Peer Review of ICARDA Barley Program

April 2008

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Peer Review of Barley Breeding at ICARDA May 2008

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1. Executive Summary

The terms of this review are focused on the barley program and the collaborative areas of Pathology, Entomology, Virology, Biotechnology, Quality and the Seeds Section. Since the direction of this program is defined by the Mandate under the CGIAR centres and ICARDA we are only able to look at a small part of the process used to set priorities and allocate resources. We are therefore limiting this review to define the Barley Program in the context of a "Global Mandate": to develop barley aimed at the resource-poor farmers in developing countries.

Global Recommendations

Over the next 2 months develop a detailed work plan and business plan with input from all scientists in the Barley Program and management. During this process, focus on the mandate and goals of the program in a global environment. If a facilitator is needed to help the development along, Management should make this available. When completed (June 2008) have it reviewed by at least two clients/investors. Once this process is complete and all scientists and management have a buy-in, adopt it as a work plan and use it to seek new investment partners.

Recommendation 1: An annual operational planning meeting should be convened to coordinate interdisciplinary activity, including phenotyping of mapping and validation populations by trait specialists, pathology selection within and between segregating populations, etc.

Recommendation 2: Some new investment in updating the NIRS be carried out to expand the capability of rapid testing of germplasm for quality traits. Upgrade NIR software and computer; pursue external cooperation and calibrations to expand the capability of rapid testing for quality traits

Recommendation 3: Redirecting core investment to support development of malting barley varieties is not recommended. If commercial investment can be secured to support breeding for malting quality then this should be managed as a specific stream separated from the mainstream germplasm pool. A significant opportunity exists to source current international malting varieties for evaluation of commercial potential within the target environments and potential direct release. This strategy would take advantage of the FIGS systems and expertise within ICARDA, but use it in reverse to current applications.

Recommendation 4: Place two breeders in Syria and one in Latin America, define the goals based on the target area and over the next 3 to 5 years evaluate the needs in other target areas. This could improve collaboration by giving the team leader more time to travel between programs.

Recommendation 5: ICARDA, the National Programs and regional organisations negotiate support for barley breeding (including pathology) in Latin America.

Recommendation 6: The Mexican germplasm Data Bases be added to the ICARDA database as soon as possible.

Recommendation 7: ICARDA continue to send separate International nurseries for low production zones and high production zones. Stronger systems are needed to encourage evaluation data to be returned to ICARDA.

Recommendation 8: ICARDA should put significant resources into the area of pathology and the development of lines and populations with superior levels of disease resistance for the target areas. This will require at least one dedicated scientist for barley pathology, with appropriate technical support, to work with the breeders.

Recommendation 9: A significant effort be made to keep the level of staff training in the NARS for disease identification and rating at a level that will ensure integrity of data returned to ICARDA.

Recommendation 10: The development of a capital replacement strategy, Consider looking at what CIMMYT is implementing, particularly in the design of next generation seeding equipment that may be able to be locally manufactured.

Recommendation 11: Update, modify and clean up the seed storage area to ensure seed health and viability.

Recommendation 12: Train technical staff on the proper use of equipment.

Recommendation 13: Lower priority areas are to be identified and reflected in the KPIs or formal expectations of the biotechnology group to provide a clear framework for internal prioritisation of resource allocation.

Recommendation 14: Additional core funding to be allocated to support an implementation program for MAS. Appointment of one full time laboratory technician with appropriate experience in basic molecular genetics is considered appropriate, with seasonal support from Breeding Program technicians/casual staff for leaf tissue sampling.

Recommendation 15: One of the barley breeders to be given lead responsibility for the MAS program including consolidation of materials to be screened from all breeding streams into an annual work plan and interpretation of MAS results.

Recommendation 16: The core of the ICARDA breeding program should be toward the development of elite lines containing multiple disease and multiple gene resistance to the important diseases in the target areas. Along with yield and quality this should comprise 75 to 80% of the breeding effort.

Recommendation 17: Development of programs and systems to support seed production and distribution is among the highest priorities. This should be done at the highest level of management possible with each NARS. Variety adoption is significantly limited by the existing formal seed systems, and any problems with the integration of outputs from participatory programs should be addressed. A key requirement is to improve the information flow back to ICARDA on seed sales and variety adoption levels to demonstrate the impact of the breeding program.

Recommendation 18: The business plan developed for the Barley Program must explicitly address the role, benefits and limitations of participatory efforts. Key issues to be resolved include:

- **a) Reinforcing the importance of participatory approaches to informing regional breeding priorities, supporting variety adoption and providing feedback on commercial variety performance.**
- **b) Highlighting the technical importance of conducting plant breeding trials in the target environment and within the target farming systems.**
- **c) The role of farmers requires deliberate definition. The review panel recommends farmer engagement should be focussed on evaluation of potential new varieties and exclude involvement in evaluation of early generation breeding material and segregating populations.**
- **d) The terminology used to describe the participatory efforts must be revised to manage misconceptions and reflect the nature of the program. "Participatory Variety Selection" is recommended by the review panel as a more appropriate term and also has the benefit of consistency with the ICWIP program.**

Recommendation 19: On farm trials focus on fixed line evaluation. The merit of testing segregating populations on farms in addition to Tel Hadya or Breda was not clear and therefore requires technical justification to be continued.

Recommendation 20: The requirements and preferences for segregating and/or fixed lines of each of the NARS groups to be mapped in the business plan. The balance of outputs can then be used to inform the relative resource allocation of different breeding and selection schemes.

Recommendation 21: Critical traits are to be identified for NARS receiving segregating populations. Selection strategies should be implemented to increase the frequency of desirable alleles (or reach fixation) for these traits.

2. Background to Review and Terms of Reference

Peer Review 2008

ICARDA in consultation with Barley Program staff and the review team established the Terms of Reference for the Peer Review. The review was not framed in the context of the MTP, instead seeking to examine all aspects of the program influencing the effective delivery of outputs ranging from breeding methodology and operations, strategic direction through to delivery and adoption of new varieties. The review is to include a consideration of the following aspects:

1. The adoption of varieties developed using ICARDA germplasm either directly or as parents in crosses/pedigrees.
2. The effective delivery of new barley varieties to resource-poor farmers.
3. The different regional environments, and the relative acreages of barley being grown that are adapted to these environments.
4. The global reach of the program, including CWANA (Central & West Asia, and North Africa) and non-CWANA regions (Sub-Saharan Africa, South Asia, China, and Latin America).
5. The different end-uses for barley being grown by resource-poor farmers (e.g. food, animal feed, forage, malt, industrial use).
6. Linkages with national programs in the targeted regions.
7. Linkages, scope and scale of international advanced R&D collaborations (public and private; developed and developing world) that underpin variety development plans.
8. Linkages with farmers, farmer associations, Civil Society Organizations and Non-Governmental Organizations.
9. The breeding methodologies being used, including the application of new technologies such as GxE analysis (e.g. AMMI, cluster and ordination analyses, biplots), molecular marker validation, marker-assisted selection, transformation.
10. Infrastructure and mechanisation investment vs. labor costs/efficiency/effectiveness of breeding operations, and the development and use of shared searchable databases.
11. Integration of plant protection, genetic resources, biotechnology, training and other activities at ICARDA.

