

Project Report No. 472

September 2010

£9.00

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By

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This is the final report (Project RD-2005-3229) of the twenty-four month project that started in April 2008. The work was funded by a contract from HGCA (£25,000) and the Welsh Assembly Government (£86,733) through the Supply Chains Efficiencies Scheme (part of the Rural Development plan for Wales).

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ABBREVIATIONS

AMMI	Additive Main effects and Multiplicative Interaction
BG	β -glucan
DM	Dry matter
GS	Growth stage
HFN	Hagberg Falling Number
ICARDA	International Center for Agricultural Research in the Dry Areas
IBERS	Institute of Biological, Environmental and Rural Sciences, Aberystwyth University
N	Nitrogen
n	Number
nd	No data available
NS	Not significant
PC/PCA	Principal component/ Principal Components Analysis
PGR	Plant growth regulator
QTL	Quantitative trait locus
SENRGY	School of the Environment, Natural Resources and Geography, Bangor University
SpWt	Specific weight

ACKNOWLEDGEMENTS

The authors would like to thank: Karl-Josef Mueller (Cereal Breeding Research, Darzau, Germany), William Handley (HGCA), Mike Ambrose (John Innes Centre) and Simon Phillips (Syngenta New Farm Crops) for provision of barley samples; Llinos Hughes and Mark Hughes for field and glasshouse technical support; Ian Harris, Farm Manager at Henfaes Research Centre; Debbie Evans for the β -glucan testing; M.D. Keerio for laboratory and glasshouse assistance, The four farmers who grew crops of Lawina; Glanmor Thomas (IBERS) for seed cleaning and testing; Julian Wiseman (Nottingham University) for amino acid testing; Gareth Edwards-Jones (SENRGY) and Simon Hook (HGCA) for helpful advice and guidance throughout the project.

1. ABSTRACT

Under-utilisation of barley as a human food in the UK is potentially a missed opportunity for public health as components of barley grain, especially β -glucan soluble fibre, have the proven ability to ameliorate diet-related health problems, including obesity, type-2 diabetes and high cholesterol. The development of a health food market for barley could also benefit UK barley growers. All current UK barley varieties have covered grain and the hull must be removed by pearling to render the grain edible. Pearling also removes the nutritious bran and germ. Naked barley grains thresh freely from the *pales* (that form the hull) so that the whole grain can be used without processing.

This project evaluated the agronomic and grain quality characteristics of a collection of exotic naked barley varieties under field conditions in Wales over two years, and compared them with those of UK hulled varieties. Spring and autumn sowing were compared and grain β -glucan and amino acid content were measured. As a test of the potential to breed UK-adapted naked barley, selected naked lines from a cross between a conventional UK hulled and exotic naked barley were assessed for agronomic properties.

Many of the exotic naked barley varieties had high levels of foliar disease and lodging and only a limited yield response to fungicide. Conversely naked grain lines with modern UK parentage had stiff straw and good resistance to disease. The only agronomic problem specific to the naked grain trait was poorer crop establishment, due to the vulnerability of the exposed embryo to damage during harvesting, and to weaker coleoptile growth. Solutions for this are to ensure careful harvesting and handling of seed crops (e.g. reduce combine drum speed to 600-700rpm) and to delay sowing of spring varieties to ensure a warm seedbed. However, some naked Himalayan varieties, and progeny from Himalayan x UK crosses, had excellent seedling vigour, indicating that careful crossing and selection for early vigour may resolve establishment problems in future. There was wide variation in β -glucan concentration between genotypes (3.0 - 7.0g/100g DM), but also considerable variation between environments.

Lawina, a released German naked variety, was grown by four farmers to assess its possible use in a supply chain for food manufacturers. It showed a consistently low yield and failed to give a substantial yield response to fungicide, so the project concluded that it is not suitable for UK cultivation. Better-adapted varieties must be developed. Processors developed and evaluated a range of products (including speciality breads, flours and flakes) made from Lawina grain. Responses from the public to these were positive, indicating that there may be a viable market for UK naked barley.

