

**Center Commissioned External Review of
CIMMYT's
Wheat Breeding Activities**

March 1-7, 2004

**Final Report
12th March 2004**

Executive Summary

Background

1. The CIMMYT Board of Trustees commissioned a review of CIMMYT's wheat breeding activities, with a particular focus on how improved wheat varieties have, and will, contribute to poverty reduction in developing countries. The Center-Commissioned External Review (CCER) was undertaken in Mexico at CIMMYT headquarters, El Batán, and at the main wheat field station at Cd. Obregon in Sonora, from 1 to 7 March 2004.

Observations and Recommendations

Introduction and Impacts

2. In reviewing CIMMYT's wheat breeding activities, the Panel consulted widely within the three Programs (Genetic Resources, Rainfed Wheat Systems and Intensive Agroecosystems) involved with wheat breeding activities. On the basis of these consultations and the information made available to the Review, the Panel, in general, was very impressed with the quality of the activities. Given that CIMMYT is recognised internationally for the strength of its wheat improvement activities, the Panel believes that wheat improvement must stay as the major activity of CIMMYT's wheat strategy, and consider that it is vital that the activities be adequately resourced.

3. The data from past studies of CIMMYT's impacts demonstrate the huge effects that CIMMYT has had, and is continuing to have, on the global wheat industry, in terms of the varieties grown and improvements in yields per hectare. In this context, CIMMYT should continue to have rigorous mechanisms for monitoring impacts on yields and poverty. However, additional economic resources are likely to be needed for this.

Recommendation 1 : The Panel recommends that resources be made available to ensure that impact assessment and priority setting for wheat breeding activities can be carried out adequately in the future.

Mission, Structure, External Relationships:

4. The Panel was unanimous in the view that the new program structure embracing a systems approach was an excellent framework for continuing and enlarging CIMMYT's commitment to poverty alleviation in their target regions of the developing world. Within this framework, the Panel is convinced that CIMMYT's comparative strength and impact is the quality of its germplasm, and that in this context, wheat improvement must stay as the major activity at the heart of CIMMYT's new approaches. The Panel believes that CIMMYT's current choice of target regions is appropriate. However, the definitions of the key environments will need continuous monitoring and refinement as systems change and develop.

Recommendation 2 : The Panel recommends that a review system is in place to monitor CIMMYT's choice of target regions so that it can rapidly respond to new needs.

5. The Panel believes that both centralized and decentralized approaches are essential in targeting CIMMYT's client needs.

6. CIMMYT's new Program structure provides a framework for greater co-operation and integration between breeding activities and allied science groups (including pathology, genetic resources, biotechnology, agronomy, physiology, quality, etc). Its focus on farming systems ensures that the activities will be concentrated directly on the areas of greatest need. However, there is a necessity for careful co-ordination between the three Programs (Genetic Resources, Rainfed Wheat Systems and Intensive Agroecosystems) involved in wheat improvement activities.

Recommendation 3: The Panel recommends that there should be mechanisms in place to formally monitor the interactions of the three Programs involved in wheat improvement on a regular basis.

7. The Panel sees a need to urgently communicate the Program changes to both the staff and CIMMYT's co-operators and clients.

Recommendation 4 : The Panel recommends that CIMMYT management needs to clearly communicate changes in CIMMYT structure as it relates to both staffing and funding to maintain both confidence and motivation to international and national staff.

Recommendation 5 : The Panel recommends that CIMMYT senior management, including Program Directors, should begin the task of meeting with all NARS and ARI partners to provide a communication bridge as CIMMYT moves forward with its new mission statement and programs.

8. The Panel supports the development of succession planning and post-doctoral programs within CIMMYT, and co-operative arrangements with NARS, to overcome difficulties with demographic trends.

Recommendation 6 : The Panel recommends that the CIMMYT administration develops a clearer, implementable, strategy for succession planning.

Recommendation 7 : The Panel recommends that CIMMYT considers the re-establishment of an active post-doctoral training program in wheat improvement across all programs.

9. The Panel recognizes that training has been a major output of the CIMMYT wheat improvement strategy, particularly through the hands-on experience gained in working with the CIMMYT wheat researchers.

Recommendation 8 : The Panel recommends that CIMMYT re-start its training programs for wheat improvement specialists from target regions urgently.

10. As CIMMYT embarks into its new structure and focus on cropping systems for the poor, it is essential that both CIMMYT and ICARDA clearly define their own unique roles as well as rationalize each center's collaborative role in wheat

improvement research, especially in the WANA region. This is a matter of urgency. On the other hand, the Panel has not seen a clear case that an alliance with IRRI will benefit the wheat improvement activities, *per se*, in terms of efficiency or scientific needs.

Recommendation 9 : The Panel recommends that discussions at the highest possible levels are undertaken to rationalise and stabilise the relationship with ICARDA.

Evaluation of Breeding Strategies

11. CIMMYT's wheat breeding activities have made CIMMYT a respected force on the international agricultural scene. However, following recent budget stringency, the Panel believes that the wheat breeding activities are under-resourced, and that backup resources are needed for each of the senior breeders in the Intensive and Rainfed Programs.

Recommendation 10 : The Panel recommends that there is a need to provide greater staff resources in wheat breeding to ensure greater outputs, improved succession planning, and greater coordination with ICARDA and the NARS.

12. The Panel sees an urgent need for capital allocations to improve the cost efficiency of the field program by further mechanization of the breeding program in, at least, the following areas: seed packaging, improved seed magazine systems for seeders, warehousing technology to manage the seed and sample inventory, automated data acquisition and harvesting equipment. The Panel was impressed by the quality of the breeding strategies employed, and had a number of recommendations in relation to shuttle breeding, incorporation of novel genetic resources into useful varieties, international nurseries, size of crossing blocks and segregating populations, use of limited backcrossing, characterizing parental material and participatory variety selection. The Panel believes that CIMMYT still needs to develop finished varieties, as well as advanced lines and segregating populations, according to the needs of individual NARS.

Recommendation 11 : The Panel sees an urgent need for capital allocations to improve the cost efficiency by further mechanisation of the breeding program.

Recommendation 12 : The Panel endorses many of CIMMYT's wheat breeding strategies and recommends further development of the shuttle breeding concept, including special nurseries to broaden the base of disease resistance, stress tolerance and adaptation.

13. The Panel strongly supports the continuation and strengthening of the bread and durum wheat programs in both the Rainfed Wheat Systems and the Intensive Agroecosystems Programs. A particular issue for the Rainfed Program is the relationship with ICARDA.

14. We endorse the breeding approaches being used in both the bread and durum wheat breeding programs, particularly the use of 'Smart crosses' for better parental selection, the incorporation of durable disease resistance, and the concept that the management of yield trials should reflect crop management systems such as

reduced/zero tillage, stubble retention and precision agriculture. The adaptation of triticale in these systems should also be explored.

15. CIMMYT has promoted farmers involvement in Participatory Varietal Selection and the Panel supports this concept as incorporated in the Mother-Baby approach, although it is concerned that appropriate NARS support is needed for such approaches.

16. The Panel acknowledges the current and historic contribution CIMMYT made in triticale research and development. It is desirable to sustain the experience of CIMMYT in this important area of activity although the Panel urges CIMMYT to seek external funding for such activities, rather than using resources from core budget.

17. The amount of effort that CIMMYT has made through externally funded projects on hybrid wheat research has been substantial, and has paid off in the characterization of parental lines and heterotic groups, and in the development of several cytoplasmic male sterile systems. CIMMYT should seek to maintain this hybrid research activity through externally funded grants.

18. The Panel endorses the CIMMYT's breeding strategy of the use of international nurseries and yield trials as a major output for global evaluation and usage by the various national programs. The seed health and quarantine activities are an integral part of CIMMYT's strategy, and the present transparent record keeping gives confidence to the clients and importers that their interests are well safeguarded.

Recommendation 13 : For a range of technical and logistic reasons, the Panel believes that the international nursery program is best managed from within the breeding activities in CIMMYT's Rainfed Wheat Systems and Intensive Agroecosystems Programs.

