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Breeding oats for milling, feed and possible new food and industrial markets

by

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Abstract

The overall aim of the project was to enhance the value of oats to cereal growers and meet the needs of end-users through the development of oat germplasm and genetic stocks leading to new varieties. Oats are a valuable crop due to their unique properties. As a result of discussions, we defined clear industry pull for genetic improvement for diverse industries including feed for poultry, oat milling, breakfast cereal manufacturing, functional foods and feeding to pigs and ruminants. Common requirements for all these varied end-users are improvements in agronomic characteristics, e.g. grain yield, increased resistance to lodging and greater pest and disease resistance.

During the three full seasons covered by this project (October 2000 to March 2004), over 644 potential varieties were assessed for various agronomic and quality characters.

For human consumption, two superior genotypes were selected. These were 96-21Cn7, as an extremely lodging resistant oat with thick straw (from an unadapted Pennsylvania line) and 96-41Cn 3 as a stiff mildew resistant line from initial trialling to entry to 2004 NL trials.

For naked oats for poultry production, excellent progress was made in combining high yield and high oil content. Both are necessary for the crop to be economically acceptable and to enter least cost formulated poultry diets. Preliminary results obtained in 2003 showed 95-240Cn3/1/1 to yield 4.2% more than Grafton with oil content 30% above Grafton. The line was entered into 2004 NL trials. The advances made are in sharp contrast to selection for high protein in the 1980's which proved unachievable.

From earlier work that has come to fruition, Hendon, the first dwarf naked oat, and Buffalo, the first dwarf husked oat, entered the CEL Recommended List in 2003. The incorporation of dwarfness was a major step forward, since it confers resistance to lodging and the production of PGR-free grain. For naked oats, it allows late targeted application of N fertiliser to produce higher yields of high protein/energy grain for feeding to monogastrics. The high yielding conventional height naked oat, Expression, and Mascani, a high quality milling oat, entered the Recommended List for 2004. These new varieties, like previous varieties such as Gerald (entered 1993 on RL and won the NIAB Cereals Cup in 2003), Grafton (2000), Kingfisher, Viscount (both 1999) and Lexicon (1997), developed through previous HGCA projects, look highly likely to be profitably embraced by farmers and end-users.

The benefits for levy payers are clear in terms of improved economic competitiveness and enhanced end use characteristics of the lines in terms of oats for feeding to poultry and for

milling. The work will be taken forward in a SAL Link project – OatLink- involving sponsorship from Defra and SEERAD and cash and in-kind contributions from SW Seed, BOBMA, HGCA, Bernard Matthews, British United Turkeys, the British Poultry Association, Svalof-Weibull, GB Seeds, Elm Farm Research Centre and Oat Services.

Summary

The overall aim of the project was to enhance the value of oats to cereal growers and meet the needs of end-users through the development of oat germplasm and genetic stocks leading to new varieties.

Relationship of the project to other oat projects at IGER

The work in this project was a key stage in the IGER (Institute of Grassland and Environmental Research) oat breeding and research programmes and was jointly funded by Defra (Department of Environment, Farming and Rural Affairs) and HGCA. The initial identification and incorporation of variation in the oat programme was funded by a separate Defra project. BOBMA (British Oat and Barley Millers Association) supports the evaluation of husked oats meeting the UK Milling Industry's quality needs. Semundo (now SW Seed) carried out the marketing and development of varieties. The whole project was underpinned by fundamental research funded by BBSRC. In a recent Defra Review, the oat breeding programme at IGER was cited as being an excellent model for private and public funding in plant breeding.

Consultations with Industry and BOBMA involvement

At the start of the project, we defined the needs of industry through a Forward Look meeting involving end-users, HGCA and Defra. In addition, we took account of the key requirements identified by HGCA levy payer 'focus groups' which was used to revise the HGCA R & D Strategy. Throughout the course of the project we had 144 logged discussions with end-users.

In response to HGCA and Defra's wishes, we were pleased that BOBMA agreed to support the evaluation of husked oats, meeting the UK Milling Industry's quality needs. BOBMA funding enabled IGER to significantly re-instate the level of work associated with the evaluation of husked oats, since the application to HGCA specified that 70% of effort be directed towards naked oats. It continues the underpinning and developing work funded by HGCA and Defra on the identification and incorporation of novel variation and selection of oat germplasm and genetic stocks. In a visit of BOBMA to IGER in July 2001, it was emphasised that, although the BOBMA part of the overall programme was clearly identifiable, it was the way in which things interact that is important.

By its nature, plant breeding is a long process with at least 10 years elapsing between the initial cross and a variety being added to the RL. It is essential that there are clearly defined targets as the response time in breeding for new traits is slow. We have continued to have numerous discussions with industry to identify current and potential requirements. It is clear that

continued effort is necessary to maintain the economic competitiveness and fulfilment of end-user requirement. The programme seeks to make radical changes to oats for the benefit of the oat industry and already has notable successes, e.g. development of naked oats, high oil naked oats, high yielding winter oats and also dwarf oats.

Varieties entered to RL and NL during project – earlier work that has reached fruition

During the period of this project, four varieties were added to the HGCA Recommended Lists.

Hendon, the first dwarf naked oat, was added to the 2003 Recommended List. Hendon is clearly superior to a previous naked dwarf variety Icon (added to the National List but withdrawn from 2002 Recommended List trials) in terms of yield and disease resistance.

Buffalo, the first dwarf husked oat, was recommended for special use for the 2003 RL. It is very high yielding but has a low kernel content and poor mildew resistance. The special use was given in that it will allow production of PGR free grain. The commercial uptake of the variety will be dependent on the value the industry places on PGR free grain on the one hand and low kernel content on the other. Feedback from industry states that the low specific weight of Buffalo could be detrimental to commercial marketing of the variety.

