

Centre Commissioned External Review of the

,

**International Winter Wheat
Improvement Program
(IWWIP)**

Final Report

By

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Executive Summary

The importance of the Turkey-CIMMYT-ICARDA Winter Wheat Improvement Program (IWWIP) in addressing current and future food insecurity in the CWANA region cannot be underestimated. The current program is not delivering to its potential and every effort must be made to ameliorate the shortcomings of the program. The IWWIP mandate countries are particularly vulnerable to escalating food insecurity as many are among the poorest in the world; wheat *per capita* consumption is the highest in the world; the national wheat breeding capacity with the exception of Turkey, is well below best practice and this region is and will be among those most affected by climate change.

One of the major constraints to genetic improvement is the extremely poor field plot technique. This has been a constraint since the inception of IWWIPs predecessors and no improvement has been achieved. This must be addressed for IWWIP and also to improve the effectiveness of national programs. The solution, a dedicated experimental farm with the necessary infrastructure managed by IWWIP, will be very costly but it is an investment that must be made to minimize the food insecurity for the region.

A major restructuring of IWWIP is required to establish two closely collaborating subprograms: Modified Pedigree (MPSP) and Introgression/Research (IRSP) Subprograms. Yield and quality evaluation has to commence early in the MPSP before genetic variability for these traits has been severely truncated. This evaluation must sample the production environments in the region more comprehensively.

Product quality has been cited as another reason for the poor market share of IWWIP varieties in the region. The precision of the quality results generated and the turnaround capacity are significant constraints as is the lack of understanding of the technical requirements to deliver the diverse range of wheat consumer products in the region.

Yellow rust susceptibility is a major contributor to food insecurity and leaf and stem rust are also of concern with the significance of stem rust considered to escalate with climate change. Emphasis must be given to coordinating the pathotyping capacity in the region to allow more objective resistance breeding and to provide timely advice to farmers concerning the loss of resistance of the variety they are growing. It is similarly imperative that IWWIP specifically target the development of germplasm with durable resistance for all three rusts.

Commencement of breeding or the development of better breeding technologies is imperative for Sunn Pest, crown rot, tan spot, cereal cyst nematode and bunt.

A number of abiotic stresses are currently constraining regional food security and the impact of most of these will be considerably exacerbated by climate change. These include heat stress and drought stress. Changes in phenological development patterns will also be important to match varieties to the constraints

of changing production environments due to climate change. Salinity due to naturally high soil salinity levels and long term inappropriate irrigation practices can and must be addressed through genetic improvement.

Fifty percent of the time for the leader of the Introgress/Research subprogram should be devoted to the development and/or deployment of advanced technologies in IWWIP and for the development of new breeding tools. These technologies include doubled haploids, MAS, database implementation, association mapping and genomic selection. The remainder of the time for this appointee will be devoted to, in collaboration with trait specialists, the introgression of traits that are not suitable for the MPSP into elite breeding material for exploitation by national programs as well as IWWIP.

The lack of a robust data management system for IWWIP is a major constraint to the efficiency of the program and for the adoption of some of the advanced technologies identified above. The requirements for this system include, but are not limited to, the storage of large volumes of phenotypic and genotypic data, electronic management of all aspects of the program, field data capture and advanced statistical and genetic analysis tools. Above all, this system must be intuitive so that irregular users can readily use it.

IWWIP has a responsibility to assist CWANA countries to establish an effective and efficient winter wheat breeding capacity and variety release and uptake system.

Genetic variability is the lifeblood of plant improvement. It has become even more important with the advent of climate change as additional variability will be required for current traits and variability will be required for new traits. The collection, curation, storage, evaluation and exploitation of the wheat land races found in Turkey is a singularly important initiative to provide the genetic resources required to address food insecurity in CWANA.

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Recommendations

No	Recommendation	Priority*	Page
1	Productivity and wide adaptation be given a high priority for the IWWIP mandate region for all major production systems and selection should commence early in the breeding program and there must be better sampling of geographic and temporal environmental variability across the whole primary IWWIP mandate region. It is suggested that F ₂ derived F ₄ s or similar material should be evaluated.	1	29
2	IWWIP promote the development of a coordinated rust pathotyping capacity by seeking funding from an agency such as the Australian Centre for International Agriculture (ACIAR) to provide some infrastructure improvement, training and coordination and oversight by someone such as Dr Collin Wellings. This would be part of an integrated leaf rust, yellow rust and stem rust control strategy.	1	31
3	The current breeding strategy for yellow rust resistance should be augmented by a specific introgression activity to incorporate high levels of adult plant yellow rust resistance into recurrent parents exhibiting adaptation to all yellow rust prone regions.	1	32
4	The current IWWIP program to develop stem rust resistant cultivars should be augmented to include a comprehensive region wide pathotyping capacity and the introgression of adult plant stem rust resistance into varieties adapted to the IWWIP mandate region.	1	33
5	In concert with the yellow and stem rust pathotyping activity advocated above, a similar capacity should be established for leaf rust. Also, as for yellow and stem rust, a trait introgression activity should be established to introgress adult plant resistance into varieties adapted to the IWWIP mandate region.	2	33
6	An introgress/research program targeting the development of breeding technologies for breeding Sunn Pest resistance varieties should be set up within IWWIP though not wholly dependent on IWWIP for funding. This program will introgress Sunn Pest resistance into elite germplasm determined by IWWIP.	1	34
7	IWWIP explore the options of establishing an effective tan spot breeding capability in the current modified pedigree program through consultations with Ms Fernanda Munza, ICARDA. If this cannot be done, then a dedicated introgression program should be established under Ms Munza's leadership.	3	35

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|----|---|---|----|
| 8 | The current threat to regional food security due to crown rot in the IWWIP mandate region other than Turkey should be determined as a matter of urgency due to the anticipated increase in importance of this disease due to climate change and the increase adoption of CA. Subsequently | 2 | 36 |
| | IWWIP should seek access to sources of resistance to crown rot from Australia (Professor Trethowan and Drs Neat, Dieters and Wallwork) including material produced through investment to pyramid resistances. These would be in addition to the sources of resistance located in the CIMMYT root health program. An introgression activity should be commenced within IWWIP to introgress this resistance into varieties adapted to Turkey. | | |
| 9 | The current impact of CCN on food security in the IWWIP mandate area should be determined before undertaking breeding focused on regions other than Turkey. Based on information obtained, IWWIP undertake a breeding program to introgress resistance to <i>Heterodera filipjevi</i> into varieties adapted to Turkey. Multiple gene resistance should be targeted to reduce the probability of “breakdown”. | 1 | 37 |
| 10 | Breeding for resistance to root lesion nematode should not be undertaken at this time. There should be a concerted effort to document the impact of <i>Pratylenchus</i> sp. on wheat productivity in the region. | 2 | 38 |
| 11 | Breeding for bunt resistance should be maintained by IWWIP with the emphasis on known sources of durable bunt resistance and employing field based phenotyping. | 2 | 39 |
| 12 | The development of cultivars with elite performance in moisture limited environments should be addressed by selecting for elite performance in a regionally representative set of target production environments. This will involve testing across locations and years. | 1 | 39 |
| 13 | IWWIP should seek to engage with the global community concerned with understanding the genetic control of phenological development with the aim of documenting and implementing the technologies required to develop varieties whose development pattern minimizes the impact of heat stress on productivity. | 2 | 40 |
| 14 | IWWIP embrace/develop the technologies (germplasm, phenotyping, and genotyping) required to develop varieties with high levels of heat stress tolerance at the grain filling stage and incorporate this into the Ankara node of IWWIP. | 1 | 40 |

15	The current emphasis on developing salinity tolerant germplasm should be maintained but it should be as introgression activity only.	3	41
16	IWWIP give much greater emphasis to producing varieties that meet the various end-product requirements for the region. A major component of this, and one that is urgently required, is to determine the specific quality traits required to produce these products, and an understanding of the effect of environment on the expression of seed storage proteins on end-products.	1	46
17	The breeding objective of the Ankara node of IWWIP should be limited to high yield and wide adaptation, winter hardiness, heat tolerance, product quality and resistance to yellow, leaf and stem rust and bunt. Tan spot should only be included in the Ankara node of IWWIP if effective phenotyping can be incorporated and its inclusion in this program will not compromise genetic advance for other traits.	1	47
	An introgression program should be established to introgress the following traits into well elite adapted backgrounds: durable resistance to yellow, stem and leaf rust, salinity tolerance, Sunn Pest resistance, CCN resistance and crown rot resistance. Tan spot should be included in this list if it cannot be managed effectively in the Ankara node of IWWIP. The object is to provide germplasm for incorporation into IWWIP's now modified pedigree breeding program and for selection by national programs.		
18	Survey and crop loss assessments be undertaken to determine the need to instigate winter wheat improvement activities to ameliorate the impact of the cereal leaf beetle and Russian wheat aphid.	3	48
19	IWWIP evaluate, as a matter of urgency, the utility of the quality laboratory facilities at Tel Hadya, Ankara (new), and Konya to meet the capacity, turn-around and data precision required by IWWIP. A number of assessment criteria have been suggested.	1	54
20	IWWIP explore the option of exploiting the skill base in rusts and necrotrophic pathogens at Tel Hadya to enhance the selection for rust and tan spot resistance.	1	54
21	IWWIP develop and implement strategies to greatly increase the provision of data generated by national programs on IWWIP distributed nurseries to IWWIP.	3	56
22	A very substantial increase in capacity in Central Asia and,	1	57

- possibly the Caucasus, is required to facilitate the exploitation of IWWIP germplasm in a timely and effective manner and to provide the advocacy required to amend current policies to decrease the time required for evaluation, release and seed multiplication. Also, where possible, larger amounts of seed of nursery entries should be provided to the national programs for trials to eliminate the time required for seed multiplication for trial purposes.
- | | | | |
|----|--|---|----|
| 23 | IWWIP should engage the pathologists, entomologists, and breeders of national programs to generate and disseminate information that characterizes the response of all of the new cultivars and currently released cultivars to the suite of biotic and relevant abiotic stresses listed as breeding priorities. | 2 | 58 |
| 24 | The collection, characterization and curation of wheat landraces in Turkey is strongly endorsed as it will provide valuable genetic variability that can enhance the global effort to adapt for climate change as well as ameliorating many current constraints to productivity. | 1 | 60 |
| 25 | One member of IWWIP be designated to participate in the global public sector development of genomic selection and have responsibility for its implementation in IWWIP. | 2 | 62 |
| 26 | IWWIP engage appropriate soil salinity expertise to characterize the predominant ions contributing to salinity in CWANA. | 3 | 63 |
| 27 | IWWIP develop breeding technologies with others such as Dr Ram Sharma (ICARDA, Tashkent) to promote the rapid development of salinity tolerant varieties of winter and facultative wheat. | 3 | 63 |
| 28 | Capacity building for root health pathology be undertaken with the objective of understanding the incidence and importance of root diseases with particular emphasis on crown rot and cereal cyst nematodes. This information would be used to set breeding targets. | 2 | 64 |
| 29 | The pedigree program at Tel Hadya is to be discontinued in a manner that permits the full exploitation of the material generated to date. An introgression/research program that provides technologies and germplasm to national programs and the IWWIP modified pedigree program in Ankara will replace this program. | 1 | 66 |
| 30 | IWWIP undertake a comprehensive program of genotyping and phenotyping potential parents in order to identify parental | 3 | 67 |

	combinations that enhance the ability of IWWIP to generate germplasm that meets the needs of the mandate region.		
31	ICARDA, Tel Hadya, undertake to develop 10,000 doubled haploids per year for IWWIP. The parental combinations should emphasize full complementarity and high levels of commonality for the target traits/alleles to maximize the cost efficiency of using this technology. The entire IWWIP team should agree upon the parental combinations.	2	68
32	The seed of the doubled haploid populations should be multiplied, evaluated, and distributed to other national programs for selection within three years of production.	2	68
33	It is recommended that, at least initially, the breeder/research hired to lead the introgression program at Tel Hadya spend 25% of his/her time on the development and implementation of molecular marker technology in IWWIP.	1	69
34	Establish a breeding station for IWWIP that has the capacity for use by Turkey wheat breeding programs as well as IWWIP. This facility must have all the facilities for seed processing, seed storage, offices, training and the conduct of high quality field breeding experimentation.	1	70
35	The training needs and the ability to absorb and implement the training should be documented for the whole region. The assessment should be discussed with authorities in each country and training programs implemented where there is a high need, ability to absorb and implement.	3	70
36	ICARDA promote the development of a private sector seed industry for commercialization of IWWIP germplasm through promoting UPOV membership, streamlining variety release and evaluation processes and developing protocols for allocating exclusive license to seed companies to selected IWWIP developed lines.	3	71
37	IWWIP, as a matter of urgency, retain a consultant to evaluate the utility of the currently available plant breeding databases or ones nearing completion and their utility for IWWIP. These include GCP's Plant Breeding System, DArT's KDDArT and an enhanced version of KDDArT being developed by the Mexican Government's "Seeds of discovery" program.	1	72
38	IWWIP host an annual information exchange meeting for all those concerned with the development of technologies that may impact on winter and facultative wheat improvement for CWANA. Attendees are identified through annual consultations	1	73

with the relevant ICARDA and CIMMYT managers.

39	TAGEM with CIMMYT and ICARDA management work with its national universities so that TAGEM, CIMMYT and ICARDA staff who supervise graduate students in their thesis projects are treated as equal partners in the assessment of the student's progression to their degree and publication of manuscripts.	3	78
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1 Introduction

1.1 Review Process

CIMMYT and ICARDA retained the services of Drs Daniel Danial, Ron De Pauw and Paul Brennan to review the International Winter Wheat Improvement Program that is funded through co-investment with the Republic of Turkey Ministry of Food, Agriculture and Livestock (TAGEM), CIMMYT and ICARDA. The review team was requested to report against fourteen criteria listed in the Terms of Reference for the review (Appendix 1).

The process for the review included perusal of an overview document prepared by the project team, consultation with a wide range of international experts on different aspects of the program, perusal of pertinent scientific and other literature, inspection of breeding and associated activities at ICARDA HQ (Aleppo, Syria – Dr Brennan) and consultation with project team members in Turkey, Iran and Uzbekistan. Review activities in Turkey included consultations with Drs Alex Morgounov, Mesut Keser, Yuksel Kaya, Ram Sharma and R. M. Jalal-Kamali in Istanbul. This was followed by inspections and consultations at Edina, Ankara, Haymana, Eskisehir, Konya, and Cumra. The inspection and consultations of breeding activities in Kazakhstan and Uzbekistan was a private initiative of Dr Brennan's. A large number of people from Syria, Morocco, Turkey, Iran, Uzbekistan and Kazakhstan were consulted during this phase of the program (Appendix 4).

1.2 IWWIP Overview

Agreement between the Republic of Turkey and CIMMYT to co-invest in winter wheat breeding was reached in 1980 (Appendix 5). This agreement was updated in 1986 (Appendix 6) and the current arrangements between TAGEM, and ICARDA were updated in 2011 (Appendix 7).

At the time of the review IWWIP had two nodes, one centered in Ankara, Turkey, (Table 1) and one at ICARDA headquarters at Tel Hadya near Aleppo, Syria, (Table 2). Both nodes made use of regional locations for the conduct of their programs. IWWIP's primary mandate is to produce facultative and winter wheat varieties for an area stretching from the Atlas Mountains to Afghanistan/Pakistan (Table 3).

IWWIP also has the mandate to solicit winter and facultative breeding material and varieties from the global winter and facultative wheat improvement community and make this material available based on Material Transfer Agreements, including IWWIP generated material, to programs that request it.

Table 1. IWWIP germplasm movement and the number entries in different nurseries for key locations in Turkey¹

Generation	Adapazari	Ankara (including Haymana)	Diyarbakir	Edirne	Eskisehir	Erzurum	Izmir	Konya
Crosses					400 (WxW)		700 (WxS; WxSxW)	
F1&F1Top							1000	
F2	800 (Leaf rust small plots)				800 (irrigated)			
F3		700 (Yellow rust small plots)			700 (irrigated)			700 (rainfed)
F4	600 (Leaf rust small plots)				600 (irrigated)			600 (rainfed)
F5		500 (Yellow rust small plots)						500 (irrigated) 500 (rainfed)
F6 Head Rows					20,000 (irrigated)			
F7 Preliminary Yield Trial	2000 (Leaf rust small plots)	2000 (Yellow rust small plots)			2000 (irrigated)			
F8 Yield Trials	500 (Leaf rust small	500 (Yellow rust small		300 (irrigated)	300 (irrigated)			300 (irrigated)

	plots)	plots)			200 (rainfed)			200 (rainfed)
F9 Advanced Yield Trials		200 (Yellow rust small plots) 150 (rainfed)	150 (irrigated)	150 (multiplication)	300 (irrigated and rainfed)	150 (irrigated)		300 (irrigated and rainfed)
F10 FAWWON & IWWYT								100 International distribution

¹ Drought stress screening trials were located at Cumra

Table 2. Description of breeding/screening activities implemented by Aleppo node breeding program

Year	Comment
1	500-600 F ₁ , 2-300 BC ₁ F ₁ and 70-140 TC ₁ generated.
2	Plant F ₁ s, BC ₁ F ₁ s and TC ₁ s in yellow rust nursery and discard susceptible crosses
3	F ₂ : All F ₂ populations space planted and single plants selected, grain is selected for physical appearance
4	F ₃ : Plot grown for every single plant selected in the previous generation and selected on agronomic appearance: plots bulk harvested
5	F ₄ : Four row plots grown from previous generation, selected for type, bulk harvested
6	F ₅ : as for F ₄ but 3-5 single plants selected / selected plot
7	F ₆ : plant rows and selected on agronomic appearance
8	F ₇ : Preliminary Yield Trials at Tel Hadya, one dryland and one irrigated; 1-200 entries and samples sent to Turkey for rust testing
9	F ₈ : Yield Trials: 500-600 entries; dryland and irrigated at Tel Hadya
10	F ₉ : Advanced Yield Trial, 2-400 entries, dryland and irrigated trials at Tel Hadya; Full quality analysis
11	F ₁₀ : Advanced Yield Trial at key locations in Iran, Kazakhstan, Uzbekistan, Afghanistan and Turkey; receive a full quality evaluation
12	F ₁₁ : Elite lines provided to CIMMYT, Turkey, to include in International Nurseries

2 Operating environment

2.1 Primary mandate region

The primary mandate countries for IWWIP are the facultative and winter wheat growing areas of Central and Western Asia and North Africa (CWANA), Iran, Afghanistan and the Caucasus and the mountainous regions of Pakistan border (Table 3). The total wheat area in CWANA is approximately 52 million ha which

include bread wheat, spring durum wheat, and winter/facultative (WW/FW) wheats. The latter occupies in total almost 18 million ha.