Impact of Allied Science Groups on CIMMYT Wheat Improvement

19. The Panel strongly supports the activities relating to *agronomy and farming systems* and the strategy of the breeders for conducting yield selection experiments under current and emerging farming practices and systems. The Panel also supports the characterization of soil fertility on the research station, and the involvement in the *Harvest Plus* program focusing on biofortification of nutrients in the grain.

20. The Panel recognises that *Marker-Assisted Selection* (MAS) has a key role to play in future breeding and that this activity has recently made great progress in becoming integrated with both the breeding programs and allied sciences, and is delivering a valuable service to such programs. The Panel believes that to have a major impact on CIMMYT's wider wheat improvement programs, a major increase in sample throughput must be achieved. There needs to be an integrated service laboratory to ensure that the breeders are able to use the selection markers that they want. The Panel recognized the value of genetic analysis for the discovery and the development of new markers and encourages a strong relationship between the pathology and MAS staff. The Panel was also greatly encouraged by the strong interactions of the MAS staff with CIMMYT staff in allied sciences including

physiology, quality and wide crosses and ARIs, and believe that these will be crucial to the further development of this activity.

Recommendation 14 : The Panel recommends that the technical and operational capabilities of the MAS program are enhanced.

21. In the work on *pathology*, the Panel considers CIMMYT's work on durable disease resistance for leaf and yellow rust, and the work on root diseases, is of high international significance and value. The Panel was impressed with the advances in introgressing slow rusting genes for leaf and yellow rusts using the limited backcross strategy. The Panel believes that CIMMYT should consider seeking alliances to develop further markers for disease resistance. The Panel consider that emerging problems are likely to need more resources, and believes that rust monitoring networks have played an important role and should be strengthened in some areas, particularly in Africa.

Recommendation 15 : The Panel recommends that, in addition to rusts, priority within pathology research lies with the need to provide root pathology services to the Mexican based breeders.

22. The Panel strongly supports the use of *physiological approaches* for the characterisation of parents for crosses and the development of selection tools for stress and high potential environments, and compliments the group for their close interaction with the breeding programs.

23. *End use quality* has become a major issue for CIMMYT in meeting the varying quality needs of its clients, involving the development of varieties with higher gluten strength and flour extraction, and increased levels of nutrient fortification. These moves are supported by the Panel. However, the Panel recognizes that the resources in the quality work are limited although the recent acquisition of NIR equipment, and the potential it has in improving quality testing, will be of great value.

Recommendation 16 : The Panel recommends that there is a strengthening of the technical capabilities of the quality work, particularly through the use of NIR with robust calibrations.

24. The Panel recognizes the contributions of the work on *molecular genetics and functional genomics*, in terms of molecular characterization and documentation of genetic diversity in wheat landraces and advanced synthetic-derived lines. The participation of CIMMYT in the Genetic Resources Challenge Program is fully supported. In the future, as further molecular tools are developed to aid in characterization and utilization, it is important that the molecular genetics and functional genomics work is closely associated with both the wheat breeding and all allied science teams.

25. The Panel supports the application of *genetic transformation* in developing stable transgenic lines, and in understanding gene expression and discovering new and useful traits. As future traits are included in the research agenda, the Panel encourages that prioritization should be carried out with all the plant improvement teams. The

Panel recommends that clear strategies for the exploitation of genetic engineering technology be thoroughly understood. Furthermore, CIMMYT should begin to develop strategies regarding release of transgenic wheat with select NARS.

Recommendation 17 : The Panel recommends that CIMMYT establishes the freedom to operate and commercialisation needs for planned uses of the transgenic material in both Mexico and CIMMYT mandate countries.

Genetic Resources Program

26. Genetic resources activities are at the core of CIMMYT's wheat breeding activities and the molecular biology activities. Recognizing its central role under the new structure of CIMMYT, the Panel feels that there should be thorough and periodic discussion with the stakeholders of the wheat breeding and allied sciences in prioritizing the target traits that are of interest. The informatics and knowledge sharing activities of the Genetic Resources Program need attention. The Panel recommends that the genetic resources information coming from test sites, other evaluated attributes, and molecular information, should all be used in the information system. There is considerable opportunity to update this as a matter of priority.

Recommendation 18 : The Panel recommends that there is an urgent need to upgrade the data acquisition, data management and gene bank user interface through investment in information systems

Wheat Improvement and Intellectual Property Management

27. The Panel welcomed the new CIMMYT Material Transfer Agreement for the exchange of designated and non-designated germplasm. The Panel believes that, as a matter of urgency, freedom to operate and commercialisation issues are clarified for planned uses of the transgenic material in both Mexico and CIMMYT mandate countries.

Information Systems

28. Given the importance of the information system for the wheat breeding activities, the Panel strongly supports the immediate development of integrated informatics systems at CIMMYT that are capable of meeting the needs of all in the Programs associated with wheat breeding.

Recommendation 19 : The Panel recommends that CIMMYT gives a very high priority to developing new integrated informatics systems for servicing the many different needs across the wheat breeding activities.

Introduction to the Review

The International Maize and Wheat Improvement Center

CIMMYT (the International Maize and Wheat Improvement Center) is an internationally-funded, non-profit, scientific research and training organisation, which has its headquarters in Mexico. CIMMYT works with agricultural research institutions worldwide to improve the productivity and sustainability of maize and wheat systems for poor farmers in developing countries. It is one of 16 similar centres supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR comprises over 50 partner countries, international and regional organisations and private foundations. It is co-sponsored by the Food and Agriculture Organisation (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP).

CIMMYT was founded on the basis of its wheat breeding activities and these have been central to its mission. However, there is a continuous need to monitor the capabilities so that CIMMYT can maintain focus on its mission. Thus, at the beginning of 2004, the CIMMYT Board of Trustees commissioned a review of CIMMYT's wheat breeding efforts with a particular focus on how improved wheat varieties have, and will, contribute to poverty reduction in developing countries. The review took place the 1st to 7th March 2004, with visits by an expert Panel to the CIMMYT Headquarters at El Batan, and the main wheat field station at Cd Obregon in the state of Sonora. The Panel did not visit CIMMYT's regional sites in other countries, although it did receive input from regionally located scientists. The Panel consisted of :

John Snape, John Innes Centre, Norwich, UK (Leader)
Andrew Barr, Australian Grain Technologies, Adelaide, South Australia, Australia
John Brennan, NSW Agriculture, Wagga Wagga, New South Wales, Australia
Hilda Buck, Buck Semillas S.A., La Dulce, Argentina
Subrahmanian Nagarajan, Indian Agricultural Research Institute, New Delhi, India
Rollie Sears, Agripro Wheat, Kansas, USA

Terms of Reference

The CCER assessed the effectiveness and efficiency of CIMMYT's wheat breeding approaches, with specific emphasis on the following issues:

1. The quality and relevance of CIMMYT's wheat breeding programs;
2. The effectiveness and efficiency of the current wheat improvement system with emphasis on the use of modern technologies, especially biotechnology;
3. Opportunities to improve the effectiveness and efficiency of the current wheat improvement programs, including the role of CIMMYT in the wheat breeding system, and the role of regional testing and feedback mechanisms;
4. The effectiveness of partnerships that CIMMYT's Wheat Program has with NARS, ARIs, NGOs and the private seed sector for wheat breeding and seed dissemination; and

5. The scope and relevance of the wheat improvement programs, particularly their impact on poverty reduction and food security in developing countries.

This report addresses the issues distilled by the Panel from the group presentations and one-on-one discussions with the CIMMYT staff. In structuring the report, we have chosen to present our observations, conclusions and recommendations pertinent to each breeding and scientific activity, where the Terms of References are addressed implicitly, rather than addressing them explicitly in sequence.

