Time on Diversity

5A. Have there been changes over the past 15-20 years in the situation in which you operate that have influenced the extent to which diversity is incorporated in your program? Please specify what they are, the time period, and the impact that they have had.

6. Impact of Funding Constraints on Diversity

6A. Does the funding available to you constrain the extent to which you can introduce and use diversity in your program?

6B. If you were to obtain additional funding for your program, please rank the areas that you would envisage putting the additional funds:

	Rank (1-10, 1 highest)
Genetic diversity for yield	
Genetic diversity for rust resistance	
Genetic diversity for other biotic resistance	
Genetic diversity for abiotic stress	
Genetic diversity for quality	
Novel sources of diversity	
Improved selection methods (including DNA markers. etc)	
Increased emphasis on quality	
Increased attention to niche markets	
Other (specify)	

7. Any Other Comments

Please return completed form to:

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Queries: If you have any queries about this questionnaire, please contact John Brennan.