Table 3: Winter/Facultative Wheat Areas in CWANA (Irrigated and Semiarid) and pertinent features of these countries

Country	Area (000 hectares)	Population		Poverty Category (World Bank) ¹	Import (‘000,000 T)	Export (‘000,000 T)	Per Capita Annual Consumption of Wheat (kg) ²
		(‘000,000)	Growth* (%/annum)				
Afghanistan	600	25.5	3.85	Low income	2.0	0	N/A
Algeria	245	37	1.51		5.2	0.025	199
Armenia	120	3.3	-21	Low/middle	0.35	0	138
Azerbaijan	234	9	0.75	Low/middle	1.3	0.005	208
Georgia	117	4.5	0.79	Low/middle	0.8	0	156
Iran	4,000	77	1.35	Low/middle	1.0	0.1	157
Kazakhstan	1,500	16.7	0.71		0.01	8.5	156
Kyrgyzstan	435	5.5	1.10	Low income	0.5	0.025	239
Morocco	198	33	1.20	Low/middle	5.0	0.75	175
Pakistan	1,000	180	1.84	Low/middle	0.2	0.3	110
Syria	100	22	2.52	Low/middle	0.6	0	163
Tajikistan	200	8	1.51	Low income	1.1	0	151
Turkey	6,900	75	1.26		3.5	3.7	200
Turkmenistan	495	5.2	1.32	Low/middle	0.1	0	194
Uzbekistan	1,317	29	1.44	Low income	1.44	0.5	173
Total	17,914	530.7			23.1	13.905	

* 2005-2010 List by the United Nations (world = 1.17)

¹ Low income: < \$1095/annum; Low/middle: \$1095 to \$3975 (World Bank, 2011)

² Global averages: 67kg/person/year, FAO STAT, Food Balance Sheet, 2009

The primary mandate area includes fifteen countries in which the production environments both within and among countries are highly variable in terms of total precipitation, elevation, soil type, maximum and minimum monthly temperatures and the availability of irrigation. In addition, prevalence and damage caused by biotic stress factors varies from one location to another. Most countries grow spring (both autumn and spring planted), facultative and winter wheat. There did not appear to be robust information on the relative extent of facultative and winter wheat areas or are there good estimates of the extent of irrigation and dryland production of winter and facultative wheats.

The fifteen countries in the primary mandate area for IWWIP have a combined population of over half a billion people or 7.6% of the global population and a population that is growing at a faster rate than the global average (Table 3). These countries with the exception of Turkey and Kazakhstan have a low or very low per capita income. The region, as a whole, is a net importer of wheat and has a very much greater per capita consumption of wheat than the global average.

As a consequence, IWWIP has a singularly important mandate to contribute to the food security for a very large and fast growing proportion of the global population for whom wheat is a major dietary component. The wheat breeding capacity in most countries, with the exception of Turkey and Syria is under resourced and there is a substantial requirement to increase the technical ability in these countries.

2.2 Production environment

An overview of the nature of the production environment can be obtained from estimates of the genotype x environment interactions (GE) for the IWWIP mandate region. Such estimates can provide guidance on the nature of the breeding strategy required to identify varieties that are well adapted to the region. The information available for GE estimates is from the international yield nurseries conducted by IWWIP each year. It is advised that this information is relatively free from biotic stresses and generally samples the environmental variability across the region (Ram Shama, *pers. comm.*). The inference that can be obtained from the data is constrained by the lack of estimates for genotype x year (GY) and genotype x year x location (GLY) interactions as few common entries were included across years. The review team acknowledges the contribution of Dr Ram Sharma (ICARDA, Uzbekistan) in assembling and analyzing the available data to provide the GE estimates (Table 4).

Table 4. Variance Component Estimates for yield across the IWWIP mandate region

Trail Series	No Entries	No. Sites	Vg	Vge	Vg/Vge
11 IWWYT IR	24	16	138775	282666	0.49

12 IWWYT IR	20	21	87344	454253	0.19
13 IWWYT IR	40	15	56488	321319	0.19
11 IWWYT SA	35	15	27754	231905	0.12
12 IWWYT SA	20	15	294317	90737	0.31

IR = irrigated series, SA = semiarid, Vg and Vge are the variance component estimates for genotypes and genotype*environment interactions.

The large magnitude of Vge relative to Vg for yield suggests that the IWWIP mandate region is very variable as there are considerable changes in the relative merit of genotypes across the region. The reported considerable year-to-year variation in precipitation and growing season temperatures and experience from similar studies in other parts of the world suggest that GY and GLY will also be quite large relative to the estimates for genotypes.

Also the large magnitude of Vge relative to Vg for irrigation and dryland trial series are similar. The unexpectedly high value for the irrigated series suggests that irrigated production conditions vary greatly. A portion of the Vge might be attributed to trials compromised by marginal plot technique which will be elaborated on in Section 4.1.1.3.

It is concluded from the information on the current production conditions that IWWIP must develop germplasm that is very broadly adapted. In other words, IWWIP germplasm must be able to perform relatively well in a wide range of production environments.

2.3 Climate change

2.3.1 Global

There is now unequivocal evidence that global warming has occurred (IPCC, 2007). The linear warming trend over the last 50 years (1956-2005) of 0.13°C / decade is nearly twice that for the hundred years from 1906 to 2005. The temperature increase is widespread, uneven and higher in the northern latitudes. This has resulted in a 1.8mm/year rise in sea levels from 1961 to 2003 and an average rate of 3.1mm/year from 1993 to 2003 suggesting that the rate of warming is increasing.

Over the period 1900 to 2005 precipitation has increased in the eastern parts of North and South America, northern Europe and northern and central Asia. Precipitation has declined in the Sahel, Mediterranean, southern Africa and parts of southern Asia (IPCC, 2007).

Global atmospheric carbon dioxide (CO₂) rates have increased from about 280ppm in pre-industrial times to 379ppm in 2005. The rate of increase from 1995 to 2005 was 1.9%/annum which is substantially larger than the rate from

1960 (when atmospheric CO₂ measurements began) to 2005 of 1.4%/annum although there is year-to-year variation (IPCC, 2007).

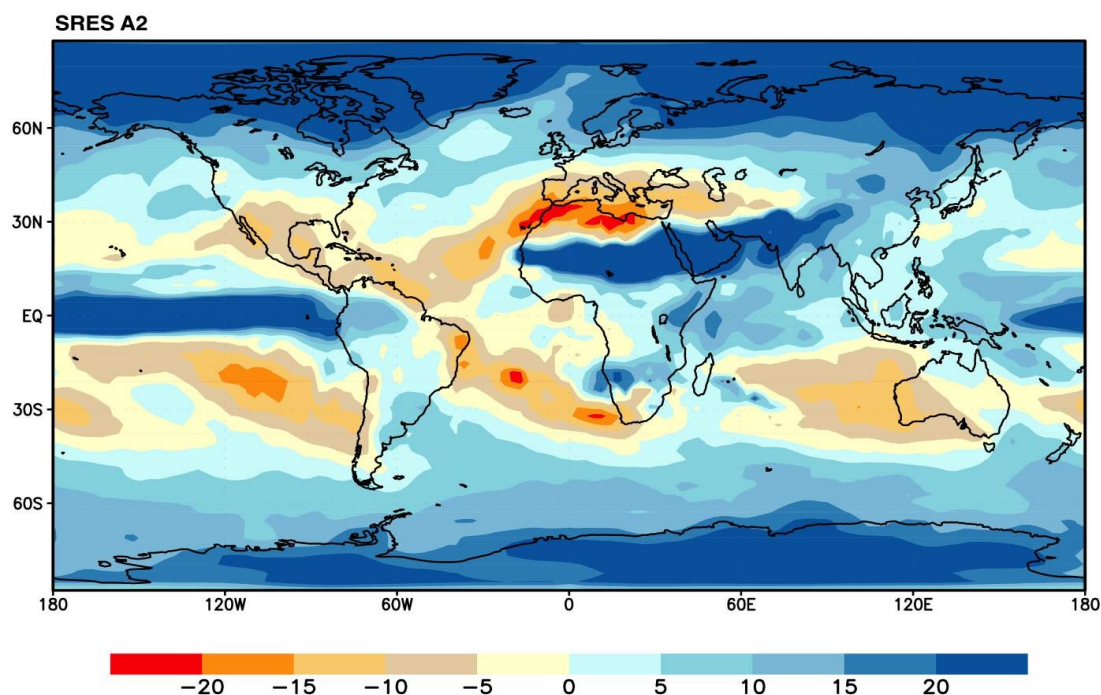
CO₂ is by far the most important greenhouse gas (GHG) and comprised 77% of the total anthropogenic GHG emissions in 2004. The growth in anthropogenic GHG emissions for 1995-2004 (0.92 gigatonnes of CO₂ equivalent/year or GtCO₂-Eq 1 year) was more than double that (0.43 GtCO₂-Eq 1 year) during the previous period of 1970-1994 (IPCC, 2007).

Provided that anthropogenic GHG emissions are kept to 2000 levels, the global increase in temperature by the end of the 21st Century will be 0.6°C higher than the average for 2000 with a likely range of 0.3 to 0.9°C. As the GHG emissions are unlikely to remain at 2000 levels, a number of scenarios for global GHG emissions have been agreed by the IPCC (2007). The rise in global temperature by the end of this century for the most optimistic scenario (B1) is 1.8°C with a likely range of 1.1 to 2.9°C. A 4.0°C rise with a likely range of 2.4°C to 6.4°C is predicted by the least optimistic scenario (AIFI).

2.3.2 Consequences of climate change for IWWIP mandate region

The climate change impact on the IWWIP mandate region, albeit variable, is predicted to be among the most severe globally (Fig 1). It is anticipated that the whole region for IWWIP will become warmer and there will be diminished rainfall. North Africa will be the most affected but the whole region will be drier and hotter (IPCC, 2007).

Fig 1. Precipitation changes anticipated as a consequence of climate change



The consequences for IWWIP are that the varieties that are appropriate to enhance wheat production now will not be those that will be appropriate in ten to fifteen years time. This is about the cycle of a winter wheat breeding program so the selection targets and methodologies that are appropriate for the future will have to be addressed now.

The major needs for varieties in 10 to 15 years will be the ability to perform well with less moisture and, probably, different moisture stress patterns. It is probable that there will be less water for irrigation so the proportion of dryland wheat and supplementary irrigated wheat production will increase. This suggests that varieties that can perform well over a wide range of production conditions should be developed.

Global warming will require changes in the phenological development patterns of the varieties developed. It is probable that there will be a significant move away from true spring wheats (planted in spring and harvested in late summer/autumn) to winter wheats. The move to winter wheat varieties should be promoted as this will probably increase productivity. It will be important to have varieties for these regions with high levels of winter hardiness.

Changes in phenological development patterns will also be required to minimize heat stress during the grain filling period. This will require winter and facultative wheat varieties that flower earlier as the date for the last frost will be earlier. It may also be necessary to have development patterns that reduce the grain filling period in order to reduce heat stress during the this period. Such adjustment to the phenological development patterns will require IWWIP to have knowledge of the most appropriate vernalization, photoperiod and rate of development loci.

Heat stress will impact negatively on productivity in the pre- and post-anthesis periods. Heat stress in the pre-anthesis period has, by far, the greatest impact on productivity as it reduces grain number (Powell *et al.*, 2012). Developing wheat varieties that flower soon after the last frost can minimize this effect. Shortening the grain filling period and/or increasing grain filling rate will minimize the impact of post-anthesis heat stress on grain size. It will also be important to enhance heat stress tolerance in the grain filling period as well.

Heat stress in the grain filling period has also been implicated in reducing end product quality (Wrigley *et al.*, 1994; Wrigley, 2006). It is probable that some alleles for high and low molecular weight glutenin subunits (H and LMWGS) will be more affected by heat stress than others. Consequently, it will be important to understand the alleles that will deliver the required processing quality for the different countries in IWWIP's mandate region.

Biotic stresses: There is generally less certainty concerning the impact of climate change on biotic stresses (Chakraborty *et al.*, 2010). In general, it is anticipated that the rate of evolution of new pathotypes will increase; some current diseases will become more important while others will become less important and new diseases may develop as has happened with the development

of wheat blast in South America. In general, diseases with a higher temperature optimum will be advantaged.

The faster evolution of new pathotypes emphasizes the need for more durable resistance to the rusts particularly yellow rust.

Stem rust, leaf rust and tan spot may also be favoured as these diseases have higher temperature optimum while septoria tritici blotch may be less favoured due to its lower temperature optimum.

Root health will be of greater significance due to lower soil water availability requiring plants to maximize the utilization of the available soil moisture. This increases the priority of having varieties resistant to cereal cyst nematode (CCN, *Heterodera filipjevi*). It will also be necessary to understand the potential impact of the root lesion nematode, *Pratylenchus thornei*, which has a high temperature optimum.

Those diseases linked to the uptake of conservation agriculture, such as crown rot (*Pseudograminearum culmorum*) and tan spot (*Pyrenophthora tritici-repentis*) may become more important. This will be considered in more detail later.

2.4 Government policy and regulation

Changes in government policy have impacted on winter wheat variety breeding and will impact on winter wheat breeding in the future. These changes have included and may include in the future:

- Payments for wheat processing quality
- Reduction in the post breeding release process and
- Enacting legislation to promote private sector involvement in breeding and/or variety commercialization (UPOV type legislation)

It is also emphasized that, while government policy may not change, the actual policy settings will change as governments endeavor to achieve a particular outcome.

The government of Turkey has, in the recent past, adjusted policy to upgrade the processing quality of the Turkish wheat crop by favouring the production of higher quality lower yielding varieties. It is probably that this maybe a trend that will become more wide spread in the IWWIP mandate region as living standards rise as has happened in Kazakhstan.

The variety release time (as opposed to the variety breeding stage) has been substantially reduced in Uzbekistan. This has very significant food security impacts as it enables elite varieties to get into farmer field much faster. It is probable that this will be a trend that will be adopted in other countries and IWWIP has an important role to play in promoting this change due to its involvement in breeding.

The role of the private sector in varietal commercialization could and should be greater as a number of countries in the IWWIP mandate area have enacted plant

variety rights legislation (Table 5). The implementation of such legislation should be fostered by IWWIP as it may result in the expansion of local private sector seed industries and the more rapid exploitation of IWWIP germplasm. This may require IWWIP to negotiate exclusive access to potential new varieties which is permissible under new CGIAR policies.

Table 5. Countries in the IWWIP primary mandate area that have adopted UPOV acceptable plant variety rights legislation

Country	UPOV Version	Year
Azerbaijan	1991	2004
Georgia	1991	2008
Kyrgyzstan	1991	2000
Morocco	1991	2006
Turkey	1991	2008
Uzbekistan	1991	2004
Kazakhstan		Application current

It is noted that commercial interests may result in the promotion of undesirable varieties. This could be discouraged by IWWIP through specifications in license agreements.

2.5 Conservation agriculture

Reduced or no-tillage farming systems (collectively called conservation agriculture, CA) have and are being adopted in many countries. The reasons for promoting and adopting conservation agriculture include the reduction of erosion, accumulation of snow cover to reduce winter kill and increase moisture accumulation. All these reasons are significant in the IWWIP mandate region. The accumulation of soil moisture will become more important as there is reduced precipitation due to climate change. There is already a quite high level of adoption of conservation agriculture in Kazakhstan and it is being widely promoted in Turkey and Uzbekistan.

Conservation agriculture has some downsides that include establishment difficulties and increases in necrotrophic diseases such as tan spot and crown rot. Tan spot tends to be a disease of higher moisture conditions and is likely to be promoted by irrigation and supplementary irrigation (Brennan *pers comm*). Crown rot is pronounced under lower moisture conditions (Brennan *pers comm*). This suggests that crown rot, in particular, but also tan spot will become more important diseases of wheat in the IWWIP mandate region as climate change progresses.

It will be important to monitor the extent to which crop establishment is compromised by conservation agriculture and to collaborate with agronomists and equipment manufacturers to determine if appropriate equipment and technology is required or changes in plant architecture is required. Establishment problems are likely to be less of a problem in most winter wheat areas as semi dwarfs are not widely used.