A slightly taller dwarf Penderi is in RL trials 2004, which has better kernel content than Buffalo (similar to Gerald). Recent information indicates that Penderi has a specific weight lower than 50kg/hl. This is a likely barrier to acceptance of the variety by grain merchants.

For the naked oat, it allows late targeted application of N fertiliser to produce a higher yield of high protein/energy grain for feeding to monogastrics.

The high yielding conventional height naked oat, Expression, entered the Recommended List in 2004. Expression contains a different source of nakedness and provides additional options for growers of naked oats. Expression yielded 82% of husked controls (fungicide-treated) compared with 71% for Grafton on the 2004/05 Recommended List.

Mascani, a husked oat which is well suited to the miller's requirements, was added to the 2004 Recommended List. The variety has excellent milling quality.

These new varieties, like previous varieties such as Gerald (entered 1993 on RL), Grafton (2000), Kingfisher, Viscount (both 1999) and Lexicon (1997), developed through previous HGCA projects, look highly likely to be profitably embraced by farmers and end-users.

In addition to the above, Gerald was awarded the NIAB Cereals Cup 2003. It was voted by growers as the variety which has done most to promote profitability on the farm

Approaches and objectives used in 2383

General objectives

The overall aims of the project were

- 1) To develop and select oat germplasm and genetic stocks leading to varieties for premium feed and human consumption
- 2) To investigate possible new food and industrial markets
- 3) To obtain greater involvement of industry in the targeting of required characteristics and evaluating the material produced from the project.

Potential varieties were tested at several sites throughout the UK, generally in 25 entry trials using a balanced lattice design. These lines had already undergone some selection in terms of agronomic characteristics at earlier stages in the breeding programme. The candidate lines were compared against standard control varieties and each other. A range of characters was assessed during the growing season.

Resistance to lodging

As well as selecting for shorter, thicker-strawed or better anchored varieties meeting the requirements of farmers for whom straw is a profitable output, we have used a dwarf gene to dramatically reduce crop height and increase resistance to lodging.

In the last two seasons, we conducted lodging trials where we included all the candidate lines and some controls and deliberately tried to lodge them by applying generous amounts of N fertiliser at the wrong time of season.

Resistance to pests and diseases

Continued selection for improved pest and disease resistance was a common theme through out the project. New sources of mildew resistance were incorporated earlier in the Defra funded part (AR706). There already exists reasonable crown rust resistance as seen in Millennium and Mascani, although some complex races can overcome this. Resistance to soil-borne viruses especially Oat Mosaic Virus (OMV) which can seriously reduce yield (and is doing so in areas of Shropshire) is a desirable character in potential varieties. Gerald is susceptible to OMV and in some oat growing areas of Shropshire, OMV is reducing yields, emphasising the need for a successor to Gerald. We also tested for resistance to stem and cereal cyst nematodes, which is another desirable trait in potential varieties.

We continue to have close dialogue with UKCPVS in order to react rapidly to any new disease threat.

Meeting the special needs of the milling industry

Close dialogue with BOBMA indicated the priorities as economic competitiveness compared to wheat and other crops, in order for millers to be able to purchase oats at a reasonable price, high milling quality and, more recently, resistance to lodging in order to reduce the risk of plant growth regulators residues in the grain. Important milling quality traits are high kernel content, uniform size, low screenings and low grain blackening and PGR-free grain. Higher beta glucan content and lower fat were also desirable potential targets.

Meeting the special needs of oats for the poultry industry

In this project we were directed to concentrate on improving the naked oats with particular respect to poultry feed. The AFENO project ran concurrently and established the value for the use of naked oats as a poultry feedstuff. The breeding project proved to be integral to the AFENO project and provided much of the material used including high yielding conventional and dwarf naked oats and high-oil experimental lines.

The general aims of selection of naked oats were similar to those for husked oats in terms of increased yield and better agronomic characteristics. In addition, specific objectives are high naked expression, clean (non-discolored) grains and high oil content. Continued effort was used to broaden the genetic base for the naked oats. As with the husked oats there is a major effort to reduce the height of naked oat varieties and this requires major breeding effort to break the link between short straw and poor yield.

The major benefit of dwarf naked oats is their resistance to lodging. This allows targeted N application to produce high protein grain which can be used as a poultry feed. The benefits of using oats as poultry feed have been reported in the AFENO final report. This has provided much valuable data on the chemical composition and nutritional value of oats. It has shown some of the existing data to be inaccurate, as much of the work had been completed 15-20 years ago on varieties which are no longer grown.

Selection for high oil is undertaken by analysing the oil content of the grain of F3 clumps during the winter and then multiplying up the best varieties from a spring sowing in order to establish yield trials the following autumn.

Dissection of the components of quality for feeding oats to ruminants

Cowan, Valentine and Jones, 2003 examined the components of feeding value of the oat grain for ruminants. The work has also examined an unadapted genetic source from Canada (AC Assiniboia) containing a dominant gene for low husk lignin (Thompson et al. 2000). It arose by a chance investigation (Rossnagel pers comm.) of Canadian varieties to examine the possibility of low lignin trait in oats similar to that of the brown midrib genes in maize (Barriere and Agrillier 1993). This offers considerable scope for dramatically improving metabolisable energy (ME). The gene confers up to 2MJ/kg DM increase in predicted metabolisable energy for ruminants. As well as the obvious importance of this improvement to the on-farm feeding of oats, this characteristic could make husked oats of value for inclusion in feed compounds, saving on imported protein and energy and also making oat husks a more valuable by-product of milling.