2. SUMMARY

2.1. Background and objectives

Naked barley differs from covered barley in that the grains thresh freely from the outer covers of the flower, known as the *pales*. All current UK barley varieties are of the covered type, where the *pales* are tightly cemented to the grain and must be removed by pearling to render them edible for humans. No varieties of naked barley have been bred for UK conditions and food use, although naked barley has been grown in Asia for thousands of years. Asian varieties may possess variation for food and health traits that have been eliminated from European barley by selective breeding for malting quality. Exotic (including European) naked barley varieties are not well adapted to UK conditions. The German variety Lawina was identified in previous work as being the most appropriate for testing on a larger scale and with farmers, due to its good performance with food processors and being a variety released in a neighbouring European country.

The main aim of this project was to evaluate available exotic naked barley varieties alongside UK hulled varieties to identify agronomic requirements, develop a supply chain and produce best-practice agronomic guidance for the crop. A further aim was to identify pre-breeding material, lines and strategies for developing varieties better adapted to the UK climate.

The objectives of the trials were: i) to determine whether naked barley differs from covered barley in its agronomic management requirements; ii) to assess if it was viable to grow the available continental naked barley varieties in the UK climate; iii) to act as a pre-breeding screen to evaluate the usefulness of exotic varieties, including those from the Himalayas and Japan, as parents for crossing with UK covered varieties to introduce new variation into the UK barley gene pool; and iv) to give a better understanding of how genotype and environment interact to determine grain β -glucan content.

2.2. Materials and Methods

Replicated field trials were conducted at Bangor University's Henfaes Research Centre in North Wales during the 2008 and 2009 growing seasons. Varieties used were: the German naked barley varieties Lawina and Taiga; the covered UK control varieties, Cocktail, Optic, Static and Tipple; 26 naked lines from the breeder of Lawina, Cereal Breeding Research Darzau; three naked six-row semi-dwarf varieties bred by ICARDA, Aleppo, Syria; Koean, Himalayan and Japanese accessions from the John Innes Centre, Norwich. A small number of crosses were made between UK hulled and exotic naked varieties, and 21 selected lines were tested in 2009.

In order to assess the disease resistance of the different varieties all trials in 2008 were not treated with fungicides. In 2009, a fungicide programme based around triazole and strobilurin chemistry was used alongside untreated controls. Trials in 2008 showed that poor establishment and lodging were potential causes of loss of yield so that in 2009, a factorial experiment was carried out using Lawina sown at four seed rates, treated with trinexopac-ethyl (Moddus) PGR or untreated.

Laboratory tests were conducted for seed germination rate prior to sowing. Grain β -glucan content was measured with a standard Megazyme protocol.

2.3. Results and Discussion

2.3.1. Germination and establishment of naked barley

Germination percentages of naked barley were usually lower than those of covered barley varieties, possibly due to vulnerability of the exposed embryo to mechanical damage during harvesting. Increasing combine drum speed at harvest from 800rpm to 1200rpm decreased germination rate of Lawina from 95% to 85%.

Naked barley varieties consistently had lower establishment, compared to hulled barley, even when seed rates were increased to compensate for lower germination. Typically, only 80 plants were established for every 100 viable seeds sown. Many

naked barley accessions had poor seedling vigour and weak coleoptile growth. Overall establishment rates were better in 2009 than in 2008 (Figure S1). This is likely to be due to the combined effect of very wet conditions prior to harvest in 2007 followed by a cold seed bed during spring sowing in 2008.