Impacts of CIMMYT's Wheat Breeding Activities

CIMMYT is known internationally for the strength of its wheat improvement activities, and the data from past economic studies demonstrate the huge impacts that CIMMYT has had, and is continuing to have, on the global wheat industry, in terms of the varieties grown and improvements in yields per hectare. The use of CIMMYT-developed improved wheat and maize germplasm has been a key success in helping to alleviate hunger, in assisting the provision of more stable cropping systems, and in improving economies in the developing world. Perhaps one of the most visible and measurable impacts of the CIMMYT wheat improvement program is the wide adoption of CIMMYT developed wheat germplasm, either as direct lines released as varieties or used as parents in crosses by wheat breeders around the world. An estimated 80% of the planted spring wheat area in developing countries (excluding China) directly or indirectly traces to CIMMYT wheat germplasm.

It was unexpected that the greatest percentage improvements in the most recently reviewed studies were achieved in the more marginal Mega-environments, at least until 1995. There is a need to continue that analysis beyond 1995, to ensure that any more recent trends are identified. Little information was presented on poverty impacts, *per se*, and there is a need to develop analysis to determine impacts, particularly in view of the new Program structure. In determining its impacts in intensive systems, CIMMYT should consider an analysis based on measures such as yield improvement per day as well per hectare, since that may be a more appropriate measure of progress within complex production systems.

The Panel recommends that CIMMYT should continue to have rigorous mechanisms for monitoring impacts on yields. In addition, CIMMYT should consider introducing more formalized priority setting (drawing on economic analysis where appropriate) into the wheat breeding activities. At present, the economic inputs into wheat improvement activities associated with the three program areas are generally low, and it is uncertain how such future impact assessments or priority setting can be undertaken without additional resources.

Recommendation 1 : The Panel recommends that economic resources be made available to ensure that impact assessment and priority setting for wheat breeding activities can be carried out adequately in the future.

Overarching Comments on Mission, Structure and External Relationships

Mission

The Panel spent five days with the scientists involved in most aspects of CIMMYT's wheat breeding activities in Mexico, and was very impressed with the professionalism, technical expertise and dedication of the staff. The Panel was unanimous in the view that the new program structure, embracing a systems approach, was an excellent framework for continuing and enlarging CIMMYT's commitment to poverty alleviation in its target regions of the developing world. Within this framework, the Panel believes that CIMMYT's comparative strength and impact is the quality of its germplasm, and that in this context, wheat improvement must stay as the major activity at the heart of CIMMYT's new approaches. Under this banner, CIMMYT should use both centralized and decentralized approaches as appropriate for particular target clients.

The Panel believes that CIMMYT's choice of target regions (based on Mega-environments, now being refined into Targeted Production Environments) is appropriate. However, the new structures have been in place only a very short time before this review, and we feel that the concept and the definitions of the key environments will need continuous monitoring and refinement as systems change and develop.

In redefining and refocusing CIMMYT, emphasis should continue to be placed on; 1) people and livelihoods, 2) global and eco-regional priorities focused on cropping systems; 3) responsive partnerships and networks that provide innovation and impact, 4) a commitment to sharing knowledge. The Panel endorses this as a holistic system for poverty alleviation and envisions that under this broad-based systems approach further refinement in CIMMYT's wheat germplasm will enable the more precise targeting of germplasm to customers needs.

Recommendation 2 : The Panel recommends that a review system is in place to monitor CIMMYT's choice of target regions so that it can rapidly respond to new needs.

CIMMYT's New Program Structure

The Panel did not review the new Program structure within CIMMYT, *per se*, but only as far as it relates to wheat breeding. Within this context, the Panel endorses the new CIMMYT program structure based on farming systems. We believe that it provides a framework for greater co-operation and integration between breeding activities and allied science groups (including pathology, genetic resources, biotechnology, agronomy, physiology, quality, etc). Its concentration on farming systems ensures that the activities will be focused directly on the areas of greatest need.

However, there is a need for careful co-ordination between the three Programs (Genetic Resources, Rainfed Wheat Systems and Intensive Agroecosystems) involved

in wheat improvement activities. The difficulties with co-ordination are enhanced by the fact that the three wheat-related Program Directors are also located in different regions. The Panel is concerned that there should be mechanisms in place to formally monitor the interactions of the three Programs involved in wheat improvement on a regular basis, to ensure that the close coordination is maintained and enhanced. Additionally, the decentralised Program structure will need to be communicated clearly to all relevant NARS, ARIs, donors and other clients, to ensure CIMMYT maintains its reputation and position in the global research system. It will need special attention to ensure that CIMMYT does not lose effectiveness in regions where the Program Directors are not located.

Recommendation 3: The Panel recommends that there should be mechanisms in place to formally monitor the interactions of the three Programs involved in wheat improvement on a regular basis

Management of Change

Change always causes apprehension as well as excitement. The Panel recognizes that there is still some apprehension and even confusion regarding structure and priorities both within CIMMYT and within its client community. Early and consistent communication regarding the changes in structure and mission are critically important to the successful implementation of the new strategy, and the Panel recommends that this issue is addressed. Confusion regarding the implementation of changes in structure and philosophy has been aggravated because of the recent cutbacks in the wheat research funding in 2003, and the consequential changes in staffing and programs that have occurred. The Panel recognizes that the recent cuts in funding for the wheat activities were not directly related to the changes in the mission of CIMMYT. However, the Panel senses the urgency to communicate changes in funding and mission to both the staff and CIMMYT's co-operators and clients.

Recommendation 4 : The Panel recommends that CIMMYT administration needs to clearly communicate changes in CIMMYT structure as it relates to both staffing and funding to maintain both confidence and motivation to international and national staff.

Recommendation 5 : The Panel recommends that Program directors should begin the task of meeting with all NARS and ARI customers to provide a communication bridge as CIMMYT moves forward with its new mission statement and programs.

Staffing Levels and Succession Planning

During the past 18 months a significant reduction (approximately 35%, overall, about 14 senior scientists) in staffing has occurred within the former Wheat Program. The Panel is very concerned that the critical mass required to continue wheat improvement is at an alarmingly low level. The loss of one or two key senior international staff at this juncture would clearly have a very significant negative impact on CIMMYT's mission and impact. Therefore the Panel would like to address key issues within this context.

1. A well executed plan is required to retain corporate knowledge as staffing changes occur. It is clear that there is a demographic imbalance in the system. The international staff at CIMMYT represent a very unique blend of education and philosophy that extends across both their science as well as their experiences working to alleviate hunger across the world. It is critical that this knowledge is communicated and bridged as changes in staffing occur. It also may be necessary for CIMMYT administration to recognize that some key positions require significant overlap between successors and that overlap be anticipated and planned for well in advance so that funding can be planned for the transition.

Recommendation 6 : The Panel recommends that the CIMMYT administration develops a clearer and more implementable strategy for succession planning.

2. CIMMYT, throughout its history, has developed a well-organized and funded Post-doctoral fellows program. This program has helped train outstanding young scientists and has enabled post-doctoral appointments to understand and appreciate the unique opportunities and challenges in working at an international center. It has also provided the CIMMYT staff an opportunity to evaluate each post-doctoral fellow as a potential member of the international staff. A large majority of current CIMMYT staff have begun their careers at CIMMYT as post-doctoral fellows. Staffing of post-doctoral fellows has also allowed flexibility to enable senior staff to concentrate on specific high priority programs as well as travelling to NARS locations for vital exchanges between CIMMYT breeders and NARS breeders. CIMMYT post-doctoral fellows have effectively supervised the breeding and germplasm development programs when program leaders are travelling. During the past decade the post-doctoral program has been gradually reduced. The Panel recommends that CIMMYT also explores the possibility of inviting young scientists from NARS programs to spend a one or two year sabbatical, where NARS institutions support the program through base salary, and CIMMYT provides facilities and per-diem for the visiting scientists. This could help to alleviate the immediate staffing problems that are present because of funding constraints.

Recommendation 7 : The Panel recommends that CIMMYT considers the re-establishment of an active post-doctoral fellows program in wheat improvement across the relevant programs.