Seven varieties (Gerald, Kingfisher, Millennium, AC Assiniboia, Buffalo and the naked oats Hendon and Expression) were grown in 6 row 1m replicated plots at Gogerddan. These were autumn and spring sown as this is known to influence oil content. Quality analyses were undertaken on the grain from one of the central rows of each plot. For the husked oats, the grains were de-husked to determine kernel content, the groats and husks were then analysed separately.

The Thomas *et al.* (1980) prediction equation (Predicted ME for ruminants = $0.14 * \text{NCGD} + 0.25 * \text{oil}$), as reported by Haigh and Bradshaw (1998) was used as an approximation of the metabolisable energy of groats and husks. NCGD (neutral cellulase gamanase digestibility) measures cellulase digestible organic matter after neutral detergent extraction (Anon, 1998a, Kitcherside *et al.*, 2000). In addition, we measured neutral detergent fibre (NDF) (Anon, 1998a) which estimates cellulose, lignin and hemi-cellulose content, acid detergent fibre (ADF) which estimates cellulose and lignin (Anon, 1998b), and lignin (van Soest, 1963, van Soest and Wine, 1967, Kitcherside *et al.*, 2000). Oil was determined by the acid hydrolysis method (Anon, 1998c).

Results

During the three full seasons covered by this project (October 2000 until March 2004), over 644 potential varieties were assessed for various agronomic and quality characters.

Naked oats

In 2001, 95-240Cn3/1/1 was identified with 29% higher oil content than Grafton, yielded broadly similar to Grafton at three locations.

The parentage of this line is Krypton x 91-221Cn4. 91-221Cn4 was derived from complex cross containing N361-3, a spring unadapted high oil line from Iowa.

In the following year, 95-240Cn3/1/1 yielded 72.9% relative to Grafton at 69.9% of controls in a January sown trial, with oil 29.7% above Grafton.

At this point, it was decided to produce pure stocks of the variety.

In 2003, 95-240Cn3/1/1 yielded 4.2% and oil content 30% above Grafton (6.02t/ha and 6.94% oil). The variety was also tested at Rosemaund, as part of the AFENO trials. In these trials, it yielded less than Grafton but above the previous experimental lines Chris and Fatso.

On the bases of the variety's generally good performance over three years, it was entered into NL trials 2004.

Oats for milling

In 2001, 95-25Cn2/1/1 ((Chamois x Emperor) x Viscount)) had a similar height to Gerald with a high yield (116 vs. Gerald at 99) but small grains. 95-27Cn5 (Solva x (Gerald x Viscount)) was shorter still with less yield (106). 95-75Cn5/1/1 (Viscount x Sovereign) x Millennium was about 10cms taller than Gerald with a relative yield of 109 and an excellent kernel content.

Two crosses provided lines that were eventually entered into autumn 2003 into 2004 National List trials.

96-21Cn (Millennium sib² x (Lustre² x Pa7409-125) was represented by 14 lines in 2001. Pa7409-125 was a short, thick-strawed extremely lodging resistant line with compact panicles from an unadapted Pennsylvania line. It is similar but even shorter than S172 and Milford released by ET Jones in the 30's and 40's and used worldwide (e.g. in Clintford, Walken (WalesKentucky) and Mapua. Although superficially attractive, compact paniced semi-dwarf lines are associated with small grains, this being the reason that we crossed it twice with Lustre and twice with sister lines of Millennium, the last cross being in 1996. Of the lines of this cross tested, two very closely related lines recovered stiff, short straw (99cms compared with Gerald and Millennium at 102) and high yield (108 relative to 99 for Gerald, 79 for Image, 100 for Jalna and 107 for Millennium). Both entries had high kernel content.

96-41Cn (Millennium sib² x (Gerald x (Emperor x (PC54 x Solva)))) was represented by 6 lines. PC 54 is one of the few sources of resistance to mildew available to IGER until the identification of new sources from wild species in the related project AR0706. PC 54 was identified by Roderick in IGER and Sebesta in the Czech Republic as a source of adult plant resistance to mildew. It was introgressed during the course of the Defra project CE0176 (where it was demonstrated to confer no adverse associated effects in trial with and without fungicides) and AR0706. Its resistance seems to be conferred by a single gene plus modifiers which make the resistance difficult to select for in early generations. Of the six lines tested, 96-41Cn3 was the only line to combine resistance to mildew, short straw and high yield.

In 2002, 95-25Cn2/1/1, 95-27Cn5 and 95-75Cn5/1/1 all yielded well (107, 107, and 117 respectively). 95-27Cn5 was notably short. On the basis of these results, 95-27Cn5 and 95-75Cn5/1/1 were entered into 2003 National List trials. 95-75Cn5/1/1 grew taller than desirable in this year. 95-27Cn5 yielded similar to Gerald. Although there was some case for continuing with 95-27Cn5, both varieties were withdrawn in favour of Penderi and newer varieties in response to the view of industry. They were judged to not have sufficient advantage over existing and new potential varieties. In the case of the former variety, the decision was marginal as it possesses resistance to OMV which Gerald lacks. OMV could become an increasing problem in view of the continuing popularity of Gerald.

96-21Cn7 and 96-41Cn3 yielded well (112 and 121). 96-21Cn4 showed excellent resistance to OMV (0). 96-41Cn yielded particularly well (121) and showed zero mildew and OMV.

In 2003, 96-21Cn7/1 and 96-41Cn3/2 continued to do well with valuable characters as described previously – exceptional resistance to lodging and to mildew respectively - and were entered into 2004 National List trials in autumn 2003.

Dissection of the components of quality for feeding oats to ruminants

The analyses of groats showed that oat groats contained relatively low levels of NDF and ADF. Higher than expected levels of lignin were obtained, but the absolute values should be treated with caution. Groats were highly digestible with NCGD in a relatively narrow range of 94.7 to 95.8. There were significant differences between oil content of varieties, with AC Assiniboia having lower oil content (8.4-9.6%) than other varieties (10.1-12.0). Nevertheless, predicted MEs were also in a narrow range probably reflecting the greater weighting of NCGD compared to oil in the prediction equation. Autumn sowing increased oil content from an average of 9.7 to 11.0% and predicted ME from 15.8 to 16.1 MJ/kg.