2.6 Other providers of winter wheat varieties

The extent to which the IWWIP mandate region is serviced by other providers of winter wheat varieties, the characteristics of the varieties developed and the extent and nature of seed supply will impact on IWWIP. The extent to which the non-IWWIP breeding capacity in this region can be analyzed through this review is limited as Turkey was the only country in which the breeding activities were examined in detail. There was limited inspection but in depth consultation in Kazakhstan and Uzbekistan and consultations on breeding capacity in other Central Asian countries and the Caucasus.

There is a vigorous, technically sound and reasonably well funded public sector winter wheat breeding investment in Turkey. This program has limitations due to poor field plot technique, insufficient focus on durable yellow rust resistance and the probable low predictive value of quality assessment due to lack of air conditioning of laboratories and statistical rigor. However, quality testing concerns could be addressed in the new facilities at Konya and Ankara. The limited inspection of and consultation with breeding programs and reports by CIMMYT and ICARDA country representatives suggests that winter wheat breeding investments in the remainder of the IWWIP mandate region will not deliver the genetic advance necessary to address the twin challenges of population growth and climate change which will have a major and negative impact on the food insecurity of this region.

There are a number of breeding programs in eastern European countries which provide varieties to the region. Their impact in Turkey is significant for enriching the genetic variability and introducing valuable traits into IWWIP germplasm.

The Russian breeding programs in Krasnodar (Krasnodar Agricultural Institute) and Odessa (to a much lesser extent) are major providers of winter wheat varieties for the Central Asian Republics and Caucasus (CAC). The Krasnodar varieties perform very well under full irrigation and in the absence of yellow rust. They are reported to have suboptimum performance under supplementary irrigation and dryland production systems and where yellow rust is a production constraint. As a consequence winter wheat varieties from Krasnodar will not provide the long term solution to food insecurity for the CAC republics. Competing varieties will have to be a significant improvement over the Krasnodar varieties to replace them due to the entrenched position of Krasnodar as a provider of varieties.

It would appear that, without IWWIP, there would be a very significant deficiency in the capacity to produce winter wheat varieties that are appropriate for the IWWIP mandate region. The consequence of not having IWWIP varieties would be a significant short fall in meeting the demands for food security for a region that is more reliant than any other part of the world on wheat for its calorific requirements.

3 Breeding objectives

The review team was provided with a list of the breeding priorities for IWWIP (Table 6). Subsequent discussions suggested that Sunn Pest and Russian wheat aphid (RWA) were also objectives of the breeding program.

Table 6. IWWIP breeding priorities

Breeding priority	Irrigated areas	Semi-arid areas
Yield potential	*****	***
Drought tolerance	***	*****
Broad adaptation	***	***
Heat tolerance	***	****
Yellow Rust resistance	*****	*****
Leaf Rust resistance	****	***
Stem Rust including Ug99 resistance	*****	*****
Cereal Cyst Nematode resistance	***	****
Dryland Crown Rot resistance	**	****
Common Bunt resistance	***	***
Septoria resistance	**	**
Tan Spot resistance	**	**
Bread making quality	****	****
Sunn pest		
Salinity		

* Least important; ***** most important.

3.1 Yield and adaptation

The ability of a variety to yield well over the target production environments (TPE) must be the major objective of the breeding program. IWWIP addresses three major production systems (irrigated, supplementary irrigation and rainfed) over a wide geographic region. It would appear appropriate that productivity is a high priority in all these production systems if food insecurity is to be successfully addressed. Wide adaptation will be singularly important in the development of varieties that can accommodate climate change as well as to address the variable production conditions of the region as demonstrated by the inherent GE interactions for the region.

The current breeding methodology is to undertake yield evaluation in a limited range of sites late in the breeding program. The current sampling of the TPE appears to underestimate the importance of geographic and temporal GE effects and the different response patterns elicited by the three major production systems (irrigated, supplementary irrigation and rainfed). Selection for yield and wide adaptation commences late in the program when the genetic variation in the program has been substantially truncated due to selection for other traits. This will greatly reduce genetic advance for yield and wide adaptation.

The Review Team is of the view, notwithstanding the inherent costs and logistical constraints, that genetic advance for productivity and wide adaptation must be a high priority and that selection must be undertaken early in the breeding cycle, preferably at the F₄ and that there must be a much more comprehensive sampling of the TPE. This methodology has proved effective in, at least, Canada and Australia as measured by the market share of varieties developed using this methodology.

Recommendation 1

Productivity and wide adaptation be given a high priority for the IWWIP mandate region for all major production systems and selection should commence early in the breeding program and there must be better sampling of geographic and temporal environmental variability across the whole primary IWWIP mandate region.

3.2 Biotic stresses

Pest and diseases are highly significant production constraints in the IWWIP mandate region. The nature and extent of these constraints vary with geography and will change with climate change. The impact of climate change on pests and disease is difficult to predict and, like many predictions, will probably be flawed. The Review Team takes the view that it is singularly important to act on the best estimates of the impact of climate change rather than not to act. It will be important for IWWIP to monitor productivity constraints due to the current range of pests and diseases and to be aware that new pests and diseases may become significant productivity constraints in the future due to climate change.

3.2.1 Yellow rust

A pathotype of yellow rust (*Puccinia striiformis*) with virulence on Yr9 was detected in Africa in about 1986. This pathogenicity spread to the CWANA region where most varieties were protected only by Yr9 and resulted in very large reductions in productivity. Epidemics occurred in Uzbekistan in 1999/2000, 2002/3, 2005/6 and 2009/10 with total productivity losses of over 40% in one year. Other yellow rust epidemics in the region include (Sohl *et al.*, 2012): Iran in 1993 and 1995 with 30% crop loss; Turkey in 1991 with 26.5% crop loss; Azerbaijan in 1996; Tajikistan in 1997 with 60% crop loss and Central Asia, the Caucasus and Syria in 2010.

3.2.1.1 Pathotype surveys

Pathotype surveys are important to understand which seedling genes will be effective in protecting varieties and, as a consequence, to design a selection strategy that will identify breeding material with appropriate resistance. Pathotype surveys are also important for the unequivocal identification of new pathotypes so that farmers can be discouraged from growing newly susceptible varieties and sustaining loss of productivity. Refraining from growing

susceptible varieties will reduce epidemics. This has the flow on effect of reducing the probability that the pathogen would change genetically to overcome the resistance of currently resistant varieties. Pathotype surveys will provide the information necessary to determine whether there is more than one effective gene for resistance in breeding material as there is a much lower level of probability that the pathogen can develop virulence on two genes simultaneously.

There is significant but uncoordinated capacity within the IWWIP mandate area to develop an effective rust pathotyping service. This capacity is constrained by a number of factors including, understandably, government regulations that prohibit the importing of disease samples from other jurisdictions.

The current capacity includes:

- Global Rust Reference Centre (GRRC) led by Dr Mogens Houmøller that is located in Aarhus University, Denmark. This centre accepts samples from across the world but has not the capacity to process the numbers of samples required to provide a comprehensive understanding of the nature of the yellow rust flora in CWANA.
- ICARDA has a very modern recently constructed rust facility including compartmented glasshouses and laboratories. Dr Kumarse Nazari who is highly qualified and very energetic and passionate manages this facility. This facility is located in Syria which does not permit the importation of diseases.
- The Seed and Plant Improvement Institute located at Karaj, Iran, has the infrastructure and capacity to contribute effectively to a regional rust pathotyping capacity.
- Uzbekistan has recently established a modern rust research facility at Karshi, the Kashkadavya Research Institute of Grain Breeding and Seed Production. Dr Zafar Ziyev who is a wheat breeder with responsibility for rust resistance is managing this facility. The capacity of this centre has been evaluated by Dr Collin Wellings, a recently retired distinguished yellow rust scientist from Sydney University. Dr Wellings assisted with rectifying some small problems and advises that this centre could make a significant contribution to a regional rust pathotyping capacity.
- Kazakhstan has a good rust facility near Almaty whose use is constrained for a short period of the year due to lack of cooling. This site is very good for the development of field epidemics of yellow, stem and leaf rust.
- The Central Research Institute for Field Crops, Ankara, Turkey has good glasshouse facilities for rust work that would benefit from some upgrading and has capacity constraints. The competent and well trained Dr Zafer Mert leads this activity. This laboratory is engaged in pathotype surveys and could contribute significantly to a regional rust pathotyping capacity. This institute has a field station at Haymana where excellent field epidemics are readily and reliably induced.

Collectively the CWANA region appears to have the capacity which, with some upgrading, training and oversight would provide a comprehensive rust pathotyping capacity for the region. It is asserted that a sufficiently funded

initiative overseen by someone with Dr Wellings skill set could deliver this capacity for the region in the short term. Dr Wellings has an interest in Central Asia and the time and inclination as well as being very familiar with the region to facilitate the development of a regionally coordinated pathotyping capacity. This would contribute to a wheat rust control strategy for CWANA.

Recommendation 2

IWWIP promote the development of a coordinated rust pathotyping capacity by seeking funding from an agency such as the Australian Centre for International Agriculture (ACIAR) to provide some infrastructure improvement, training and coordination and oversight by someone such as Dr Collin Wellings.

3.2.1.2 Yellow Rust Breeding

The current IWWIP breeding strategy for yellow rust employs seedling screening at the Central Research Institute of Field Crops, Ankara and field screening at their field station at Haymana just outside Ankara. For yellow rust resistance, seedling screening is undertaken on a small proportion of the IWWIP breeding population. The outcome of such an approach will be the development of yellow rust resistant breeding material that is resistant to the pathotypes deployed at Haymana but most probably protected by a single seedling effective gene as happened with Yr9. This will, in the short term, provide a limited solution to the yellow rust problem in the region. The loss of effectiveness of resistance will probably continue with the consequent loss of productivity and threats to food security. Taking into account the magnitude of the problems that occurred through the development of virulent strains of wheat stem rust Ug99 and Yr9 for yellow rust, effective measures by IWWIP are required to reduce or limit the risk and prevent the spread of such strains through exploiting available sources of resistance and use of molecular technologies for developing new wheat varieties with emphasis on durable resistance.

3.2.1.3 Durable yellow rust resistance

A long term solution to preventing (minimizing) the yield loss due to yellow rust will only be achieved through the development of varieties with high levels of durable yellow rust resistance. The cultivar Bezostaya 1, released in 1959 and continues as one of the most widely grown varieties in Turkey (Mazid *et al.* 2009), has the adult plant resistance gene Yr18/Lr34 (Kolmer *et al.* 2008) and illustrates the durability and value of this gene. The development of varieties with durable resistance will take some time and require a dedicated initiative. As a consequence, the current approach should be continued for the short to medium term to provide yellow rust resistant germplasm adapted to all regions. Durable yellow rust resistance in winter wheat has challenges not found in spring wheats due to the longer juvenile stage when adult plant resistances are not effective. This is a particular concern for some parts, at least, of the IWWIP mandate area (Uzbekistan and some neighboring countries) where yellow rust

inoculum is generated year round and may infest newly established winter wheat crops when APR genes are not effective. This is very similar to the epidemiology of yellow rust in the Pacific North-West of the USA where substantial yield losses due to yellow rust are regularly experienced (Chen, *pers. comm.*). The preferred solution for this region is to develop varieties with quite high levels of APR as these become effective at early growth stages and have been found to provide high levels of protection against yellow rust (Chen, 2012). Genetic resources for yellow rust adult plant resistance are available in winter wheat (Wang *et al.*, 2012).

Recent evidence suggests that the pyramiding of some of the known APR genes for yellow rust resistance may not provide the anticipated level of resistance as the effect of these genes is not additive (Herrera-Foessel *pers comm*). This suggests that field based selection for high levels of resistance among seedling susceptible segregates will be necessary. The approach used in CIMMYT is to select in the field under high epiphytotic conditions (Sing *et al.*, 2000; Rosewarne *et al.*, 2008).

Recommendation 3

The current breeding strategy for yellow rust resistance should be augmented by a specific introgression activity to incorporate high levels of adult plant yellow rust resistance into recurrent parents exhibiting adaptation to all yellow rust prone regions.

3.2.2 Stem Rust

Stem rust (causal organism *Puccinia graminis f. sp tritici*) can be a devastating disease in many of the relatively warmer areas of the world. Currently, stem rust is significant but not a major concern in the IWWIP mandate region probably due to its relatively higher temperature optimum compared to yellow or leaf rust, and winter wheat likely escaping damage by stem rust by maturing before the inoculum builds up.

Global warming as a result of climate change may favour greater development of stem rust in the IWWIP mandate area. Also, the highly virulent and aggressive pathotype lineage derived from Ug99 is geographically proximate to the IWWIP mandate region. Also, the alternative hosts of wheat rusts, *Berberis* spp., are found in the IWWIP mandate region (Nazari, 2012) and areas in Central Russia proximal to the IWWIP mandate area (Skolotneva, 2012). In both these studies samples obtained from barberry plants contained aecia from wheat stem rust DNA was obtained suggesting that pathotype evolution will be promoted by sexual recombination in the IWWIP mandate region. As a consequence, greater emphasis in IWWIP must be given to the development of stem rust resistant varieties. It is noted that IWWIP has breeding activity to develop stem rust resistant varieties and has given emphasis to the development of varieties with resistance to the Ug99 lineage pathotypes. As with yellow rust, the understanding of the nature, extent and distribution of stem rust pathotypes is

less than optimal and require continuous monitoring in terms of virulence and movement of pathotypes.

The regional yellow rust pathotyping capacity advocated above (Section 3.2.1.1) should include the stem rust causal organism. Similarly, the current activity to develop stem rust resistant varieties should be augmented with a dedicated pre-breeding program to introgress adult plant stem rust resistance into varieties adapted to different regions in the IWWIP mandate area. High levels of APR stem rust resistance in adapted backgrounds are available from the CIMMYT spring wheat breeding program (Bharani *et al.*, 2012).

Recommendation 4

The current IWWIP program to develop stem rust resistant cultivars should be augmented to include a comprehensive region wide pathotyping capacity and the introgression of adult plant stem rust resistance into varieties adapted to the IWWIP mandate region.

3.2.3 Leaf rust

Leaf rust, causal organism *Puccinia tritici*, is currently considered less important than yellow rust and more significant than stem rust presumably as its optimum temperature lies between that for yellow rust and stem rust. It would, as a consequence, be favoured by climate change. The limitation in the current activity to develop genetic solutions for leaf rust parallel those acknowledged above for yellow and stem rust. Effective and durable APR for leaf rust resistance have been well documented (Singh *et al.*, 2000; Lillemo *et al.* 2008, and Rosewarne *et al.*, 2008, Herrera-Foessel *et al.* 2011).

It is advocated that a robust regional pathotyping capacity should be developed for leaf rust and that a dedicated trait introgression activity should be established to introgress APR from various sources such as CIMMYT spring wheats into varieties adapted to the IWWIP mandate region.

Recommendation 5

In concert with the yellow and stem rust pathotyping activity advocated above, a similar capacity should be established for leaf rust. Also, as for yellow and stem rust, a trait introgression activity should be established to introgress adult plant rust resistance into varieties adapted to the IWWIP mandate region.

3.2.4 Sunn Pest

Sunn Pest, caused by *Eurygaster integriceps*, is a major constraint to food security in the CWANA region. As little as 2-3% of grains damaged can result in unacceptable baking quality and Sunn Pest infestation at the vegetative and

reproductive stages result in substantial productivity losses (El Bouhssini *et al.*, 2009). The extent of the importance of this pest is demonstrated by the cost of chemical control which was estimated at \$US40million in 1995 (Javahery, 1995).

Genetic control of this pest is considered a very high priority for the IWWIP mandate region.

Recently a number of sources of resistance have been identified for the vegetative stage of the wheat crop (El Bouhssini *et al.*, 2009). These resistances are in very unadapted backgrounds, nothing is known of the genetic architecture of the resistance in these lines and phenotyping for resistance is difficult and costly. It is, as a consequence, inappropriate to have Sunn Pest resistance as a component of the modified pedigree breeding program. It is advocated that an introgression initiative be established within IWWIP to develop robust breeding technologies and introgress the resistance into adapted cultivars. This initiative, as it addresses a problem that transcends winter wheat, should not be wholly reliant on funding through IWWIP.

Recommendation 6

An introgress/research program targeting the development of breeding technologies for breeding Sunn Pest resistance varieties should be set up within IWWIP though not wholly dependent on IWWIP for funding. This program will introgress Sunn Pest resistance into elite germplasm determined by IWWIP.

3.2.5 Tan spot

Tan spot, causal organism *Pyrenophora tritici-repentis*, is a current significant threat to food security in the IWWIP mandate region. Tan spot is a necrotrophic disease which is favoured by warm moist conditions and survives on crop residues during the non-crop period of the year (Rees and Platz 1980 and 1983). Climate change, through increases in temperature, will favour this disease in irrigated crops, crops receiving supplementary irrigation and in dryland crops in good years. Conservation agriculture (CA) is considered an important tactic in mitigating the effect of climate change as it enhances moisture accumulation. It has the downside in that it conserves and increases the amount of necrotrophic disease inoculum in the crop. The diseases advantaged by CA include tan spot and crown rot caused by *Fusarium culmorum* and/or *Fusarium pseudograminearum* (Rees and Platz 1980 and 1983; Wildermuth *et al.*, 1997). Pathotypes of tan spot are known but their evolution is much less rapid than for the rusts.

The adoption of CA in the IWWIP mandate region is low but is anticipated to increase through the advocacy of FAO and CG centers to mitigate the effects of climate change. The availability of tan spot resistant varieties may increase the adoption of CA as it removes one of the fears of loss of production due to disease.

