Barley Breeding - Past, Present & Future

Reg Lance and Chengdao Li
Barley Breeding Australia - West

- Breeding
  - Reg Lance & Chengdao Li
- Molecular Breeding
  - Chengdao Li
- Doubled Haploids
  - Sue Broughton
- Quality
  - Allen Tarr & Stefan Harasymow
- Pathology
  - Sanjiv Gupta & Rob Loughman
- Abiotic Stress
  - Irene Waters
Barley Breeding Australia - West

• Whole of Supply Chain Approach:
  - Farmers
  - Marketers & Grain Handlers
  - Maltsters
  - Brewers
  - Consumers
• Role and responsibility of breeding node operation

• Target breeding objectives in terms of
  - Minimum disease standards
  - Expected improvement in yield (target)
  - Balance in activities between feed & malting variety development

• Update on progress in variety development with focus on lines either for commercial quality evaluation of scheduled for release within 3 years
“A productive, profitable and sustainable Australian barley industry supported by the release of commercially successful, targeted-to-market, elite malting and feed barley varieties developed through the Western Node of BBA.”
1) Barley varieties, advanced breeding lines and germplasm exhibiting improved agronomic performance, disease resistance, and abiotic stress tolerance and grain quality attributes, and targeted to malt and feed markets.
BBA-West: Outputs

2) An efficient and cost effective barley breeding program demonstrably addressing the needs of the target region/environment (West, and south east, medium to late maturity with neutral to acid soils), with effective stakeholder support, and operating collaboratively as a part of the BBA national barley breeding program.
Vic, NSW & Tas S3 lines 2006-09; A maximum of 30 entries and a minimum of 15 entries are to be submitted to the Western and Southern nodes, and max 15 min +/- 5 to the Northern node.

These materials are to be trialled at the same S3 trialling sites the nodes are using for trialling of their own S3 materials, using similar trial designs and plot sizes.

Selection decisions are to be based on the same criteria/weightings as used for the nodes' own S3 materials, including decisions regarding further quality evaluation.

Data is to be shared within BBA at the end of each crop season.
3) Develop and Implement a Communication Strategy
Australian Barley Production 1900 - 2007
Western Australian Barley Production 1900 - 2007

- Production (tonnes)
- Area (ha)

Year


Prodn (million tonnes)

0 0.5 1 1.5 2 2.5 3 3.5

Area (ha)

0 0.5 1 1.5 2 2.5 3 3.5
Western Australian Barley Yields
1900 - 2007

Yield (t/ha) vs. Area (ha)

Year

Yield (t/ha)

Area (ha)


0 0.5 1 1.5 2 2.5

0 0.5 1 1.5 2 2.5
World Barley Usage 2006/2007

- Barley crop in 2006/2007: 138.5 mln tonnes
- Usage for feed: 100.6 mln tonnes (73%)
- Usage for malting: 26.2 mln tonnes (19%)
- Usage for food: 8.5 mln tonnes (6%)

(c) e-malt.com, 2007
World Barley Imports
2006-2008
World Beer Production & Projections by Region: 1985 - 2004 (million hectolitres)

Growth = 2.7% / year
Chinese Beer Production & Projections:
1985 - 2004 (million hectolitres)

Growth = 4.7% / year
## World Malting Barley Exports by Country

<table>
<thead>
<tr>
<th>Year</th>
<th>Australia</th>
<th>Canada</th>
<th>EU</th>
<th>USA</th>
<th>Others</th>
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<td>2001/02</td>
<td>1.8</td>
<td>1.7</td>
<td>1.6</td>
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<td>2003/04</td>
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<td>0.8</td>
<td>&lt;0.1</td>
<td>0.1</td>
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<td>0.2</td>
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<td>0.1</td>
<td>1.33</td>
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<td>0.1</td>
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<td>2006/07</td>
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<td>0.1</td>
<td>1.6</td>
<td>0.3</td>
<td>0.4</td>
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<tr>
<td>2007/08</td>
<td>0.6</td>
<td>0.1</td>
<td>1.6</td>
<td>1.2</td>
<td>1.8</td>
</tr>
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</table>

*Note: The data is in million tonnes.*
World Malt Exports

2007: 4.43 mln tonnes
- EU: 40.0%
- Canada: 16.0%
- South America: 14.3%
- Australia: 13.4%
- China: 4.2%
- USA: 8.1%
- Others: 1.2%