The current review focused on the Barley Program and the collaborative areas of Pathology, Entomology, Virology, Biotechnology, Quality and the Seeds Section. Since the direction is defined in the context of mandate crop species under the CGIAR centres and the ICARDA strategic plan, only a small part of the process used to set priorities and allocate resources was examined. The review is therefore limited to examining the

Barley Program in the context of a "Global Mandate" to develop barley aimed at the resource-poor farmers in developing countries with no reference to resource allocations to other crops or the mechanisms used to prioritise core and strategic investment.

The review was conducted in April 2008 immediately following the 10th International Barley Genetics Symposium hosted by ICARDA at Alexandria. This provided the opportunity for the review team to hear formal presentations from NARS representatives, scientific collaborators and ICARDA staff in addition to informal discussion. The reviewers attended the post conference tour, which comprised an overview of research at Tel Hadya, inspection of field plots and a visit to a participatory plant breeding site. Formal review proceedings were conducted at Tel Hadya from 16-21 April with interviews of all relevant BIGM staff and inspection of facilities.

The report is structured against the individual elements of the Plant Breeding Program with observations and recommendations listed within each section. The observations and recommendations of the CCER review and the development of the Medium Term Plan were also considered.

The role and importance of barley to resource-poor farmers and the history of the ICARDA Barley Program are fully outlined in the previous reviews and the MTP documentation, and are therefore not repeated here.

3. Mission Statement

The mission of ICARDA is: "To contribute to the improvements of livelihoods of the resource-poor in dry areas by enhancing food security and alleviating poverty through research and partnerships to achieve sustainable increases in agricultural productivity and income, while ensuring the efficient and more equitable use and conservation of natural resources."

The mission statement is important for framing priorities for barley improvement and it identifies outcomes for the resource-poor as the key goal. This is achieved through partnerships, particularly with NARS and ARI's, however these groups are not the final clients. While the ICARDA Barley Program must remain responsive and relevant to the national programs in particular, leadership in the delivery of outcomes through positive influence is also a key responsibility. Integrating outputs from participatory activities with national registration systems is a must do if the goals are to be reached.

4. Structure

The new organisational structure of ICARDA came into effect in April 2007. Barley breeding is arranged within the Biodiversity and Integrated Gene Management Program, which comprises five operating units and five germplasm development, programs as shown in Figure 1.

The CG reporting and budget systems are based on the outputs defined in the ICARDA Medium Term Plan (2008-2010), which do not reflect the operational structure. This disparity complicates budget transparency and financial accountability at the operational level.

The review identified examples of strong collaboration and joint planning between the BIGM programs however there are also areas where outcomes could be improved through coordinated operational planning.

> **Recommendation: An annual operating planning meeting should be convened to coordinate interdisciplinary activity including phenotyping of mapping and validation populations by trait specialists, pathology selection within and between segregating populations, and combined operational procedures.**

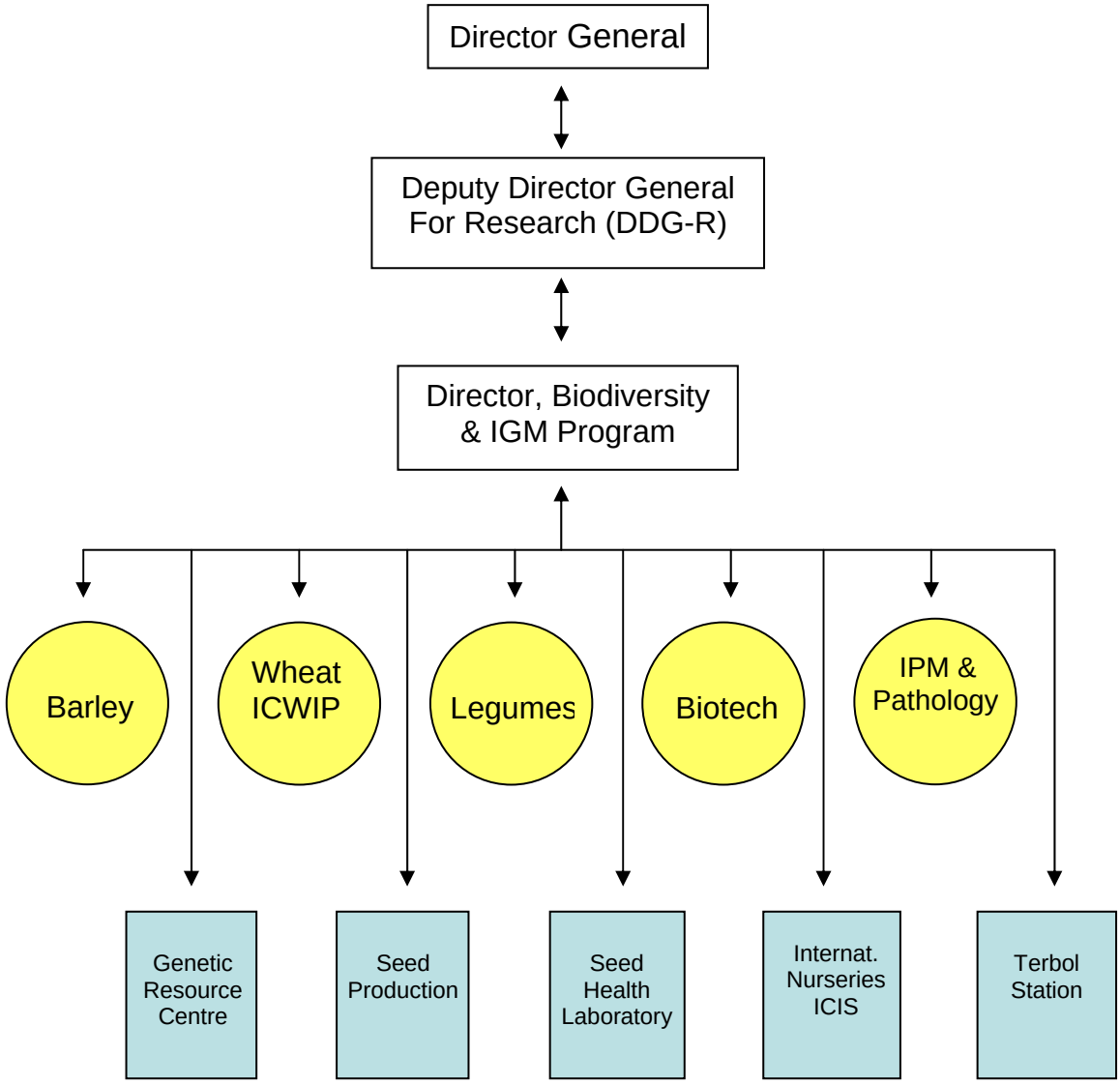

Figure 1: Organisational structure of the Biodiversity and Integrated Gene Management Program.