It does not appear that the current IWWIP breeding program has an effective strategy to select for tan spot resistance (see Table 1).

It is advocated that greater emphasis be given to the development of tan spot resistant germplasm within IWWIP. This will require the development of a dedicated screening site and highly heritable phenotyping technologies. It may be prudent to seek advice from people who have these capabilities such as Ms Fernanda Munza in ICARDA.

Recommendation 7

IWWIP explore the options of establishing an effective tan spot breeding capability in the current modified pedigree program through consultations with Ms Fernanda Munza, ICARDA. If this cannot be done, then a dedicated introgression program should be established under Ms Munza's leadership.

3.2.6 Septoria tritici blotch

Septoria tritici blotch, causal organism *Mycosphaerella graminicola*, is currently a breeding objective for IWWIP. It has a lower temperature optimum than tan spot, is a necrotrophic disease, it is promoted by CA, pathotypes exist but their evolution is much less frequent than for rusts and it is favoured by moist conditions.

The future impact of this disease is difficult to predict as higher temperatures will favour tan spot and not septoria tritici blotch but it may be promoted by the increased adoption of CA.

It would appear that more evidence of its impact on regional food insecurity is required before committing to breeding resistant varieties. Note that, although septoria tritici blotch is nominated as a breeding objective, there is no evidence of active selection within IWWIP key locations (Table 1).

3.2.7 Crown rot

Crown rot, causal organism in Turkey is *Fusarium culmorum*. A number of surveys have been conducted in Turkey to determine the incidence of crown and root rotting diseases in Turkey. Over 36% of the fields sampled in Konya Province in the Central Anatolian Plateau were found to have *Fusarium culmorum* (Aktas *et al.*, 1999). Plants from these fields had a reasonably high level of infection suggesting that there would be substantial loss of productivity. Subsequent surveys in 2001 and 2002 across the whole Central Anatolian Plateau noted that 15% of the 185 field sampled were infested with *Fusarium culmorum* and/or *Fusarium pseudograminearum* (Tunali *et al.*, 2008). About 23% of the field sampled in the Thrace Region (also a winter and facultative wheat growing region) were infested with the crown rot causing fungi and the plants in these field had a high level of infection suggesting that these would be substantial loss of productivity (Hekimhan, 2010). The crown rot causing fungi

were demonstrated to be pathogen on wheat in Turkey with *Fusarium culmorum* being the most prevalent and damaging (Tunali *et al.*, 2008). These crown rot causing fungi plus the root rot causing organism, *Bipolaris sorokiniana*, caused 24 - 26% yield loss in inoculated trials at Cumra in Konya Province (Hekimhan *et al.*, 2004). Unfortunately, there is no way of separating the effects of crown rot and common root rot in this experiment.

Additional surveys were carried out for the incidence of crown rot in Turkey in 2011 and 2012 (Dababat and Erginbas, *pers. comm.*). The results generally confirm previous surveys.

In Iran, yield loss has not been assessed in field conditions directly but on the basis of frequency of fungi isolated from root and foot of wheat and some greenhouse experiments it is concluded that *Fusarium culmorum* and *F. pseudograminearum* are the most destructive species in Iran and Iran does not have any commercial varieties resistant to them (Dariush Safaei *pers comm.*). Varieties resistant to crown rot is considered to be a priority for Iran.

Crown rot is a necrotrophic disease and, as such, it is carried on crop residues and favoured by CA. It is, in contrast to tan spot, favoured by dry conditions and tends to be more pronounced in warmer production environments. The attributes of this fungus suggest that it will be favoured in dryland production environments by climate change and enhanced by increased adoption of CA. This suggests that crown rot may be a disease of increasing importance for the IWWIP mandate region.

Evidence to date suggests that resistance to *Fusarium pseudograminearum* is also effective against *Fusarium culmorum*. Large investments in the mining of genetic resources for resistance to *Fusarium pseudograminearum* have been undertaken in Australia. Experience with these resistance sources suggests that the genetic architecture is quantitative and complex and phenotyping for resistance is costly, of low heritability and not appropriate for large scale field evaluation.

Emphasis on the development of crown rot resistant varieties for Turkey appears to be appropriate given its current importance and future impact. Breeding efforts could emphasize the pyramiding of different sources of resistance and introgressing resistance into varieties adapted to Turkey.

The extent to which crown rot is a constraint to food security in other parts of the IWWIP mandate region needs to be determined. This should be through surveys and crop loss assessments. It will require a substantial program.

Recommendation 8

The current threat to regional food security due to crown rot in the IWWIP mandate region other than Turkey should be determined as a matter of urgency due to the anticipated increase in importance of this disease due to climate change and the increase adoption of CA. Subsequently

IWWIP should aim to identify sources of resistance to crown rot from Australia (Professor Trethowan and Drs Neat, Dieters and Wallwork) including material produced through investment to pyramid resistances. These would be in addition to the sources of resistance located in the CIMMYT root health program. An introgression activity should be commenced within IWWIP to introgress this resistance into varieties adapted to Turkey and Iran.

3.2.8 Cereal cyst nematode (CCN)

Cereal cyst nematode, *Heterodera filipjevi*, is a significant production constraint in Turkey but the extent of its impact in other parts of the IWWIP mandate region is unknown (Nicol and Rivoal, 2008). There is some evidence that this nematode is a yield constraint in Iran (Ahmadi *et al.*, 2010 and 2012). Resistance has been identified, pathotypes will probably develop as they have for other *Heterodera* species, phenotyping is expensive and has moderate heritability and disease loss is greater when the crop is moisture stressed. The later suggest that the importance of CCN will increase with climate change.

The difficulty of phenotyping suggests that the development of CCN resistant varieties for Turkey and Iran should be managed through a dedicated introgression program. It is also important to appreciate the current impact of CCN on food security in the remainder of the IWWIP mandate region. Multiple gene resistance should be targeted to reduce the probability of “breakdown”.

Recommendation 9

The current impact of CCN on food security in the IWWIP mandate area should be determined before undertaking breeding focused on regions other than Turkey and Iran. Based on information obtained, IWWIP undertake a breeding program to introgress resistance to *Heterodera filipjevi* into varieties adapted to Turkey and Iran. Multiple gene resistance should be targeted to reduce the probability of “breakdown”.

3.2.9 Root lesion nematode

Surveys have identified significant populations of root lesion nematodes, including *Pratylenchus thornei* and *Pratylenchus neglectus*, in Turkey (Nicol and Rivoal, 2008). The impact of these nematodes on regional food insecurity is not fully documented and not appreciated in other parts of the region. Field based selection for resistance/tolerance to *Pratylenchus thornei* is effective with moderate to high heritability providing that a site with relatively uniform nematode population can be identified. A number of loci control resistance/tolerance to *Pratylenchus* sp. have been identified. *Pratylenchus thornei* has a higher temperature optimum than *Pratylenchus neglectus* and can be much more damaging. It is probable that *Pratylenchus thornei* may become

more significant as climate change develops. It will be important to monitor the impact of root lesion nematodes as climate change progresses across the whole IWWIP mandate region. There has been a considerable body of research on root lesion nematode in Australia and this can be accessed through Dr Jason Sheedy.

Recommendation 10

Breeding for resistance to root lesion nematode should not be undertaken at this time. There should be a concerted effort to document the impact of *Pratylenchus* sp. on wheat productivity in the region.

3.2.10 Common bunt

Resistance to common bunt is nominated as an objective of IWWIP. No information on crop losses was provided. No background literature on the relevance and need for breeding for common bunt was provided. No clear breeding strategy was provided to the review team during the consultation phase of the review. Subsequent advice suggested that IWWIP do have a common bunt breeding strategy. Inexpensive seed dressings are available to control this disease. However, rural poverty, inadequate means to treat seed in a safe manner for humans and the environment, complications to dispose of unused treated seed in a safe manner require varieties with genetic resistance to provide choice to farmers.

Common bunt caused by *Tilletia caries* and *T. laevis* has a global distribution and is considered in many countries to be a disease of considerable economic importance. Infection by these pathogens results in significant yield loss and loss of quality (Gaudet and Menzies, 2012). Infections as low as 0.05% by weight (Menzies et al., 2006), result in the harvested grain having an unpleasant “fishy” odor that will persist in manufactured products. Consequently, common bunt affected grain, even when the infection level is quite low, is unfit for human consumption and can only be sold as animal feed. Bunt spores persist in the soil for many years. There is a history of the bunt pathogens changing genetically to overcome previously effective resistances. It is also considered that the resistance in some varieties, such as the Canadian varieties Neepawa and Katepwa, has remained effective for a very long period (Gaudet and Menzies, 2012). Common bunt is reported to be the major disease of wheat in the IWWIP mandate country, Kazakhstan (Koishibaev, 2009, reported by Gaudet and Menzies, 2012).

The Review Team consider that the case for breeding for bunt resistance, while difficult to determine, must be based on indirect evidence as it would be very difficult and costly for IWWIP to generate information on crop and quality loss for their mandate region. It is considered that the global experience and distribution of common bunt and its published importance in Kazakhstan provides compelling evidence to maintain bunt resistance as a breeding objective. Also, bunt tends to be favoured by lower soil temperatures that

reinforce the assessment that it will be a significant yield and quality compromising disease for winter wheat.

The breeding objective should be for durable resistance which can be achieved using known long lasting sources of resistance, such as the Canadian varieties Neepawa and Katepwa, and employing field based screening which has been found to be effective by IWWIP and in Canada (Gaudet and Menzies, 2012).

Recommendation 11

Breeding for bunt resistance should be maintained by IWWIP with the emphasis on known sources of durable bunt resistance and employing field based phenotyping.

3.3 Abiotic stresses

Abiotic stresses are a very major constraint to food security in the IWWIP mandate region due to the generally low precipitation across the region, the prevailing continental type climate and the inherent salinity of the soil. The latter has been exacerbated through inappropriate irrigation and drainage practices. It is quite certain that these stresses will be exacerbated as climate change develops.

3.3.1 Drought stress

Productivity under moisture limited conditions is *the* highest priority goal for IWWIP. The environmental diversity and consequent variation in the timing, intensity and duration of moisture stress requires that IWWIP produce germplasm that performs well for productivity in many different environmental types. It is highly likely that environmental diversity will exist across the region within a year and across years within a region. This emphasizes that the germplasm emanating from IWWIP will be required to perform well in many different drought environments. Also, and more importantly, IWWIP material must perform well under more favourable conditions where a 5% improvement in productivity will have a much greater impact on food security than a similar increase under severe drought stress where the yield is one tonne/ha or less.

This suggests that favourable alleles at many different loci will be required to achieve excellence in productivity across the IWWIP mandate area. It also emphasizes that performance in a specific water limited environment is highly unlikely to predict performance across the range of moisture limited production environments in the IWWIP mandate area.

Recommendation 12

The development of cultivars with elite performance in moisture limited environments should be addressed by selecting for elite performance in a

regionally representative set of target production environments. This will involve testing across locations and years.

3.3.2 Heat stress tolerance

The IWWIP mandate region is characterized by continental climate that feature high temperatures during the grain filling period. This constrains productivity and processing quality (Wrigley *et al*, 1996; Wrigley, 2006 and Powell *et al*, 2012). Climate change will exacerbate this productivity constraint, as the last frost day will be substantially earlier as will the onset of ‘hot’ days. High temperatures in the post-anthesis reduce grain size which, while still significant, tends to have a lower impact on productivity than heat stress in the pre-anthesis period which causes sterility and abortion of tillers (Powell *et al*, 2012).

Modifying phenological development patterns will be very important to minimizing the effect of heat on productivity. There needs to be emphasis on understanding the phenological development patterns that will be required in the future, identifying the flowering alleles that will be necessary to provide the required development pattern and incorporating these into the breeding program. It is noted and emphasized that there are research investments in a number of countries (USA, UK, Canada and Australia at least) on ways to vary phenological development pattern to mitigate the effects of climate change. IWWIP should endeavor to engage with such programs.

Recommendation 13

IWWIP should seek to engage with the global community concerned with understanding the genetic control of phenological development with the aim of documenting and implementing the technologies required to develop varieties whose development pattern minimizes the impact of heat stress on productivity.

Variation in the ability of the wheat plant to translocate stem carbohydrates to the grain at high temperatures is now well documented (Dreccer *et al*, 2009). There is considerable global investment in this area which includes both ICARDA and CIMMYT and a SeeD funded project at ICARDA. IWWIP is engaged with components of this (Dr Marta Lopez’s program in Turkey and the program at Tel Hadya) and would be advised to engage with other components of this research. Field nurseries for screening for heat and drought tolerance are being refined at some key IWWIP locations in Turkey. Capital investments have been made at Konya to facilitate laboratory screening of traits. The purpose is to locate sources of heat stress tolerance in the grain filling period, incorporate these into the IWWIP breeding program and develop highly heritable cost effective selection technologies.

Recommendation 14

IWWIP embrace/develop the technologies (germplasm, phenotyping, and genotyping) required to develop varieties with high levels of heat stress tolerance at the grain filling stage and incorporate this into the Ankara node of IWWIP.

The functionality of glutenin proteins is modified with high temperatures in the grain filling period. This can severely compromise product quality (Wrigley *et al*, 1996; Wrigley, 2006). This understanding is restricted to two (5 + 10 and 2 + 12) of a number of high molecular weight glutenin subunits (HMWGS) coded for on chromosome 1D (Wrigley, *et al*, 1994). It is probable that the functionality of other HMWGS and, possibly, low molecular weight glutenin subunits (LMWGS) will be modified by high temperatures in the grain filling period. This will impact on IWWIP's strategy to deliver the various quality types required.

This is captured by recommendation 16.

3.3.3 Salinity tolerance

Soil salinity is reported to be a significant productivity constraint in a number of parts of the IWWIP mandate region and is due to moderate to high concentrations of sodium chloride in dryland systems (Abrol *et al.*, 1988 as quoted by Ayoub *et al.*, 2008). This is due to naturally high levels of salt in the soil in a number of regions and to inappropriate irrigation practices previously employed for cotton growing in the Aral Sea area. The importance of salinity tolerance is highlighted by the adoption of varieties with salinity tolerance. It is emphasized that traits other than salinity tolerance have been contributing factors in the adoption of Sonmez in Turkey and Dostlik in Uzbekistan but salinity tolerance was an important factor.

Research into salinity tolerance for the IWWIP mandate region has been undertaken by Drs Ogbonnaya and Sharma in a purpose built hydroponic facility at Tel Hadya and at a field site in Uzbekistan. This research has demonstrated that the hydroponic facility and the field screen can discriminate with a relatively high level of precision on salinity tolerance (Ogbonnaya *pers. comm.*). There is also a high level of agreement between the two phenotyping methods (hydroponic and field). These findings are in agreement with current Australian research where field and glasshouse phenotyping is being used to develop salinity tolerant material (Tester *pers comm*). The cost of the phenotyping precludes its use in a pedigree breeding program but would be applicable to an introgression program.

Salinity tolerance is an IWWIP breeding objective and a number of salinity tolerant lines are at an advanced stage in the breeding program.

Breeding activity should continue but as a component of the introgression/research subprogram of IWWIP.

Recommendation 15

The current emphasis on developing salinity tolerant germplasm should be maintained but it should be as introgression activity only.

3.4 Processing quality

Processing quality has recently become a much more important feature for wheat breeding in Turkey due to high premiums paid for good quality. This emphasis is likely to occur in other countries, such as Kazakhstan, with higher per capita incomes and is likely to be a longer term trend across the region. Product quality is one of the reasons for the continued popularity of Bezostaya 1 (released in Turkey in 1959, Mazid *et al.*, 2009).

There appears to be diversity across the region in the wheat end product consumed. In Turkey open textured volume bread is consumed, as is flat bread (Fig 2). While in Central Asia tandyr or naan bread (Fig 3) is preferred as is a more dense variety (Abugalieva, *et al.*, 2002, Fig 4). Volume bread similar in appearance to western style bread is also consumed (Fig. 5). Somsa, meat or vegetable wrapped in dough and cooked on the walls of a circular oven, is also very popular in Central Asia (Fig. 6). Two types of flat bread are consumed in Iran. Sangak is made from brown bread. It is flat and can be up to fifty centimeters long. Barbari bread is long, thick bread with an open texture. A different type of flat bread is popular in Syria. This tends to about circular, ten to fifteen centimeters in diameter and developed a large pocket during cooking.

Figure 2. Volume bread in Turkey

Figure 3. Central Asia tandyr bread



Figure 4. Central Asian densely textured tandyr bread



Figure 5. Volume bread consumed in Central Asia



Figure 6. Somsa consumed in Central Asia

The quality requirements in terms of the physical and chemical properties (milling yield, protein, H and LMWGS, extensibility, $H_{\max}$ and gluten quantity) required for the manufacture of these products appear not to be known. Such information is of paramount importance in defining the quality targets for IWWIP.

The relatively poor quality of a number of the varieties released from IWWIP breeding material is acknowledged by the breeding team as a significant reason for the mediocre market share of material derived from IWWIP (Table 7).