2006: 4.12 mln tonnes
- EU: 50.8%
- Canada: 13.3%
- South America: 12.0%
- Australia: 13.9%
- China: 9.7%
- USA: 5.8%
- CIS: 2.3%
- Others: 1.3%
Major World Malting Barley Imports 1997-98 (million tonnes)

Source: GPWA Trade Estimates
World Malt Imports 2006-2008

World Malt Imports 2007-2008
World Malt Trade in 2007-2008: 4.59 mln tonnes

Other 35.3%
EU 3.4%
Vietnam 4.2%
Russia 3.0%
Thailand 5.0%
Brazil 17.2%

World Malt Imports 2006-2007
World Malt Trade in 2006-2007: 4.56 mln tonnes

Other 34.8%
EU 3.2%
Vietnam 4.0%
Russia 3.4%
Thailand 5.3%
Brazil 17.1%
Japan 11.3%
Venezuela 9.7%
USA 6.3%
Mexico 5.0%
Venezuela 10.0%
USA 6.1%
Mexico 4.8%

(C) MALT.COM, 2007
Production & Disposal of Australian Barley: (1996-2007)

Production & Disposal of Australian Barley: (1996-2007)

Sources: ABS & ABARE
Disposal of Australian Barley Domestic: (1996-2007)

Sources: ABS & ABARE
Disposal of Australian Barley Export: (1996-2007)

Sources: ABS & ABARE
Australia Malt Exports

Australia Malt Exports by country of destination in 2005
In 2005 Australia exported 490,000 tonnes of malt.

- Vietnam: 22.9%
- Japan: 20.0%
- Korea: 20.0%
- Philippines: 14.3%
- Thailand: 9.8%
- Others: 13.1%

Copyright (c) E-Malt.com, 2006
Major Importers of Barley and Malt from Western Australia
Figure 4.5 Modelled topsoil pH.

Source: Australian Soil Resources Information System.
National Land and Water Resources Audit 2009
Data used are assumed to be correct as received from the data suppliers.
BBA-West: Regional Responsibilities

Breeding targets based on barley production (tonne per square km)

- More than 10
- 2 to 10
- 0.5 to 2

Source: Bureau Statistics 1996
Agricultural Census data
UWA-Plant Production Systems Workshop

SR Stage 2/3 Longer Season Neutral - Acidity

Cressy RS & SC, BYDV

Wagga Wagga & Scald Nursery

BBA-West: Neutral-Acid Soils, Longer Season, High Rainfall

Tunbridge

Mt Pleasant Labs BYDV, BNDTAS

USyd-Cobbitty LR Nursery

Colbinabbin

VIDA-Horsham BGYR & SNB

Wonwondah

Hamilton

Teesdale

Streatham

Brocklesby

Rutherglen

Hamilton

USyd-Cobbitty LR Nursery

Yanco

Jerilderie

Wagga Wagga & Scald Nursery

USyd-Cobbitty LR Nursery

Tunbridge

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BBA-West : Background

- WA & ES ... “neutral to acid soils”
  - WA - export orientated
  - ES - domestic and export

- Minimum Disease Standards
  - as appropriate

- Yield Improvement
  - Western Region : 2% per year
  - Southern Region : 1-1.5% per year

- Malt 80%; Feed 20%
BBA - West
Key Program Achievements

- Scope of nodes & realigning operations
  - BBA-West ⇒ “neutral to acid soils”
  - WA & longer season, higher rainfall southern NSW, SW- & NE Vic and Tasmania
- NSW, Vic & Tasmania “phase-out” breeding and “phase-in” pre-breeding
  - promotion of stage 2, 3 & 4 on merit
  - stage 3 & 4 trials run by BBA nodes to enable “optimum opportunity” for advanced lines
BBA-West Program

Germplasm Introduction & Evaluation

Doubled Haploids

Pathology

Breeding & Selection

Grain Products Laboratory

Crop Variety Testing

Commercial Evaluation

Improved Malting Varieties

Marker Assisted Selection

Single Seed Descent

Agronomy / Crop Physiology
### DAFWA Breeding Methods (Based on "F2 Progeny" method)