5. Resources

Staff

Staff are the most important resource in any organisation and ICARDA is fortunate to have a highly skilled and dedicated team of scientists supporting barley improvement. There is currently a good blend of experience and skills within the program and staff have a demonstrated ability to deliver quality outcomes in a challenging operating environment. A full time barley pathologist is a key appointment to be made and identifying a candidate with a broad knowledge base and enthusiasm for genetic improvement will be critical to the future success of the program.

A significant perceived competitive advantage for ICARDA is the low cost of casual labour. This is used to support the high throughput of the program, perhaps most notably in terms of field operations. The cost of labour is expected to remain low at least for the medium term. Many breeding programs are pursuing high levels of mechanisation and automation to offset rising salary costs, however this is not considered cost effective for ICARDA. However, this should be looked at more closely as efficiency and accuracy also have a cost. A limitation of the heavy reliance on casual staff is a relatively low skill base and low personal responsibility for operational tasks. Moving a proportion of these staff to contract based positions, and potentially also increased salaries, is recommended as the basis for addressing these issues.

Accommodation

The office accommodation and general facilities at Tel Hadya are good, and provide co-location of barley staff and also close proximity to the other associated programs and the Director. This is a key advantage in supporting interdisciplinary collaboration. The core components of field operations and seed preparation are located relatively close to administration and do not preclude close supervision of activities by the breeders. Planned upgrades to ICARDA Internet services will significantly benefit external communications as this seemed to be a problem to the reviewers.

Seed processing and storage

Sample processing infrastructure including seed cleaning and treating equipment is seen to be adequate for the program. The total physical space available for seed processing and storage is considered to be more than adequate, although the quality of the space within some areas of the seed processing facility is substandard and needs to be upgraded.

The seed storage facility requires an increased level of active management. While plant breeders will always argue material must be kept for long periods of time as insurance or in case of further seed requests, inspection of the facilities identified poorly stored samples, trial material and breeders lines of a range of species greater than 10 years old and material from defunct programs including pastures. Greater efficiency and rigour in management of the seed store will not only benefit hygiene issues, but will also benefit the seed processing area by facilitating timely storage of residual trial seed. If fumigation facilities are considered inadequate then it may be cost effective to obtain a shipping container to be converted to this use. Improvements in the organisation and infrastructure

supporting seed processing and storage is the responsibility of ICARDA management as the issues apply across all breeding programs.

Research stations

The main ICARDA research station at Tel Hadya is managed with a focus on preparing paddocks for trials and issues including weeds, herbicide residues and volunteers are deliberately managed. Irrigation is available to enhance disease nurseries and guarantee seed production, although it is rarely used on mainstream breeding trials. Despite the drought conditions of 2007/08, Tel Hadya is a favourable production environment and is not representative of the main barley production conditions within CWANA. However it is highly appropriate to base population development, pathology nurseries and seed production in a lower risk environment. Yield trials at Tel Hadya are also limited by crop rotations that are unlike typical barley production anywhere, with a very high frequency of barley trials sown following legume crops. Consideration should be given to sowing some advanced yield trials into cereal stubble to improve the relevance of the testing.

The Breda and Terbol research stations were not visited as part of the review, however their role and importance is relatively clear. The Breda research station is in a genuine low rainfall environment, which creates challenges in conducting trials with low error, however the Barley Program utilises continuous plot sowing to remove edge effects and has had considerable success in conducting informative trials in very low rainfall environments. Breda is considered highly representative of many of the CWANA target environments, particularly when data is analysed in conjunction with on farm trials. The Barley Program used the Terbol research station previously, although recently this has ceased. Management of the station is under the BIGM Program and therefore its use by the Barley Program should be reconsidered. Of particular importance is the potential for the station to be used for the progression of two generations per year, if not true shuttle breeding to some extent.

Field Equipment

There is a significant amount of field and plot equipment available to support all the stations activities. Much of this equipment is old and less dependable. In addition, many of the operators have not been adequately trained to operate the equipment properly. It is our understanding that there is no capital replacement policy in effect to modernize the equipment for new production practices. ICARDA could benefit by following the lead of CIMMYT by implementing a process to look at the equipment, particularly the design of next generation seeding equipment that may be able to be locally manufactured.

Financial

Barley within a privately owned, vertically integrated multinational company is currently costed at $2 per tonne of commercial production. Leading public programs in Canada and Australia currently invest $1 per tonne of production in core plant breeding inclusive of all overhead and infrastructure costs, but exclusive of applied research such as biotechnology.

The ICARDA Barley Program supports approximately 28.6 million metric tonnes of production across 16.3 million hectares in developing countries. The combined investment in breeding, biotechnology and training at ICARDA is currently approximately $0.06 per tonne of production (exclusive of infrastructure costs as this could not be determined from the available financial data).

A direct comparison on a financial basis is not entirely equitable as the ICARDA program benefits from significantly lower salary costs and regional investment by NARS. However ICARDA is also penalised by higher capital and maintenance costs, reduced efficiency of modestly trained technical staff and significant travel, training and extension costs. The relative value of these factors may be debated however the underlying fact remains that investment is at least one order of magnitude lower than 'best practice' breeding programs.

The expectations of ICARDA and stakeholder organisations need to be carefully managed in the context of the relatively low level of investment compared to global aspirations. There are always opportunities to improve cost efficiency within complex breeding programs however the magnitude of potential savings is trivial compared to the investment shortfall. Attracting additional investment to support barley breeding should be a priority regardless of any restructure or expansion plans. The review panel noted with interest that budget support for the ICWIP wheat program, despite its regional focus, is more than double that of the Barley Program.