Training

Training is a critical feature of the CGIAR Network. The Panel recognises that the training of visiting breeders has been a major output of the CIMMYT wheat improvement strategy, particularly through the hands-on experience gained in working with the CIMMYT wheat breeders. The Panel recommends that CIMMYT re-starts its training programs for wheat improvement urgently. This training needs to be built on the strengths of past experience, particularly the emphasis on hands-on experience. New training concepts such as the Open University and distance education concepts are also needed, but the Panel feels that they should complement but not replace the previous approaches to training in wheat breeding.

Recommendation 8 : The Panel recommends that CIMMYT re-start its training programs for wheat improvement specialists from target regions urgently.

Relationship with ICARDA

During the course of its review the Panel on numerous occasions noted the increasingly strained relationship between CIMMYT and ICARDA. As CIMMYT embarks into its new structure and focus on cropping systems for the poor, it is essential that both CIMMYT and ICARDA clearly define their own unique roles as well as rationalize each center's collaborative role in wheat improvement research in the WANA region.

Recommendation 9 : The Panel recommends that discussions at the highest possible levels are undertaken to rationalise and stabilise the relationship with ICARDA.

The Panel, in collaboration with CIMMYT staff, have suggested a possible framework (document not included) for a formulation of a joint CIMMYT-ICARDA program.

Relationship with IRRI

The Panel is also aware of the discussions that have been taking place regarding a formal alliance between CIMMYT and IRRI. Although the Panel recognizes that the full context of this discussion is well beyond the assignment of the CCER for wheat improvement programs at CIMMYT, we wish to comment specifically regarding the impact the alliance might have on the wheat related programs. The Panel has not seen a clear case that an alliance with IRRI will benefit the wheat program *per se* in terms of efficiency or scientific needs.

Evaluation of Breeding Strategies

Staff Resources

CIMMYT's wheat breeding activities have made it a respected force on the international agricultural scene. The Panel strongly believes that there is a need to facilitate the recovery of the wheat breeding activities from the recent period of budget stringency, and then building those activities back into pre-eminency. In general terms, the Panel believes that the wheat breeding activities are under-resourced, and that backup resources are needed for each of the senior breeders in both CIMMYT's Rainfed Wheat Systems and Intensive Agroecosystems Programs.

Some more specific observations can be made on staffing levels :

- There is no understudy for Dr. Richard Trethowan

- The replacement of Dr. Hans Braun's input into the winter wheat activities is not resolved (Dr. Braun is now Interim Director of CIMMYT's Rainfed Wheat Systems Program)
- Considerable resources now exist at ICARDA in wheat research, but the mechanisms to ensure good collaboration and co-ordination do not exist.

Recommendations 10 : The Panel recommends that there is a need for greater staff resources in wheat breeding to ensure greater outputs, improved succession planning, and greater coordination with ICARDA and the NARS.

Physical Resources

The wheat breeding activities of CIMMYT in Mexico use facilities at El Batan, Toluca and Obregon – the facilities used elsewhere (e.g. Turkey) were not considered in this review. The Panel inspected a large and impressive program at Obregon but were concerned that many of the physical resources used by the program have not been upgraded for many years, and certainly not during the recent funding crisis. Hence, despite the best efforts of the staff, the mechanisation and logistics of the breeding efforts are far from best practice. Further, as the North American Free Trade Agreement impacts the wages of national staff, it will become increasingly difficult for CIMMYT to manage the large field nurseries essential to make the genetic gains required.

The Panel sees an urgent need for capital allocations to improve the cost efficiency of the field program by mechanisation of the breeding program in, at least, the following areas

- Seed packaging – investigation of robotic systems and computerization to facilitate rapid seed loading. Recently systems have been developed by the Department of Primary Industries (Victoria) and by the University of Adelaide, Australia.
- To maximize the impact of robotic seed packaging, improved seed magazine systems for seeders are required. These are available from a number of sources including Wintersteiger and Department of Primary Industries (Victoria), the University of Adelaide, Australian Grain Technologies and Department of Agriculture Western Australia.
- Warehousing technology – to manage the seed and sample inventory using barcode and hand held scanning systems. This technology is available from many commercial providers which service retail outlets, supermarkets and commercial warehouses, and is a very cost effective way of increasing sample handling efficiency.
- Automated data acquisition – it is time replace the ageing HP systems for data acquisition with a number of alternatives. For instance, touch screen tablet notebooks and dust/moisture/impact resistant data loggers are available from many commercial suppliers. The capture of harvest yield data could also be improved by the combined use of bar-coded labels and portable scanners coupled to electronic scales.
- Harvesting equipment – much of the fleet is old and requiring heavy maintenance schedules. Further, modifications can be made to the harvesters to improve the comfort of the operators and sample throughput .

Recommendations 11 : The Panel sees an urgent need for capital allocations to improve the cost efficiency by further mechanisation of the breeding program

Breeding Strategies

The Panel examined a number of strategies used in the CIMMYT wheat breeding programs. In addition to the modified pedigree approach, the strategy of “shuttle breeding”, centralised in Mexico using, principally, the Toluca and Obregon sites, was endorsed by the Panel as the crucial and productive core of the breeding programs. Targeted de-centralised breeding (including PVS) also has a useful role, but the Panel were not convinced that participatory plant breeding techniques should assume a large role for the breeding staff. CIMMYT should be the ‘seed’ of de-centralized approaches in target regions.

More specifically, the Panel examined the CIMMYT breeding approaches of:

Targeted shuttle breeding : Traditionally, CIMMYT has used a “shuttle breeding” system to develop widely adapted spring wheats with robust disease resistance. While this strategy is still central to CIMMYT’s success, the Panel was impressed by refinements developed and executed by a number of scientists in the programs. “Disease shuttle” i.e., extra sites added to complement the range of diseases and pathotypes to which the germplasm is exposed. These include Ecuador (stripe rust), Kenya (stem rust), China (scab and powdery mildew) and the Southern Cone (scab and rusts). The Panel encourages the incorporation of these and other key sites, as required, to be added to the shuttle where quarantine and logistics allow. We believe that the strategy will add greatly to durability of the resistance base in CIMMYT germplasm. The Panel also believe that this is a particularly cost effective investment, since it is likely that considerable in-kind contributions from NARS partners can be expected. Further, we believe that such a strategy could also be an attractive project for external sponsors who would value the germplasm developed.

“Abiotic stress shuttle” : Recent improvements to the irrigation management (reduced, strategic irrigations to develop terminal stress; drip irrigation to develop a range of other cyclic and variable intensity stresses), agronomy (zero tillage, deep sowing, stubble retention), date of planting (grain filling temperature stress and grain filling rate) and site characterisation (salinity, soil depth profiling) used at Obregon will allow CIMMYT breeders to imitate stress conditions relevant to a wider range of environments than previously possible. This will be necessary for the full benefit of the germplasm diversity and physiology programs to be captured in cultivars adapted to stress, and to redress shortcomings in CIMMYT germplasm in specific stress environments. Further development of the shuttle approach is encouraged and where the science supports it and logistics allows, the addition of sites to complement stress selection at Obregon should be investigated.

The development and incorporation of novel genetic resources into useful varieties: The Panel believe this to be one of CIMMYT’s great contributions to wheat science. We noted that the spring wheat programs have raised their use of synthetic hexaploids from 10% of germplasm in 1997 to 40% in 2003. Molecular evidence from the genetic diversity studies at CIMMYT shows that the diversity of CIMMYT’s

germplasm has increased in the late nineties compared to the previous 20 years. Diversity is fundamental to continuing gains, and the Panel can only encourage further targeted work on the wheat synthetics.

The use of international nurseries/ yield trials for multi-location evaluation of improved materials: The preparation, distribution, management, data storage, analysis and interpretation of the International trials is a huge task central to the identification of elite germplasm and future parents. The international nursery system, along with the shuttle approach and training, are the heart and soul of the CIMMYT wheat improvement program. The timely use of this resource is crucial to rapid framing of new crossing strategies and rapid generation times. Hence, the Panel felt it was best managed from within the breeding activities in CIMMYT CIMMYT's Rainfed Wheat Systems and Intensive Agroecosystems Programs. We note that data has not been flowing freely from the WANA region, and are concerned about the impact of this knowledge gap on the ability to select the most appropriate parents for this region.

