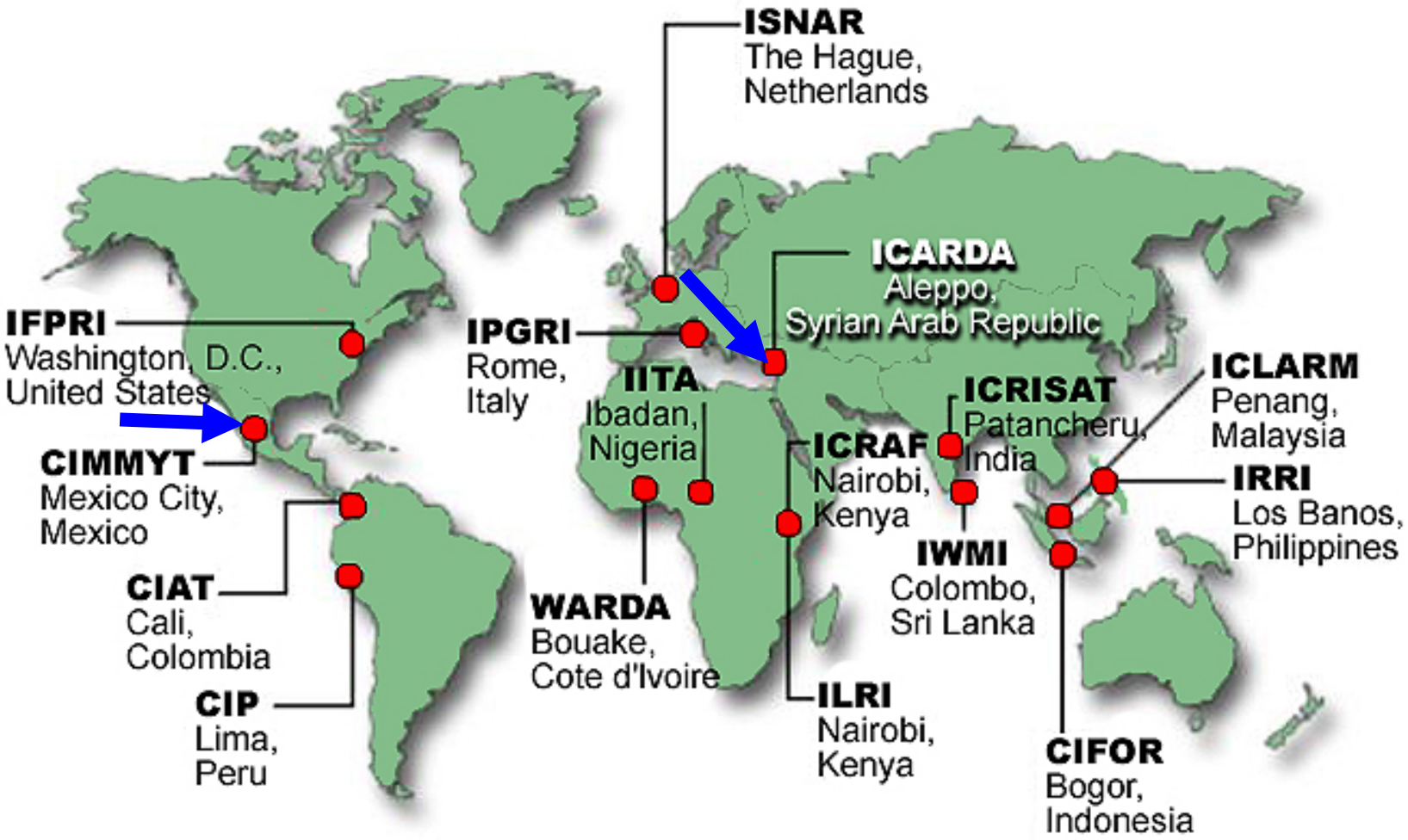
The ICARDA Program for Breeding FHB Resistance in Barley

Flavio Capettini *et al*.

ICARDA

2008 National *Fusarium* Head Blight Forum



The CGIAR Centers

ICARDA/CIMMYT Latin America Barley Breeding Program - México

- Started in 1970-72 with Dr. Norman Borlaug
  - Andean Countries for food & feed
- Conducted later by Drs.:
  - Enrique Rodriguez (1976-1984)
    - Food & feed quality - lysine
  - Hugo Vivar (1984-2000)
    - Multiple disease resistance, yield
  - Flavio Capettini (2000-2008)
    - Multiple disease resistance, yield, malting
- Followed the same *shuttle breeding* scheme of CIMMYT's bread wheat program


Winter
(27°29' N, 109°56' W)
Summer
(19°17' N, 99°40' W)
Arizona
New Mexico
Oklahoma
Arkansas
Mississippi
Texas
Louisiana
México
Gulf of Mexico
Phoenix
Tucson
El Paso
Dallas
Houston
San Antonio
Austin
Chihuahua
Hermosillo
Ciudad Obregón
Los Mochis
Monterrey
Torreón
Durango
Guadalajara
Puebla
Toluca
Mérida
Guatemala

Number of crosses (Single + Top) made in the Barley Program from 1998-2006.