6. Evaluation of Breeding Strategies

Centralisation and Global Reach of the Barley Program

There is a feeling that there needs to be a great deal more communication between the scientists and management to map out a direction for the development of a Global Internationally recognised center for barley research at ICARDA. The first question that

needs to be asked is “Is it really possible to have a global mandate in barley based only in Syria”? This will require determining new levels of core funding toward the delivery of elite germplasm to the NARS. To do this ICARDA must seek out new partners from Industry and governments. The charging of the costs of land back to the scientists will not only limit the ability of the programs to deliver globally adapted germplasm but will repeat the problem that ICARDA and CIMMYT had in Mexico which caused the closing of the Barley Program in Mexico for Latin America. This will potentially limit Latin America program support of over $150,000 per year at present and discourage new research partners from investing in the area.

With all the new changes due to retirements and changes in the management of ICARDA, all three breeders are not sure of their future and are seeking consultative direction from management. There is a unanimous recognition that there is a need for input into China and Latin America in order to be global. This is not possible without new core funding. There needs to be specific definition of target areas (low/high input, wide/specific adaptation, geographic coverage and the types of NARS).

There must be an effort to prioritise the importance of end use (malt, feed and food). Without significant financial input it is not likely that ICARDA can do everything. Consider working with ARI’s to supply the germplasm for malting barleys from developed malting breeding programs around the world and concentrate the breeding on feed and food.

There needs to be a proper shuttle breeding program to ensure two generations a year for a large number of populations. The locations need to be selected so that there is at least one month between generations. This was possible for early generation material in Mexico between Toluca and Obregon. It may also be possible in a range of locations. However, it needs to be determined if disease resistance for scald, stripe rust and other diseases in the two locations complement each other. There are limited possibilities in Syria but these should be explored. With the merger of two breeding germplasm pools each making 1500 crosses a year for target environments there will be a need to explore more efficient breeding platforms and more selective targeted crosses. Some targets may need to be combined. Either way, the present core funding will not be acceptable without diminishing the ability of the program to meet global needs.

In order to attract new partners for the Barley Program, ICARDA needs to balance the project money coming in with the mandate and priorities of the program. The outside

funds should complement, not distract from, the program objectives. The stronger the core program the more likely that it will attract outside project funds. It is difficult to attract outside funding to enhance your breeding programs if the funder is expected to fund the core with a high percentage of the overhead and salaries. Core funding should be 1:1 or 1:2 as a target. As outside directed funds go up it will require increased core support to maintain the level of directed support. This will be difficult without looking at the overall cost and efficiency of the total organisation and reducing overhead as well as prioritising within and between programs.

Seed production and variety release is a problem mostly in Syria. This problem must be solved if the impact of the Barley Program is to be fully realised. This may require intervention at the highest possible level in the government and in ICARDA. It will most likely take training and a modification to the government trials and variety release program. The statistics show that only a small amount of certified seed is sold each year, which means that the predominant source of seed is from farmer to farmer. This makes it very difficult to maintain any type of varietal purity or a record of variety acceptance.

Recommendations: For the Barley Program structure there are four options, each with benefits and liabilities:

1. **Keep all three breeders in Syria and divide up the global target. Major disadvantages are high travel costs, lack of extensive shuttle breeding opportunities, the need to cut breeding programs to fit resources and the lack of extensive plant pathology support.**

2. **Keep all three breeders in Syria and divide the program by end use (malt/ feed/food). This has the same disadvantages as option one. In addition there will be parallel programs with less contact with target areas. Duplication of nurseries and a complicated reporting network with the NARS.**

3. **Send breeders to three important target areas and define their goals based on priorities in the target area. This proposal gives the best coverage of end-use, disease and productions systems. It also provides the important shuttle breeding for all programs. Communication between breeders will be more difficult and will tend to lead to three separate breeding programs if there is not a special effort to pull the team together. Management will also be separated in the decentralised programs. It also leads to questions of how the different programs will access pathology, quality and biotech services. It will cost for some infrastructure services but could reduce travel costs and increase profile with the NARS.**

4. **Place two breeders in Syria and one in Latin America. Define the goals based on the target area and over the next 3 to 5 years evaluate the needs in other target areas. This has similar advantages to option three, but could improve collaboration by giving the team leader more time to travel between programs. It also reduces the amount of needed infrastructure and gives management time to review global needs and delivery systems.**

Option 4 is recommended by the review team, however the structure of the Barley Program should be considered in the context of the operating and business plan to be developed as a major outcome of the review.

Opportunities for malting barley

The reviewers do not agree with the previous recommendations to put significant resources into breeding for malting barley. The large-scale use of malting germplasm in crossing will undermine the superior adaptation and disease resistance of the current germplasm base. Significantly increasing the number of traits under selection will fundamentally decrease the rate of future genetic gain for fundamental production traits. If investment opportunities can be secured to develop malting barley germplasm for specific target areas then these should be managed as separate breeding streams to maintain the integrity of the core germplasm pool. An alternative opportunity is to utilise the FIGS systems to identify production areas that could support production of existing international malting varieties. ICARDA is well positioned to source a diverse range of current malting varieties and evaluate their direct commercial potential within a range of target environments. This could be described as FIGS in reverse. Successful implementation of this strategy would remove many of the challenges inherent in malting barley including detailed quality testing, market development and commercial acceptance.

Germplasm

The Barley Program has access to very diverse germplasm, in addition to collections of landraces and wild barley. The use of varieties from a broad range of international sources is also evident in the crossing program and pedigrees of breeding material. One possible deficiency is the lack of activity targeting inter-specific crossing. There is excellent work being done to computerise the germplasm, however this needs to link to the CIMMYT database as much of the information from the Latin American Barley Program doesn't seem to be available.

Crossing program

3000 crosses per annum – too many? With better planning and collaboration between scientists a more efficient program can be developed with less than half the number of crosses. Currently the Barley Program has a large emphasis on straight crosses and relatively small population sizes. There is an opportunity to increase the number of complex crosses and then increase the frequency of desirable alleles within early generation segregating populations if MAS is implemented.

Field testing overview

Yield evaluation by the ICARDA Barley Program reflects the diversity of production environments in which barley is grown. Yield trials on dedicated research stations are supplemented by field evaluation in farmer's paddocks as a main component of participatory efforts. This approach provides an appropriate balance between reliable data generation on research stations and selection within low input, low yield potential environments represented by on farm testing.

A key competitive advantage for the ICARDA Barley Program is the extensive germplasm evaluation conducted by NARS. Figure 2 shows the number of barley nurseries distributed each year since 1997. This represents a massive level of evaluation, however the amount and quality of the data returned to ICARDA is limited. Stronger systems need to be implemented to maximise the evaluation data provided back to the ICARDA Barley Program by NARS (and ARI's).