Size of program: Despite progress in biotechnology, the Panel is convinced that rapid genetic gains will only be possible with the use of large crossing blocks and large segregating populations for generating sufficient diversity.

Limited Backcross Approach (or, BC_1 defect elimination): This strategy is fully supported since it allows breeders to concentrate on more aggressive breeding strategies, and because it has already provided some excellent parents for use in the "mainstream" breeding program.

Detailed evaluation of the parents used in the program: The Panel were impressed by the breeders attempts to better characterise their parental material by the combined use of molecular analysis of diversity, molecular analysis of genes/alleles present, physiology, quality, abiotic stress characterisation, G x E analysis of yield results from International and special nurseries, pathology and agronomy. The Panel viewed this as close to best practice.

Scope : CIMMYT still needs to develop finished varieties, as well as advanced lines and segregating populations, tailored according to the needs of individual NARS.

Participatory variety selection and participatory plant breeding: The success of participatory variety and selection is well documented in the barley program of ICARDA, the maize program of CIMMYT and in some parts of the CIMMYT wheat program. The Panel received many views regarding these options and accepted the case that where the central seed system has shortcomings, the region is isolated from NARS or CIMMYT variety testing, or where there are cultural or other barriers to uptake of new varieties, that there was a case for participatory variety selection. However, that Panel also accepted views from breeders that participatory plant breeding (PPB) was not an efficient use of their time. Complex quantitative traits such as durable rust resistance, end-use quality and multiple pest resistance would need to be either fixed or enriched in F_{4-6} populations. MAS could be effectively utilised when effective predictive markers are available to assist in developing such populations. Until such time when the proper technology becomes available, the Panel recommends that the PPB only be pursued as a special funding status.

Recommendations 12 : The Panel endorses many of CIMMYT's wheat breeding strategies and recommends further development of the shuttle breeding concept, including special nurseries to broaden the base of disease resistance, stress tolerance and adaptation.

Recommendations 13 : For a range of technical and logistic reasons, the Panel believes that the international nursery program is best managed from within the breeding activities in CIMMYT's Rainfed Wheat Systems and Intensive Agroecosystems Programs.

Breeding Strategy: Rainfed Wheat Systems

The Panel strongly supports the continuation and strengthening of the bread and durum wheat programs in the Rainfed Systems Program. A particular issue for this program is the relationship with ICARDA, as the WANA region is at the core of ICARDA's mandate, as well as a key part of CIMMYT's new Rainfed Wheat Systems Program.

Many of the breeding strategy issues were discussed in the previous section but the Panel would highlight and endorse the following :

- Strategies being used in both the bread and durum wheat breeding programs.
- The use of 'Smart crosses' for better parental selection in generating variability for tolerance to abiotic stress i.e., collaboration with the physiology group has provided a detailed phenotype for many of the parents with respect to physiological response to drought stress.
- The incorporation of durable disease resistance.
- The concept that the management of yield trials should reflect current and, where possible, future crop management systems such as reduced/zero tillage, stubble retention and precision agriculture.

The widespread adoption of conservation farming techniques will require changes to wheat varieties in disease resistance (particularly stubble-borne disease such as tan spot, Septoria and root rots such as common root rot and crown rot); coleoptile length (where uneven seeding depth, ability to exploit receding moisture and tolerance to soil active herbicides is required); adaptation to widened row spacings and weed competition. Most of these issues were being covered in the crop establishment and crop management strategies used in the breeding plots. However, continuous review of developments in tillage equipment, crop establishment techniques and fertiliser placement and type is required to ensure that breeders plots are relevant to emerging farming systems. The Panel recommends that the management of yield trials should continue to reflect current and, where possible, future crop management systems such as reduced/zero tillage, stubble retention and precision agriculture. To this end, the Panel suggests that CIMMYT staff review developments in dryland farming technology in Canada, South Africa, USA, Southern Cone and Australia where the science and practice of zero tillage is evolving rapidly.

Intensive Agroecosystems

In many areas of the developing world, farming systems are production intensive, diverse, and increasingly market oriented. Intensive agriculture often has to satisfy increasing urban needs, and it should promote the efficient use of inputs in order to

increase yield in a sustainable environment. Water availability is becoming a major concern since these high production systems are often irrigated, and efforts should be directed towards achieving water and input efficient varieties.

The Panel supports the continuation and strengthening of the bread and durum wheat program for intensive agroecosystems. However, it is concerned that CIMMYT's yield gain in bread wheat appears to have been static in recent years, due, in part, to the need to increase disease resistance and improve quality, but recognizes that the apparent yield plateau is now being addressed. The adaptation of triticale in these systems should also be explored with the assistance of project funding.

The Panel strongly supports the major efforts towards increased yield in the bread and durum wheat varieties adapted to this agroecosystem.

In some areas the currently available varieties are not well adapted to the needs of some farmers, and seed production can be a constraint. CIMMYT has promoted farmers Participatory Varietal Selection and the Panel supports this concept as incorporated in the Mother-Baby approach, although it is concerned that appropriate NARS support is needed for such approaches. The Panel thus strongly supports both centralized and decentralized systems of breeding to achieve the required objectives.

The Panel strongly suggests that a Participatory Varietal Selection strategy includes close co-operation with NARS in targeted regions to ensure efficient dissemination of its products.

Triticale and Hybrid Wheat Improvement

The Panel acknowledges the current and historic contribution that CIMMYT has made to Triticale research and development. The earlier emphasis of breeding it for an alternate grain cereal is now a low priority and the current approach of making it a dual-purpose forage-grain crop is likely to give rich dividends. It also fits into the new CIMMYT mandate of systems diversification, as this would promote cereal growing for alternate purposes.

Triticale has advantages in the acidic soil areas or upper reaches of the mountainous tracts in different parts of the world. It is therefore felt desirable to sustain the experience of CIMMYT in this important area of activity, and efforts should be made to win competitive grants to continue progress.

The amount of effort that CIMMYT has made through externally funded projects on hybrid wheat research has been substantial, and this has paid off in spin-offs in the form of parental lines and the development of several cytoplasmic male sterility systems. However, although commercially viable heterotic combinations have been identified, their impact has been muted by better yielding traditionally bred bread wheat varieties. This 'run-over' of the technology is a real issue for hybrid research. However, the fact that there is tremendous opportunity for yield advances through hybrids, even under harsh environment where most of the poor live, makes the Panel believe that a hybrid research activity should be sustained through externally funded grants. The cytoplasmic male sterility lines developed by the program can be extended to NARS and a global hybrid research strategy can be planned. Involvement

of the CIMMYT gene pools and derivatives of the single backcrosses in hybrids could further add to yield gains.

International Nurseries and Seed Health:

The Panel endorses CIMMYT's breeding strategy of the use of international nurseries and yield trials for global evaluation and usage by the various national programs. The nurseries are planted at hot spots for pests and diseases, and where abiotic stresses of various kinds prevail. The global data helps to identify potential donor lines and some of the advanced NARS use them in their crossing blocks. The yield nurseries are also of significance to the developing NARS as some of them can use the best performers for subsequent promotion at their national level to release as varieties. However, there is a complicated multiplicity of nurseries with several sister lines often repeated in more than one nursery. Although this is already being addressed, there is a need to revisit this to identify the useful sets, the correct hot spots, and provide a wider gene pool rather than sending many sister lines.

The nurseries, as of now, must be planned a year in advance. It will be efficient if these activities are co-ordinated with the cooperating breeding programs, to enable them to keep contact with their NARS counterparts to get quick feed back on the performance of the material. We are aware that there is a discussion going on within the system to split responsibilities into 1) nursery composition and dispatch, and 2) data reporting, which are to be dealt with separately. In the Panel's opinion this may hinder the efforts in using the nurseries to address regional germplasm improvement needs. Periodic visits by the breeders to the sites will enable CIMMYT to acquire first hand knowledge on the problems and performances, and cut out the cost and time involved in developing acceptable germplasm.