Cycle	Type	Year								
		1998	1999	2000	2001	2002	2003	2004	2005	2006
Obregón and Toluca	Single	329	469	641	804	1207	261	688	1012	563
	Top	920	516	616	940	263	50	282	80	144
	Total	1249	985	1257	1744	1470	311	970	1092	707
Winter Toluca		233	163	156	104	175	-	94	44	58

Latin America Regional Program Outputs

- Germplasm requested by 75 countries in 27 years, 40-50 countries per year
- Varieties released in 20 countries
- Possible wide adaptation among more favorable environments
- Barleys resistant to 5, 7 or more major diseases
- High yield potential and attractive agronomic types

ICARDA

Objectives

- Barley types
  - Six and two-row
  - Covered and Hulless
  - Spring
  - Spring x winter

Objectives

- Disease resistance
  - Scald (*Rhyncosporium secalis*)
  - Stripe rust (*Puccinia striiformis*)
  - BYDV
  - Leaf rust (*Puccinia hordei*)
  - FHB (*Fusarium graminearum*)
  - Net blotch (*Dreschlera teres*)
  - Spot blotch (*Bipolaris sorokiniana*)
  - Stem rust (*Puccinia graminis* fsp. *hordei*)

Objectives

- Disease resistance
  - Covered smut (*Ustilago hordei*)
  - Loose smut (*Ustilago nuda*)
  - Russian wheat aphid (*D. noxia*)
  - Enanismo de Nariño
  - Bacteria (*Xantomonas campestris, Pseudomonas syringae*)

Leaf Rust at Ciudad Obregón

- Spreader rows inoculated
- Whole breeding program infected

Stripe Rust at Toluca

- Natural infection in segregant material
- Inoculation of spreaders at nurseries

Scald Severity at Toluca

BYDV

- Infection of aphids with PAV, MAV, RPV
- Application of aphids to plots
- Aphid-free check with insecticide


Courtesy of Pat Hayes, OSU

FHB - Background

- Caused by:
  - ***Fusarium graminearum***
  - *Fusarium culmorum*
  - ***Fusarium avenaceum***
  - *Fusarium poae*
  - *…*

FHB - Background

- Genetics
  - Quantitatively inherited
  - No immunity
  - Very high GxE
  - Intermediate to low selection effectiveness

ICARDA FHB Program

- 5000 barley accessions screened in 1986
- Only 23 found with resistance
- 2-3 sources pyramided in elite lines
- ‘Gobernadora’ released as Zhenmai-1 in China
- Gobernadora used in mapping studies (Zhu et al., 1999)
- Collection of resistance sources made available to other programs when was mostly needed – after 1993
- Searching for novel sources of resistance – Barley Program & GRU are screening entries in Mexico
- Variability is being found for FHB resistance and also other diseases – yellow rust, scald, etc.

Screening Enviroments

- Toluca
- El Batán
- Hanghzou, China
- Brazil, Ecuador, Peru, Uruguay, USA, etc.

FHB Genetics

Heritability estimates obtained by components of variance (line-mean basis) of FHB in Populations 1, 2, 3, and 4 in all the environments tested

Population	1995	1996		1997				All Environments
	Crk	Crk	Mo	StP	Crk	Mo	Hz	
				FHB				
1	0.62	**0.26**		0.43	0.77		0.51	0.48
2		0.48	**0.84**		0.63		0.75	0.68
3		0.37	0.57		0.52			**0.76**
4		0.34	0.76	0.57		0.51		0.48

Crk: Crookston, StP: St. Paul, Mo: Morris and Hz: Hangzhou.

Capettini et al. 2003 Crop Sci. 43:1960-1966

Levels of infection of FHB

FHB - Background

- Types of resistance
  - Type I – resistance to the fungus penetration
  - Type II – resistance to the spread of the fungus within the head
  - Type III – resistance to toxin production
  - Etc.
  - Resistances are independently inherited

Misting and floret inoculation

Does Type II Exist In Barley?!!

Table II.5. Mean number of *F. graminearum* infected kernels 21 days after point inoculations in two- and six-row genotypes in Experiments 1, 2 and 3. Genotypes are ranked by number of infected kernels at each experiment.