The much higher fibre content of oat husks was clearly observed. Significantly, Assiniboia had less than a third of the lignin content (3.0%) of other varieties (9.1-11.5%) irrespective of whether it was autumn or spring sown. This was reflected in much higher NCGD (58.4-59.4% compared to 12.5-28.2%) and predicted ME values (8.3-8.4% compared to 1.8-4.3%). Although values for husk oil content were low, there were clear variety differences, with the husk of Kingfisher having twice as much oil (1.2 – 1.3%) as Gerald, Millennium and AC Assiniboia (0.4-0.8%).

We have used the predicted MEs of groat and husk and the proportion of groat (groat%) to determine the predicted ME of whole grain. The two naked varieties Hendon and Expression had the highest ME values, with Assiniboia having significantly higher ME than the other husked varieties.

We have predicted what improvements could be attained by incorporating the low lignin husk trait into varieties with different oil levels. Assuming a high groat content of 77% and husk oil of 1.2% with a husk NCGD of 59% and groat NCGD of 95%, then increasing the groat oil content to 11% and 14% would result in predicted MEs of 14.3 and 14.9, respectively. If the groat content was increased from 77% to 79% with the same levels of oil this would result in predicted MEs of 14.5 and 15.1 respectively.

Investigation of possible new food and industrial markets

Various novel uses have been studied during the course of the project. The completion of the OATEC report studied the feasibility of fractionation of oats for industrial utilisation of different components. Beta glucan was identified as a target by the millers and we have attained two HGCA bursary students to develop methods for rapid screening of lines for beta glucan analysis with the ultimate aim of adding beta glucan determination to the NIR analysis we currently do. This calibration proved difficult to fully validate and this is consistent with reports from industry on the accuracy of beta glucan determination in oats. Beta glucan also has a role in functional food and is the major constituent for the heart health claims for oats in the USA.

The European Oat Conference in Uppsala 2001 in Sweden looked primarily at oats as a functional food. Ceapro are a company in USA who specialise in oat fractionation and industrial use of the products. Changes in the proportions of components can make large differences to economic viability of the process. We looked with them at high value antioxidants called avenanthramides which have potential in the pharmaceutical industry. Similarly high oil oats also have a role in altering the economics of fractionation. Generally there are only small amounts of the high value products so any manipulation to alter this and

also identify novel use for the more common constituents e.g. starch, could significantly alter the economics of fractionation.

Conclusions and Implications

The benefits for HGCA levy payers are clear in terms of improved economic competitiveness and enhanced end use characteristics of the lines produced by the programme at IGER.

As a result of the naked oats produced in this project and the demonstration that naked oats can be utilised in poultry diets, short chain production contracts are being offered by two major seed traders to commercially assess their inclusion in poultry diets. Their benefits lie in an alternative starch-based raw material and in their high oil content which is able to substitute for oil from tallow or recovered from deep fat frying which are being outlawed by the EU.

For naked oats for poultry production, a line 95-240Cn3/1/1, combining high yield and high oil was entered into 2004 NL trials. The advances made are in sharp contrast to selection for high protein in the 1980's which proved unachievable.

Additionally there has been increasing interest in using naked oats for feeding to pigs. This is potentially another large market. It is thought that naked oats would compliment lupins very well.

High oil oats make industrial fractionation a more attractive prospect. In strategic terms, green chemistry is likely to become much more important as change from reliance on petrochemicals is enforced by shortage of supply.

For human consumption, two superior genotypes were selected. These were 96-21Cn7, as an extremely lodging resistant oat with thick straw (from an unadapted Pennsylvania line) and 96-41Cn 3 as a stiff mildew resistant line from initial trialling to entry to 2004 NL trials. Their main advantage over other varieties lies in their extremely high resistance to lodging and mildew respectively, and in the light of concerns of millers and the increasing calls for sustainable agriculture, for production with reduced plant growth regulators and fungicides.

Very high-yielding dwarf winter oats have been released in the period of the report but the project has not been able to improve the kernel content of dwarf husked oats.

We have shown in the project that major gains in metabolisable energy of oats could be made by selecting for thin low lignin husks and high oil groats. Concentrated breeding effort is being

made at IGER to incorporate the low lignin trait from an unadapted source into UK oats. We believe that

- this would represent a quantum leap in the value of the oat crop for feeding to ruminants (and possibly monogastrics),
- with high ME (higher than wheat) and their nutritional benefits, oats would be incorporated at much greater levels than at present in feed compounds
- the greater demand for oats would be beneficial to sustainable agriculture

This work is being continued in five year Sustainable Arable LINK project sponsored by Defra and SEERAD in which HGCA, SW Seed Ltd, BOBMA, Bernard Matthews Foods Ltd, British United Turkeys, British Poultry Council, GB Seeds Ltd, Svalof Weibull Ab, Roslin Institute, ADAS, Oat Services, and Elm Farm Research Centre are partners, that will maintain the integrity of the programme and have also clearly identified the targets of each of the funding bodies. Oatlink seeks to incorporate important traits underlying sustainable development of the oat crop through combining “conventional” phenotypic selection with molecular technologies.

Technical Report

INTRODUCTION

The aims of this HGCA funded project 2383 were to enhance the value of oats to cereals growers through the development of oat germplasm and genetic stocks in order to develop economically competitive varieties that would meet the foreseeable demands of the major end users.