Table 7. Share of IWWIP originated winter wheat varieties in total area of the crop in Central and West Asia

Country	Wheat Area (ha)	WW Area (ha)	IWWIP Area (ha)	% of Wheat Area	% of WW area
Afganistan	2.150.000	1.720.000	500.000	23,3	29.1
Armenia	112.100	108.021	10.000	8,9	9.3
Azerbaijan	571.100	568.980	10.000	1,8	1.8
Georgia	89.800	85.000	45.000	50,1	52.9
Iran	6.915.000	3.700.000	162.200	2,3	4.4
Kazakhstan	12.704.000	400.000	1.030	0	0.3
Kyrgyzstan	420.100	400.000	133.200	31,7	33.3
Tajikistan	320.200	185.595	25.200	7,9	13.6
Turkey	8.300.000	5.976.000	868.902	10,5	14.5
Turkmenistan	783.000	626.400	80.000	10,2	12.8
Uzbekistan	1.234.000	987.200	75.000	6,1	7.6
Total	33.599.300	14.757.196	1.910.532	5,7	12.9
Algeria		500,000			
Morocco		500,000			

Recommendation 16

IWWIP give much greater emphasis to producing varieties that meet the various end-product requirements for the region. A major component of this, and one that is urgently required, is to determine the specific quality traits required to produce these products, and an understanding of the effect of environment on the expression of seed storage proteins on end-products.

3.5 Overall assessment of breeding objectives

IWWIP seeks to deliver elite germplasm to the national programs in the CWANA region that are concerned with winter wheat improvement. This germplasm should exhibit genetic improvement for fourteen traits, many of which have complex genetic architecture (Table 6). The analysis of the relevance of these traits and the manner in which they are currently being addressed suggests that:

- IWWIP is tackling too many traits to deliver the required genetic improvement for all of them
- Effective selection for some of these traits does not appear to be possible with the current structure and facilities of the program
- A different approach is required to complement the current methodology to achieve a longer term solution for the rusts.
- The currently available phenotyping technology for some traits is high cost and cannot be implemented in the modified bulk program conducted through IWWIP.
- Other traits are located in agronomically poor backgrounds and should be incorporated in elite backgrounds before being addressed by the modified pedigree program.
- There is a question in the minds of the Review Team as to whether resistance to septoria tritici blotch will be a longer term requirement for the region given that it is currently a low priority and it may not be favoured by climate change.

For the reasons above, it is suggested that IWWIP focus on a subset of the traits currently targeted in the modified-bulk component of the program. The remainder should be targets of individual introgression programs. Traits recommended as targets for the Ankara node are:

- High yield and wide adaptation
- Winter hardiness
- Heat tolerance
- Yellow rust resistance (seedling and adult plant resistance) using the current methodology but selecting the pathotypes for field assessment based on a knowledge of the pathotype variability across the whole region
- Leaf rust resistance (seedling and adult plant resistance) with the same conditions as stated for yellow rust

- Stem rust (Ug99 lineage) resistance (seedling and adult plant resistance) with the same conditions as stated for yellow rust
- End product quality with a specific focus on the end products required in each region
- Tan spot resistance if effective phenotyping can be implemented
- Bunt resistance with the emphasis on using known durable resistance sources and field based phenotyping.

The following traits are recommended as targets for introgression into elite parents for the IWWIP mandate countries:

- Durable yellow rust resistance
- Durable stem rust resistance
- Durable leaf rust resistance
- Salinity tolerance if effective phenotyping can be implemented
- Tan spot resistance if effective phenotyping cannot be implemented in the Ankara node program
- Sunn Pest
- Cereal cyst nematode
- Crown rot

The target of this introgression is to provide germplasm for selection by national programs and for incorporation in the IWWIP Ankara node if effective phenotyping is possible and the resources are available to increase the size of the Ankara node program.

Recommendation 17

The breeding objective of the Ankara node of IWWIP should be limited to high yield and wide adaptation, winter hardiness, heat tolerance, product quality and resistance to yellow, leaf and stem rust and bunt. Tan spot should only be included in the Ankara node of IWWIP if effective phenotyping can be incorporated and its inclusion in this program will not compromise genetic advance for other traits.

An introgression program should be established to introgress the following traits into well elite adapted backgrounds: durable resistance to yellow, stem and leaf rust, salinity tolerance, Sunn Pest resistance, CCN resistance and crown rot resistance. Tan spot should be included in this list if it cannot be managed effectively in the Ankara node of IWWIP. The object is to provide germplasm for incorporation into IWWIP's now modified pedigree breeding program and for selection by national programs.

3.6 Possible new traits

There was insufficient information available to determine of the need for winter wheat breeding activity for resistance to the Russian wheat aphid (*Diuraphis noxia*), root lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) and the cereal leaf beetle (*Oulema melanopus*). It is recommended that surveys and crop

loss assessments be undertaken to determine the extent and nature of the threat to food security of these pests.

Recommendation 18

Survey and crop loss assessments be undertaken to determine the need to instigate winter wheat improvement activities to ameliorate the impact of the cereal leaf beetle and Russian wheat aphid.

4 Assessment of the IWWIP breeding program

IWWIP is required to deliver benefit in four main activities and assessment of the breeding program in this review has been based of the achievements in these four areas.

4.1 IWWIP Activities 1 and 2

The outputs specified for Activities 1 and 2 have been combined and are:

‘Winter and facultative germplasm development targeting irrigated and semi-arid environments.’

The assessment made by the Review Team is that IWWIP should be doing better and needs to do better. This assessment is based on the following:

- Mediocre market share across the region (13%) with particularly low market share in Azerbaijan, Kazakhstan, Iran and Uzbekistan (Table 7)
- The results of the two surveys conducted by IWWIP found that just under half the respondents did not find IWWIP germplasm to be very useful
- With the exception of Turkey, winter wheat improvement is very under resourced and the technical capacity requires considerable improvement. In these circumstances IWWIP should have achieved a much greater market share.
- The breeding technologies used can be better targeted to the needs of the region.

IWWIP in its various forms has been operating since 1980 and, as a consequence has had ample time (25 years) to make a much more significant impact in this region. Winter wheat breeding is much longer cycle than spring wheat breeding as only one breeding cycle can be achieved each year but this does not fully account for the mediocre market share. It is also acknowledged that the national processes for the exploitation of IWWIP germplasm are a major constraint to uptake. For example at the Almaty breeding facility in Kazakhstan it takes three years for IWWIP germplasm to progress through quarantine and a further three years of germplasm evaluation before IWWIP germplasm is provided to the breeders. The variability in the material provided to the breeders is greatly truncated by this process and substantially and unacceptably delays breeder access to IWWIP germplasm. This greatly compromises the value of the material

to the breeding program. It is advised that similar procedures exist in a number of other countries.

Knowledge of these constraints to the exploitation of IWWIP germplasm is not new and should have been addressed much sooner. It is noted that, when these constraints are addressed as has happened in Uzbekistan, the time taken to get IWWIP germplasm into final evaluation has been halved. Opportunities to address this constraint will be considered under capacity building.

IWWIP undertook surveys of those receiving IWWIP germplasm in 2007 and 2012. The results were remarkably similar in both surveys in that just over half (~ 52%) of respondents found IWWIP germplasm very useful. The concern is that just under half found the germplasm not useful (5% Iran) or useful suggesting that it did not fully meet the needs of the national program.

The following concerns the survey results from the IWWIP mandate area only. In the 2007 nursery a high proportion of respondents indicated that the IWWIP nurseries were useful for yield potential (79%) and yellow rust resistance (63%). The level of satisfaction with all other traits was below 50% suggesting significant room for improvement. The level of satisfaction for yield potential (87%) and yellow rust (65%) in the 2012 survey was also commendable. The high level (70%) of requests for yellow rust germplasm is in apparent conflict with the level of satisfaction expressed with the level of yellow rust resistance in IWWIP nurseries and suggests that IWWIP germplasm is not filling the regional requirements for yellow rust resistance. The other traits requested were Ug99 resistance, Sunn Pest (39%), cold tolerance (48%) and drought tolerance which suggests that these traits are inadequately addressed in the current program.

The lack of plant breeding expertise and/or inadequate facilities constrains winter wheat improvement in many of the countries except Turkey in the IWWIP mandate area. This is a long term problem that has resulted in a significant reliance on the breeding program at Krasnodar on the Black Sea in Russia. This program is well resourced and has a large capacity to produce and market seed of its varieties. It was reported that this breeding program had produced 18.5 thousand tonnes of seed in the 2010/2011 season. Winter wheat varieties from Krasnodar were reported to be well adapted to full irrigation but have sub-optimum performance in supplementary irrigation and dryland production systems. They are also quite susceptible to yellow rust. These performance deficiencies suggest that growers should have been preferentially sourcing IWWIP material due to its yellow rust resistance and putatively superior performance in dryland and supplementary irrigation production systems.

The inability of IWWIP germplasm to compete successfully with the apparently inferior Krasnodar varieties might be due to the entrenched reliance on these varieties. This lends support to the notion that more could and should have been done to advocate the adoption of IWWIP material.

4.1.1 Constraints to effectiveness

There are a number of features of the current IWWIP program that could be improved on. Some of these have been considered:

- Tackling too many traits
- Not adequately exploiting genetic variability
- Poor field plot technique
- Suboptimal exploitation of current facilities
- Tel Hadya is marginal for cold hardiness selection.

4.1.1.1 Number of traits

IWWIP purports to be addressing genetic improvement in a large number of traits. A number of these traits have complex genetic architecture which includes the influence of a considerable number of loci whose individual effect is probably quite small. IWWIP is, as a consequence, endeavoring to assemble a large number of allele/loci combinations in its germplasm. The addition of every additional allele to be selected for increases the size exponentially of the population required to have an individual with all the desired alleles. It is conservatively estimated that, for the truncated number of traits listed in section 3.5, over thirty alleles would have to be assembled in the one individual. The number of alleles that have to be assembled in the one individual for all the traits nominated by IWWIP is conservatively estimated at well over forty-five. The population size required for there to be high probability of having an individual with all the required alleles would be many orders of magnitude larger than that required for just over thirty alleles.

4.1.1.2 Better exploitation of genetic variation

IWWIP produces a large number of crosses and generates large populations from these crosses. These populations are heavily selected for traits other than yield/adaptation and processing quality until the F₇ generation. It is highly probable that much of the genetic variation for yield/adaptation across the region and processing quality has been lost limiting the genetic advance that can be made. It is advocated that the IWWIP program structure be amended to enable effective selection for these complex traits to be undertaken earlier in the breeding cycle before there has been a large truncation of the genetic variability generated.

This will be considered in more detail in section 7.

4.1.1.3 Field plot techniques

A consistent and distressing feature of the breeding sites inspected in Turkey was extremely sub standard field plot technique. This included very heavy weed growth, missing rows within a plot, very uneven plot length and very large variation across the plot area consistent with, in some cases, the location of alley ways between plots in previous years (Figures 7-9). The extent of the effects observed was so great as to severely compromise the genetic improvement that could be made by IWWIP. It is emphasized that the inspection made would only

identify a few of the potential sources of errors. Other sources of error could include: incorrect seed prepared for the plot, planting mistakes, incorrect labeling at harvest and transcription errors when data is entered for analysis.



Figure 7. One row of seeder not dispensing seed for 20 of 32 passes across 50 ranges.



Figure 8. Uneven growth conditions affects all plots in several ranges to left and right affect a number of experiments.



Figure 9. Poor weed control affected most plots in several yield trial

There have been unsuccessful ongoing efforts by IWWIP to have the problems corrected since the early stages of the Turkey/CIMMYT winter wheat breeding program.

More distressingly, the compromised field experiments were not confined to IWWIP but were wide spread in the TAGEM breeding program inspected. Consequently, the efficiency and effectiveness of the national program is severely compromised and it will not deliver the extent of benefits to Turkey that would be anticipated from the national investment in winter wheat breeding.

This is a deficiency that must be rectified as a matter of urgency as it directly affects the food security of the region. The amelioration activities must be different from those attempted in the past as these have clearly failed. These activities must also include the TAGEM program and it is probable that they will be relevant in capacity building for the whole region.

Solutions, albeit costly, will be considered in section 7.

4.1.1.4 Sub-optimal use of available facilities

Both ICARDA and CIMMYT have capacity that is not effectively used and has been nominated as available for IWWIP.

Much of IWWIP's requirement for processing quality determination is undertaken at the TAGEM quality laboratory at Ankara. This laboratory has a very large work load as it services much of the national program with the consequence that turn-around time for IWWIP samples is sub-optimal. Also, this laboratory is not air conditioned and does not use the now well established statistical procedures to remove variation due to changes in temperature during the day of the laboratory and equipment, particularly milling equipment. Such lack of control severely compromises the heritability of the results obtained. A new biotechnology and processing quality facility has been retrofitted and air-

conditioned at Konya. A new biotechnology and processing quality facility being constructed at Ankara will be air-conditioned. There were no formal indications that these laboratories will have the turn-around capacity or the technical skill (Konya) to meet IWWIP's requirements.

There is a quite modern and air conditioned wheat quality laboratory at ICARDA head quarters at Tel Hadya. This facility is reported to have the capacity to provide the turn around required by IWWIP but lacks the statistical capacity to remove effects due to temperature variation. This capacity could be acquired from a number of people including Professor Brian Cullis, University of Wollongong, Australia.

There are three laboratories (Ankara, Konya and Tel Hadya) that may be able undertake the substantially quality testing requirements for IWWIP. There are a considerable number of unknowns concerning the capabilities of each of these laboratories to provide the high level, high volume and short turn around needs of IWWIP. It is suggested that IWWIP undertake a detailed assessment of these facilities to determine the extent to which each laboratory could meet IWWIP's needs. Note that it may be that IWWIP's requirements could be met using more than one laboratory. The following are suggested criteria on which to assess the quality evaluation options:

- Does the laboratory have the professional and technical skill and experience to provide a high level of service including advice on the interpretation of the information generated?
- Does the laboratory have the equipment necessary to evaluate for the range of wheat based products consumed in the IWWIP mandate region.
- Has the laboratory implemented internationally accepted evaluation methods such as the approved methods for the American Association of Cereal Chemists?
- Is the laboratory air-conditioned?
- Are there quality assurance systems in place or is there the intention to implement a quality assurance system in the near future?
- Is there a robust audit system to ensure that QA requirements are being met?
- What are the costs of using each facility?
- Will the identified capacity to meet IWWIP's needs be maintained in the long term?
- Does the laboratory have statistical procedures in place, or the intention to implement such procedures, to minimize error due to temporal (time of day) effects?
- Does the laboratory have the capacity and commitment to provide the 'turn around' time required by IWWIP? Note that there may be different requirements for material from different generations in the program? This specifically refers to requirement to have quality testing completed between the harvest of one generation and planting the next.
- What is the probability that there would be unacceptable disruption to the timeliness of quality evaluation by having to transport samples across international borders?

- Would samples for quality evaluation be subject to seed health requirements in Syria?
- Could the optimum quality capability for IWWIP be delivered by more than one of these laboratories?
- Would the laboratory and local management be amenable to an annual performance review by the IWWIP partners and implement changes to meet IWWIP requirements?

Recommendation 19

IWWIP evaluate, as a matter of urgency, the utility of the quality laboratory facilities at Tel Hadya, Ankara (new), and Konya to meet the capacity, turn-around and data precision required by IWWIP. A number of assessment criteria have been suggested.

ICARDA HQ at Tel Hadya is well endowed to undertake rust research and breeding. These include a very modern compartmented and air-conditioned rust glasshouse, well established yellow rust field screening capacity and well established field stations for leaf and stem rust screening. The skilled and enthusiastic rust pathologist, Dr Naziri Kumarse, manages this capacity. Such a facility provides the capacity to undertake the development of germplasm with high levels of adult plant yellow, stem and leaf rust resistance.

This will be considered further in section 7.

There is also excellent capacity in necrotrophic diseases at Tel Hadya. Pathologist Ms Fernanda Munza, who leads this activity, has a strong record and commitment to servicing breeders leads this. Ms Munza emphasized that she has the capacity and desire to become more involved with IWWIP and could provide the skill required to enhance the tan spot screening for IWWIP.

Recommendation 20

IWWIP explore the option of exploiting the skill base in rusts and necrotrophic pathogens at Tel Hadya to enhance the selection for rust and tan spot resistance.

ICARDA have a state-of-the-art doubled haploid generating facility at Tel Hadya. This is a relatively new capacity and there have been disruptions to the services that can be supplied due to mite infestation. There is optimism that this problem has been effectively addressed and this capacity is available to IWWIP who has made some use of this facility. Winter wheat has a long cycle time that can be substantially shortened using doubled haploid technology. The crosses used for doubled haploid production must be well targeted in that both parents have many of the required traits.

This is captured in recommendation 36.

Molecular markers for parent generation and population enrichment are now a relatively mature technology and the cost of application is becoming more affordable for breeding programs. CIMMYT (El Batan) routinely providing marker assisted selection (MAS) support for breeders. ICARDA has molecular capacity that tends to be focused on crops other than wheat. The efficiency improvement opportunities are such that IWWIP is advised to seek to deploy MAS as a matter of urgency and should consult with CIMMYT and ICARDA to determine the most appropriate marker implementation strategy.

This is captured in recommendation 35.

4.1.1.5 Cold hardiness selection at Tel Hadya

A central question for the efficiency of IWWIP is the effectiveness of Tel Hadya as a site for selection for cold hardiness. The minimum temperatures for the last decade at Tel Hadya were provided by ICARDA. This information was made available to North American winter wheat breeders for comment (Table 8). Consultations were undertaken with Professor Stephen Baenziger (winter wheat breeder, Nebraska) and Professor Brian Fowler (winter wheat breeder, Saskatchewan). The advice obtained was conflicting but Professor Fowler advised that Tel Hadya was marginal for screening for cold hardiness and Professor Baenziger deferred to Professor Fowler.