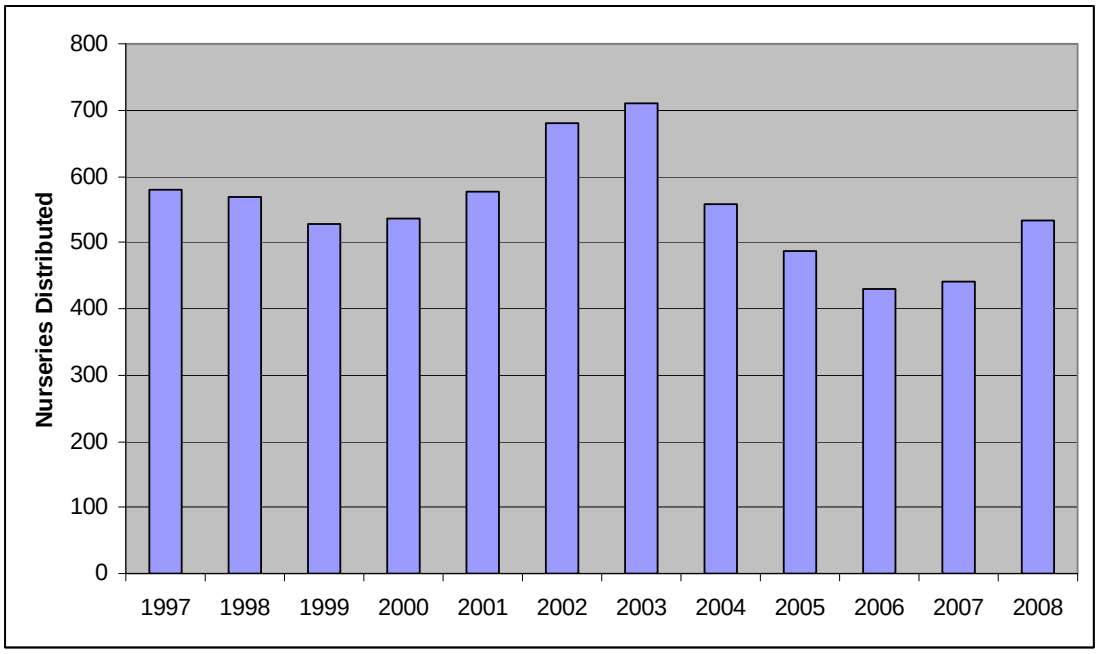

Figure 2: International nurseries distributed by ICARDA in the period 1997 – 2008.

Breeding Methodology

The ICARDA Barley Program develops and provides both fixed lines and segregating populations. A breakdown of the requirements of different clients was not available for the review. However it was clear that as NARS groups increase skill levels and experience there is a shift in preference to segregating populations to allow local selection for specific adaptation.

Significant opportunities exist to increase the value of the segregating populations developed by the Barley Program. The program is currently characterised by a very large number of crosses with small population sizes and subsequent selection between crosses. Selection strategies should be implemented to increase the frequency of desirable alleles within populations. This can be applied using phenotypic selection, MAS or a combination of both. For example; F2 populations can be sown as spaced plants, leaf tissue taken and screened to identify homozygous CCN resistance, the seedlings can then be inoculated with net blotch and susceptible individuals culled. A bulk population can then be harvested that is fixed for CCN and net blotch resistance but still segregates at all other loci allowing subsequent fixed line selection to address other traits. Application of this type of strategy requires significantly larger population sizes and development of cross specific selection strategies however successful outcomes can be achieved with fewer targeted crosses. This approach can also be used to partition a cross into subpopulations that may target different environments. For example a cross segregating

for BYDV and CCN resistance could be screened with markers and the subset resistant to CCN may be sent to a very different location to that resistant to BYDV. Implementation of these strategies significantly improves the efficiency of population development in addition to adding value to the final populations. Implementation of selection strategies within segregating populations will also benefit the fixed line development undertaken by ICARDA.

Recommendation: The requirements and preferences for segregating and/or fixed lines of each of the NARS groups to be mapped in the business plan. The balance of outputs can then be used to inform the relative resource allocation of different breeding and selection schemes.

Recommendation: Critical traits are to be identified for NARS receiving segregating populations. Selection strategies should be implemented to increase the frequency of desirable alleles (or reach fixation) for these traits.

Recommendation: The core of the ICARDA breeding program should be toward the development of elite lines containing multiple disease and multiple gene resistance to the important diseases in the target areas. Along with yield and quality this should comprise 75 to 80% of the breeding effort.

Participatory Breeding

The application of decentralised participatory breeding was pioneered by the ICARDA Barley Program. The development of these systems sought to address two key issues limiting the ability of ICARDA to increase farm productivity in developing countries.

Plant breeding has generally been conducted in favourable environments on the basis of improving the reliability and heritability of field testing. This approach has supported significant genetic gain in crops such as wheat, which are typically produced in more favourable or irrigated environments. However barley is typically grown in more marginal environments and published studies have demonstrated crossover interactions between germplasm best adapted to low yield compared to high yield conditions. It is therefore critical for the ICARDA Barley Program to conduct significant field evaluation within the target environments. The participatory breeding efforts have successfully provided a system of field testing in both the target production environment and the target farming system.

The second key issue that participatory breeding sought to address was improving adoption rates of new varieties. Formal pure seed systems are inherently limited in the context of subsistence farming where crop production is predominantly supported by

farmer saved seed and 'over the fence' trade of seed. The participatory system engages farmers in the evaluation and selection process and provides a local source of seed of new varieties.

The profile of participatory breeding within the Barley Program and adoption of this approach by other organisations in a range of crops is a significant measure of success however there are also a number of negative issues from both a perceived and technical perspective. The alignment of varieties developed through participatory approaches with requirements of local variety registration procedures and the formal seed sector was identified as a key issue during the review. Perceptions on the balance between farmer observations and quality scientific analysis in selection decisions were also seen as a source of different perspectives on the merit of participatory breeding among stakeholders and investors.

Recommendation: The business plan developed for the Barley Program must explicitly address the role, benefits and limitations of participatory efforts. Key issues to be resolved include:

- **a) Reinforcing the importance of participatory approaches to informing regional breeding priorities, supporting variety adoption and providing feedback on commercial variety performance.**
- **b) Highlighting the technical importance of conducting plant breeding trials in the target environment and within the target farming systems.**
- **c) The role of farmers requires deliberate definition. The review panel recommends farmer engagement should be focussed on evaluation of potential new varieties and exclude involvement in evaluation of early generation breeding material and segregating populations.**
- **d) The terminology used to describe the participatory efforts must be revised to manage misconceptions and reflect the nature of the program. "Participatory Variety Selection" is recommended by the review panel as a more appropriate term and also has the benefit of consistency with the ICWIP program.**

Recommendation: On farm trials focus on fixed line evaluation. The merit of testing segregating populations on farms in addition to Tel Hadya or Breda was not clear and should therefore requires technical justification to be continued.