Relationship of the project to other oat projects at IGER

The work in this project, mainly involving the selection and assessment of oat germplasm and genetic stocks, was a key stage in the IGER (Institute of Grassland and Environmental Research) oat breeding and research programmes and was jointly funded by HGCA and Defra. The initial identification and incorporation of variation in the oat programme was funded by a separate Defra project. BOBMA (British Oat and Barley Millers Association) supports the evaluation of husked oats meeting the UK Milling Industry's quality needs. SW Seed Ltd (previously Semundo) carried out the marketing and development of varieties. The whole project was underpinned by fundamental research funded by BBSRC. In a recent Defra Review, the oat breeding programme at IGER was cited as being an excellent model for private and public funding in plant breeding.

Consultations with Industry and BOBMA involvement

At the start of the project, we defined the needs of industry through a Forward Look meeting involving end-users, HGCA and Defra. In addition, we took account of the key requirements identified by HGCA levy payer 'focus groups' which was used to revise the HGCA R & D Strategy and over 60 logged consultations and discussions with end-users. Throughout the course of the project we had 144 logged discussions with end-users.

In response to HGCA and Defra's wishes, BOBMA agreed to support the evaluation of husked oats, meeting the UK Milling Industry's quality needs. In a visit of BOBMA to IGER in July 2001, it was emphasised that, although the BOBMA part of the overall programme was clearly identifiable, it was the way in which things interact that is important.

By its nature, plant breeding is a long process with at least 10 years between the initial cross and a variety being added to the RL. It is essential that there are clearly defined targets as the response time in breeding for new traits is slow. The programme seeks to make radical changes to oats for the benefit of the oat industry and already has notable successes, e.g. development of naked oats, high oil naked oats, high yielding winter oats and also dwarf oats.

Recommended Winter Oat Varieties from previous HGCA work that has come to fruition

Gerald, a product of previous work at IGER, has been the most widely grown oat of the last decade. Gerald by virtue of its short stiff straw, has transformed oat growing in the UK. It won the NIAB Cereal Cup award in 2003, for the cereal variety that, in the opinion of farmers, has done most to improve profitability on UK farms. This cup was won by Optic (Spring Barley) in 2002 and by Pearl (Winter Barley) in 2004. Gerald has been in the RL listing for winter oats since 1993. Whilst being a popular and reliable high yielding variety there is a need for a successor to increase economic competitiveness and overcome susceptibility to oat mosaic virus.

A mark of success of the current and previous HGCA projects is the IGER winter oat varieties on the current Recommended List 2004 (Table 1). There are 4 husked and 3 naked entries on the list. The naked oat Grafton and husked oat Millennium were added in 2000. Two dwarf high-yielding oats were added to the 2003 list, Buffalo (husked) and Hendon (naked). Expression, a high yielding naked oat and Mascani milling quality oat added to the Recommended List for 2004 offer greater potential market opportunities for growers.

Table 1. IGER varieties on current 2004 CEL Recommended List of Winter Oats

	Husked oats				Naked oats		
	Gerald C 1993	Millennium C 2000	Buffalo S 2003	Mascani P1 2004	Grafton C 2000	Hendon P2 2003	Expression P1 2004
Yield as % treated Control (7.7t/ha)							
Treated	102	101	106	102	71	77	82
Untreated	91	97	98	96	67	68	74
Resistance to lodging	7	6	9	7	7	9	6
Straw length	121	123	90	123	124	77	136
Ripening (days +/- G)	0	0	0	-1	-2	0	0
Winter Hardiness	8	7	6	7	7	7	7
Resistance to disease							
Mildew	4	4	2	5	5	5	5
Crown Rust	6	9	7	8	6	5	6
Quality							
Kernel content (%)	72.1	77.1	70.6	77.1	-	-	-
Specific wt (kg/hl)	53.5	52.1	51.0	55.0	64.5	60.5	61.8
Sieving %<2.0mm	3.3	2.1	4.1	1.4	20.1	41.7	20.1

APPROACHES AND OBJECTIVES USED IN 2383

The overall aims of the project were

- 1) To develop and select oat germplasm and genetic stocks leading to varieties for premium feed and human consumption
- 2) To investigate possible new food and industrial markets
- 3) To obtain greater involvement of industry in the targeting of required characteristics and evaluating the material produced from the project.

Potential varieties were tested at several sites throughout the UK, generally in 25 entry trials using a balanced lattice design. These lines had already undergone some selection in terms of agronomic characteristics at earlier stages in the breeding programme. The candidate lines were compared against standard control varieties and each other. A range of characters was assessed during the growing season:

- Winter hardiness, habit, ear emergence, straw height, and incidence of disease usually mildew and crown rust, maturity date, lodging and brackling, and plot yield. After harvest, grain quality characters are also recorded this varies on whether it is a husked or naked oat.
- For husked oats we monitored husk colour, thousand grain weight, number of dehulled grains, kernel content, groat blackening, and also measured a screening index. The dehulled groats were analysed by NIR for determination of oil and protein. Special tests on husked oats included lignin staining of husk, beta glucan determination and some digestibility studies.
- For naked oats we recorded thousand grain weight, number of husked grains, groat blackening, hairiness and oil and protein by NIR. We also determined oil content using wet chemistry both cold Soxhlet (method used to calibrate NIR) and acid hydrolysis ethyl extract (AHEE) method; the latter involves a double extraction process so almost all the oil is measured.

Major effort has been applied to produce new varieties which have improved resistance to lodging. This is important as it ensures easier harvesting and also results in improved grain quality. Traditionally lodging was the main reason for not growing oats as harvesting a flat crop was expensive in terms of time and machinery. The newer oat varieties from IGER have generally overcome this problem. One of the reasons why Gerald is so successful is its ability to stand which gives farmers greater flexibility at harvest time. Two main methods have been employed, choosing candidate lines which are short to lessen the chance of lodging, generally resulted in selection of potential lines which are shorter than Kingfisher (this variety was on the RL list until 2003). The other is to identify thicker or stiffer strawed lines to give more resistance to lodging. This also highlights a paradox. Kingfisher is popular with organic growers who also utilise the straw. In some cases organic straw is worth as much as the grain, so there is the possibility for a niche variety.