<table>
<thead>
<tr>
<th>Year</th>
<th>Generation</th>
<th>Traits</th>
<th>Technologies</th>
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<tbody>
<tr>
<td>0</td>
<td>G/H</td>
<td>P1 x P2</td>
<td></td>
</tr>
<tr>
<td>0 S</td>
<td>G/H</td>
<td>F1</td>
<td></td>
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<tr>
<td>1</td>
<td>Spaced plants</td>
<td>F2</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>S1, (1-0)</td>
<td>F2/3</td>
<td>A Y Q (D)</td>
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<tr>
<td>3</td>
<td>Stage 1-1</td>
<td>F2/4</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>4</td>
<td>Stage 1-2</td>
<td>F2/5</td>
<td>A Y D</td>
</tr>
<tr>
<td>5</td>
<td>S2, (2-0)</td>
<td>F5/6</td>
<td>A Q</td>
</tr>
<tr>
<td>6</td>
<td>Stage 2-1</td>
<td>F5/7</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>7</td>
<td>Stage 2-2</td>
<td>F5/8</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>8</td>
<td>Stage 3-1</td>
<td>F5/9</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>9</td>
<td>Stage 4-1</td>
<td>F5/10</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>10</td>
<td>Stage 4-2</td>
<td>F5/11</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>11</td>
<td>Release</td>
<td>F5/12</td>
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</table>

A = Agronomic, Y = Yield, Q = Quality, D = Disease
## DAWA Breeding Method
(Based on “F₂ Progeny” method)

<table>
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<th>Year</th>
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<th>Field Program Entries</th>
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<td>P₁ x P₂</td>
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<td>0 S</td>
<td>G/H</td>
<td>F₁</td>
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<td>1</td>
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<td>2</td>
<td>S₁, (1-0)</td>
<td>F₂/₃</td>
<td>A(Y)Q(D)</td>
</tr>
<tr>
<td>3</td>
<td>Stage 1-1</td>
<td>F₂/₄</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>4</td>
<td>Stage 1-2</td>
<td>F₂/₅</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>5</td>
<td>S₂, (2-0)</td>
<td>F₅/₆</td>
<td>A(Y)Q(D)</td>
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<td>6</td>
<td>Stage 2-1</td>
<td>F₅/₇</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>7</td>
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<td>F₅/₈</td>
<td>A Y Q D</td>
</tr>
<tr>
<td>8</td>
<td>Stage 3-1</td>
<td>F₅/₉</td>
<td>A Y Q D</td>
</tr>
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<td>9</td>
<td>Stage 4-1</td>
<td>F₅/₁₀</td>
<td>A Y Q D</td>
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</tr>
<tr>
<td>11</td>
<td>Release</td>
<td>F₅/₁₂</td>
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</tr>
</tbody>
</table>

A = Agronomic, Y = Yield, Q = Quality, D = Disease
Barley Breeding Objectives
Agronomic Performance

- **Increased Production Efficiency**
  - yield, adaptation
  - shattering, lodging resistance
  - stiff straw, semi-dwarf

- **Resistance to Environmental Stresses**
  - mineral nutrient stress: Al, B, Mn, Zn, Cu
  - acid soils, alkaline soils
  - salinity, waterlogging,
  - moisture stress
  - heat, cold, frost
Pathology
Prominent Diseases
Pathology Aims

• Pathology support to barley breeding
• Phenotyping resistances for genetic studies
• Marker-trait linkages and validation
• Disease management (K. Jayasena and Rob Loughman)
1. Pathology Support to Breeding

Type of material

- Introductions
- Current barley varieties
- Early generation material
- Advanced lines
- Interstate elite barley lines
- Segregating Populations
- Differential / Near-isogenic lines
### Australian Standard Barley Grain Specifications

<table>
<thead>
<tr>
<th>Grain Quality Trait</th>
<th>Level</th>
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<tbody>
<tr>
<td>Plump barley above 2.5mm</td>
<td>88 % min</td>
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<tr>
<td>Screening below 2.2mm</td>
<td>4 % max</td>
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<tr>
<td>1000 Kernel weight</td>
<td>40 grams min</td>
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<tr>
<td>Test weight</td>
<td>70.0 kg/hl</td>
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Analytical methods as per ‘Analytica EBC’
Source: e-malt.com
## Malt Standard Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>2 Row Spring</th>
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<tbody>
<tr>
<td>Extract fine grind/dry malt</td>
<td>&gt; 80.5%</td>
</tr>
<tr>
<td>Extract dif. fine-coarse</td>
<td>1.0 - 2.5%</td>
</tr>
<tr>
<td>Wort colour in EBC</td>
<td>2.5 - 4.0</td>
</tr>
<tr>
<td>Post colouration</td>
<td>5.0 - 7.0</td>
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<tr>
<td>Total nitrogen on dry malt</td>
<td>&lt; 11.5%</td>
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<tr>
<td>Soluble protein</td>
<td>4.0 - 4.7%</td>
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<tr>
<td>Kolbach Index</td>
<td>36 - 45</td>
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<tr>
<td>Viscosity</td>
<td>&lt; 1.58 cp</td>
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<tr>
<td>Diastatic Power</td>
<td>250 min</td>
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<tr>
<td>FAN (mg/100g)</td>
<td>140 min</td>
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<tr>
<td>Soluble glucan</td>
<td>200 max</td>
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Analytical methods as per ‘Analytica EBC’