Table 8. Number of frost days and the absolute minimum temperatures for Tel Hadya

Year	Tel Hadya (Alt 284 m)	
	No. of days	Min Temp
2000	37	-8.7
2001	13	-5.8
2002	32	-5.5
2003	16	-2.7
2004	36	-8.8
2005	28	-7.2
2006	42	-7.4
2007	48	-6.1
2008	48	-10.3
2009	17	-7.5
2010	11	-5.3
2011	21	-5.1
2012	22	-5.5

This suggest that germplasm emanating from the selection program would be unsuitable for much of the IWWIP mandate area and would contribute to the mediocre market share of IWWIP derived varieties as cold tolerance is a priority trait for at least half the programs.

4.2 IWWIP Activity 3: Germplasm Exchange

Under 'Activity 3' IWWIP undertakes:

"The facilitation of global winter/facultative germplasm exchange."

The assessment is that IWWIP does an outstanding job in acquiring germplasm from many winter wheat breeding programs globally and distributing this to a large network of breeding programs. The large number of programs that request and exploit this germplasm each year demonstrates the value of this activity. On average, 25 to 30 winter/facultative breeding programs provided IWWIP with breeding material for distribution. A similar number of nurseries were distributed.

Availability of germplasm, particularly if it is characterized, is fundamentally important to the success of a breeding program. IWWIP's contribution to the international exchange of winter wheat germplasm will make a significant contribution to addressing global food security.

Of concern is the relatively low numbers of collaborators providing data to IWWIP on the nurseries (40%-50%). This will detract from IWWIP's capacity to deliver elite germplasm to national programs.

Recommendation 21

IWWIP develop and implement strategies to greatly increase the provision of data generated by national programs on IWWIP distributed nurseries to IWWIP.

4.3 IWWIP Activity 4: Promotion

IWWIP 'Activity 4' requires:

'Promotion of new improved winter/facultative germplasm in the region'

While there are some significant successes in the promotion of winter wheat germplasm in the region much more needs to be done, this is considered to be one area where IWWIP could and should have much greater impact.

The success for IWWIP include the high market share of varieties derives from IWWIP material in Afghanistan (30%), Georgia (53%) and Kyrgyzstan (33%). The recent change in the evaluation and release process coupled with the guidance of the national program in Uzbekistan has greatly reduced the time between the arrival of IWWIP germplasm and its release to growers. Additional reductions in time could be made through the provision of large quantities of seed of the entries in nurseries going to Uzbekistan. This would allow the

conduct of field evaluation without requiring additional years for seed multiplication. Also, there is an urgent requirement for more regionally located capacity to guide the local programs in their exploitation of IWWIP material and to provide the advocacy required to stream line the exploitation of IWWIP germplasm through the variety evaluation, multiplication and delivery to farmers processes. It is noted that Dr Ram Sharma, who has delivered the above benefits to Uzbekistan, also has responsibility for many other crops in Central Asia which limits his considerable ability to speed up the exploitation of IWWIP germplasm.

Recommendation 22

A very substantial increase in capacity in Central Asia and, possibly the Caucasus, is required to facilitate the exploitation of IWWIP germplasm in a timely and effective manner and to provide the advocacy required to amend current policies to decrease the time required for evaluation, release and seed multiplication. Also, where possible, larger amounts of seed of nursery entries should be provided to the national programs for trials to eliminate the time required for seed multiplication for trial purposes.

Discussions with Dr Zewdie Bishaw, Head ICARDA Seed Section, suggested that it would be possible to engage the local private sector seed industry and/or local farmers in the promotion of new varieties providing that there was an incentive system. The incentive system could be through an exclusive license in one country for variety commercialization as this is now permitted through the CGIAR System. A similar system is operating in Ethiopia. This was developed through collaboration between CGIAR Centres, FAO and the local responsible ministry. These arrangements have the added advantage that the private sector may advocate for pre-release procedures to be reduced, IWWIP data to be used to support release and seed multiplication to be undertaken during the evaluation phase.

This will be considered further in section 7.

A considerable number of the winter wheat breeding programs in Turkey were evaluating a large amount of IWWIP germplasm. There was evidence of seed multiplication for release and use in crossing programs. A number of these breeders provided glowing endorsements of the IWWIP germplasm and of the IWWIP team as collaborators and providers of advanced technologies. The latter is singularly valuable and any adjustments to IWWIP should ensure that this level of technology transfer to national programs is maintained or enhanced.

The uptake and adoption of released cultivars by producers depends upon information available through demonstration in field trials, published materials and internet based materials. Information on the performance of new cultivars relative to established cultivars for the entire suite of biotic and abiotic stresses ensure producers have the information to compare the new cultivars to their current cultivar.

Recommendation 23

IWWIP should engage the pathologists, entomologists, and breeders of national programs to generate and disseminate information that characterizes the response of all of the new cultivars and currently released cultivars to the suite of biotic and relevant abiotic stresses listed as breeding priorities.

4.4 IWWIP Activity 5: Capacity building

This activity requires IWWIP to:

“Engage in capacity building and training of researchers in the area.”

IWWIP achievements in this area are very impressive (Appendix 8) whereby a great deal of useful capacity building has already been implemented by IWWIP and include providing opportunities for:

- Higher degree training
- Trainees to work in IWWIP
- Large number of focused workshops
- Conference attendance
- Training in English in preparation for additional studies

Also, travelling seminars are conducted every two years. Scientists from national programs visit breeding sites with IWWIP staff and have in-depth discussion on wheat breeding and IWWIP's focus. These seminars would appear to be excellent venues for technology transfer between IWWIP and national program scientists and their continuation is highly recommended.

It is considered that, in terms of capacity building IWWIP is doing all it has the resources to undertake. This notwithstanding, there are a number of priority areas for capacity building including:

- Development of a regionally coordinated rust pathotyping service
- Expose more national scientists to successful national wheat breeding programs
- Development of robust pre-release, seed multiplication and release procedures in a number of countries
- Advocacy for national policy changes to develop time efficient procedures for the exploitation of the germplasm provided by IWWIP
- Expanded training in breeding and related technologies augmented by training in English
- Engagement with and development of the commercial seed sector including providing incentives to promote varieties.

Some of the above have been argued previously in this report. More discussion will be included later in the report (section 7).

5 Outstanding features of IWWIP

Reviews often emphasize perceived deficiencies in a research activity without acknowledging the contributions made. It is important that these contributions are acknowledged and recorded as they form the basis for future improvement.

5.1 Breeding group

The review team acknowledges the highly professional, hard-working, motivated and committed core team of scientists from TAGEM, CIMMYT, and ICARDA. The contribution from national program scientists in Turkey, Uzbekistan and other countries who provide the capacity for field experimentation, quality evaluation and rust resistance screening contributes greatly to the program.

The very considerable contribution of the IWWIP core breeding team to the region was readily and enthusiastically endorsed by many national scientists.

It is noted and endorsed that the IWWIP breeding team is heavily involved in research and the publication of this research. Many of these publications result from collaborative investigations with scientists at advanced institutes in many countries around the world. This activity has forged important global collaboration that delivers considerable benefit to the region.

The pivotal role of IWWIP in the distribution of genetic resources, the lifeblood of breeding programs, to many winter wheat breeding programs globally has also been acknowledged previously.

An important current activity is the use of the University of East Anglia meteorological database to understand and document the impact of climate change on the IWWIP mandate region. This information will be pivotal in determining the varietal requirements necessary to adapt for climate change in a region that appears to be greatly impacted by global warming and can anticipate continuing above average increases in temperature and decreases in precipitation.

5.2 Landrace conservation

IWWIP has undertaken the systematic collection, characterization and conservation of the wheat landraces in Turkey. The need to expand the global genetic variability has never been greater as adaption for climate will require breeders to have access to genetic variability for new traits, both biotic and abiotic, and additional genetic variability for existing traits such as heat stress tolerance. Turkey is of particular relevance for the augmentation of global wheat genetic variation as it is one of the original centers of diversity for the genus *Triticum* and associated genera and as a consequence has had the time to accumulate large amounts of genetic variation. Turkey is diverse in climate and geography which will also enhance the genetic variation in this very valuable germplasm.

The extraction of value from this collection has already commenced as it is being evaluated for heat stress tolerance and yellow rust resistance both at the seedling and adult stage. It was noted that one of these landraces exhibiting heat and drought tolerance (number 254) and also exhibited adult plant resistance at Haymana although it was susceptible in seedling screening at Ankara.

This activity was nominated by the FAO as a high priority to address global food insecurity and climate change (FAO 2010; Mba *et al*, 2012).

Recommendation 24

The collection, characterization and curation of wheat landraces in Turkey is strongly endorsed as it will provide valuable genetic variability that can enhance the global effort to adapt for climate change as well as ameliorating many current constraints to productivity.

6 Research and development

A number of R and D needs have been documented above and others will be argued below as necessary to maximize the capacity of IWWIP to meet the food security needs for wheat of this region. These include:

- Rust Control Strategy
- Identification of genetic variability for heat stress tolerance and the development of breeding tools
- Wheat culinary and processing quality requirement for the region
- Development of genomic selection
- Understand the genetic architecture and develop breeding tools for Sunn Pest resistance
- Understand the genetic architecture and develop breeding technologies for salinity tolerance
- Implement marker technology
- Undertake yield loss assessments and develop breeding methodology for CCN, CR and septoria

6.1 Rust Control Strategy

A detailed and on-going understanding of the regional pathotype flora is fundamentally important for IWWIP. Primarily it will provide guidance concerning the pathotype to use in screening to ensure that the germplasm developed by IWWIP has effective resistance to all pathotypes of all rusts across the region. There is evidence, albeit indirect, that the yellow rust resistance in some of the germplasm developed by IWWIP may not be effective in other parts of the IWWIP mandate region.

Also, knowledge of the development of a new pathotype will provide early warning to farmers to switch from a newly suspected variety to a resistant

variety and thus avert the threats to food security that have occurred in the last decade due to yellow rust.

A CWANA Rust Control Strategy includes analysis of effective genes to use, pyramiding genes, use of durable resistance genes, molecular technologies, and chemical control in emergencies.

The R&D proposal has been argued elsewhere (section 3.2) and will not be reproduced here.

This is captured in recommendations 2, 3, 4 and 5.

6.2 Heat stress tolerance and avoidance

High terminal heat stress is currently a feature of CWANA. IWWIP and the University of East Anglia research has demonstrated that heat stress has increased recently and the predictions from climate change scenarios is that heat stress will increase as the climate changes. This will vary in intensity across CWANA. Pre-anthesis heat stress is a major constraint for food security and can be minimized by adjusting flowering time such that a variety flowers very soon after the most probable date for the last spring frost. This will require IWWIP to understand the required flowering date to the future for each region and to incorporate the appropriate flowering control alleles in the breeding programs.

Post anthesis heat stress is less, though still very significant, of a constraint to food security than pre-anthesis heat stress. Amelioration technologies include adjusting phenological development patterns to promote early ripening and heat stress tolerance *per se*.

A number of sources of heat stress tolerance (including QTLs, Pinto *et al.*, 2010) are known and more are and will be discovered through the Mexican Government's 'Seeds of Discovery (Seed)' investment in Mexico (CIMMYT), Turkey (CIMMYT, Dr Marta Lopez) and Aleppo (ICARDA). These programs are and will identify sources of heat stress tolerance. It will be important to understand the genetic architecture for this trait and to develop appropriate breeding technologies.

Heat stress tolerance and the required response from IWWIP has been argued in section 3.3.2, recommendation 14.

6.3 Quality

It is highly probable that the penetration of IWWIP germplasm has been constrained by poor quality characteristics. It is also probable that the market for wheat in the region will become more discriminating in the quality of the wheat based products they consume. These vary across the region (see section 3.4) and the traits required to manufacture these products are unknown. It is

important for IWWIP to generate the information concerning the discrete product quality so that appropriate breeding technologies can be developed.

See recommendations 19 in section and 16 in section 3.4.

6.4 Genomic selection

Genomic selection (GS) has particular utility in long cycle breeding programs, such as winter wheat breeding, as it can shorten the cycle time very substantially. GS will also have application in providing cost effective breeding technologies for complex priority traits for IWWIP such as heat stress tolerance, and crown rot.

Genomic selection (GS) breeding values are based on assessment of all the alleles that impact on a trait across the whole genome. This includes QTLs and alleles of small effect that are significant in trait building. It does not provide information on the nature of the genetic diversity for the trait in the population of sources of the trait.

GS was developed for animal breeding and has facilitated very significant genetic gains for complex traits, such as milk production. The gains exceed expectation of genetic gain from more traditional breeding approaches.

Plant geneticists are well advanced in adapting this technology for plant improvement and have focused on traits with less complex genetic architecture. There are expectations that GS can be adapted for traits with complex genetic architecture such as yield. The development of this application is ongoing. Currently, CIMMYT, Cornell and NIAB (UK), at least, have commitments to developing this technology for the public sector. GS is believed to be extensively adopted by the private sector who appear to be unwilling to share this technology with the public sector.

Recommendation 25

One member of IWWIP be designated to participate in the global public sector development of genomic selection and have responsibility for its implementation in IWWIP.

6.5 Sunn Pest

Sunn Pest resistant cultivars are a priority for the IWWIP mandate region and resistance at the vegetative stage has been located recently (section 3.2.4). The resistance is in very unadapted backgrounds, the genetic architecture is unknown and the phenotyping technology is very time consuming. There is an urgent requirement to address these three issues to allow affective and efficient breeding technologies to be developed. Also, linkage drag is likely to be a significant constraint to variety development. Next generation sequencing technologies such as genotype by sequence (GBS) can be employed to quantify the extent of the recovery of the recurrent parent in an introgression program. It

will also facilitate the identifying of individuals with minimal DNA from the donor parent associated with the gene(s) of interest. These will be individuals with minimal linkage drag.

See recommendation 6 in section 3.2.4.

6.6 Salinity

A considerable number of sources of salinity tolerance have been identified and the search for tolerant germplasm is ongoing. The genetic architecture and, as a consequence, the most appropriate breeding methodology is not understood. It may be appropriate to use association mapping (GWAS) to understand the genetic architecture due to the large number of sources of tolerance available. The specific ions that contribute to soil salinity have not been characterized for the mandate area. For example sodium tolerant germplasm may not be tolerant to sulphate and magnesium salts. It also appears necessary to have higher levels of salinity tolerance in varieties for some parts of the IWWIP mandate region.

The emphasis for IWWIP is to develop robust breeding technologies and to develop parental stocks with high levels of tolerance.

Recommendation 26

IWWIP engage appropriate soil salinity expertise to characterize the predominant ions contributing to salinity in CWANA.

Recommendation 27

IWWIP, develop breeding technologies with others such as Dr Ram Sharma (ICARDA, Tashkent) to promote the rapid development of salinity tolerant varieties of winter and facultative wheat.

6.7 Marker assisted selection

The importance of marker assisted selection has been argued previously and a recommendation made (Recommendation 23 see section 4.1.1.4).

6.8 Crown rot and cereal cyst nematode

The incidence and importance of crown rot (CR) and cereal cyst nematode (CCN) in Turkey is reasonably well understood. The incidence and importance (crop loss) is poorly understood for the rest of the IWWIP mandate region. This severely limits IWWIP's ability to set breeding targets for these diseases. The options to determine the importance of these diseases include:

- Systematic surveys in farmers fields and

- Use of 'probe' genotypes in which trials are grown that include resistant (tolerant) and susceptible (intolerant) lines so that the extent of crop loss can be estimated.

Both these options would require a substantial increase in root health pathology in the region.

Recommendation 28

Capacity building for root health pathology be undertaken with the objective of understanding the incidence and importance of root diseases with particular emphasis on crown rot and cereal cyst nematodes. This information would be used to set breeding targets.

6.9 Parental Germplasm Characterisation

The utility of the parents used by IWWIP and the germplasm generated by IWWIP will be enhanced by having much more comprehensive information concerning the material. This is considered in more detail in section 7.4.

7 Structural changes to IWWIP

IWWIP is of fundamental importance to the food security of the region for a number of reasons. These include:

- Relatively poorly developed winter and facultative wheat breeding system in most of the mandate countries with the significant exception of Turkey and Syria.
- The impact that IWWIP is having by supplying elite germplasm for national programs albeit that it needs considerable improvement
- Capacity building potential of this program. IWWIP is doing an excellent job with the resources available but more is required
- Climate change will probably have a greater impact on food security for the IWWIP mandate region than most other parts of the world.
- This region has the highest *per capita* consumption of wheat based products in the world

The major structural change for IWWIP is to develop two different but complementary wheat improvement strategies that will both generate germplasm for selection by national programs as well as providing parental material for the other node. One breeding strategy will build on the modified pedigree program conducted by Turkey, CIMMYT and ICARDA based in Ankara. The other is an introgression/research program that would replace the current program at Tel Hadya. The reasons for this change have previously been argued and include:

- IWWIP addressed too many objectives to make the necessary genetic advance on any one of them

- The current breeding methodology for a number of priority traits are not applicable to a modified pedigree based breeding system and genetic gain will not be made
- Some traits are in poorly adapted backgrounds and relatively sophisticated breeding and research technologies will be required to introgress these traits into farmer ready germplasm in the shortest possible time.