Buffalo, the new dwarf husked oat, is very high yielding but has a low kernel content and poor mildew resistance. Further breeding is necessary to improve kernel and disease resistance.

In the last two seasons, we conducted lodging trials including all the candidate lines and controls, in which we have used N mis-management to identify lodging-susceptible varieties.

Continued selection for improved pest and disease resistance was a common theme through out the project. New sources of resistance to mildew and crown rust were incorporated. Millennium

and Mascani have major gene resistance to crown rust, although not unexpectedly, some complex races can overcome this. Resistance to soil-borne viruses especially oat mosaic virus (OMV), which can seriously reduce yield (and is doing so in areas of Shropshire) is a desirable character in potential varieties. We also tested for resistance to stem and cereal cyst nematodes.

Oats for human consumption

Close dialogue with BOBMA indicated the priorities. Millers look for good kernel content, uniform size, low screenings, low grain blackening and more recently PGR-free grain. Higher beta glucan content and lower fat were also desirable potential targets.

Millennium has yielded well in breeders' trials and has exceptionally high kernel content. However, it has not established itself in the market. Possible reasons are lower yields in fungicide-treated trials (with some evidence that this is due to the negative effects of chlormequat) and the fact it was not initially recommended due to its yellow husk which was erroneously associated with the thick, difficult-to-dehull husks of Mirabel. The new variety Mascani (2004 RL listing) has high kernel weight, high specific weight and low screenings.

Buffalo, the first dwarf husked oat to be added to the RL list in 2003 for special use category, is a high yielding oat but has low mildew resistance and a poor kernel content. The special use was given in that it will allow production of PGR free grain and the commercial uptake of the variety will be dependent on the value the industry places on PGR free grain. Concerted effort to produce improved husked oats with greater disease resistance and grain quality is a priority. A slightly taller dwarf Penderi, which is in RL trials 2004, has better grain quality. The dwarf nature has the potential to revolutionise the industry in a similar fashion to the arrival of dwarf wheat in the 1960's.

Naked oats for poultry and other applications

In this project we concentrated on improving the naked oats with particular respect to poultry feed. The AFENO project ran concurrently and established the value for the use of naked oats as a poultry feedstuff. The breeding project proved to be integral to the AFENO project and provided much of the material used including high yielding conventional and dwarf naked oats and high-oil experimental lines.

Conventional naked oats

The general aims were similar to those for husked oats, namely to increase yield and good agronomic characteristics being sought together with good naked expression, clean grains and good quality. Continued effort was used to broaden the genetic base for the naked oats. During the project a high yielding conventional height naked oat Expression was added to the RL list

2004. Expression contains a different source of nakedness to previous varieties conferring very high expression of nakedness. The variety yields 82% of husked controls compared with 71% for Grafton (RL 2004 data).

Dwarf naked oats

Another major breakthrough during the project was Hendon, being the first dwarf naked oat added to the RL 2003 list. Previously Icon, a dwarf naked oat, was added to the NL list, but this was withdrawn from RL trials in favour of Hendon which was clearly superior in terms of yield, disease resistance and grain quality.

Dwarfness in naked oats confers their very high resistance to lodging. This in turn allows targeted N application to produce high protein grain which can be used as poultry feed. The benefits of oats as poultry feed have been reported in the AFENO final report. This has provided much valuable data on the chemical composition and nutritional value of oats. It has shown that some of the existing data to be inaccurate as much of the work had been completed 15-20 years ago on varieties which are no longer grown.

The implications of the inclusion of oats in the poultry ration are a doubling of the oat area. The benefits include a traceable safe protein source and environmental benefits in the reduced fungicide/herbicide / insecticide applications.

High oil naked oats

From the crosses made in 1999, approximately 1350 F3 oil clumps were sown in October 2001. These were harvested during August 2002, separated into talls and dwarfs, and assessed using NIR to determine oil and protein content. The best 94 lines, with oil greater than 10.5% determined by NIR, were spring sown in 2003 as F4 rows to multiply them up. These were harvested in August 03 and 41 lines were sown in two yield trials in October 03. The remaining 53 lines were sown in the nursery plots to provide sufficient seed for future oil trials in the 2004-05 season. The objective of the trial was to provide high yielding agronomically superior naked oats which have higher than normal oil content. These would have potential in the poultry industry as a high energy feed.

The original sources of high oil used in the programme were obtained from Frey in Iowa. These were unadapted spring husked oats derived from recurrent selection based on *Avena sterilis*. Several hybridisations and cycles of selection were necessary in order to introgress this material into UK adapted winter oat material. Further lines from later cycles of the Iowa programme were recently obtained from Jan Luc Jannick, Iowa).

Previously selections had been made exclusively for naked oats where high oil equated to high energy grain for monogastrics. The AFENO project indicated there was a possibility of using husked oats. Therefore we have recently commenced introgressing high oil into husked oats. Towards the end of the project, there was increasing interest in using naked oats for feeding to pigs, particularly young pigs. This is potentially another large market. It was also thought that naked oats would complement lupins very well.

Feed for ruminants

Thin husked oats with high oil such as Millennium have potential as a ruminant feed since ruminants are capable of utilising the fibrous husks. Historically oats were utilised in arable farming as a livestock feed. We need to dispel the idea that oats not good enough for human consumption can be used as animal feed.