Experiment 1			Experiment 2			Experiment 3			Mean		
Genotype	No. of Infected Kernels		Genotype	No. of Infected Kernels		Genotype	No. of Infected Kernels		Genotype	No. of Infected Kernels	
Two-row											
Misc. Cal. 21	0.6		Misc. Cal. 21	2.1		Zhedar 1	1.6		**Misc. Cal. 21**	**1.5**	
Gobernadora	1.8		Svanhals	2.2		Misc. Cal. 21	1.7		**Svanhals**	**2.4**	
Fredrickson	2.7		Zhedar 1	2.8		Gobernadora	1.9		**Gobernadora**	**2.6**	
Svanhals	3.0		Fredrickson	3.4		Fredrickson	2.0		**Fredrickson**	**2.7**	
Zhedar 1	4.2		Gobernadora	4.1		Svanhals	2.1		**Zhedar 1**	**2.9**	
Mean	2.5	A		2.9	A		1.9	A	**Mean**	**2.4**	**A**
$LSD_{0.05}$	ns[I]			ns			ns			**ns**	
Six-row											
GD2-27	2.9	a	Chevron	4.8	a	M95-4	1.6	a	**Chevron**	**4.9**	**a**
Chevron	3.2	ab	GD2-18	6.2	a	MNBrite	1.6	a	**M95-4**	**5.1**	**a**
Stander	5.0	abc	M95-4	7.2	ab	GD2-27	2.3	ab	**GD2-27**	**5.1**	**a**
Foster	6.6	abcd	Foster	8.2	abc	Stander	3.5	abc	**Stander**	**5.8**	**a**
Robust	7.5	bcd	M93-192	8.8	abc	M93-192	4.5	abcd	**Foster**	**6.2**	**ab**
M93-192	7.6	cd	Stander	10.5	bc	Foster	4.9	abcd	**MNBrite**	**6.4**	**ab**
M95-4	8.8	cde	MNS 93	10.8	bc	GD2-18	5.6	abcd	**M93-192**	**6.5**	**ab**
GD2-18	9.1	cde	MNBrite	11.1	bc	Chevron	6.1	bcd	**GD2-18**	**6.7**	**ab**
MNBrite	9.6	cde	Steptoe	11.9	c	Robust	6.9	cd	**Robust**	**8.4**	**bc**
MNS 93	9.7	cde	GD2-27	12.1	c	Steptoe	7.8	d	**MNS 93**	**9.3**	**c**
Steptoe	12.5	e	Robust	12.1	c	MNS 93	8.4	d	**Steptoe**	**10.2**	**c**
Mean	7.5	B		9.4	B		4.8	B		**7.3**	**B**
$LSD_{0.05}$	4.4			4.1			4.1			**2.5**	

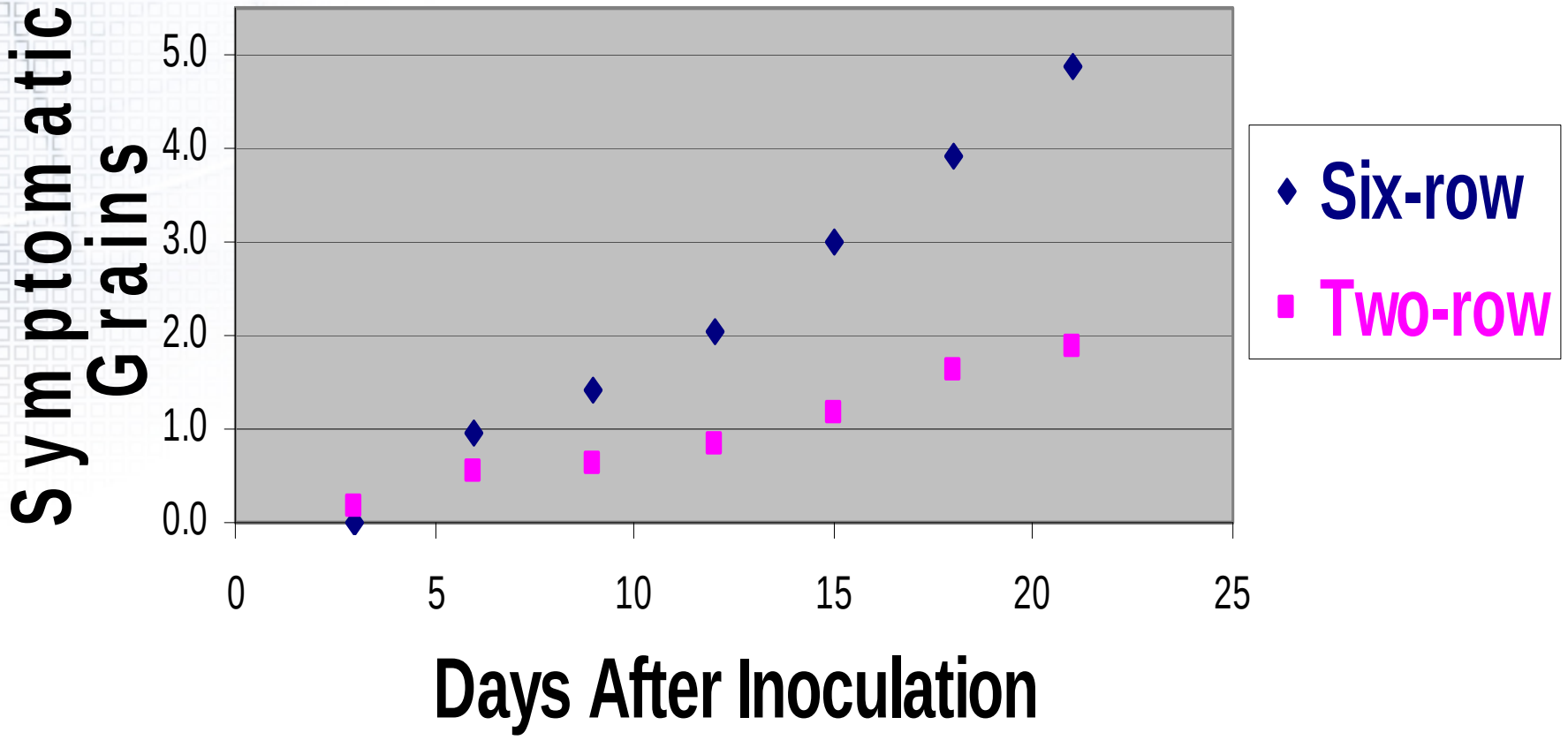
[H]: means of two- and six-row followed by different capital letters at each experiment are significantly different ($p \leq 0.05$).