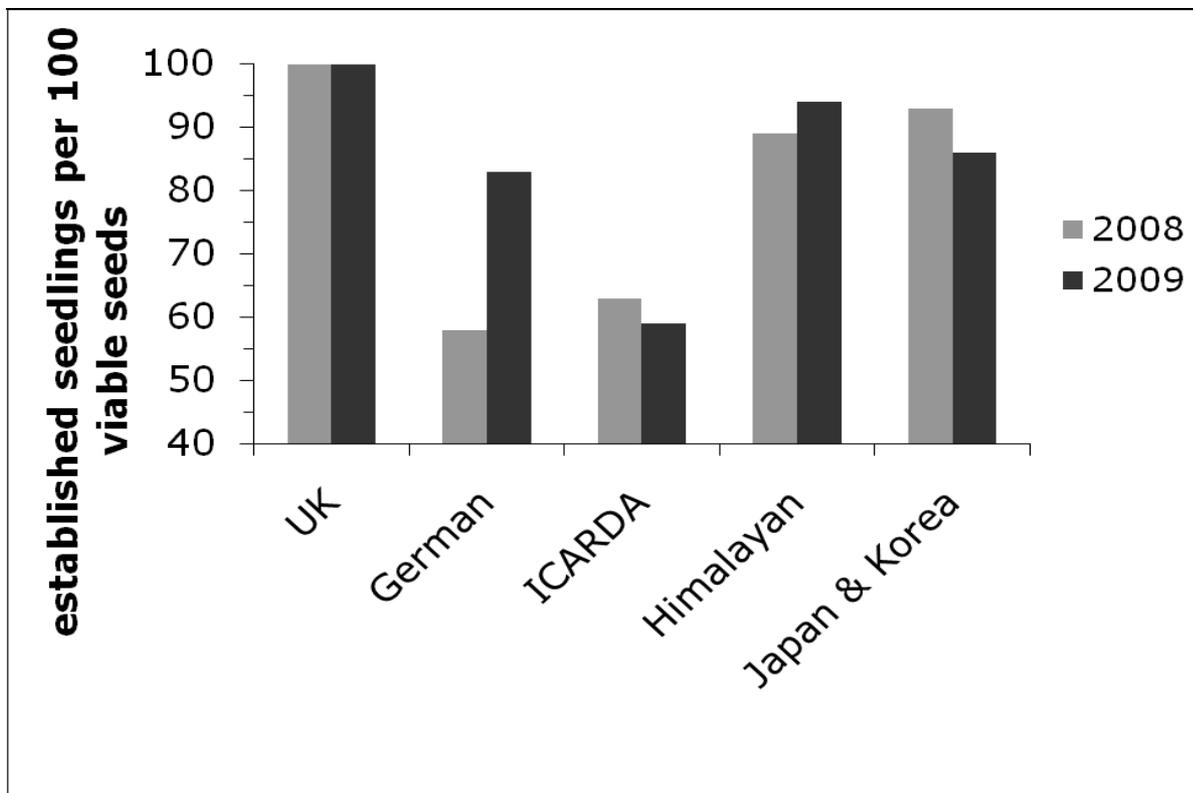


Figure S1. Establishment of spring barley varieties in 2008 and 2009. 'UK' are all covered-grain varieties (n = 4); 'German' are all naked-grain varieties (n = 28), 'ICARDA' are 6-row semi-dwarf naked varieties (n = 3); 'Himalayan' (n=13) and 'Japan & Korea' (n = 11) are naked-grain landrace varieties.

Although it was not formally tested under field conditions, the standard spring barley seed dressing Raxil-Pro (containing prothioconazole, tebuconazole and triazoxide) decreased laboratory germination of naked barley. It is strongly recommended not to use seed treatment of any kind on naked barley until further research is done.

2.3.2. Agronomy of naked barley under UK conditions

Yields of all varieties of naked barley were very low in the wet summer of 2008, illustrating their lack of adaptation to the wet UK climate and problems with disease and lodging. Yields were higher in 2009 (Figure S2, Table S1). The non-UK-adapted lines had a substantial yield penalty due to their poor agronomic characteristics, for example poor resistance to disease and lodging. However, it is not simply a case of comparing covered with naked varieties. The importance of modern agronomic traits to current UK cultivation was illustrated by the low yields of Haidd Enlli, a covered variety that lacks modern traits. In addition, naked barley usually yields around 15% less than otherwise equivalent covered barley as the weight of the hull is excluded from the yield.