7.1 Introgression/Research Sub-program

This component would best be undertaken at Tel Hadya as:

- The selection environment at Tel Hadya is considered to be marginal for cold hardiness selection. There would be a higher probability of germplasm selected at Tel Hadya having insufficient cold hardiness for the mandate region.
- The winter wheat breeder at Tel Hadya has moved to spring wheat breeding so it is an opportunity to employ a person with a slightly different skill base. The skills require for the new role include an understanding of advanced genetic analysis (such as association mapping and genomic selection) as well as plant breeding skills
- Tel Hadya has most of the sophisticated technologies and skills necessary for the Introgression/Research sub-program (IRSP). Co-location of this skills set with the IRSP would create important synergies. These skills include:
 - High level phenotyping skills (both seedling and adult plant) for the rusts as well as modern facilities
 - High level phenotyping skills and the necessary phenotyping capacity for Sunn Pest
 - High level field phenotyping skills and infrastructure in Uzbekistan and glass house (hydroponic) phenotyping capacity at Tel Hadya for salinity
 - High level skills and phenotyping capacity in foliar necrotrophic diseases
 - Well developed doubled haploid production capacity
 - Well developed molecular marker capacity which will be required to assist in the breakage of undesirable linkages between the target alleles for introgression and deleterious (for the development of varieties) closely linked alleles. This capacity will also be important for the quantification of recurrent parent recovery during introgression.

Not all the necessary skills and facilities are located at Tel Hadya as the introgression program will require phenotyping support for crown rot and cereal cyst nematode. These skills and facilities are located at the CIMMYT/ICARDA office in Ankara.

Input required

It is estimated that each introgression program would require about 10% of the time of the research scientists in each of the skills listed above for the development and supervision of the required for phenotyping and about 5% of the time of a molecular biologist for molecular marker support. The breeding skills and technical support would come from the current winding down of the modified pedigree program at Tel Hadya.

Recommendation 29

The pedigree program at Tel Hadya is to be discontinued in a manner that permits the full exploitation of the material generated to date. An introgression/research program that provides technologies and germplasm to national programs and the IWWIP modified pedigree program in Ankara will replace this program.

7.2 Limited set of traits

It has previously been argued that IWWIP currently does not select effectively for a number of high priority traits and that the number of traits is too large for the required level of genetic advance to be made for many of the breeding objectives. It is recommended that the modified pedigree program conducted by Turkey, CIMMYT and ICARDA in Ankara focus on a limited set of traits while the remainder be addressed through introgression/research program at Tel Hadya (Section 7.1). The Ankara node should focus on:

- High yield and wide adaptation for irrigated, supplementary irrigation and rain fed systems for the region
- Yellow, leaf and stem rust resistance using the current methodologies but using more targeted pathotypes
- Product quality for all the major wheat products consumed in the region
- Heat stress tolerance
- Tan spot resistance if selection capacity can be developed for the Modified Pedigree Sub-program

This has been captured in recommendation 18, section 3.5.

7.3 Early generation selection for yield and quality

The current modified bulk breeding system provide for selection for high yield /wide adaptation and product quality late in the breeding cycle. The genetic variability within the breeding program is greatly truncated by this time due to selection for other traits. Limited genetic advance will only be possible for yield, wide adaptation and product quality due to the low level of variability remaining in the breeding population.

The current IWWIP modified bulk breeding methodology does not adequately address the large genotype x environment interactions identified for this region. It is suggested that the current modified bulk breeding methodology be changed

to allow early generation yield and quality evaluation (about F₄) at representative sites that adequately sample the genotype x environmental interactions in the region.

The added advantage of this approach will be that the widely adapted germplasm developed will be better able to accommodate the environmental changes that take place in all countries as a consequence of climate change.

This methodology has been used to considerable advantage for the highly variable dryland wheat production system in Canada and Australia for wide adaptation and product quality. The success metric for the methodology is the high market share for varieties developed in this manner both in Canada and in Australia.

It is emphasized that the system changes suggested above will require substantially increased resources and the risks will include suboptimal field experimental techniques.

This is captured in recommendation 1.

7.4 Genotyping and phenotyping of parents

A variety with all the required traits will only be produced from a cross in which the parents collectively have all these traits (complementary). The probability of producing a variety from the cross is enhanced when alleles for some to many of the required traits are common to both parents (commonality). The probability of producing varieties with higher levels for a quantitative trait, such as yield, will be achieved when the alleles for the trait are different which may be a function of lack of relatedness (low consanguinity). It is also critical that the mid-parent value for proposed cross combinations is high. Consequently, genetic improvement in a breeding program will be enhanced when the breeder has detailed knowledge of the traits available in potential parents that will be obtained from comprehensive phenotyping and genotyping of potential parents and identifying crosses using the criteria above.

Recommendation 30

IWWIP undertake a comprehensive program of genotyping and phenotyping potential parents in order to identify parental combinations that enhance the ability of IWWIP to generate germplasm that meets the needs of the mandate region.

7.5 Doubled haploids

The use of doubled haploid population will substantially increase genetic gain over time as generation time is substantially truncated. The cost efficiency of deploying doubled haploids is enhanced when there is a high level of

commonality and complementarity in the parents for the target traits. The choice of parents to make doubled haploid populations requires comprehensive knowledge of the genotype and phenotype for all biotic and abiotic attributes, end-use quality, winter hardiness, yield and adaptation. The use of doubled haploid to generate breeding populations has resulted in the release of commercially successful varieties in Canada (DePauw et al. 2011) and Australia.

Winter wheat breeding generally has a long cycle time due to the length of the crop cycle. Consequently, the use of doubled haploids has a particular advantage in winter wheat breeding for the early delivery of genetic advance.

ICARDA has a well-appointed laboratory and glass house facility at Tel Hadya for the production of doubled haploid populations. This facility has an, as yet, undetermined capacity as it is still in the set up phase. It is anticipated that this facility could produce about 10,000 doubled haploids per year for IWWIP. Molecular markers could be applied on haploids to accelerate the targeted incorporation of high value genes. This would require about half the capacity of the Tel Hadya facility.

Recommendation 31

ICARDA, Tel Hadya, undertake to develop 10,000 doubled haploids per year for IWWIP. The parental combinations should emphasize full complementarity and high levels of commonality for the target traits/alleles to maximize the cost efficiency of using this technology. The entire IWWIP team should agree upon the parental combinations.

Recommendation 32

The seed of the doubled haploid populations should be multiplied, evaluated, and distributed to other national programs for selection within three years of production.

7.6 Marker assisted selection

Molecular markers are becoming a cost effective technology for increasing the efficiency of plant breeding by increasing the heritability of a trait and decreasing phenotyping costs. It can be deployed to assist in the objective identification of cross combinations that have a high probability of producing a variety (see section 7.4).

Molecular markers have utility in population enrichment particularly where the population size is small and when low frequency recombination is required (see section 7.5).

CIMMYT have considerable experience in the development of marker assisted selection, ICARDA has a well-appointed molecular marker facility and cost effective chip based marker systems are available. The cost of sequence based

marker, such as GBS, are rapidly decreasing. This technology has the potential to be cost effective for breeding as it bypasses the need to develop and purchase chips.

Recommendation 33

It is recommended that, at least initially, the breeder/research hired to lead the introgression program at Tel Hadya spend 25% of his/her time on the development and implementation of molecular marker technology in IWWIP.

This should be undertaken using the resources at Tel Hadya, El Batan and commercial providers such as DArT Pty Ltd. The utility of MAS has been argued in section 4.1.1.4 and IWWIP action documented in recommendation 23.

8 Capacity building

It has been acknowledged that IWWIP has made a very significant contribution to improving winter wheat improvement capacity in their mandate region. It has been emphasized that this has been constrained by resources notwithstanding the importance of capacity building in addressing food insecurity for this region in the medium and long term.

A number of priority areas for capacity improvement have been argued above and will be grouped below.

8.1 Trial management

The very poor trial technology used in IWWIP has been emphasized. This is so bad that it is a major constraint to varietal development in Turkey and the rest of the IWWIP mandate region. It is emphasized as the same poor field trial technology noted for IWWIP field trials was widespread in the Turkey breeding programs. There was only very limited inspection of trial programs in other countries in the IWWIP mandate region so there was no assessment of the trial technology in countries other than Turkey. It is emphasized that only a certain type of error could be noted with the scrutiny during the review. These are many other opportunities to introduce errors into field trials.

It is further noted that serious attempts have been made in the past to rectify these problems which have existed since the inception of the Turkey/CIMMYT winter wheat improvement investment. The nature of the problems noted were:

- Site variability due to the effects from trial programs in previous years
- Abundant weed growth
- Uneven plot length and
- Missing rows within a plot

It is also noted that the efficiency of IWWIP is substantially impaired by the geographic dispersal seed handling facilities.

The solution to these problems must include:

- Improving research station management including weed control
- Allowing, at least, two to three years between trials on the one area
- Development of practices that enable plots of even length to be planted
- Development of practices and equipment that minimize the incidence of missing rows within plots
- Development of procedures for checking and rechecking that the correct seed is placed in a plot and that all seed is correctly labeled
- Improvements are directed at IWWIP, the Turkey breeding programs and those in the IWWIP mandate region
- Centralizing all IWWIP processing and storage activities
- Electric data capture to minimize transcription errors.

It is recommended that a new research station be established that is under the direct control of IWWIP. The soil on this station must be suitable for high quality field experimentation (even and no soil constraints) and have a significant irrigation capacity. The infrastructure must include the farm maintenance and plot equipment necessary for best practice and comprehensive seed processing and storage equipment. The sites must be suitable for selecting for cold tolerance. It must include a training unit, possibly including accommodation depending on the location, for training in all aspects of plant breeding, research station management, field plot technique and related disciplines. The unit would emphasise the improvement of research station management, field plot techniques and breeding for national programs.

Recommendation 34

Establish a breeding station for IWWIP that has the capacity for use by Turkey wheat breeding programs as well as IWWIP. This facility must have all the facilities for seed processing, seed storage, offices, training and the conduct of high quality field breeding experimentation.

8.2 Training

The already extensive commitment to training by IWWIP should be expanded. The low level of technical skill in Central Asian countries is absolutely constraining the national programs to mount effective winter wheat improvement programs. The requirement for training, the capacity to absorb training and the political will to provide the infrastructure to capitalize on training varies greatly with country. A country-by-country requirement for training (including English) and the capacity to absorb and exploit the training offered should be developed. The local capacity must develop to assume responsibility for their own destiny as soon as possible.

Recommendation 35

The training needs and the ability to absorb and implement the training should be documented for the whole region. The assessment should be discussed with authorities in each country and training programs implemented where there is a high need, ability to absorb and implement.

8.3 Seed industry engagement

The capacity to deliver elite wheat varieties into farmer fields is constrained by long and often unnecessary variety evaluation systems and relatively ineffective seed multiplication systems. This does not apply to all countries especially Turkey.

A number of countries are member of UPOV (Azerbaijan, Georgia, Kyrgyzstan, Turkey and Uzbekistan). It is probable that other countries in the IWWIP mandate region have application pending to join UPOV. UPOV harmonized national legislation provides some incentive for the private sector investment in plant breeding and/or variety commercialization. It is highly probable that the nature of national UPOV harmonized legislation and enforcement system would not guarantee sufficient return on investment to encourage the establishment of private wheat breeding entities. It is probable that there could be a sufficient return to justify the establishment of a private sector variety evaluation, multiplication and commercialization industry providing that exclusive licensing arrangement were available.

It is suggested that Dr Bishaw, ICARDA, has many of the skills and experience to assist countries in the IWWIP mandate region to achieve UPOV membership; to enhance the capacity of local seed companies in this region in seed multiplication and commercialization; work with governments to streamline the variety evaluation and release protocols and to work with IWWIP to develop a process for providing seed companies with exclusive access to IWWIP breeding material for the purpose for variety commercialization.

Recommendation 36

ICARDA promote the development of a private sector seed industry for commercialization of IWWIP germplasm through promoting UPOV membership, streamlining variety release and evaluation processes and developing protocols for allocating exclusive license to seed companies to selected IWWIP developed lines.

8.4 Pathotype surveys

The imperatives and one option for developing a regional rust pathotyping capacity have been discussed previously in this report and recommendations (section 3.2 and 4.4).

8.5 Data acquisition and handling

The current data management system relies on excel files, AgroBase and manual transcription of field data into electronic format. AgroBase has many advantages but it is considered that it will not have the capacity to store and analyse large volumes of molecular data that are anticipated for new marker systems such as GBS. Manual transcription of field data to electronic format is time consuming and prone to error. Also, comprehensive breeding program management systems will improve the efficient use of the resources in the breeding program. It is recommended that IWWIP retain a consultant to work with them to identify a database system that includes:

- Meets all the current requirements of the breeding program including seed inventory, cross identification, pedigree management, field book generation and selection
- Has the capacity to meet anticipated future needs
- Supports electronic data capture
- Can be customised to the needs of IWWIP
- Has the statistical and genetic analysis tools (including genomic selection) required by the program and
- Possible supports the collection of meteorological data

A number of options for database management systems are available and include GCPs Plant Breeding System, DArT's KDDArT and one being developed by the Mexican Government's "Seeds of Discovery" (SeeD) program which is being managed through CIMMYT. The system being developed by SeeD will be a version of KDDArT with a number of the molecular visualization tools developed by the James Hutton Institute (formerly SCRI) through Dr David Marshall's group. KDDArT is based on open source software, has the capacity to process large amounts of molecular data and only requires the development of the user interface before being deployed in a breeding program. It has Android based dataloggers. The user interface will be developed by DArT in consultation with the users so that it meets the needs of users.

Recommendation 37

IWWIP, as a matter of urgency, retain a consultant to evaluate the utility of the currently available plant breeding databases or ones nearing completion and their utility for IWWIP. These include GCP's Plant Breeding System, DArT's KDDArT and an enhanced version of KDDArT being developed by the Mexican Government's "Seeds of discovery" program.

8.6 Planning and reporting

Some wheat improvement related activities that are pertinent for IWWIP are occurring in the region that IWWIP does not have any knowledge of or input into. It is singularly important that all wheat improvement related activities that may impact, even remotely, on IWWIP are brought to IWWIP's attention as it is quite probable that IWWIP:

- May provide advice that would enhance these activities,

- Nominate germplasm that would make the activity more relevant to IWWIP
- Determine process to implement the derived technology into breeding activities at the earliest possible opportunity.

It is imperative that annual 'show and tell' meetings are held that include all those engaged in wheat improvement technology development as well as IWWIP to enhance the outcomes for these activities as well as wheat improvement. The IWWIP leader should consult with the directors of ICARDA's Biodiversity and Integrated Gene Management Program and CIMMYT's Global Wheat Program to identify attendees. CWANA spring wheat and durum breeders should also be involved.

Recommendation 38

IWWIP host an annual information exchange meeting for all those concerned with the development of technologies that may impact on winter and facultative wheat improvement for CWANA. Attendees are identified through annual consultations with the relevant ICARDA and CIMMYT managers.

9 Response to Terms of Reference (TOR)

The Review Team determined that the TOR for the review did not provide the optimal logical framework for addressing the review objectives. The Review Team acknowledges that it has an absolute obligation to demonstrate that it has met the requirements of the Review TOR. This has been attempted below by summarizing the Review Team's response to the fourteen components of the TOR.

9.1 Overall impact and priority setting (TOR #1,)

TOR: Impact of IWWIP developed germplasm in terms of variety adoption in the target countries, i.e. Afghanistan, Armenia, Azerbaijan, Georgia, Iran, Kazakhstan, Kyrgyzstan, Tajikistan, Turkey, Turkmenistan, Uzbekistan) and germplasm utilization as parental material in cooperating programs.

Response: The impact of IWWIP was considered less than satisfactory notwithstanding the long cycle time in a winter wheat breeding program and a number of constraints to the adoption of IWWIP germplasm. The details of the Review Teams concerns are argued in sections 3 and 4. A considerable number of recommendations have been made to address these concerns and are relevant to many aspects of IWWIP's activities.

9.2 Target regions, needs and activities (TOR #2)

TOR: The scope and relevance of IWWIP germplasm and research priorities as defined in MTP of ICARDA and CIMMYT and WHEAT)

Response: WHEAT has established a number of Strategic Initiatives (SI) that CGIAR centers are required to deliver on. A number of these refer to IWWIP and the performance of IWWIP in relation to these SIs has been tabulated below (Table 9).

Table 9. Observations made by the Review Team on the performance of IWWIP against the relevant Strategic Initiatives specified in WHEAT

Strategic Initiatives		IWWIP Performance
4	Productive wheat varieties	The contribution from IWWIP is less than satisfactory. There are a number of contributing factors and options to be address which have been identified in many parts of the Review Report. In some cases, productive varieties were developed but were not released due to their susceptibility to the stem rust race Ug/99 in Iran.
5	Durable resistance and management of diseases and pests	The current IWWIP rust resistance breeding strategy does not objectively address the development of durable rust resistance and a number of important pests and diseases are not addressed satisfactorily.
6	Enhanced heat and drought tolerance	More effort needs to be undertaken and more innovative approaches implemented for effective delivery of new heat and drought tolerant varieties.
7	Breaking the yield barrier	More needs to be done and better approaches adopted.
8	More and better seed	Considerable achievements have been made in some countries but much more is required to improve on the efficiency of seed production, marketing and delivery to growers.
9	Seeds of Discovery (SeeD)	IWWIP is cooperating very well with the SeeD project in Turkey but was unaware of the SeeD projects in ICARDA. Better communication is required to address this.
10	Strengthening capacity	IWWIP has been heavily involved with capacity building but more is required. IWWIP needs to develop a region wide strategic plan for capacity building and seek funding to implement the plan.