Source: e-malt.com
# QUALITY ASSESSMENT PROTOCOL

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<th>F12</th>
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<td>2-1</td>
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<td>1 Barley grain quality tests</td>
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<td>10 Industry approval</td>
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</table>
Integration of Biotechnologies

• Increase rate of genetic gain
• Improve selection efficiencies
• Reduce cycle time
  - time from primary cross to second cycle cross
• Reduce time to release new varieties
Barley Doubled Haploids

Key activities

1. Production of DH for breeding and special purpose crosses (eg. genetic mapping, and research)

2. Bulking seed of DH lines prior to lines entering field trials and includes;
   - DH lines rated for flowering & plant height
   - DH lines sub-sampled for long term storage and molecular marker testing
Doubled Haploids - Fixed Lines, Fast

Parents: AABB x aabb

$F_1$ (hybrid): AaBb

Haploid gametes, e.g. pollen cells

Doubled Haploids

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>b</th>
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<tr>
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<td>Ab</td>
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<td>a</td>
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<td>ab</td>
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$\downarrow$

Chromosome doubling

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<td>aB</td>
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<tr>
<td>ab</td>
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</tbody>
</table>
Conventional Vs DH Breeding

Conventional Breeding

Crossing to generate F1 (hybrid) seed

Doubled Haploids

Doubled haploid production takes less than 12 months

Year
1
2
3
4
5
6
7
8
9
10
11
12

F1
F2
F3
F4
F5
F6
F7
F8
F9
F10
F11
F12

1 2 3 4 5 6 7 8 9

Early generation crossbred lines
Single plant re-selections
Yield tests of homozygous lines
Wide-scale evaluation in Crop Variety Testing Program
Variety release

Year
1
2
3
4
5
6
7
8
9
One of the biggest changes has been the increase in pre- and post screening donors and regenerant plants for a range of disease, quality and agronomic traits;

AL - Aluminium/acid soil tolerance
B-amy - thermostable B-amylase
BVP - basic vegetative period
BYDV - Barley Yellow Dwarf Virus
CCN - Cereal Cyst Nematode
EXT - malt extract
Frost tolerance
LR - leaf rust

NTNB - net type net blotch
PHS - pre-harvest sprouting
PM (mlo) - powdery mildew
PPD - photoperiod
PPO - polyphenol oxidase
Seed dormancy
SC - scald, SDW - semi dwarf
STNB - spot type net blotch
Barley DH Production in WA

- DHs have been used in the WA barley breeding program since 1993 - over 30,000 DH lines produced.

- Now comprise about 25-30% of the total breeding program and advanced DH lines are undergoing commercial malting/brewing evaluation prior to possible release.

- Anther culture was the main method of production from 1993-1998. In 1999 we began evaluating potentially more productive methods, such as microspore culture. Currently, both methods are used.
DH program in 2007-08

- Production target increased to 7,250 DH with crosses destined for WA and NSW
- Aim to send plants to NSW in vitro and will commence with a small number in 2007 (~ 1,000 plants) increasing in 2008 to > 2,000
Marker Assisted Selection and Doubled-Haploids

\[ P_1 \times P_2 \]
\[ AA \xrightarrow{\text{F}_1} \text{(MAS) DH} \]
\[ F_1 \times P_2 \]
\[ AA : aa \]
\[ F_2 \]
\[ AA : Aa : aa \]
\[ \text{BC}_1 \text{F}_1 \text{ (MAS)} \]
\[ AA : a \times AA : a \]
\[ \text{DH (MAS)} \]
\[ AA : aa \]
\[ \text{All AA} \text{ or AA : aa} \]
\[ \text{DH (MAS)} \]
\[ AA : aa \]
\[ \text{All AA} \text{ or AA : aa} \]
Implementation of molecular markers

- Acid soil/Al tolerance
- Basic vegetative period
- Loose smut
- Beta-amylase (Bamy1)
- Boron toxicity tolerance
- BYDV
- CCN
- DP
- Malt extract
- Kernel discoloration
- Frost tolerance

