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Evolving usage of materials from CIMMYT in developing Australian wheat varieties

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Abstract. Wheat genetic materials developed at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico for developing countries and varieties developed from those genetic materials have resulted in yield increases in Australia. The usage of the genetic materials obtained from CIMMYT has evolved over time, with fewer Australian varieties resulting from either direct CIMMYT crosses or having a CIMMYT line as a parent. There has been an increasing tendency to use adapted Australian lines with CIMMYT ancestry, rather than CIMMYT lines, as parents. These changes are examined, both in terms of varieties released in Australia and for the shares of wheat area sown to crosses of different origins, for each Australian state. The results demonstrate that for the benefits of international developments to be made available to Australian producers, Australian-based breeding programs are essential.

Additional keywords: research, spillover, yield, adoption.

Introduction

Australia has been importing material from CIMMYT since the 1960s (Brennan and Fox 1995; Brennan and Quade 2004). However, few of those imported lines have been suitable for direct release for commercial production in Australia. In most cases, the CIMMYT lines have been used as parent or donor lines in Australian wheat breeding programs. Breeders have combined them with other Australian varieties to develop improved varieties adapted to the Australian environment, thereby enabling Australia to obtain the gains provided through germplasm from CIMMYT.

In this paper, an examination is made of the role of genetic materials obtained through CIMMYT in the development of improved wheat varieties in Australia. The evolving way in which those materials have been used, both in terms of the varieties released and for the share of varieties from different crosses, is analysed.

Alston and Pardey (2001) highlighted the difficulties relating to attributing research outcomes to particular sources. CIMMYT has extensively used wheat genetic resources from around the world and, as a result, the countries from which those genetic resources originated have some claim on the benefits of CIMMYT's research. An important strength of CIMMYT has been its ability to enhance and further develop genetic materials, thereby adding considerable value to genetic material globally. For convenience, in this paper, all the benefits of those genetic materials are attributed to CIMMYT, without implying that the prior contributions of other countries are unimportant.

There have been 2 phases to the effects of CIMMYT's wheat breeding program on wheat productivity (Byerlee and Moya 1993; Byerlee and Traxler 1995):

- Initial introduction and usage of semi-dwarf wheats derived from CIMMYT (Phase 1);
- Replacement of the earlier semi-dwarfs by higher-yielding varieties through the continuing use of CIMMYT materials in breeding programs (Phase 2).

Brennan and Quade (2004) showed that from both the Phase 1 semi-dwarfs and the Phase 2 post-semi-dwarfs, the varietal yield gains for Australia attributable directly to CIMMYT averaged 4.6% by 2001. For South Australia and Western Australia, the gains were 2.0% by 2001, whereas for other states they were higher, with Queensland 10.5%, NSW 7.9%, and Victoria 7.4%.

Materials and methods

The data on area, yield, and production of Australian wheat, by state, were obtained from the Australian Bureau of Statistics (ABS) and the Australian Bureau of Agricultural and Resource Economics (ABARE) (ABARE 2004*a*, 2004*b*).

The data on the share of varieties in the total wheat area were based on several different sources. Up to 1988, the data relate to the percentage area sown to each variety in each state, as collected by the ABS. Since 1989, data have not been available on the *area sown* to different varieties, so it has been necessary to use the available data on the variety shares of the wheat received by the Australian Wheat Board

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(now AWB Limited). From 1989 to 1994, data on the share of AWB wheat receivals were obtained from the Australian Wheat Board. From 1995 onwards, confidential data have been obtained from AWB Limited on the percentage share of AWB receivals (AWB Limited, pers. comm., 2004) for each state. The latest data available were for the 2003 season.

Since deregulation of the domestic wheat market, a large proportion of production has been marketed through channels other than AWB Limited (Brennan *et al*. 2004). Given that prior to deregulation in 1989, the Australian Wheat Board controlled the vast majority of wheat marketed in Australia, the data on shares of AWB receivals prior to that time were taken as representative of all production. However, following deregulation, many other marketing channels opened up, and increasing amounts of wheat (particularly speciality types) have been traded through those other channels, and the extent to which AWB receivals represent all wheat production has decreased in recent years (Brennan *et al*. 2004). However, as no other variety share data are available for each state, the AWB data are taken in this analysis to be representative of the entire wheat crop.