The seed health and quarantine activities are integral parts of CIMMYT, and the Panel is impressed that they are well managed. Efforts initiated in diagnosing transgenic seed (contamination or otherwise) in the seed lots are a necessary improvement. The Seed Health Unit should continue to keep a periodic inventory of quarantine issues of various client nations, periodically educate them, and interact globally with the International Seed Testing Association for harmonizing the cleansing procedures. The present transparent record keeping gives tremendous confidence to the clients and importers that their interests are well safeguarded.

Recommendations 13 : For a range of technical and logistic reasons, the Panel believes that the international nursery program is best managed from within the breeding activities in the Rainfed Wheat Systems and Intensive Agroecosystems Programs.

The Impact of Allied Science Groups on CIMMYT Wheat Improvement

Agronomy and Farming Systems Activities

The Panel believes that the resource-conserving technologies are receiving wide acceptance by various clients. Therefore, the Panel sees a need for the breeders to conduct yield selection experiments under current and emerging farming practices and systems. Some of the NARS already have integrated breeding for cropping systems in their approach to develop superior genotypes. Further augmenting these efforts will add to systems efficiency in the intensively cultivated areas, as these technologies lead to greater water use efficiency, gradually build up the soil organic matter, and augment the soil flora and fauna. All these issues need attention as part of a holistic technology development process. The CIMMYT/NARS integration, along with NGOs and self-help groups, in these activities would ensure that the technology spreads to every part of CIMMYT's mandate.

The agronomy and farming systems team must promote higher per day productivity rather than focusing on the productivity of a crop that may vary due to reasons of maturity duration and other reasons. In the intensively cultivated areas, introducing a short duration grain legume / forage crop should be considered. The soil fertility characterization of the experimental farm to account for yield variation and for deciding the type of nursery to be planted for evaluation is a welcome approach.

The Panel feels that there is an underlying commonality between the drought production physiology, micronutrient fortification and root health. Greater understanding of the genetics, physiology and functions of the root system is essential, and an integrated approach is recommended. The Panel supports the *Harvest Plus* program and the focus to biofortification of *Zn* and *Fe* in the bread wheat grain. Additional *Zn* also enables better and robust seedling growth under difficult environments, and the extent of genetic variation available is impressive. This should be harnessed to provide improved nutrition to people living below the poverty line. The choice of wheat varieties used in this work needs careful consideration, so that efforts focus on improving the currently accepted popular varieties, rather than the historically accepted ones.

Marker-Assisted Selection

The Panel recognises that Marker Assisted Selection (MAS) has a key role to play in future breeding and that this activity has recently made great progress in becoming integrated with both the breeding programs and allied sciences, and is delivering a valuable service to such activities. Annually, around 6000 assays are undertaken. Currently, DNA extractions can be performed at around 200-250 per day and the Panel believes this is below current best practice. Recent advances in gel interpretation and multiplexing also hold the potential for greatly increased throughput. The Panel believes that to have a major impact on CIMMYT's wider wheat improvement programs, a major increase in sample throughput must be achieved.

When marker throughput is limited, careful attention to the strategy of marker application is required for its use in the priority areas of :

- key parent building
- accelerated backcrossing, especially for recessive traits
- building disease resistance pyramids where phenotypic selection is difficult
- selection of quarantine traits or traits where phenotypic selection is not practical
- use in gene introgression or doubled haploid production where the material is worth considerably more than the usual breeding materials
- validation of pure seed, identity and IP issues

As throughput grows, many programs have found that selection for genes from the minor parent(s) in 3- and 4- way cross F_1 's is particularly valuable, as it so strongly changes gene frequency in subsequent generations, so that genetic gain is dramatically improved. Only when throughput is at very high levels is it normally feasible to undertake selection of a large proportion of the fixed lines in a program as large as CIMMYT's.

There needs to be an integrated marker service laboratory to ensure that the breeders are able to use the selection markers that they want. Close consultation between breeders and MAS staff is required to optimise the selection strategy and efficiency. It is recommended that QU-CIM simulations be undertaken to optimise the deployment of MAS within the breeding programs.

The Panel recognised the value of genetic analysis for the discovery and the development of markers for genes for disease and pest resistance, and encourages a strong relationship between the pathology and MAS staff. The Panel suggests that a strong collaboration can also be forged around the "BC₁ strategy" of defect elimination (see Pathology and New Initiatives sections below) where it is hoped that MAS will greatly aid the selection of resistance genes from the donor parent and recovery of key genes from the donor parent.

The Panel was also greatly encouraged by the strong interactions of the MAS staff with staff in allied sciences including physiology, quality and wide crosses, and with ARIs, and believe that these will be crucial to the further development of this program.

Recommendation 14 : The Panel recommends that the efficiency of MAS can be increased through the following actions :

1. An integrated service laboratory to ensure that the breeders are able to use the selection markers that they want;
2. Close consultation between breeders and MAS staff to optimise the selection strategy and efficiency;
3. QU-CIM simulations be undertaken to optimise the deployment of MAS within the breeding programs;
4. CIMMYT should ensure that the technologies and operations adopted have increased thru-put to meet the breeders' needs, with particular reference to DNA extraction systems and gel interpretation;
5. A strong relationship between the pathology and MAS staff.

Pathology

Yield losses due to different pathogens are of great importance in most environments into which CIMMYT targets its varieties. The incorporation of genetic resistance into varieties, whenever this resistance is available, has been a major tool in overcoming those losses. Single major genes are frequently overcome by pathogens due to genetic changes regarding their virulence. A more durable resistance through the accumulation of several major and/or minor genes has proven to be an effective way of incorporating stable resistance.

The Panel considers CIMMYT's work on durable disease resistance for leaf and yellow rust is of high international significance and value. The very high level of integration of this work into the breeding activities ensures that the value of the work is translated into improved varieties. Similarly, the work at CIMMYT on root diseases including nematodes and soil fungi is also extremely valuable.

The Panel was very impressed with the great advances in introgressing minor additive slow rusting genes for leaf and yellow rusts using the Single Backcross strategy. A considerable number of these genes are presently available for breeders. The Panel believes that CIMMYT should consider expanding these activities, either establishing a service for using this technique by having a project of introducing durable resistance into leading varieties in client countries, or in developing a program for the dedicated training of scientists to use the strategy to do so.

The Panel believes that rust monitoring networks have played an important role and should be strengthened in some areas, particularly in Africa. CIMMYT should also establish strategic linkages with NARS and other major wheat groups to monitor wheat rust pathogen variability and its evolution at a global level.

The close integration of MAS into the wheat pathology operations has been of great value in enabling the breeders to have ready access to specific genes. The Panel believes that CIMMYT should consider seeking alliances to develop further markers.

The Panel recommends that emerging problems (leaf spots, Septoria, Fusarium) associated with increased use of conservation farming practices are likely to need more resources. Fusarium head scab is a disease of major importance not only for potential yield losses but also for the production of mycotoxins. The Panel supports continuing work on head scab in cooperation with partners, particularly China and the Southern Cone, since the Toluca site is not now so effective. Future work in the identification and mapping of resistance genes and in developing molecular markers should be considered.

Recommendations 15 : The Panel recommends priority within pathology research lies with the need to provide root pathology services to the Mexican based breeders.

Physiology

The CIMMYT wheat physiology group has developed into a leader in both concepts and applications associated with physiological strategies for wheat improvement.

Physiology as a science in wheat improvement has been absent in many ARI approaches to wheat improvement recently, and the Panel supports the leadership role CIMMYT has taken in keeping this important aspect of research, particularly as applied to improving abiotic stress tolerance.