- Leaf rust (Rph3)
- Leaf rust (Rph7)
- Net type net blotch
- Powdery mildew (mlo9 & 11)
- Powdery mildew (Mla)
- Pre-harvest sprouting
- Spot type net blotch
- Stripe rust
- Scald
- Photoperiod response
- BVP
- Vrn
### Barley Breeding: Targeted Enhancement

<table>
<thead>
<tr>
<th>Variety/Line</th>
<th>Scald</th>
<th>PM</th>
<th>NNB</th>
<th>SNB</th>
<th>LR</th>
<th>YR</th>
<th>Bmy1</th>
<th>PHS</th>
<th>Al/pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamelin</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓/a</td>
<td>✓</td>
</tr>
<tr>
<td>Gairdner</td>
<td>✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓/a</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Baudin</td>
<td>✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓</td>
<td>✓✓/a</td>
<td>✓</td>
<td>✓✓</td>
</tr>
<tr>
<td>Vlamingh</td>
<td>✓✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓✓/a</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Legend:
- ✓: Resistant
- ✓✓: Moderately resistant
- ✓✓✓: Susceptible
Farming Issues - Abiotic Stress!

Figure 8.19 Proportion of grain farms surveyed that reported significant degradation (1998/99).

- Soil acidity
- Water erosion
- Wind erosion
- Dryland salinity
- Irrigation salinity
- Dryland or irrigation salinity
- Soil acidity
- Loss of soil structure
- Surface waterlogging
- Weeds resulting in degradation

Atlas Australian Resources
Major Abiotic Issues for Barley Breeding Program

- Soil Acidity
  - pH/Al tolerant varieties
- Loss of Soil Structure and Wind Erosion
  - Zero or Minimum tillage
  - Higher organic matter
- Weather Damage
  - Pre-Harvest Sprouting
  - Kernel Discolouration
Major Abiotic Issues for Barley Breeding Program

- Waterlogging
  - Tolerant varieties
- Weed competition
  - Plant architecture (tall dwarfs!)
  - Herbicide tolerance
- Salinity
  - Tolerant varieties
Area Sown to Barley Cultivars in WA: 1991

- Stirling: 82%
- O'Connor: 6%
- Onslow: 3%
- Others: 8%
- Skiff: 1%
Area Sown to Barley Cultivars in WA: 2006

- Gairdner: 23.5%
- Baudin: 20.7%
- Mundah: 10.2%
- Hamelin: 7.4%
- Stirling: 26.8%
Program Outputs: Gairdner -1997

Summary:

- “General Malting”
- Adapted to high rainfall Southern Coastal areas
- Yields similar to Onslow
- Short stiff straw
- Excellent lodging resistance
- Similar maturity to Onslow
- Better 1000 grain wt. c.f. Fitzgerald
- BYDV resistant
Program Outputs: Hamelin - Summary

Features:

- “General Malting”
- Pedigree - Stirling/Harrington
- High malting quality; superior to Stirling
- Plump grain shape & high grain weight
- Brighter grain than Stirling
- Moderate risk of pre-harvest sprouting; same as Harrington
Program Outputs: Hamelin - Summary

Features:

- Out yields Stirling by 4%
- Slightly shorter in height and slightly less prone to lodging than Stirling
- Similar plant appearance, phenology and response to agronomy as Stirling
- Wide regional adaptation
- Similar disease susceptibility as Stirling
Program Outputs: Baudin - Summary

Features:
- “General Malting”
- Pedigree - Stirling/Franklin
- Excellent malting quality; superior to Gairdner and Stirling
- Plumper grain than Gairdner
- Low risk of pre-harvest sprouting
Program Outputs: Vlamingh - Summary

Features:

- “General Malting”
- High yield potential
- Wide adaptation - good adaptation to all Agzones with exception of Agzone 4 and parts of Agzone 5
- Strong straw, good head retention and excellent standing ability
- Good grain quality
- Moderate resistance to scald but susceptible to mildew
High yielding, plump grained, 2-row spring feed barleys

- **LOCKYER A (WABAR2288)**
  Medium - late maturity

- **ROE A (WABAR2310)**
  Early maturity

- **HANNAN A (WABAR2321)**
  Early - medium maturity
  Undergoing testing for ‘Domestic Malting’
Lockyer A - (WABAR2288)

- Medium - late spring maturity
  - Similar phenology to Vlamingh A
- Moderately plump grain
- High yield potential
- Wide adaptation
  - Competitive in Agzones 3, 5 and 6
- Intermediate resistance to scald, net-type net blotch and powdery mildew
- Good straw strength, standing ability and head retention
Roe A - (WABAR2310)