In the context of the two recommendations it could then be stated that that no resources are allocated to participatory barley breeding, while the benefits of on farm testing and input from farmers are retained. The resources allocated to PVS should reflect the importance of the individual sites in relation to barley production and in predicting varietal performance in other target regions.

7. Measures of success

Variety adoption

Variety adoption is the key success measure for all breeding programs. Information made available for the review demonstrated a major deficiency in data surrounding variety adoption levels. Production data for ICARDA varieties was clearly incomplete with values for only 32 varieties. Reservations were also expressed as to whether the information represented peak adoption or production in a specific year. The total area sown to ICARDA varieties was listed as less than 700,000 hectares. This could potentially be interpreted as a major failure of the program in comparison to the target production area of 16.3 million hectares sown to barley in developing countries. A key priority is to develop systems to improve the level of information on variety adoption including annual updating wherever possible.

The number of varieties released is a very poor measure of Barley Program impact. However in the case of ICARDA it appears to be one of the few impact measures that is accurately recorded. Germplasm developed by ICARDA has resulted in the release of 198 varieties, which is an impressive total. The number of varieties released in all countries from ICARDA germplasm is shown in Figure 3 as a function of time. There is a notable decrease in the number of varieties released since 2000; particularly considering programs in North America released five of these varieties. However, it is not possible to interpret the reduction in variety releases as reduced breeding impact in the absence of adoption and production data.

Other measures of success can be developed within the Barley Program. Improvements in grain yield within the target environment can be translated into economic benefit, and improvements in disease resistance can be translated into reduced yield losses or reduced input costs. Combining this form of summary data on the potential impact of new varieties should be possible from available trial data and would provide the Barley Program with a demonstration of success independent from the limitations in accurate determination of adoption levels. Success and impact can also be assessed within the germplasm pool by examining changes in trait frequency over time. For example demonstrating that the proportion of the germplasm resistant to RWA or CCN is significantly increasing in response to breeding and selection could be used as a measure of success, and this approach would be particularly relevant.

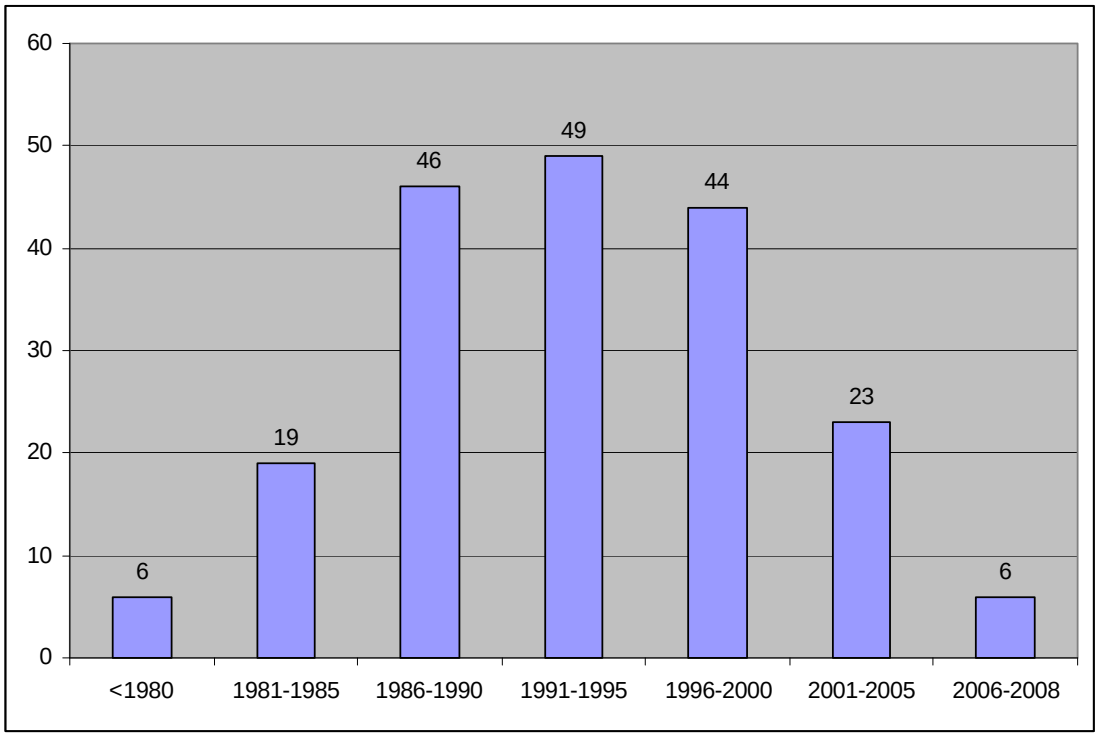

Figure 3: Number of barley varieties released from ICARDA germplasm in all countries.

8. Impact of Allied Science on the Barley Program

Agronomy and Farming systems

There was very little evidence that research into best production practices was being carried out for barley at ICARDA. We are left to hope that this research is being carried out by the NARS with support from agronomists in other CGIAR systems. For example it was noted that seeding rates are extremely high and while it was unclear if this was due to seed quality or other factors however little attention was paid to final plant density.

Molecular Genetics and Biotechnology

The Biotechnology Program at ICARDA is a central research laboratory working across all target crop species. Research is funded primarily through competitive grants with only the salary of the program leader and some periodic contributions to capital made through core funding. The most significant funding sources currently include BMZ, the Generation Challenge Program and Arab Development funds supplemented by a range of smaller individual projects.

The research projects typically feature international collaboration with ARI's and utilisation of the genetic diversity and field screening capacity available at ICARDA. Significant effort is made to maintain a balance of research activities across the crop

species despite the natural variation in funding levels for specific crops over time. The involvement of barley breeders in the development of proposals and the execution of research has been an important factor in sustaining competitive project based funding. ICARDA has provided financial support to maintain key staff during 'gaps' between projects. This is essential to maintaining research capability within a competitive funding environment and should be recognised and encouraged as a very positive approach by ICARDA management.

Research within barley has largely focussed on genetic analysis of varietal performance under drought stress, consistent with the objectives at the breeding program and organisational level. The approaches have largely focussed on classical mapping within populations derived from bi-parental crosses utilising a range of adapted ICARDA germplasm, wild barley accessions and elite international varieties. More complex strategies have been recently undertaken such as Advanced Backcross QTL analysis to systematically mine wild barley for improved alleles and association mapping to examine a broader range of materials held within the germplasm collection. Field based phenotyping has been integrated with the Barley Program and has also utilised international testing in both target and contrasting environments ensuring relevance of project outcomes.