Table 10. CIMMYT Commitments to IWWIP as per Page 11 of the 1986 Agreement between Turkey and CIMMYT

No	Commitment	Comment
1	Locate one CIMMYT wheat	CIMMYT has located two CIMMYT breeder In

	breeder in Turkey	Turkey since 1986.
2	CIMMYT staff available for consulting	CIMMYT Mexico staff regularly consult to IWWIP
3	Enhance introduction of germplasm into Turkey	The IWWIP international nursery system brings large quantities of advanced breeding material into Turkey each year
4	Training for young Turkish scientists in CIMMYT, Mexico	Annually 2-3 young scientists attend Wheat Improvement Training Course in Mexico - 3 months now 6 months in the past
5	CIMMYT will fund 1 to 2 senior Turkish scientists to visit CIMMYT Mexico	On average 1-2 senior scientists visit CIMMYT Mexico per year for one week - ten days.
6	Attempt to supply essential equipment	Minor equipment has been supplied: seed dividers, seed treatment, seed cleaning machines, etc.
7	Increased breeding nurseries in Turkey	IWWIP conducts a very large number of breeding trials at TAGEM research stations each year
8	Support attendance of Turkish scientists at international meetings	2-3 scientists annually
9	CIMMYT support will amount to about US\$0.8M over 5 years	Done.

Table 11. ICARDA Commitments to Winter Wheat Improvements in the 2011 Memorandum of Understanding between the Turkish Government and ICARDA

Article	No	Commitment	Comment
II	(a)	Undertake genetic improvement of wheat	ICARDA has located an ICARDA breeder with the IWWIP team in Ankara and has a winter facultative wheat breeder at Tel Hadya
	(f)	Conservation and use of genetic resources	ICARDA maintains one of the largest genetic resource collections of wheat and has an ongoing commitment to exploit this material
	(g)	Transfer genetic resources of Turkish origin to Turkey	ICARDA has started the repatriation of all accessions from Turkish origin held in its genebank to Ankara genebank. More than 2300 accessions of winter and facultative wheat from the highlands of Iran, Turkey and Europe were sent for evaluation in Turkey by Turkish-CIMMYT-ICARDA researchers. The repatriation process will be done over years to be able to transfer more than 11,000 accessions of various species originating from Turkey.
III	(a)	Exchange scientists and technologies	ICARDA has two wheat breeders engaged in developing winter wheat germplasm and uses technologies developed by ICARDA in this endeavour. Germplasm evaluation is carried both in Syria and Turkey by breeders from ICARDA and Turkey. Ankara Genebank staff visited ICARDA on three occasions for training on best practices, management of genebanks and conservation of genetic resources (Total of 8 participants).
	(b)	Exchange of breeding material and germplasm	ICARDA supplies breeding material for evaluation in Turkey, and similarly the Turkey based program sends germplasm to Syria for evaluation to yellow rust, drought tolerance and yield potential. Furthermore, about 2300 wheat genetic resources accessions were sent to Turkey for evaluation for drought, cold tolerance and resistance to yellow rust.
	(c)	Exchange scientific literature, information and technologies	Information, literature and technologies are supplied as requested.
	(d)	Import and export	All items requested have been supplied by

		of items for cooperative research	ICARDA
	(e)	Invite each other to technical meetings	There is a regular co-involvement in meetings relative to winter wheat improvement. ICARDA, Ankara and Izmir Genebank staffs are fully involved in several meetings related to conservation and sustainable use of agrobiodiversity and in strengthening the regional integration and collaboration including within the NENA-PGR network.
IV	(a)	Consultation and assistance for national research activities	ICARDA breeders work closely with Turkish breeders. ICARDA also develops DH populations and mapping populations and shares this material on request.
	(b)	Reside expat staff where necessary	ICARDA has located an ICARDA breeder with the IWWIP team in Ankara.
	(c)	ICARDA will provide short term visiting scientists	Upon availability of funds, ICARDA-provides training in breeding, biotechnology, DH production, biometrics, quality analysis, seed technology, IPM, and genetic resource characterization, evaluation and documentation.
	(d)	ICARDA will provide specialist training	Turkish scientists are regular attendees at training courses in wheat breeding, biotechnology, biometrics and other courses conducted by ICARDA. Upon request and availability of funds ICARDA-GRS will provide needed training on best practices for conservation of genetic resources and management of genebanks.
	(e)	Co-supervise graduate students	ICARDA scientists co-supervise MSc and PhD students from the CWANA region in wheat breeding, biotechnology, pathology, entomology and other topics upon request and the availability of bilateral projects.
	(f)	ICARDA will provide seed for trials and demonstrations	Seed from the Tel Hadya winter wheat breeding program is provided in the quantities required for trails and demonstrations. These are provided to Turkey and other key countries in the region. ICARDA Tel Hadya based breeders work with the winter wheat breeders in Turkey to identify entries for international nurseries and to distribute these to co-operators.

9.3 Co-ordination and co-operation between IWWIP partners (TOR #3)

Response: The Review Team was advised that there were concerns within IWWIP related to effectiveness of individual partners contributions and possible duplication. The Review process identified a number of shortcomings that include:

- Poor quality of the field operations in Turkey
- Inadequate communication on wheat improvement initiatives
- Some duplication
- Suboptimal use of the resources in ICARDA

Recommendations to address these concerns are included in this Report.

9.4 Partnerships (TOR #4)

TOR: Are current partnerships with other CGIAR centers, advanced research institutions, civil society, national programs and the private sector, appropriate for advancing IWWIP's future work on R&D

Response: IWWIP has established a large number of very beneficial relationships with research agencies both nationally and internationally. These have contributed in a very substantive manner to the technology employed by IWWIP. There needs to be greater engagement with national governments and breeding programs as well as the domestic seed industry to achieve greater uptake of IWWIP germplasm. Partnerships between Turkish universities and TAGEM, CIMMYT and ICARDA have deficiencies. Joint supervision of graduate students at Turkish universities could be improved so that TAGEM, CIMMYT, and ICARDA staff are true partners in training and evaluation of students.

Recommendation 39

TAGEM with CIMMYT and ICARDA management work with its national universities so that TAGEM, CIMMYT and ICARDA staff who supervise graduate students in their thesis projects are treated as equal partners in the assessment of the student's progression to their degree and publication of manuscripts.

TOR: Does IWWIP respond adequately to stake holders / beneficiaries needs

Response: IWWIP needs to do more to address productivity, durable disease resistance and the process quality requirements of the region.

TOR: Are capacity building and regional cooperation adequate?

Response: IWWIP has contributed greatly to building capacity in the region and has reached the limits of its resources to do so. There is more required and IWWIP must be resourced to do this.

9.5 IWWIP structure (TOR #5)

TOR: The operational and management structure of IWWIP related to achieving breeding goals in the most efficient way.

Response: There are a number of opportunities to improve the operational and management structure of IWWIP in order to address the food insecurity needs of the region. These include:

- Improved communication concerning all activities related to wheat improvement in CWANA
- The development of two distinct subprograms in the breeding program:
 - Introgression/Research based primarily at ICARDA
 - Modified Pedigree breeding program with a main node in Ankara
 - Restructuring of the modified breeding program to promote genetic advance for yield and quality

TOR: The balance of research activities in Turkey and Syria vs activities in other countries (Iran and Uzbekistan)

Response: There needs to be more regionalization of the field evaluation program to enhance genetic gain for yield and quality. There is also a pressing requirement for a much better understanding of the importance of biotic and abiotic stresses in IWWIP mandate countries. There is a requirement for greater promotion of IWWIP germplasm in IWWIP mandate countries other than Turkey and Syria.

TOR: Does the present IWWIP research in Turkey and Aleppo address the implications of Global Climate Change on IWWIP?

Response: Adaptation for global climate change will require IWWIP germplasm with greater heat and drought stress tolerance as well as different phenological development patterns. Inference from a low moisture experiment at one location is very unlikely to predict drought tolerance across the region and across years. Alternative technologies have been suggested to develop widely adapted germplasm. Heat stress tolerance will be a major requirement and more emphasis is required. Climate change will result in a shortened frost period and an earlier onset of high temperatures. IWWIP germplasm will require phenological development patterns to match these changed conditions. IWWIP must engage with national programs in the developed world that are addressing this.

The nature of the effect of climate change on biotic stresses is less certain. This notwithstanding recommendations have been made that emphasise changed biotic stresses resulting from climate change.

9.6 Capital mechanization and modernization (TOR #6)

TOR: Is the infrastructure / mechanization adequate for IWWIP;

Response: A number of infrastructure and mechanization concerns were identifies:

- Lack of timely provision of quality assessments

- Poor precision of quality data
- Very suboptimal field plot technique
- Insufficient use of ICARDA facilities

The nature of these concerns have been comprehensively argued in the report and recommendations for amelioration nominated.

TOR: Are capital investments required?

Response: The major requirement for IWWIP is greatly improved field plot technology. This has been a major issue since winter wheat breeding was commenced by Turkey and CIMMYT and has not been addressed effectively in this time. The field plot technology is so bad that it is a major constraint to genetic gain to address food insecurity in the region. The Review Team has determined that the solution to this is a dedicated experiment station for IWWIP and TAGEM breeding activities and for training Turkey scientists and those from IWWIP mandate countries in field plot technique. This facility must be under IWWIP management.

9.7 Potential staff and / or disciplines gaps in IWWIP (TOR #7)

Response: The introgression/research activity proposed for IWWIP will require skills in genomics advanced genetic analysis, data management and new generation molecular markers as well as breeding.

9.8 Wheat breeding methodologies (TOR #8)

TOR: The effectiveness and efficiency of the current wheat improvement system with emphasis on breeding methods and the application of conventional and molecular technologies and opportunities for improvement.

Response: Very substantial changes to the current breeding system have been nominated. These include:

- Greater emphasis on early generation testing for yield and quality across the entire IWWIP mandate region.
- The development of an Introgression/Research capacity.
- Development of capability in genomic selection
- Implementation of MAS
- Much greater use of doubled haploids
- Use of sources of durable resistance in the breeding program

9.9 Wheat International Nurseries (TOR #9)

TOR: Do International Nurseries meet the demand and priorities of NARS and do they deliver germplasm in most efficient way

Response: The IWWIP international nursery system performs very well. The short fall is in the return of trial data to IWWIP. This needs to be addressed.

TOR: IWWIP distributes germplasm to more than 50 countries. Does the seed production and nursery preparation assure healthy seed distribution?

Response: Seed health was not nominated as a concern except for the importing of seed into Syria and then only occasionally. However, the facilities to clean, process, dress seed with chemicals, package seed of elite lines for distribution in international nurseries are inadequate. The facilities for short and medium term storage require updating. The new breeding station as per Recommendation 39 is to include appropriate facilities to assure healthy seed is distributed.

TOR: IWWIP supports regional networks. Are they efficient to provide germplasm to NARS?

Response: Seed of advanced breeding material is supplied to IWWIP for distribution to global winter wheat breeders. This activity is well supported globally and there does not appear to be room for improvement.

9.10 Biotechnology (TOR #10)

TOR: Application of MAS

Response: The application of MAS in IWWIP is much below world standard and much improvement is required. It is suggested that the major activity for the leader of the Introgression/Research component of IWWIP should have responsibility for the implementation of MAS in IWWIP. See section 6.7.

TOR: Utilization of doubled haploids

Response: The use of doubled haploids could make a very substantial improvement in genetic grain to address food insecurity. DH has not been sufficiently implemented in IWWIP and it is recommended that IWWIP and ICARDA collaborate to enhance the use of the ICARDA DH facility.

TOR: Application of new molecular tools, e.g. Genome wide selection

Response: IWWIP has aspirations to use genomic selection and this is strongly endorsed by the Review Team. Genomic selection is not at the stage of development where it can be incorporated in IWWIP notwithstanding the wide spread use of this technology in breeding by the private sector. Also, GS requires access to database systems that have the capacity to store the phenotypic data from breeding program, the genotyping of much of the breeding population and sophisticated statistical and genetic analysis tools. IWWIP does not have this capacity and there is an urgent requirement to acquire such capacity. The Review Team are aware that there are a number of initiatives to develop such a capacity for wheat improvement and have suggested that IWWIP retain the services of a consultant to work with the IWWIP Team to evaluate these systems and, if found to have the required utility, to work with the IWWIP Team and the database developer to adapt the system to the requirements of IWWIP.

Association mapping (GWAS, NAM and other variations) has the capacity to determine the genetic architecture for a trait in a population of sources of the trait and to identify closely linked markers for QTLs in an efficient and effective manner. This technology has particular relevance for IWWIP in the development of breeding technologies for traits such as salinity tolerance. It is recommended that the leader of the Introgression/Research component of IWWIP has skills in association mapping or has the ability to develop these skills.

Advanced marker systems such as GBS and the 9K SNP chip will be singularly important tools to facilitate the introgression of new traits from unadapted backgrounds into advance breeding material with a minimum of linkage drag. It is important that the leader of the Introgression/Research component of IWWIP has ready access to such technologies.

9.11 Wheat pathology activities (TOR #11)

Response: Pests and diseases are very important constraints to wheat productivity in CWANA and breeding options are the most effective amelioration strategies. These have been addressed extensively above and are summarized below:

- The structure of the pathotype flora for all three rusts is not determined for the IWWIP mandate countries. It is a priority to understand this. There are facilities in a number of IWWIP mandate countries that are intended for pathotype surveys. A region wide pathotyping capacity can be readily achieved through the coordination of the current pathotyping capacity in the region together with some capacity building.
- Yellow rust: the current breeding strategies will give short term relief but will produce varieties whose resistance can and will be broken down by the causal organism. Durable resistances are available and the introgression of this resistance into advanced breeding material is a high priority.
- Leaf rust: the current breeding strategies will give short term relief but will produce varieties whose resistance can and will be broken down by the causal organism. Durable resistances are available and the introgression of this resistance into advanced breeding material is a high priority.
- Stem rust: the current breeding strategies will give short term relief but will produce varieties whose resistance can and will be broken down by the causal organism. Durable resistances are available and the introgression of this resistance into advanced breeding material is a high priority. It is probably that stem rust will become more significant in the winter and facultative wheat growing areas of CWANA as climate change progresses.
- Sunn Pest: this is a major constraint to food security in CWANA and, until recently, resistance was not available. Resistance at the vegetative stage has recently been identified and SeeD is investing in the discovery of new sources of resistance at the vegetative and reproductive stage. The development of breeding technologies and the introgression of the

currently available resistance into advances breeding material is a priority for the Introgression/Research component of IWWIP.

- **Tan Spot:** this is a significant concern in CWANA and will probably become a greater constraint to productivity as climate change progresses and there is a greater adoption of conservation agriculture. CIMMYT, Mexico, has developed effective field phenotyping for resistance to this disease and IWWIP are encouraged to see if they can develop this capacity for winter wheat. If this cannot be achieved, introgression of tan spot resistance should become a priority for the Introgression/Research component of IWWIP.
- **CCN:** This is a significant contributor to reduced productivity in Turkey and is of unknown significance in other IWWIP mandate countries. IWWIP are encouraged to develop cost efficient phenotyping capacity for the Modified Pedigree component of IWWIP. If this cannot be achieved, introgression of CCN resistance into elite breeding material should become a priority for the Introgression/Research component of IWWIP. Emphasis should be given understanding the importance of CCN in other IWWIP mandate countries.
- **Crown Rot:** This is a significant contributor to reduced productivity in Turkey and it is likely to become more significant as climate change progresses and there is increases adoption of conservation agriculture. It is of unknown significance in other IWWIP mandate countries. IWWIP are encouraged to develop cost efficient phenotyping capacity for the Modified Pedigree component of IWWIP. If this cannot be achieved, introgression of crown rot resistance into elite breeding material should become a priority for the Introgression/Research component of IWWIP. Emphasis should be given to understanding the importance of crown rot in other IWWIP mandate countries.
- **Bunt:** Resistance breeding should emphasise field based phenotyping of material derived from durable sources of resistance.
- **Septoria tritici blotch:** The continued importance of this disease in the IWWIP mandate region is undetermined.

9.12 Wheat industrial and nutritional quality (TOR #12)

Response: The less than optimum industrial quality of IWWIP germplasm was cited as a significant constraint to the adoption of IWWIP germplasm in a number of countries. The technical requirements for the diversity of wheat based products consumed in CWANA are poorly understood. IWWIP is encouraged to develop more robust quality assessment capacity, give priority to understanding the quality requirements for the wheat based products consumed in the region and to make adjustments to the current breeding objectives to deliver quality similar to or better than that for Bezostaya 1 until better guidance is provided by the research activity above.

9.13 Data acquisition and management ((TOR #13)

TOR: Distribution, timeliness and quality of international nursery data provided to co-operators

Response: The feedback from users of the IWWIP international nurseries suggests that IWWIP is providing a highly valued service to global winter wheat improvement programs. The concern for the Review Team is that the level of return of data by collaborators is unacceptably low. This compromises the ability of IWWIP to make determination of the value of their germplasm and how it is subsequently exploited in the IWWIP breeding activities. It is recommended that IWWIP give greater emphasis to encouraging the return of data from collaborators in the international nursery system.

9.14 Capacity building (see above TOR#14)

Response: It has been acknowledged that IWWIP has made a very significant contribution to improving winter wheat improvement capacity in their mandate region. It has been emphasized that this has been constrained by resources notwithstanding the importance of capacity building in addressing food insecurity for this region in the medium and long term.

A number of priority areas for capacity improvement have been argued throughout this report and have been grouped in section 8. The areas for improvement include:

- Trial management
- Training
- Seed industry engagement
- Data acquisition and management
- Rust pathotyping
- Planning and reporting

10 Acknowledgements

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11 References