The Panel was impressed with the close ties that have been developed between the physiology unit and the breeding programs. It is obvious that both groups are benefiting from these alliances. The physiological characterization of key CIMMYT breeding parents over the past 3-4 breeding cycles has led to a strategic plan to converge key physiological traits via “smart crossing”, which has the potential of improving abiotic stress tolerance. The Panel strongly endorses this approach and envisions the implementation of a limited backcross approach using key physiological parameters in much the same way that durable disease resistance is being introgressed. Heritability and GxE interactions involving abiotic stress will still need to be better understood, but the ongoing approach has many potential applications. The Panel supports the close interaction and encourages further interaction as a path forward for both the development of new physiological selection tools as well as new and useful germplasm.

The Panel strongly supports the interaction between the transformation and physiology groups concerning the drought investigations involving the Arabidopsis DREB1 transcription factor gene. As new traits are transformed into wheat, the Panel encourages the close cooperation and involvement of the physiology group.

As new tools are developed, the Panel would like to encourage the physiology group to support research involving root health. Although root research remains a considerable challenge, the Panel feels that a greater understanding of root growth, such as rooting patterns involving the synthetics, will provide a path forward in improving and stabilizing yield in many environments.

Quality

In the past, yield was the most urgent problem for CIMMYT’s wheat breeding to address. However, from the early 1990s, greater effort has been put into improving bread and durum wheat quality. End use quality has become a major issue for it has to meet people’s (clients) preferences in their daily intake, and also enable them to meet market demands, since in many cases wheat has become a cash crop in the developing world. These quality needs have varied according to specific regional requirements, but a common theme has been the development of varieties with higher gluten strength and flour extraction, and increased levels of nutrient fortification. The developments in CIMMYT’s wheat quality work have meant that industrial quality is a key consideration when choosing parents. As a result, the work on parental assessment has involved extensive testing for both high and low molecular weight glutenins and gliadins, the 1B/1R translocation, targeted crosses in different regions and breeding programs, and the introgression of good quality bread wheat proteins into durum wheat. These moves are all strongly supported by the Panel, as well as the project for achieving higher protein content in future varieties.

However, the Panel recognizes that the resources in the quality work are limited and may need strengthening if greater testing is required. The recent acquisition of NIR equipment and the potential it has in improving quality testing, will be of great value, but appropriate calibration will be difficult to obtain, given the wide range of CIMMYT's germplasm.

Recommendation 16 : The Panel recommends that there is a strengthening of the technical capabilities of the quality work, particularly through the use of NIR. An accumulation of a library of samples over years and environments is an urgent need for the achievement of robust NIR calibrations, and collaborations with experienced specialists in ARIs may be required.

Novel genetic variation in the synthetics and other germplasm sources is being explored, but this could become a project for which special funding is obtained. The germplasm exchange over recent years with NARs and private breeding programs from the Southern Cone has resulted in enhanced quality of CIMMYT's germplasm, and the Panel believes that it should not be discontinued.

Molecular Diversity

The Panel recognizes the significant contributions made in molecular characterization and documentation of genetic diversity as it relates to wheat landraces stored in the gene bank and CIMMYT-developed advanced lines. CG centers and especially CIMMYT have been criticized for narrowing the germplasm base during the post green revolution era of wheat improvement. The molecular results recently generated clearly support previous phenotypic and pedigree lineage studies, indicating that genetic diversity has indeed increased during the post-Green Revolution period, especially during the past 15 years. CIMMYT's activities as a leader in germplasm and information exchange have directly contributed to this trend.

Further development of molecular tools to provide a clearer understanding of genetic diversity as well as understanding genetic recombination and gene-evolution in interspecific and intergeneric crosses are important. The specific results of the synthetic hexaploid studies, which relates to genome evolution when distant genomes are combined and interspecific progenies selfed, is of great importance in understanding possible pathways for genetic exploitation of wild relatives of wheat. The proposed approaches of linkage disequilibrium mapping as a means of describing marker-trait associations from the diversity studies is encouraged and supported. The Panel supports the publication of the molecular diversity results as an indication of the usefulness of molecular approaches in a breeding context.

The participation of CIMMYT in the Genetic Resources Challenge Program is fully supported. The characterization of the CIMMYT wheat working collection along with carefully selected advanced inbreds and synthetics is a valuable approach. The Panel would encourage that the most recent emerging varieties from both the Rainfed and Intensive breeding programs are included in the analysis.

In the future, as further molecular tools are developed to aid in germplasm characterization and utilization, it is important that the molecular genetics and functional genomics work is closely associated with both the wheat breeding and

allied science teams. These interactions are important for CIMMYT and should be cultivated both by the individual scientists involved, as well as being monitored by management.

Genetic Transformation

The genetic transformation group reported significant progress as it relates to transformation efficiency and the development of stable transgenic lines. The Panel supports the application of this technology to understand gene expression and to discover and improve useful traits. It seems clear to the Panel that transgenic technology for developing countries can and perhaps should be introduced via the CG centers. Poor farmers will initially not be in a position to afford new technologies developed by the private sector, and the introduction of such technologies by CIMMYT will provide a path forward in terms of the use of the technology, as well as the concurrent possibility for improved economic growth.

The planned drought experiments with transgenic wheat lines in the greenhouse is a good example of just such an approach, and should provide extremely useful and interesting data to explore the effects of heterologous genes on such a complex trait. CIMMYT has taken a leadership position in developing transgenic wheat for the developing world and the Panel is impressed with the thoughtful approach and careful preparation of the experiments. The bio-safety procedures associated with the transgenic program appear to be up to date and carefully thought out. As future traits are included in the research agenda, the Panel encourages that prioritization should be carried out in collaboration with all the plant improvement teams. The drought work, which includes characterization of phenotypic physiological measurements, is an excellent starting point for continued close collaboration.

The Panel recommends that clear strategies for the exploitation of genetic technology be thoroughly understood. Freedom to operate should be established for both the current as well as the future suite of genes, both inside and outside of Mexico. Furthermore, CIMMYT should begin to discuss strategies regarding release of transgenic wheat. Costs associated with documentation for safety and novel trait status in both developed and developing countries are excessive. CIMMYT should have a well thought out path forward if beneficial traits are discovered.

Many countries and individuals around the world have clearly seen the development of transgenic wheat as unique and different from transgenic corn, soybean or cotton. CIMMYT has done a good job in education and communication as regards to Bt corn in Africa. Transgenic wheat will no doubt provide additional unique challenges, and CIMMYT should continue to play a lead role in science-based understanding of transgenic technology.

Recommendation 17 : The Panel recommends that CIMMYT establishes the freedom to operate and commercialisation needs for planned uses of the transgenic material in both Mexico and CIMMYT mandate countries.

Genetic Resources Program

Genetic resources are at the center of a vibrant plant breeding program as the source of novel gene and gene combinations that the plant breeder needs to produce superior and acceptable germplasm for use by NARS and other clients. Hence, they are at the core of the CIMMYT's wheat program and the molecular biology activities. The Panel recognizes the central role of genetic resources in the new structure of CIMMYT and strongly supports regular discussions with the wheat breeders and allied science groups in prioritizing the target characters that are of interest for pre-breeding activities. The changed approach also demands a re-evaluation of the germplasm for traits that now require greater attention (drought, heat, root growth, head scab resistance etc.).

A discussion between genetic resources and breeding staff may also cover the possibility of a global germplasm evaluation network, as some of the NARS have well developed institutes for such purposes. The informatics part and the knowledge sharing aspects of the Genetic Resources Program need attention. Also tied up with this are the issues involved in sharing this wealth of material with all interested parties through the system of Material Transfer Agreements, Intellectual Property rights and Farmer's Rights.

There is an excellent germplasm collection, mainly durum wheat, at ICARDA, and so both CIMMYT and ICARDA should come together in benefiting globally from the material kept under their custody. This will also forge an alliance and working partnership between the Centres, and with NARS and other interested agencies.

The Panel recommends that the genetic resources information coming from test sites, other evaluated attributes and molecular information, should all be placed into an enhanced information system as a matter of priority. There is scope to use and develop need-based knowledge management systems as part of the Genetic Resources Program.