Student projects have recently completed the validation of marker/trait associations within ICARDA germplasm supported by phenotyping in the target environments. Most notably this has included validation of the effectiveness of both Ha2 and Ha4 in providing effective resistance to cereal cyst nematode species prevalent in CWANA, Rrs1 scald resistance, and Yd2 and Yd3 resistance to barley yellow dwarf virus. The molecular markers associated with these traits are available for immediate implementation within the Barley Program.

Construction of improved facilities to support transgenic research is expected to commence during 2008. This will further improve capacity for involvement in large international research initiatives. There is significant international research activity seeking transgenic solutions for abiotic stress tolerance and productivity traits and it is appropriate for ICARDA to seek collaborative involvement in these initiatives. However the current lack of field validated transgenic lines demonstrating improved productivity means that work in this area should be clearly defined as research, not germplasm development or core breeding. Transgenic approaches offer future promise in improving the impact of the ICARDA Barley Program however significant advances are required

before any specific traits or constructs can be considered to have a reasonable probability of success in improving productivity.

Collaboration with ARI's has provided links and access to cutting edge molecular biology and genetic analysis techniques, and joint projects have contributed significantly to a strong publication record. The biotechnology program makes a major contribution to training, and demand for these programs appears to be growing following the commissioning of 'biotech centres' in a range of target countries. The competing demands of attracting external investment, executing significant research, maintaining publications and supporting Masters and PhD students are typical of the international research environment. However the diversity of the crop species and the quantum of training activity reduce the focus and effectiveness of the biotechnology program.

The infrastructure and equipment supporting the biotechnology program is generally adequate, although limited investment in routine maintenance of both facilities and equipment is now somewhat impacting on output from the program (e.g. UPS and plant growth facilities). The available equipment is considered broadly appropriate for continued and anticipated applied research projects, and capacity is available to conduct a significant MAS program without major capital investment.

Recommendation: Lower priority areas are to be identified and reflected in the KPI's or formal expectations of the biotechnology group to provide a clear framework for internal prioritisation of resource allocation.

Marker Assisted Selection (MAS)

ICARDA does not currently conduct MAS as a component of mainstream selection within the Barley Program.

Significant marker development and validation exercises have been completed within the Biotechnology Program providing the platform for immediate implementation of MAS for a number of specific traits. Extensive publications and other resources are available providing detailed information on genetic analysis, validation of marker/trait associations, the magnitude or scale of available genetic variation and the MAS programs conducted by international breeding programs. The prior use of key germplasm used within these studies as parental material within the Barley Program supports the implementation of many markers with no further formal validation by ICARDA.

MAS is an established selection tool within cereal breeding, with implementation in mainstream programs commencing in 1994. The lack of novelty in applying even the most advanced MAS strategies largely precludes this from funding support through competitive grant funding.

MAS provides a significant opportunity to improve the effectiveness of plant breeding regardless of the breeding methodology. MAS is applied at various stages of different breeding programs reflecting the crossing and selection strategies used. It is recommended that initial MAS within the ICARDA program focus on: (a) Doubling the frequency of desirable alleles within complex cross F1 generations, and (b) selecting homozygous individuals from segregating bulk populations as a component of fixed line development.

Recommendation: Additional core funding to be allocated to support an implementation program for MAS. Appointment of one full time laboratory technician with appropriate experience in basic molecular genetics is considered appropriate, with seasonal support from breeding program technicians/casual staff for leaf tissue sampling

Recommendation: One of the barley breeders to be given lead responsibility for the MAS program including consolidation of materials to be screened from all breeding streams into an annual work plan and interpretation of MAS results.

Physiological Approaches

Currently there is no specialist plant physiology conducted on barley at ICARDA, however the genetic basis of physiological traits and their role in adaptation to low rainfall environments has been examined in a number of collaborative research projects. This scientific discipline has been notoriously difficult and has yielded few practical outcomes of benefit to breeding for drought stress to date, however ongoing technology development offers hope of critically understanding the physiological basis for adaptation. Further involvement in collaborative research projects is justified given the potential benefits to barley improvement. Significant new opportunities for physiological analysis of key ICARDA germplasm may arise from the construction of the ‘Plant Accelerator Facility’ in Australia, which is expected to provide detailed assessment of plant responses to abiotic stress in high throughput controlled conditions. Ongoing assessment of opportunities for collaborative research projects is expected from both Barley Program staff and ICARDA management.

End use quality

The ICARDA quality laboratory comprises infrastructure and equipment for the determination of basic quality parameters including physical grain quality, NIR based measures including protein content and atomic absorption for limited elemental analysis.

(i) Food

Food applications for barley vary significantly on a regional basis and range from the use of pearled grain as an ingredient through to the use of covered and hulless barley as a staple food. The highest usage of barley for food tends to occur in resource poor regions and where production of alternative food crops is limited. A continued effort by ICARDA to improve the productivity and quality of varieties for these regions is a priority.

The quality laboratory currently conducts tests for beta-glucan content, cooking time and micronutrient content, in addition to standard assessments of physical grain quality. Although there is increasing interest in barley as a 'functional food', much of its benefits can be ascribed to the inherent characteristics of barley and the magnitude of genetic variation is perhaps of questionable impact on measures of economic or health benefit. The current level of targeted variety development and selection is considered appropriate, however extension activities and subsequent variety adoption in some of the target regions poses specific challenges if specialised food varieties do not at least match the agronomic performance of feed varieties.

(ii) Feed

Barley utilisation for animal feed represents approximately 75% of global production and is significantly higher in a number of key target regions such as North Africa, West Asia and India due to very high levels of small ruminant animals in the farming systems. The global shortage of feed grains and concomitant increase in price combined with threats from climate change make improvements in productivity and stability the dominant breeding objectives. However restricted feed grain availability has also increased the global focus on feed grain quality to improve efficiency and economic returns of both technologically advanced and resource poor farmers.

Traditional measures of feed grain quality have focussed on physical grain parameters that have been shown to have little or no relationship to actual feeding value. However these characteristics still form the basis for estimating

value in domestic and international grain trade, and should therefore continue to be the dominant selection criteria in feed variety development.