[I]: Numbers in the same column are non-significant at $p \leq 0.10$.

[']: means within the same column followed by the same letter are not significantly different ($p \leq 0.05$).

Does Type II Exist?!!

Spread of Infection



FHB Program

- **Main sources of resistance in barley based on data from the USA, Canada, China, Ecuador, Brazil and Uruguay**

Genotype	Head Type	Genotype	Head Type
Atahualpa	**2**	Fredrickson	**2**
Azafrán (Misc. Cal. 21)	**2**	Gobernadora	**2**
Chamico	**6**	Humai 10	**2**
Chevron	**6**	PFC 88209	**6**
Shyri	**2**	Shenmai-3	**2**
Clho 4196	**2**	Svanhals	**2**
		Zhedar-1	**2**

FHB – Selected Genotypes

	Cross	Rows	Damage (%) Type I	Damage (%) Type II
1	TOCTE//GOB/HUMAI10/3/ATAH92/ALELI	2	5.6	7.1
2	PENCO/CHEVRON-BAR	6	1.5	17.3
3	ZHEDAR#1/SHYRI//OLMO	2	5.7	8.0
4	ATAH92/GOB	2	5.8	9.1
5	ATAH92/GOB	2	4.9	4.3
6	CANELA/ZHEDAR#2	2	5.3	5.3
7	MNS1	6	3.4	17.1
8	ZHEDAR#1/4/SHYRI//GLORIA-BAR/COPAL/3/SHYRI/GRIT/5/ARUPO/K8755//MORA	2	3.2	4.0
9	SVANHALS-BAR/MSEL//AZAF/GOB24DH	2	3.3	8.8
10	SVANHALS-BAR/MSEL//AZAF/GOB24DH	2	6.3	8.4
	Checks			
	AZAFRAN (MR-R)	2	8.5	8.3
	GOBDH83(R-R)	2	5.1	7.6
	GOBDH89(S-S)	2	13.4	27.7
	PENCO/CHEVRON-BAR (R-MR)	6	4.7	12.1

Collaboration with ARIs & Special Projects

U.S. Wheat and Barley Scab Initiative (USWBSI)

- Before USWBSI: deployment of sources of resistance after 1993
- Deployment of germplasm originated from the FHB breeding program EGS – 150-200 lines/year
- China nursery – participation with lines in advanced testing
- NABSEN – cooperative multi-location nursery with elite lines
- Mining of new genes from ICARDA Gene Bank
- Pre-breeding program – introgression of resistant genes into US germplasm pool.


18 9 2003


Courtesy of Paul Schwarz, NDSU

U.S. Wheat and Barley Scab Initiative

Germplasm tested and deployed for the USWBSI by ICARDA from 2002 to 2008							
Nursery Name	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Germplasm Deployed							
Early Generation Screening (EGS)	**50**	**120**	333	161	241	282	-
NABSEN	8	8	8	8	8	8	-
China nursery	93	60	60	100	100	110	114
Germplasm Tested							
NABSEN	54	54	54	54	54	54	-
ICARDA Genetics Resources Unit (New)							
Palestina					19		2
Ethiopia					295	155	87
ICARDA 2005					277	150	97
ICARDA 2006					1200	198	580
ICARDA 2007						1371	352
ICARDA 2008							1569

Diving into the gene pool

Do still are undiscovered sources of resistance somewhere?

A rational approach to exploiting large genetic resource collections

Kenneth Street, GRU, ICARDA

ICARDA

Almost 70,000 barley & landrace accessions registered in the global barley register

What genebank – which accessions ?

A needle in a haystack



Scientist wants a few hundred accessions to evaluate for a particular trait

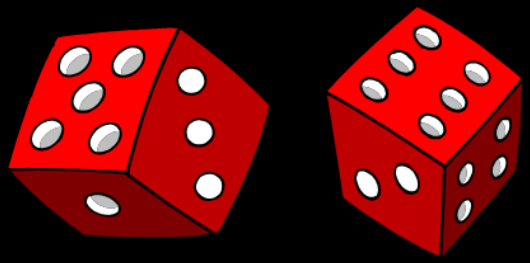
How do they select a small subset likely to have the useful trait?

Increasing the odds

How can we increase the chance of finding what we want?