The data on the varieties released in Australia and their pedigrees have been mainly derived from information retained at the Australian Winter Cereals Collection (M. Mackay, AWCC, pers. comm.). In recent years, varietal release data have been based on information available from the Plants Breeders' Rights website (PBRO 2004).

Following Heisey *et al*. (2002), the varieties released in Australia since 1973 were classified as follows:

- CIMMYT cross (made by CIMMYT);
- Australian cross, with at least one CIMMYT parent;
- Australian cross, with CIMMYT ancestor in pedigree but no direct CIMMYT parent;
- Australian cross, semi-dwarf from source other than CIMMYT;
- Australian cross, non-semi dwarf;
- other cross (made by another country's breeders).

The categories for each variety were determined by examining their pedigrees, with confirmation from Peter Martin, wheat breeder (P. Martin, pers. comm., June 2004).

The area sown to varieties in the different categories of crosses was determined by aggregating the percentage share of each variety in each state each year into the categories of the crosses. The national aggregate figures were derived by converting the state data to hectares, then aggregating nationally, then subsequently converting those figures to percentages at the national level.

Origin of wheat varieties released in Australia

From 1973 to 2003, in total, 216 wheat varieties were released for commercial production in Australia. Of those, 195 varieties (89%) had at least one CIMMYT line in their pedigree. A full list of the CIMMYT-derived varieties is provided in Brennan and Quade (2004). In developing those varieties, the Australian breeders used a range of strategies, including directly releasing a variety developed by CIMMYT, using CIMMYT varieties as a parent in a crossing program, or using CIMMYT-derived lines as parents in the crossing program.

All varieties released in Australia since 1973 were classified on the basis of the origin of their cross (Table 1). The approach of breeders in the years immediately following the release of the first semi-dwarf varieties in 1973 was to release CIMMYT crosses as varieties or to use CIMMYT lines as parents. However, because of the need to adapt the varieties to Australian low-yielding environments, the main strategy in more recent years has been to use lines with CIMMYT ancestry as parents, and to make the crosses between improved Australian lines/varieties. Therefore the use of CIMMYT in the programs has focussed mainly on the release of varieties with CIMMYT ancestry rather than varieties with direct CIMMYT parentage. Almost two-thirds (137 varieties) of all varieties released since 1973 have been Australian crosses with some CIMMYT ancestry in at least one of the parents, but with no direct CIMMYT parent. Only 3% have been direct CIMMYT introductions, and a further 23% have had at least one CIMMYT parent.

Table 1. Origin of crosses of Australian wheat varieties released, 1973–2003
(*Numbers of varieties released*)

	1973–82	1983–92	1993–02	2003	Total
CIMMYT cross	2	2	1	1	6
Australian cross:					
At least one CIMMYT parent	14	11	24	0	49
With other CIMMYT ancestry	13	48	70	6	137
Other semi-dwarf	5	3	1	1	10
Tall	6	0	2	0	8
Other cross/unknown	0	0	5	1	6
Total varieties released	*40*	*64*	*103*	*9*	*216*
% with CIMMYT contribution	*73%*	*95%*	*92%*	*78%*	*89%*
% with direct CIMMYT contribution	*40%*	*20%*	*24%*	*11%*	*25%*

The figures in Table 1 reveal a trend away from direct use of CIMMYT lines for release or for use as parents, and an increasing trend towards the release of varieties with CIMMYT in earlier stages of the pedigree. This reflects the value of introducing CIMMYT characteristics to already-adapted Australian varieties rather than introducing new varieties that are less well adapted to the Australian production environments. In addition, there has been a shift away from 'other semi-dwarf' varieties and tall varieties and a recent increase in the number of varieties introduced from other countries.

Adoption of CIMMYT-derived varieties in Australia

Adoption of semi-dwarf varieties

The adoption of semi-dwarf wheats in Australia from the release of the first varieties in 1973 was very rapid (Table 2). By 1976, over 1.5 million ha were sown to semi-dwarfs, over 1.2 million ha of which were CIMMYT-derived semi-dwarfs. By 1990, the area of semi-dwarfs had reached over 8.0 million ha, and in 2003 was 12.2 million ha.