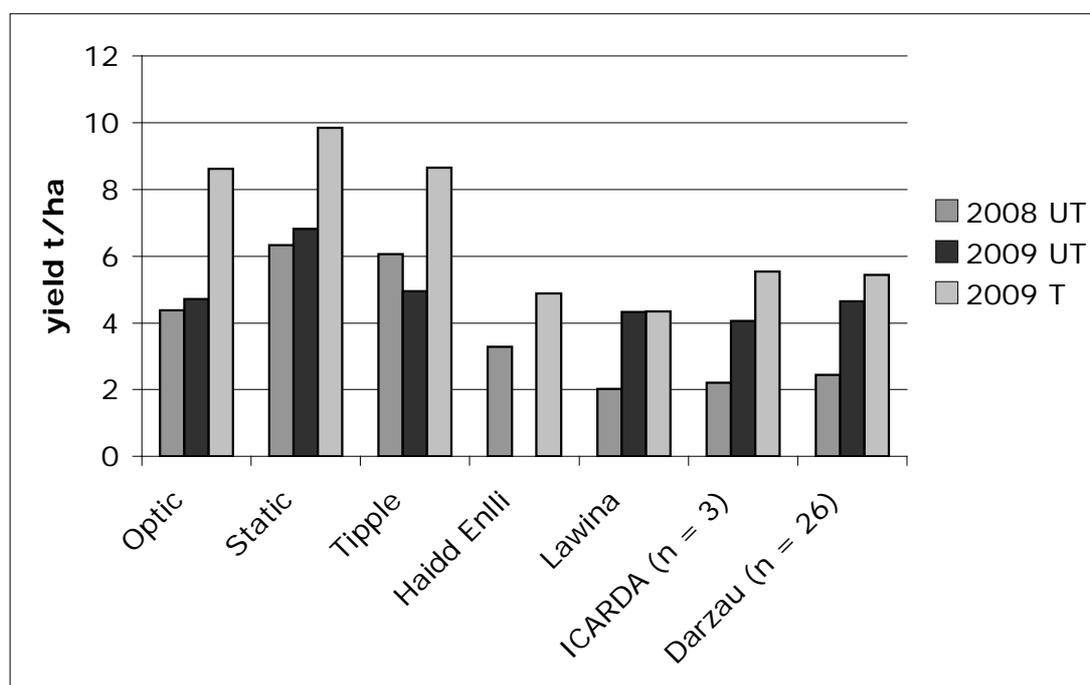


Figure S2. Grain yields of selected varieties and mean grain yields of the Darzau and ICARDA naked barley lines. Plots were untreated (UT) in 2008: and fungicide treated (T) or untreated (UT) in 2009.

Many naked barley accessions were very susceptible to powdery mildew (*Blumeria graminis*). It is likely that they lack the resistance genes found in modern UK varieties. Rhynchosporium (*Rhynchosporium secalis*) and brown rust (*Puccinia hordei*) infected both covered and naked barley types. The naked six-row 93.747, bred by

ICARDA, showed the lowest level of infection by *Rhynchosporium* of any of the accessions tested.

Use of fungicides increased yield and specific weight and decreased brackling in most naked barley lines and covered UK control varieties, although it increased lodging in many of the tall, non-UK-adapted lines.

An experiment to test the effects of seed rate and PGR on Lawina showed that Moddus (trinexapac-ethyl) significantly reduced straw length by 6cm and increased ear number, grain yield and specific weight.

There was wide variation in β -glucan concentration between genotypes (Last column in Table S1), but also considerable variation between environments. There was no evidence to support β -glucan concentration being diluted by higher grain yields, contrary to the situation for grain protein concentration. Foliar fungicide generally decreased β -glucan concentration, although in some accessions there was an increase. Sequential harvesting showed that grain β -glucan concentration increased initially as the grain matured, then decreased rapidly due to weather damage and sprouting, suggesting an optimum harvest window to ensure maximum β -glucan concentration.