✓Limited resources $$$

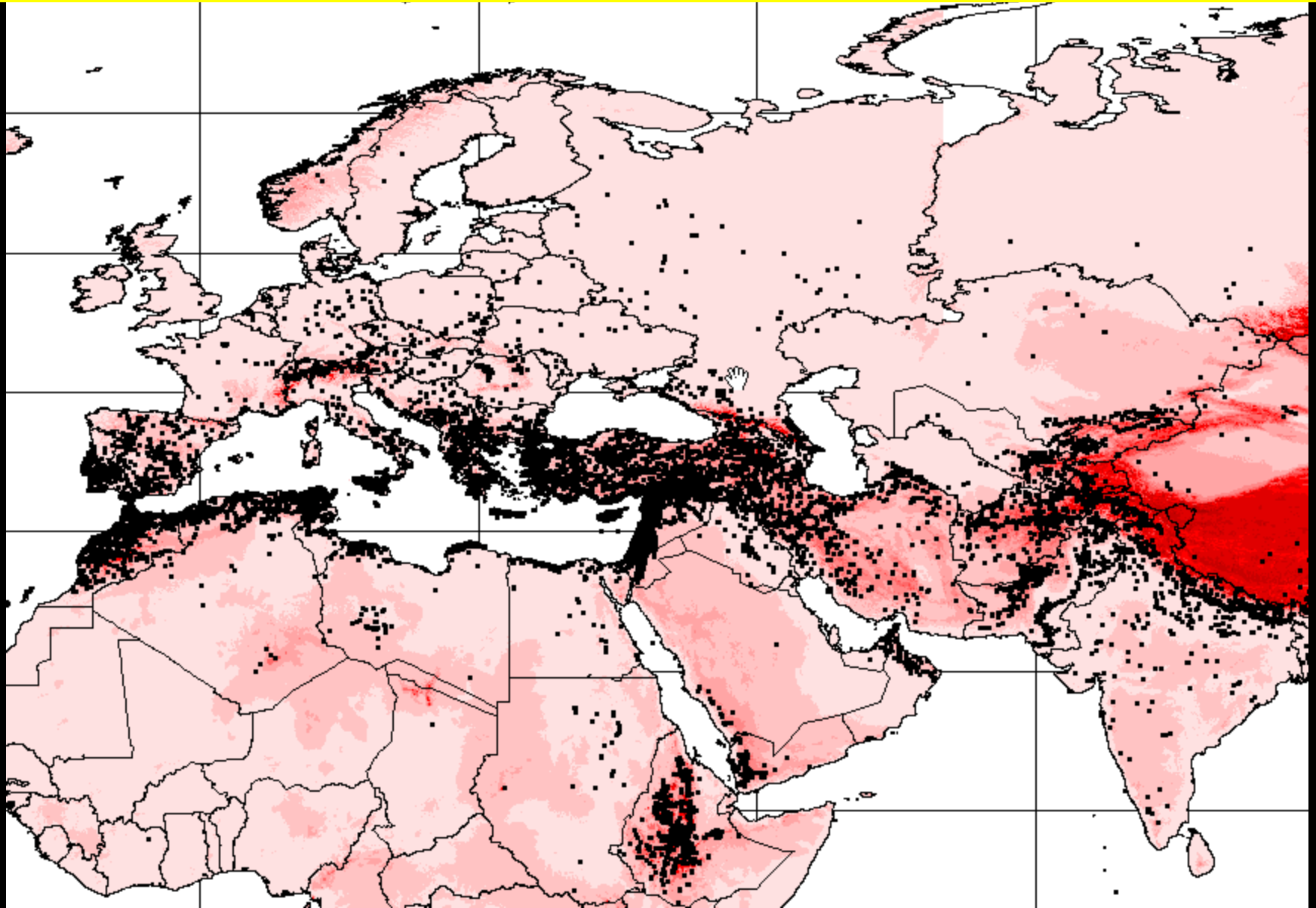
✓Need a repeatable, rational method



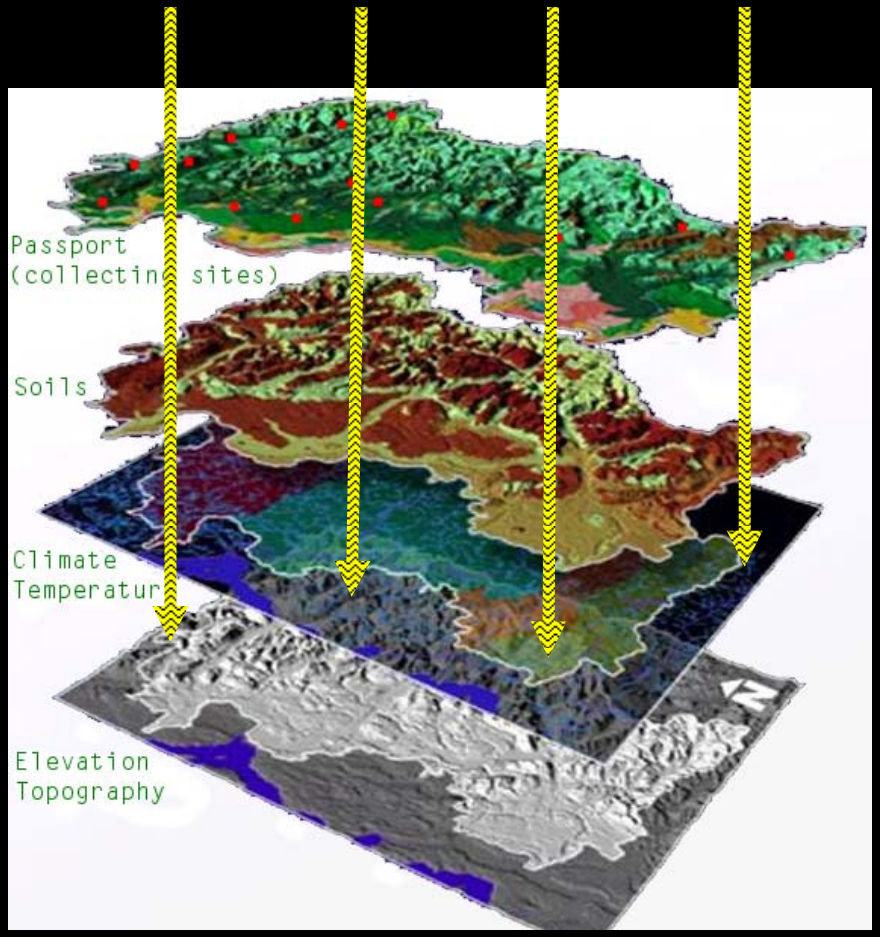
Focusing in on the ‘best bet’ accessions