In percentage terms, the area of CIMMYT-derived semi-dwarfs increased to 44% of the total Australian wheat area

Table 2. Area sown to Australian wheat varieties, by origin of cross ('000 ha)

Year	CIMMYT cross	At least one CIMMYT parent	CIMMYT ancestor	Total CIMMYT-derived	Other semi-dwarf	Total semi-dwarf	Tall	Other cross
1974	0	81	0	81	28	109	8026	0
1975	0	471	0	471	102	573	7674	0
1976	0	1262	3	1265	275	1540	7183	0
1977	0	2497	9	2506	385	2891	6928	0
1978	0	2994	119	3114	396	3510	6561	0
1979	0	3615	546	4161	506	4668	6267	0
1980	7	4309	684	5000	549	5549	5207	0
1981	182	3717	1416	5315	787	6102	5391	0
1982	298	2712	1974	4984	770	5754	5430	0
1983	619	2383	2997	5999	984	6983	5669	0
1984	1128	1963	2882	5973	1112	7084	4702	0
1985	1643	2384	3134	7161	1229	8391	3073	0
1986	1516	2965	2472	6953	1462	8415	2555	0
1987	856	2688	2690	6234	1069	7303	1673	0
1988	835	2344	3337	6516	944	7460	1319	0
1989	929	2206	3715	6849	790	7638	1211	0
1990	1147	2150	4080	7377	664	8041	976	0
1991	685	1254	3965	5904	538	6443	704	0
1992	1082	1821	4765	7669	548	8217	846	0
1993	856	1707	4676	7239	426	7665	675	0
1994	754	1533	4691	6978	380	7358	635	0
1995	857	1826	6035	8719	342	9062	650	1
1996	967	2039	7392	10 398	358	10 756	564	0
1997	652	1881	7125	9658	315	9973	429	2
1998	787	1842	8314	10 943	275	11 218	338	6
1999	1058	1751	9004	11 812	229	12 041	263	1
2000	1100	1738	9243	12 081	128	12 208	184	1
2001	957	1598	9710	12 266	89	12 355	130	0
2002	625	1275	8947	10 847	85	10 933	90	0
2003	598	1399	10 138	12 135	64	12 198	135	0

by 1980, and 80% by 1990. In 2003, they covered 98% of the total Australian wheat area.

The on-farm use of CIMMYT-derived varieties for each state from 1974 to 2003 is shown Fig. 1. Detailed state adoption data for CIMMYT-derived varieties up to 2001 are shown in Brennan and Quade (2004). The rapid adoption in NSW and Queensland is evident, as is the initial slow rate of uptake in Western Australia. By 1993, all states except Western Australia had more than 90% of the area planted to CIMMYT-derived varieties. Given the recent increases in Western Australia, CIMMYT-derived varieties had by 2003 reached 96% of the wheat area in all States. Since 91% of the varieties released since 1993 have been CIMMYT-derived (Table 1), those varieties have tended to be relatively more popular than the non-CIMMYT varieties released.

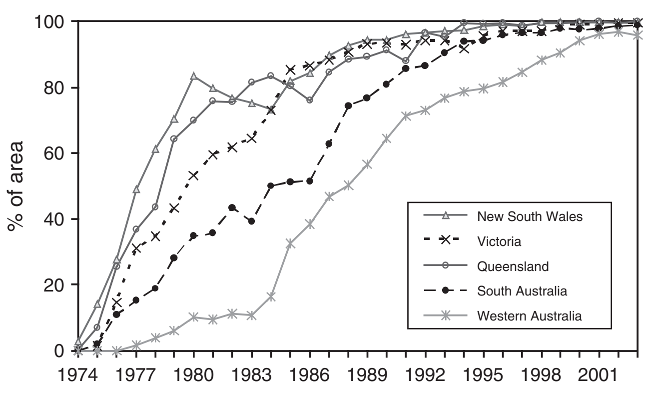

Fig. 1. Adoption of CIMMYT-derived varieties, Australian States.

Adoption of CIMMYT-derived varieties, by origin of cross

At the Australian level, the area sown to direct CIMMYT crosses has always been less than 15% of the total area, and has declined to around 5% in recent years[1] (Fig. 2). Although Australian crosses using at least one CIMMYT parent formed the bulk of the initial semi-dwarf impact, that contribution has declined from its peak in the late 1970s to only around 10% of the total area. Although there has been some use over

[1]Note that the figures given here are slightly different from those in Brennan and Quade (2004) because an error in classifying the variety Oxley in that study has been corrected here.