In 2001 and 2002, we conducted a study to dissect the components affecting digestibility in husked oats. Seven varieties were grown in 6 row 1m replicated plots at Gogerddan. These were autumn and spring sown as this is known to influence oil content. Quality analyses were undertaken on the grain from one of the central rows of each plot. For the husked oats, the grains were de-husked to determine kernel content thousand grain weight and kernel content were recorded. Oil content (measured by AHSE), lignin, ADF, NDF, NCGD were subsequently determined on separate husk and groat samples.

Predicted metabolisable energy (ME) using the formula by Thomas et al 1980 ($0.14 \times \text{NCGD} + 0.25 \times \text{oil}$) was calculated.

The experiment included a genetic source, Ac Assiniboia, an unadapted spring oat variety from Winnipeg, containing a dominant gene for low husk lignin. This offers considerable scope for dramatically improving metabolisable energy (ME). The gene confers up to 2MJ/kg DM increase in predicted metabolisable energy for ruminants. As well as the obvious importance of this improvement to the on-farm feeding of oats, this characteristic could make husked oats of value for inclusion in feed compounds, saving on imported protein and energy and also making oat husks a more valuable by-product of milling.

Parallel to this study, Ac Assiniboia was crossed with various winter oat lines.

Novel uses

Various novel uses have been studied during the course of the project. The completion of the OATEC report studied the feasibility of fractionation of oats for industrial utilisation of different components. High level of beta glucans was identified as a target by the millers. Beta glucan also has a role in functional food and is the major constituent for the heart health claims for oats in the USA.

A conference in Uppsala 2001 in Sweden looked primarily at oats as a functional food. Changes in the proportions of components can make large differences to economic viability of the process. In conjunction with Ceapro, a company in Canada specialising in oat fractionation and industrial use of the products, we have assessed variation in high value antioxidants called avenanthramides. Similarly high oil oats also have a role in altering the economics of fractionation. Generally there are only small amounts of the high value products so any manipulation to alter this and also identify novel use for the more common constituents e.g. starch, could significantly alter the economics of fractionation.

Waxy starch is another area where we have investigated possibilities of new uses. Through collaboration with John Innes Institute (Norwich) we had access to waxy starch mutant diploid plants. The waxy starch (amylopectin) possesses different properties to non waxy starch (amylose). There is a quick staining test which differentiates these two very well at the diploid level. Unfortunately it does not work at the hexaploid level. Starches that are high in amylopectin are reported to be digested and absorbed more quickly than starches with high amylose. The waxy gene encodes the granule bound starch synthase enzyme. Whereas the diploid oat contains one locus in the cultivated oat there are three loci, one in each genome. An HGCA bursary student used 1-D gel electrophoresis to identify the presence or absence of the enzyme protein encoded at each locus in an attempt to identify lines with non-functional alleles that would confer partial waxiness. Through contacts in USA, Dr Graybosch, we obtained samples of cultivated oats which are purported to be different and also a range of waxy, partially waxy and non waxy wheats. We modified the protocols and established that we can discriminate in starch types in the diploids but are unable to identify variation in the hexaploids. A possibility is to use molecular markers that have been associated with rice and wheat. However there is no guarantee they will work in oats.

A six-month extension

A meeting chaired by HGCA, involving diverse sectors of Industry and Defra, was held in August 2003 to discuss carrying forward the work within a SAL Link project. There was

considerable Industry pull from the Milling and Poultry sectors. As a result, we successfully applied for an extension to the existing project.

RESULTS

Development of germplasm and screening of useful traits for potential new varieties of husked oats especially for human consumption.

2000-01

There were 31 conventional height and three dwarf entries in second year and 138 conventional height and two dwarf entries in first year trials.

Three lines in trials for the second year were ear-marked for further development. 95-25Cn2/1/1 ((Chamois x Emperor) x Viscount)) had a similar height to Gerald with a high yield (116 vs. Gerald at 99) but small grains. 95-27Cn5 (Solva x (Gerald x Viscount)) was shorter still with less yield (106). 95-75Cn5/1/1 (Viscount x Sovereign) x Millennium was about 10cms taller than Gerald with a relative yield of 109 and an excellent kernel content.

Two crosses provided lines that were entered in autumn 2003 into 2004 National List trials.

96-21Cn (Millennium sib² x (Lustre² x Pa7409-125) was represented by 14 lines. Pa7409-125 was a short, thick-strawed lodging resistant line with compact panicles. It is similar but even shorter than S172 and Milford released by ET Jones in the 30's and 40's and used worldwide (e.g. in Clintford, Walken (WalesKentucky) and Mapua. Although superficially attractive, compact panicked semi-dwarf lines are associated with small grains, this being the reason that we crossed it twice with Lustre and twice with sister lines of Millennium, the last cross being in 1996. Of the lines of this cross tested, two very closely related lines recovered stiff, short straw (99cms compared with Gerald and Millennium at 102) and high yield (108 relative to 99 for Gerald, 79 for Image, 100 for Jalna and 107 for Millennium). Both entries had high kernel content. Their main advantage over other varieties lies in their extremely high resistance to lodging, and in the light of concerns of millers and the increasing calls for sustainable agriculture, for production without the need for plant growth regulators and the risk of chemical residues.

96-41Cn (Millennium sib² x (Gerald x (Emperor x (PC54 x Solva)))) was represented by 6 lines. PC 54 is one of the few sources of resistance to mildew available to IGER until the identification of new sources from wild species in the related project AR0706. PC 54 was

identified by Roderick in IGER and Sebesta in the Czech Republic as a source of adult plant resistance to mildew. It was introgressed during the course of the Defra project CE0176 (where it was demonstrated to confer no adverse associated effects in trial with and without fungicides) and AR0706. Its resistance seems to be conferred by a single gene plus modifiers which make the resistance difficult to select for in early generations. Of the six lines tested, 96-41Cn3 was the only line to combine resistance to mildew, short straw and high yield.