- Focused
- Identification of
- Germplasm
- Strategy

Since the majority of the ICARDA genetic resource collection is geo-referenced we can plot the collection sites over a suite of agro-climatic and edaphic surfaces



Link environmental data to collection sites



Adapted from diagram by
D T F Endresen (NGB)

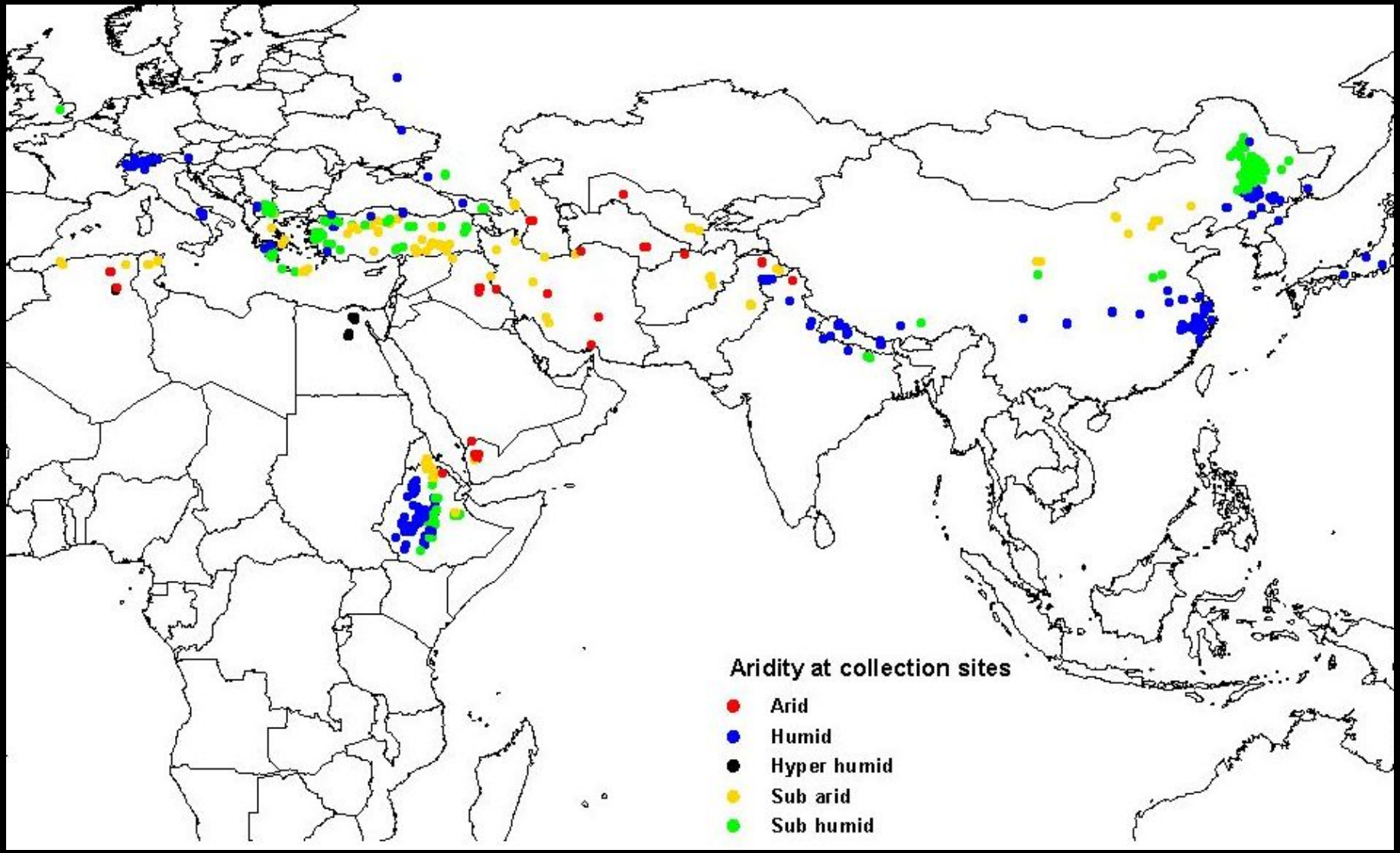
Model environments that would favor selection pressure for a given trait and choose accessions from that environment for screening.

For diseases, select material from environments that favor high disease load

% of UG99 resistant accessions predicted in small sets drawn from 7000 accessions screened for UG99 resistance

Method	% resistant accessions within set
Core	9.7%
Random	10.7%
FIGS-set 1 (PCA on total set)	13.8%
FIGS-set 2 (Stratified clustering)	17.8%

Distribution of collection sites for barely Net Blotch FIGS set accessions



Represents 734 accessions selected from a total of 67,664 barley landraces documented in the global barley register and currently being screened.