The availability of NIR within the quality laboratory provides an opportunity to select for improved feed grain value, or at least to apply negative selection to cull the lowest value fraction of the germplasm pool. Implementation of breeding for feed quality in barley should not have a detrimental effect on the Barley Program where yield, agronomy and disease resistance are the most important economic factors in the target areas. The feed quality characters of importance and their genetic control, is poorly understood for small ruminants. Therefore the breeders must not put a high level of selection pressure on these traits. Where possible quick, and easy testing can be done (hull content, protein, water sensitivity germination, test weight, kernel plumpness) this should continue. Since the quality laboratory does have a NIRS 5000 instrument this machine should be updated with the new software and a new computer. Working with ARI's and with Internet capability this technology can be used to rapidly screen thousands of samples a year.

The value of barley straw is well recognised by the Barley Program. NIR calibrations have been developed for components of straw quality in conjunction with the ICARDA Livestock Program and voluntary intake is assessed on stubble from on farm yield trials. These initiatives are commended and should be further refined and implemented to support the development of varieties that meet whole of local farming system requirements. Specific measures should be taken to determine the level of grain left on the ground following harvest (either from head loss, shattering or from harvest operations) as this can sharply alter livestock preferences.

(iii) Malting

The CCER Review recommended the ICARDA Barley Program pursue the development of malting barley varieties. The Latin American breeding stream has incorporated malting germplasm into the crossing program for a significant period of time, reflecting the almost exclusive use of barley for malting in countries comprising the Southern Cone. More recently the CWANA breeding stream has utilised malting germplasm for crossing in response to NARS requests and growing market demand within particular target countries. Specific material within the ICARDA breeding germplasm therefore now segregates for

some malting quality traits, however there is currently no routine assessment for malting quality available to the program.

Selection for malting quality requires expensive infrastructure and significant specialist skills that are not currently available within ICARDA. The review team does not support the major capital investment and recruitment that would be required to implement mainstream selection for malting quality.

NIRS calibrations have been developed by a number of organisations that can predict a large range of malting quality traits with acceptable accuracy based on scanning whole grain samples. It may be possible for ICARDA to negotiate access to these calibrations however the review team recommends extreme caution in implementing external calibrations for malting quality. The calibrations will have been developed based on a very different germplasm base regardless of the source and therefore applicability to the ICARDA germplasm is unknown. There are potentially environmental effects inherent in calibration development that may further diminish predictive power. Interpreting the complex interrelationships between malting quality characteristics is not trivial and it is further compounded by environmental interactions. The interrelationships of individual traits and their associations with commercial performance are not constant at elevated grain protein levels, therefore NIRS approaches are just as reliant on samples being within acceptable grain protein levels as micromalting and wet chemistry. Examination of data from the quality laboratory suggests grain protein levels of 9-12% will be difficult to achieve in trials at Tel Hadya and virtually impossible at Breda. Robust NIRS calibrations require active maintenance through the addition of further samples each year to reflect changes within the germplasm pool. This requires representative lines to be evaluated using the reference methods for each trait. Further operational issues that would need to be addressed include fine temperature control of the NIRS laboratory, provision for sample temperature equilibration and uniformity of harvest technique (It was noted that casual staff rarely adjust the concave settings or drum speed during harvest).

There are a range of low cost methods that can be implemented within the existing laboratory to identify lines with very poor malting quality. Husk content is negatively correlated with malt extract levels, therefore testing using the NaOH method could be applied to putative malting quality germplasm. The

standard EBC methods for water sensitivity and germinative energy can also be used to give a very basic insight into potential processing problems within putative malting quality germplasm.

Evaluation of elite lines immediately prior or during registration testing is typically conducted in collaboration with malting and brewing companies. This provides detailed quality assessment and simultaneously serves as initial market development for new varieties. There is only one commercial malting company in Syria servicing two breweries. Total malt production is less than 4,000t per annum and the company does not have micromalting, pilot scale malting or detailed analysis equipment that could be employed to support variety development. Linkages with the local industry have been used to arrange plant scale malting of a new variety grown under contract on the research farm and this should provide an opportunity for quality laboratory staff to gain some knowledge of the quality preferences and processing challenges faced by the local industry. There are no significant links with malting and brewing industry in other CWANA countries and knowledge of relationships between national programs and industry is limited.

Recommendation: ICARDA work with existing malting barley programs and became a clearinghouse for testing their elite material for adaptability with the goal of finding varieties adapted to the target areas with industry acceptance. This could be described as FIGS in reverse.

(iv) Biofuels

The CCER review recommended ICARDA pursue higher value end uses for barley and specifically suggested biofuels. Barley is a very poor feedstock for ethanol production and this industrial use would be in direct competition to the primary use of barley for livestock in a large proportion of the ICARDA target areas. Development of barley varieties specifically suited for biofuels production is not currently pursued at any significant scale in the world. Investment in barley for biofuels production is not supported by current review.

Recommendation: Upgrade NIR software and computer, pursue external cooperation and calibrations to expand the capability of rapid testing for quality traits

Plant Pathology

Pathology (breeding and genetics of disease resistance) is obviously the area where ICARDA has a competitive advantage in germplasm development in a Global program. However, it is an area that has not received the attention it deserves. There has been a steady decline in pathology research and support for the breeders since the early 1980's. In spite of this breeders have made significant advancement especially in the Latin America germplasm. Each target area has different spectrums of disease and the races have different levels of virulence. This makes it almost impossible to breed in only one central location. Artificial inoculation in less that optimal environments and seedling screening has been shown to not correlate to adult plant reaction and pathogen virulence. For these reasons breeders must have access to testing sites where the disease differential can be measure and selection can be made on both early generation and advanced lines in the Barley Program.

There is also a concern that there is a lack of training in the NARS for recognizing and scoring disease in the plots and returning good data to the center. This will require a significant effort by the pathologist and breeders to train these staff and ensure useful data is collected. This data is extremely important in order to monitor changes in virulence of the diseases over time.

If there is one area where ICARDA has a competitive advantage over regional programs it is in the area of developing disease resistance. Over the last 25 years the Latin American program has developed multiple gene and multiple disease resistant germplasm that is being used worldwide.

Recommendation: It is our opinion that ICARDA should put significant resources into the area of pathology and the development of lines and populations with superior levels of disease resistance for the target areas. This will require at least one dedicated scientist for barley pathology with appropriate technical support to work with the breeders.

Recommendation: We also recommend a significant effort be made to keep the level of staff training in the NARS for disease identification and rating to a level that will ensure data integrity.

9. Acknowledgements

The review team would like to thank the ICARDA management and the scientist for the candid response to the review team and the time each of you took to make the review process a pleasurable experience for the review team. We hope that we have given you a response that will help ICARDA to become an even greater impact in global barley research. We see a great potential within the ICARDA team to make a real difference in the lives of the “resource poor farmers” around the world.

If there are questions that arise from this report please feel free to contact the review team for clarification.