- Early maturity
  - Similar phenology to Mundah A
  - Relatively earlier flowering with May sowing
- High yield potential
- Wide adaptation
  - Competitive for all Agzones except Agzone 6
- Plump grain shape
- Intermediate resistance to powdery mildew
- Good straw strength, standing ability and head retention
Hannan A - (WABAR2321)

- Early - medium maturity
  - Similar phenology to Stirling and Hamelin A
- Competitive in all Agzones
  - High yield potential
  - Wide adaptation
- Plump grain
- Moderately resistant to scald
- Undergoing testing for “Domestic Malting”
Superior Varieties
BBA-West

• WABAR2315
  - mid - late maturing, high yielding malting

• WABAR2481
  - acid soil/Al tolerant Hamelin

• WABAR2474
  - acid soil/Al tolerant Baudin

• WABAR2385
  - early maturing, higher yielding, plumper
    “Harrington”
BBA-West : Outputs

- Acid soil tolerant Baudin - WABAR2478
- Acid soil tolerant Hamelin - WABAR2481
Recurrent Introgression for Population Enrichment (RIPE)

After Prof. Duane Falk

- Cultivars
- Introductions
- Elite
  - msg
  - msg
  - msg
- High
  - 87.5%
- Intermediate
  - 75%
- Base
  - 50%
Male Sterile Genetic (\(\text{Msg}6/\text{msg}6\))
Orange Lemma (\(O/o\))
Shrunken Endosperm Xenia (\(\text{Sex}1/\text{sex}1\))

\[
\begin{align*}
\text{MsgMsg-OO-SexSex} & \quad \text{x} \quad \text{msgmsg-oo-sexsex} \\
(\text{male fertile - normal lemma - plump}) & \quad (\text{male sterile - orange lemma - shrunken})
\end{align*}
\]

\[
\begin{align*}
\text{F}_1 & \quad \text{Msgmsg-Oo-Sexsex} \\
(\text{male fertile - normal lemma - plump})
\end{align*}
\]

Self

\[
\begin{align*}
\text{F}_2 & \quad \text{MsgMsg-OO-SexSex} \quad \text{Msgmsg-Oo-Sexsex} \quad \text{msgmsg-oo-sexsex} \\
1 & : \quad 2 \quad : \quad 1
\end{align*}
\]

[Falk et al. 1981]
Elite MSFRS Populations and Parents

- **Early Maturing**
  - WABAR 2094
  - WABAR 2096
  - Hamelin
  - WABAR 2110
  - Baudin
  - Vlamingh

- **Late Maturing**
  - Fitzgerald
  - Gairdner
  - WABAR 2147
  - WABAR 2242
  - Baudin
  - Vlamingh
Barley Yield Potential - Current

current potential barley yield based on:
RAINFALL & TEMPERATURE

Prepared using
*Department of Agriculture's
map unit database
*Department of Meteorology
climate surfaces
*CSIRO Orch 2.01 Beta
*SCS model
scenario A2, CSIRO Mk2
*Modified Penman and Schulz
equation and crop temperature
criteria
Prepared for Ian Kinnimonth -
Climate Change Project.
Prepared by Dennis van Goor
March 2005
Barley Yield Potential - 2050

2050 potential barley yield based on: RAINFALL & TEMPERATURE

Prepared using:
*Department of Agriculture's map unit database
* Bureau of Meteorology climate surfaces
* CSIRO Decem 2.01 atlas of long term weather normals
* CSIRO Mc2 climate model
* Modified Penman-Monteith equation for crop temperature criteria

Prepared for Ian Keimonth, Climate Change Project
Prepared by Dennis van Gool
March 2005
barley yield change
(when > 1021 kg/ha)
Barley Industry : Future

- Barley Industry in Australia has a “Bullish” future
  - Challenges :
    - yield and adaptation
    - quality to meet better defined markets
    - multiple disease resistance pyramiding
    - abiotic stress tolerance
Barley Industry: Future

- Climate Change
  - Drier, hotter, “high frost incidence”, more variable seasons: “break” and “finish”
  - Better; crop production, quality, disease prediction
  - Rural Industries restructure: move to production regions which are currently smaller holdings with “intensive grazing & livestock”
Barley Breeding : Future

- Deregulation of markets
  - market size & specifications
- Barley Breeding Australia continuation
- “Privatisation” of Public Barley Breeding
- International collaborations
- Pre-breeding and interactions with breeding programs