The Genetic Resources Program, through its vast inventory, should quickly respond to seed requests by developing more efficient protocols. The Panel endorses the pre-breeding efforts, although it feels that issues such as the proposed DNA bank, and sharing with NARS the new diversity of CIMMYT, require further strengthening through project funding.

Recommendations 18 : The Panel recommends that there is an urgent need to upgrade the data acquisition, data management and gene bank user interface through investment in information systems.

Public-Private Partnerships

CIMMYT has provided the public sector with knowledge and skills, and the Panel welcomed the partnerships that CIMMYT has, and continues to develop. Information flow and sharing with all CIMMYT's partners should be a priority. The CIMMYT wheat germplasm and collective knowledge base is extremely valuable, and should be

utilized to partner with interested parties to acquire information, germplasm and technology.

CIMMYT greatly benefits from alliances with advanced research institutes and private companies in the developed world by having access to advanced technology and funding. The collaboration with Australia has been an excellent example that has provided extensive benefits to both parties. The Panel believes that there is a need to expand the diversity of funding sources to other major partners. The Panel encourages CIMMYT to continue pursuing partnerships to exchange information, germplasm and technology where it seems reasonable and prudent.

Regarding smaller private companies worldwide, the Panel feels that these could be important partners for germplasm exchange and multi-location evaluation, and also in providing resources on a basis of medium or long term agreements for specific objectives. CIMMYT should actively seek and promote these partnerships. CIMMYT germplasm, information and technology are extremely valuable and should be actively shared rather than simply being provided on request. In the new systems approach, partnership with farmers should be strengthened, but the Panel recommends that this must involve close coordination and cooperation with the NARs.

Wheat Improvement and Intellectual Property Management

The Panel welcomed the new CIMMYT Material Transfer Agreement for the exchange of designated and non-designated germplasm dated 3/1/2004 as a logical, fair and clear basis of germplasm exchange between CIMMYT and its partners. It greatly simplifies and clarifies the confusion surrounding germplasm exchange which has existed for an extended period.

The Panel examined the IP issues pertaining to the transformation program, where currently biolistic transformation is used to insert a number of genes into wheat, namely,

- DREB1 and 2 transcription factors
- A number of disease resistance factors from collaborators in Adelaide, including Thaumatin like protein and b-glucanase
- BYDV construct
- In future, a number of drought implicated genes

Federal regulations in Mexico now allow field trials with GM plants and the first of these with transgenic wheat is underway at El Batan. The IP position with respect to the genes and technologies used in transformation is somewhat relaxed in Mexico compared to other countries. Nonetheless, the Panel believes that, as a matter of urgency, freedom to operate and to commercialise needs to be established for planned uses of the transgenic material in both Mexico and CIMMYT mandate countries. (see Recommendation 17 above)

Information Systems

An efficient and effective information system is critical for the operation of the wheat breeding activities, particularly in view of the new structure where the activities are spread across three Programs. In the past, the International Wheat Information System (IWIS) developed at CIMMYT has proved very useful. However, we were advised that this system is now reaching its maintenance limits, and that a new system is required. Given the importance of this system for the wheat breeding activities, the Panel strongly supports the immediate development of integrated informatics systems at CIMMYT that are capable of meeting the needs of all in the Programs associated with wheat breeding. Whether this is the ICIS system, or uses another platform, the new systems need to link all scientific activities in a seamless form, and should integrate information from IWIS and other current databases associated with the wheat breeding and germplasm activities.

Recommendation 19 : The Panel recommends that CIMMYT gives a very high priority to developing new integrated informatics systems for servicing the many different needs across the wheat breeding activities

Recommendations for New Initiatives

The Panel recognises that the above discussion raises issues in terms of the requirements for new initiatives. The Panel have made an attempt to prioritise these (see below), and these are presented in priority order with the details of each described below under the headings : Problem, Solution, Implications.

1. Succession planning for wheat breeding activities in CIMMYT's Rainfed Wheat Systems and Intensive Agroecosystems Programs.
2. Globalisation of the shuttle breeding system to ensure durability of disease resistance.
3. Development of a global rapid backcross service to develop durable rust resistance for successful varieties whose disease resistance has failed.
4. Improved data acquisition, search tools and web access for genetic resources.
5. Improved economic resources for impact assessment and priority setting.
6. Investment in research in the improvement of root health.

Priorities for New Investment

1. Succession planning for wheat breeding activities in CIMMYT's Rainfed Wheat Systems and Intensive Agroecosystems Programs

Problem : The reduced human resources in this program are limiting the overall management structure and potential genetic gain. At least 3 problem areas exist. Currently, the durum wheat crop representing ca. 10% of global wheat production is managed by only 1 part time person. The Rainfed Systems breeder has no understudy. The Head of the winter wheat program is a program manager and this will reduce input into that programme.

Solution : An extra appointment in wheat breeding to ensure critical mass.

Implications : This should be viewed as part of a strengthened succession planning initiative as well as an improvement to the overall strength of the wheat improvement effort.

2. Globalisation of shuttle breeding system to ensure durability of disease resistance

Problem : Virulence in major diseases is not fully represented in CIMMYT's Mexican nurseries. NARS programs may not have resources and expertise to tackle the problem of multi-location testing and handling the shuttle breeding materials.

Solution : Implementation of a globalised shuttle system including, for instance, Ecuador - yellow rust; Kenya - stem rust, China - Scab and mildew where CIMMYT breeders and pathologists compile the genetic materials and use NARS collaborators to assist in the nursery management.

Implications : A small CIMMYT cash investment will leverage NARS contributions to achieve common goals. The risk of poverty will be reduced by reducing the likelihood of epidemics in ALL mandate countries.

3. Improving the logistics of breeding

Problem: The facilities, software and systems for handling the harvest samples and acquiring the field and harvest data are old and sub-optimal.

Solution : A capital injection to allow purchase and implementation of logistics solutions from current warehousing technology, robotic seed and sample handling, new harvesting equipment, etc.

Implications : The wheat programs will be able to manage the population sizes required to maximise genetic gain in a timely manner.

4. Development of a global rapid backcross service to develop durable rust resistance for successful varieties whose disease resistance has failed

Problem : Each year new virulent pathotypes of many wheat diseases evolve causing yield loss and reducing the benefit of CIMMYT's wheat variety development.

Solution : Development of a defect elimination service introducing several genes for partial resistance via rapid, limited backcrossing using marker assisted and phenotypic selection. NARS collaborators could either nominate varieties to the program, undertake the defect elimination under supervision or be trained in the techniques.

Implications : Rapid deployment of durably disease resistant versions of elite varieties which will be rapidly adopted by local farmers, since the performance of the recurrent parent is well known.

5. Improve data acquisition, search tools and web access for the Genetic Resources Unit

Problem : The public face of a genetic resources collection is determined by 3 major factors - the rapid entry of data into the genetic resources database; the user interface for searches, data analysis and seed requests; the speed with which seed requests are processed. In all of these areas, systems could be improved with capital investment

Solution : Capital funds allocated to improved warehousing technology and web systems would have immediate impact

Implications : Greatly improved access and use of the genetic resource collection.

6. Improved economic resources for impact assessment and priority setting

Problem : There are inadequate resources to ensure that impact studies and economic inputs into priority setting within the Programs are continued in the future.

Solution : Extra resources either as economics staff (CIMMYT's Rainfed Wheat Systems Program) or funding for external assessment.

Implications : Continued assessment of impacts on yields and poverty to use as support for future funding

7. Improvement of root health

Problem : The poor health of roots due to the combined effects of nematodes, fungi and abiotic stress is seriously reducing the yield, quality and reliability of wheat in many environments. Experience accumulating from the joint Turkey/CIMMYT/ICARDA project show great opportunities for productivity gains arising from understanding these problems.

Solution : Development of a complementary root pathology program in Intensive Agroecosystems Programs to service the wheat improvement projects.

Implications : Greater productivity in wheats derived from genetic improvement programs and better management strategies. We expect this appointment to work in concert with physiologists and breeders to improve overall root performance. This appointment will also help bring the pathology expertise in CIMMYT back closer to critical mass.

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