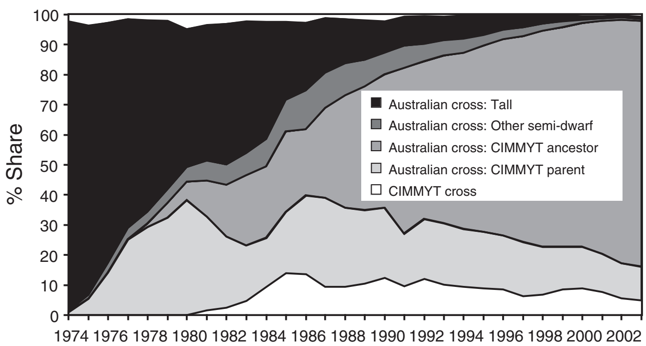

Fig. 2. On-farm usage of wheat varieties, by origin of cross, Australia.

the period of non-CIMMYT semi-dwarfs, the overwhelming proportion of the area has been sown to varieties based on Australian crosses using parents with CIMMYT ancestry. By 2003, the overwhelming majority of the wheat area in Australia was sown to varieties with CIMMYT ancestry, although not with a direct CIMMYT parent. That proportion increased strongly from 6% in 1980 to 44% in 1990, and to 82% in 2003.

The adoption of varieties differs among states in the origins of the crosses. Although NSW has a broadly similar pattern to that at the national level, its level of direct CIMMYT crosses was higher (over 30% in the early 1990s) (Fig. 3), largely because of the widespread use of the varieties Hartog and Dollarbird. The early dominance of the varieties Condor and Egret, both Australian crosses using a CIMMYT parent, is also evident in the 1970s. More recently, though, Australian crosses built on those early varieties and other adapted lines with CIMMYT ancestry have generally dominated.

Victoria has shown a strong reliance on direct CIMMYT introductions and crosses with at least one CIMMYT parent (Fig. 3). After initial widespread adoption of Condor and Egret in the 1970s, the variety Millewa (a CIMMYT cross) was widely grown in the mid-1980s. Meering, a Condor selection, was a popular variety in the 1990s, so it was not until after 1995 that varieties without a direct CIMMYT parent became dominant in Victoria.

Queensland also showed strong use of varieties with a CIMMYT parent in the 1970s, particularly through the widespread use of Oxley (Fig. 3). During the 1980s, the use of varieties without direct CIMMYT parentage expanded rapidly, although the widespread use of Hartog, a CIMMYT cross, meant that a high proportion of the total area in Queensland was sown to direct CIMMYT crosses in the early 1990s. Since that time, the area has been mainly sown to varieties with a CIMMYT parent, to a greater extent than in other states.

On the other hand, South Australia and Western Australia have grown few direct CIMMYT introductions or varieties with a direct CIMMYT parent (Fig. 3). Those states have relied most strongly on Australian crosses using parents that were not direct CIMMYT introductions. There was some reliance on lines with a CIMMYT parent in the late 1970s in South Australia, and in the late 1980s in Western Australia (mainly associated with Condor and Aroona, respectively). However, lines with CIMMYT ancestry but more adapted to the lower rainfall environments needed to be developed in these states before the semi-dwarf wheats had an effect on farms. These locally developed varieties have generally been dominant in these two states for the period to 2003. The later adoption of CIMMYT-derived varieties in Western Australia compared with other states (as shown in Fig. 1) is also evident in Fig. 3.

It is also notable that Victoria has had the lowest reliance on non-CIMMYT semi-dwarfs, whereas the other states have all used them to some extent. Kite, Gutha, and Tincurrin have been the most significant non-CIMMYT semi-dwarf wheats grown.

Discussion of results and implications

Studies have shown that CIMMYT has had a significant effect on the Australian wheat industry (Brennan and Fox 1995; Brennan and Quade 2004). Brennan and Quade (2004) estimated that the spillover benefits from CIMMYT's research, aimed at developing countries but nevertheless valuable in Australia, are valued at an average of A$30 million per year. The nature of those effects, and the way in which they have manifested themselves in Australia, are indicated in the analysis shown above.

The semi-dwarf wheats developed at CIMMYT and disseminated round the world had a yield advantage in Australia, most notably in the eastern states. The release and adoption of these higher yielding varieties were delayed in Australia compared with comparable countries, and Brennan and Fox (1995) identified 2 reasons for that delay. First, the Australian industry's requirement for good-quality white wheat meant that breeding was required to ensure that white rather than red grain and adequate quality were instilled in the varieties before release. Second, the CIMMYT lines needed to be crossed with Australian varieties that were better adapted to the lower rainfall environments in which they would be grown. These requirements meant that few CIMMYT lines have been released directly in Australia as varieties. The most significant exception to that is the variety Hartog, which was developed at CIMMYT as Pavon. Other CIMMYT crosses released in Australia have generally had selection in Australia, such as Millewa, Dollarbird, and Diamondbird.