Alberta Agriculture - Canada

- Development of germplasm with multiple disease resistance
  - Screening for:
    - **FHB**
    - Stripe Rust
    - Scald
    - BYDV
- Use of germplasm in the program
  - Covered smut resistance
  - Net Blotch
  - Spot Blotch
  - Scald
- Over 2000 elite lines screened at 4 locations in Canada and 3 in Mexico
- Lines having resistance to 5 to 6 diseases were identified

Barley breeding lines having the best multiple disease resistance to scald and FHB, , BYDV, stripe rust and smuts. (Helm et al. 2005)

Barley Line	Scald	FHB	Net Blotch	BYDV	Stripe Rust	Smuts
H94050005	R	R	R	R	S	R
H94050009	R	R	R	R	S	R
H94050010	R	R	R	R	S	R
H94019001	R	R	R	R	S	R
H94039004	R	R	R	R	R	S
H94020198	R	R	R	R	S	R
H92066207	R	R	S	S	R	R
H92067002	R	R	S	S	R	R
H93014003	R	R	S	R	R	R
H93014014	R	R	R	S	R	R

Busch Agricultural Resources Inc. (BARI – Anheuser-Busch Co.)

- Development of germplasm with **multiple disease** resistance:
  - FHB & low DON
  - BYDV
  - Yellow rust
  - Net blotch
  - Scald
  - Etc.
- Malting quality for ICARDA

Busch Agricultural Resources Inc. (BARI – Anheuser-Busch Co.) (Cont'd):

- Use of their malting barley varieties
  - Legacy (6-row)
  - Tradition (6-row)
  - Merit (2-row)
- Generation of 11 populations in 2000
- Collaboration with malting quality testing

Objectives – Multiple Disease Resistance

Results of F7 at Toluca 2003

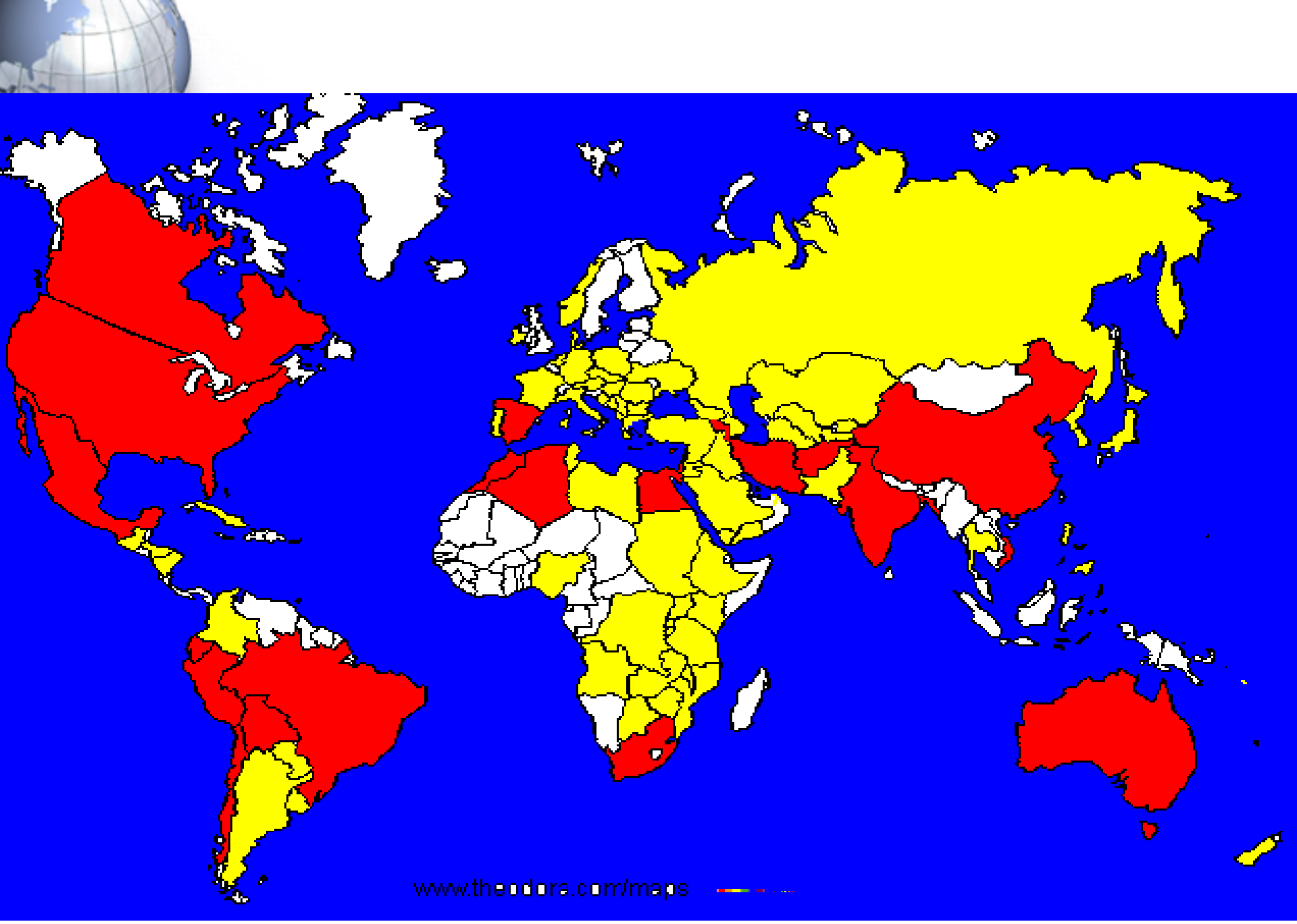
			FHB (Type I %)		
Population	Cross	No. Lines	Mean	Min	Max
1	LEGACY/4/TOCTE//GOB/HUMAI10/3/ATAH92/ALELI	110	3.34	0.13	16.93
2	LEGACY//PENCO/CHEVRON-BAR	130	2.82	0.26	8.48
3	LEGACY/3/SVANHALS-BAR/MSEL//AZAF/GOB24DH	110	5.01	0.64	14.56
4	LEGACY/5/ATACO/BERMEJO//HIGO/3/CLN-B/80.5138//GLORIA-BAR/COPAL/4/CHEVRON-BAR	80	4.23	1.04	12.46
5	LEGACY/CHAMICO	210	3.25	0.00	11.24
6	MERIT,B//CANELA/ZHEDAR#2	40	4.77	1.29	8.84
7	MERIT,B/4/GOB/HUMAI10//CANELA/3/ALELI	30	5.82	1.97	10.64
8	6B89.2027/4/TOCTE//GOB/HUMAI10/3/ATAH92/ALELI	10	10.28	5.47	17.93
9	6B89.2027/CHAMICO	50	3.33	0.00	13.07