2.3.3 Pre-breeding screening of 'exotic' germplasm and progeny of crosses between UK hulled and exotic naked types

Many of the Himalayan accessions showed much greater seedling vigour and stronger coleoptile growth. This translated into higher rates of crop establishment, typically 90 plants for every 100 viable seeds sown. Naked grain lines derived from Himalayan parentage appeared to retain this vigour, suggesting that it may be possible to overcome the establishment problems of naked barley by selective breeding.

Many of the non-UK-adapted naked barleys were very susceptible to lodging. Himalayan lines had very weak straw and Japanese and Korean lines were susceptible to root lodging. When Japanese and Korean lines were sown in autumn the plants were taller but there was no lodging, probably as a result of stronger crown root growth over the longer season.

Himalayan lines are adapted to the short growing season at high altitude by having a very short vegetative development phase and producing very few tillers, so that in these trials they could not take advantage of the longer UK growing season and hence had low grain yields. However, naked lines derived from crosses with stiff-strawed UK varieties such as Static and Tipple were resistant to lodging and had higher grain yield than Lawina.

Table S1. Summary of agronomic traits and β -glucan content of hulled and naked varieties tested in 2009 spring-sown trials. Disease assessment was made at GS 61, and uses the key for NL trials. Data for the Darzau (German) and ICARDA (Syrian) lines are either means of all varieties or the range of all varieties. Haidd Enlli was only grown with fungicide treatment and Line 15 (a naked line derived from a cross between Static (UK hulled) and a naked variety from Pakistan) was only grown with no fungicide treatment (nd = no data).

Variety	Covered (C) or Naked (N)	Ear emergence (days +/- Static)	Mildew (1 = no infection, 9 = dead)	Rhynchosporium (1 = no infection, 9 = dead)	Lodging (%)	Treated Specific Weight (kg/hl)	Untreated Specific Weight (kg/hl)	B-glucan (g/100g dry matter)
Optic	C	+3	8	8	3	60.8	47.5	4.0
Static	C	0	1	8	0	57.7	53.3	4.9
Tipple	C	+3	1	8	0	57.2	51	3.9
Haidd Enlli	C	0	nd-	nd	100	63	nd	5.4
Lawina	N	+3	7	6	5	73.4	73.4	5.4
ICARDA (n = 3)	N	-2	8	2-4	20	69.4	70.9	3.0 - 7.0
Darzau (n = 26)	N	-3 to +3	1-8	2-8	60	70.7	72.7	3.0 - 6.2
Line 15	N	+1	1	4	0	nd	70.3	5.0

2.3.4 Prospects for barley as a functional food

Awareness amongst farmers, processors and consumers of the potential of naked barley has increased during this project. Bread made from a mixture of naked barley and wheat flour by a bakery based near Bangor has sold very well and won second place in the national 'True Taste of Wales' competition in 2009. Any future development of a supply chain depends on the development of UK-adapted varieties. Breeding priorities must focus on maximising the health benefits of naked barley in processed food products and at the same time they must address improving production under UK conditions. It should be possible to improve β -glucan and amino acid content in UK naked barley through conventional breeding.

2.4. Key Conclusions

- Naked barley varieties from Europe, Middle East and Asia are low yielding, susceptible to lodging and foliar diseases when grown in the UK
- Establishment rate of naked barley is lower than for hulled barley, however, establishment of 85% can be obtained by reducing combine drum speed at harvest.
- The German naked variety Lawina is not suitable for UK agriculture.
- Pre-breeding screening and selection trials have shown that 'exotic' varieties of naked barley have high β -glucan levels that can be incorporated into higher yielding genetic backgrounds by crossing with UK varieties.
- A pre-breeding programme has identified promising novel varieties from crosses between naked and hulled varieties.
- With appropriate management naked barley lines can produce yields as high as 70% of those of covered varieties in the UK.
- Concentration of β -glucan in barley grains varies due to genetic and environmental factors and changes over time during grain development.