The initial effect of CIMMYT's semi-dwarfs was felt through varieties from Australian crosses using parent lines obtained from CIMMYT. A key accession from CIMMYT was the red-grained line WW15, which had wide adaptability, outstanding yield under good conditions, and resistance to most strains of stem rust then present in Australia

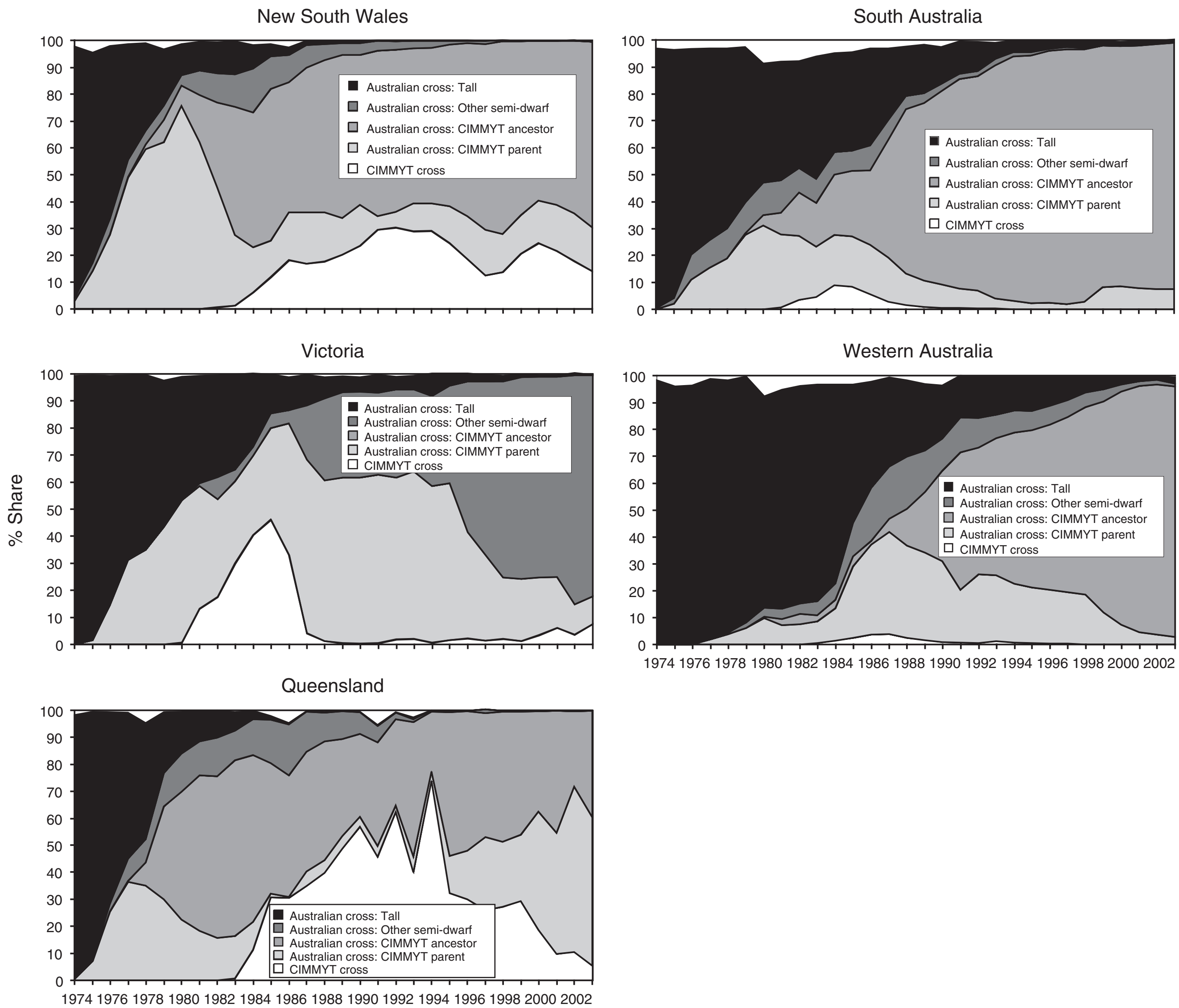

Fig. 3. On-farm usage of wheat varieties, by origin of cross, by State.