- Lines that also show resistance to Yellow Rust, Scald, BYDV, Spot & Net Blotch, etc. and probably enhanced malting quality, in an attractive agronomic background

- Objectives are being reached

Program Highlights

ICARDA


www.theodora.com/maps

LARP - Highlights Barley Program

- **Other High Yielding germplasm:**
- **Australia**
  - **The University of Western Australia Report of the "Barley Improvement through germplasm Introduction, Evaluation and Enhancement" (Page 6):**
    - **The highest yielding lines from the earlier time of sowing were WABAR2332, T20559 and four CIMMYT/ICARDA lines. *The 20 highest yielding lines mainly came from CIMMYT/ICARDA*, which also produced very large grain."**
    - **"The *highest yielding lines from the later time of sowing were two CIMMYT/ICARDA lines* imported from Mexico (F.Cappettini)"**

ICARDA

Central Brazil

- Foram avaliados 60 materiais.

Tratamento	Rendimento (kg/ ha)	Class 1ª (%)	Proteína (%)
Desempenho Superior			
CMM 414	**11.830**	**61**	**10,6**
CMM 681	9.700	82	13,0
CMM 404	9.338	62	11,0
CMM 348	9.299	89	11,4
CMM 374	9.289	83	9,1
CMM 691	9.026	94	12,3
CMM 814	8.986	90	12,0
CMM 4	8.966	94	12,0
CMM 915	8.951	90	11,6
CMM 376	8.609	84	11,9
BRS 180	**5.556**	**84**	**9,8**
Desempenho Inferior			
CMM 304	**4.287**	**95**	**8,9**
CMM 936	**4.085**	**89**	**11,0**
CMM 696	**3.725**	**95**	**12,3**
CMM 1	**3.511**	**95**	**12,7**
CMM 678	**2.661**	**87**	**12,2**

Conclusions

- FHB breeding at the ICARDA Program is based on pyramiding different sources and testing a wide base of genetic resources
- Global network allows access to genetic diversity and multi-location testing (e.g. USWBSI, BARI, Agri Food Canada and NARs)
- Screening for different resistance types makes it possible to identify complementary parents
- Different programs make different use of the same germplasm and obtain different results

Future

- Continue collaboration with ARIs and use germplasm developed and research results to help developing countries
- Continue screening gene banks – not finished yet!
- Determine how different are the genes being used
- Introgress resistance into germplasm adapted to different countries
- More focus on molecular markers to accumulate resistance types and different genes/alleles - use of MAS (?)

Acknowledgements

- **ICARDA –** ***Hugo Vivar***, Jan Valkoun, Jan Konopka, Ken Street
- **CIMMYT** – ***Lucy Gilchrist***, **Etienne Duveiller, Monica Mezzalama,** Maarten van Ginkel, Tomohiro Ban, Janet Lewis, Javier Peña, Hans Braun, Jaime Segura, Francisco López, Vicente Morales, Bernardo Ramírez, Juan Ramírez, Ernesto López
- **USWBSI** – Sue Canty, Rick Ward, David van Sanford
- **Alberta Agriculture** – Jim Helm, Joseph Nyachiro, Pat Juskiw, Laura Leggott
- **BARI –** Les Wright, Linnea Skoglund, Blake Cooper
- **UMN** – Ruth Dill-Macky, Brian Steffenson, Kevin Smith, Ed Schiefelbein
- **NDSU** – Rich Horsley, Stephen Neate, Jerry Franckowiak, Paul Schwarz
- **Agriculture and Agri-Food Canada** – Bill Legge, James Tucker
- **Zhejiang University** – Bingxin Zhang
- **INIA Uruguay** – Silvia Pereyra, Silvia Germán, Juan Díaz
- **EMBRAPA Brazil** – Gerardo Arias, Euclydes Minella, Renato Amabile


Scab Team at CIMMYT
16 8 2006

Collaborative Research with Alberta Agriculture

Busch Agricultural Resources, Inc.

USWBSI Team at Toluca, México

Yunnan Province, China

PBI Sydney


Don Rasmusson
Flavio Capettini


Thank You!