(Syme and Pugsley 1975). It was crossed with a number of other parent lines and selected for white grain. Single backcrosses of WW15 made by Syme and selected for white grain and improved quality gave rise to Condor, Egret, and Oxley (Martin 1981). Condor in particular was very widely grown in many states.

Subsequently, such varieties were used as parents in further breeding efforts to find improved varieties. As a result, Condor has been used as a parent for many successful varieties such as Banks (released 1979), Vulcan (1985), and Janz (1989), each of which was a leading variety in its time.

This pattern has continued even in more recent years, beyond the adoption of semi-dwarfs (Brennan and Quade 2004). Although Australian breeders have continued to use CIMMYT lines in their breeding programs, they have generally continued to use them to develop appropriate characteristics in parent lines, and to use those adapted parent lines to develop the new varieties. As a result, the CIMMYT effect has become increasingly indirect, rather than a close relationship with the use of CIMMYT lines as parents.

This is evident in Fig. 4, where CIMMYT's direct contribution to the cross used to develop the varieties is shown for each year since 1973. The measure of the contribution of CIMMYT in the first generation, W_t, is calculated as follows:

$$W_t = \sum_i (x_i p_{it})$$

where x_i is the proportional direct contribution of CIMMYT to the pedigree of variety i, and p_{it} is the percentage

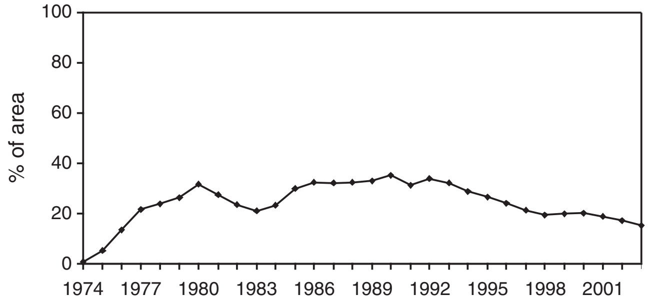

Fig. 4. Contribution (%) of CIMMYT to gains from CIMMYT-derived wheat varieties, based on origin of parents used in cross.

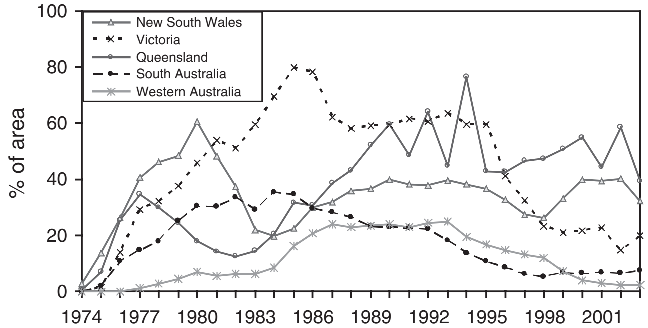

Fig. 5. Contribution (%) of CIMMYT to gains from CIMMYT-derived wheat varieties, by State, based on origin of parents used in cross.

of the area sown to variety i in year t. Compared with the increasing importance of CIMMYT-derived varieties in Australia shown in Fig. 1, the actual CIMMYT contribution in the first generation at the national level peaked at 35% in 1990 and has declined since that time to approximately 20% (Fig. 4).

The overall pattern of CIMMYT contribution varies considerably in each state (Fig. 5). NSW and Victoria both reached peaks above 60% in the 1980s, and have declined since. Queensland reached its peak of almost 80% direct CIMMYT contribution in the 1990s. In contrast, both SA and WA have had lesser reliance on direct CIMMYT inputs, with peaks of no more than 35% and levels of less than 10% direct CIMMYT contribution in recent years.

An important implication of these results is that, although significant benefits flow from CIMMYT to Australia, and to Australian wheat producers in particular (Brennan and Quade 2004), an essential component is the Australian wheat-breeding operation. The benefits available from the germplasm improvement made at CIMMYT have been realised in Australia by further considerable input from Australian breeders. The lines developed at CIMMYT for developing countries are not well enough adapted in general to make a significant impact in Australia, without considerable adaptive breeding within Australia. The continuing ability to use the valuable characteristics in CIMMYT materials and adapt them to the unique Australian production conditions will be reliant on breeding activity in Australia.

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