Of lines containing mildew resistance from *Avena sterilis* (Av series produced by Mike Leggett in CE0176), 96-89RCn4 involving Av5611 gave a high yield (108) but was about 12cms taller than Gerald. A number of entries in 2000-01 trials contained unadapted lines in their pedigrees. These were from North and South Carolina, and Texas. Most entries yielded poorly, probably because their early maturity curtailed grain fill. They were discontinued but will be stored for future use and testing in the face of climate change.

In the small number of dwarf lines, 94-116Cn4/1 (later named Penderi) yielded much better (100 relative to controls) than Buffalo, in the first year of NL trials. Notably Penderi had excellent kernel content (78.5%).

Although we managed to drill the trials (with the exception of the high oil naked trial), we were unable in the face of exceptionally wet weather to sow the breeding nursery in autumn. In order not to lose a year, the material was sown in the spring, starting with advanced material on 6 March and finishing with the F3 generation on 26 March. Some germplasm responded better than others to spring sowing. Dwarfs and some material derived from Solva (including Kingfisher) were severely blasted.

In the 2001 crossing programme, a conscious effort was initiated to ensure, for reasons of genetic vulnerability and millers' perception of quality, that despite Millennium conferring high yield and other characters to the breeding programmes, breeding material is generated without Millennium in its parentage. We used the spring oat Firth and 96-503Cn32, a high fertility line from previous Defra funding, in the programmes.

2001-02

122 advanced lines of husked oats were selected for continued assessment of yield, agronomic and quality characteristics in 2001-2002 season. This included 6 dwarf husked lines.

High infections of oat mosaic virus were obtained in the special OMV nursery, in trials and in the nursery. Since Gerald is susceptible, yields of this control variety were affected and as a

result many lines out-yielded controls. 95-25Cn2/1/1, 95-27Cn5 and 95-75Cn5/1/1 all yielded well (107, 107, and 117 respectively). 95-27Cn was notably short. On the basis of these results, 95-27Cn5 and 95-75Cn5/1/1 were entered into 2003 National List trials. The crown rust nursery was inoculated with race 265, a complex race virulent on Appler, Bond, Landhafer, Trispernia, Saia and notably Millennium. Of material in trials, only lines containing a genetic source from Texas obtained via the 1996 Uniform Winter Hardiness Nursery and a single line containing the high beta-glucan source PI 504593 identified by Peterson in 1992 was resistant to this race.

96-21Cn4 and 96-41Cn3 yielded well (112 and 121). 96-21Cn4 showed excellent resistance to OMV (0). 96-41Cn yielded particularly well (121) and showed zero mildew and OMV.

97-4Cn18 (Millennium x Kingfisher) and 97-106Cn6 – which are candidates for National List in 2005- (Millennium x 96-89RCn) were among first year entries selected to go on to next year's trials.

Of dwarf entries, Penderi (108) in its second year of National List trials (outside the scope of this project but included for reference) again outyielded Buffalo (101). 97-119Cn5, a line containing the high beta-glucan source PI 504593 identified by Peterson in 1992 – entered into NL 2004 trials - yielded only 92. This line had moderate resistance to crown rust, implying that the crown rust resistance of PI 504593 contains at least two genetic factors.

At an earlier stage in the programme, lines for characters such as high fertility, low lignin and beta-glucan content are being assessed. Twenty three high yielding husked winter oats including lines containing the Dw6 dwarf gene, 3 F1s from the 2001 crossing programme, 11 genetic sources including 3 lines with high beta-glucans, 4 lines developed from *A. macrostachya* (Av5716-3, Av5727-1, Av5720-4, Av5727-5) and Ac Assiniboia were selected as parents for the 2002 winter oat crossing programme. Most of the crosses were targeted at meeting the needs of production for sustainable production for human consumption in terms of greater economic competitiveness, higher resistance to lodging and disease which will reduce applications of PGRs and pesticides, and higher milling quality. A number of crosses were also aimed at improving premium feed quality in terms of lower husk lignin (see later) and increasing oil content in husked oats. In appropriate areas, crosses were accelerated. These included crosses between high yielding husked oats and high oil naked oats, crosses with high beta-glucan sources and crosses for incorporating low lignin.

In F2, 92 husked oat populations from crosses made in 2000 and grown as F1s in 2001 were sown with the Monosem precision drill. These included crosses between high yielding husked oats (including Millennium, Kingfisher, Mascani and advanced lines including backcross lines involving APR166 and PC 68 in a Millennium background), crosses between high yielding lines and Firth, the leading spring oat, crosses between Buffalo and backcross lines involving the mildew resistant source APR166 in a Millennium background. (F2 2001/2002 F2 winter oat field book and winter oat nursery F3 2002/03 Naked Material field book 4).

In F3, crosses involved Millennium, 91-33Cn/1, Viscount, Mascani, Dunkeld, some German winter oats from a small Lochow-Petkus breeding programme, and some Australian cultivars such as Amby II and Culgoa II. At this stage, crosses involving dwarf oats were not well represented.

2002-03

There were 73 conventional and 10 dwarf lines for first year in trials and 20 conventional and 3 dwarf entries in second year trials in 2003.

The very short non-Millennium line 95-27Cn5 and the high yielding taller variety 95-75Cn5/1/1 in National List trials were judged to not have sufficient advantage over existing and new potential varieties. In the case of the former variety, the decision was marginal as it possesses resistance to OMV which Gerald lacks. OMV could become an increasing problem in view of the continuing popularity of Gerald. The latter variety grew tall in this season and presented a perceived if not actual lodging risk.

96-21Cn7/1 and 96-41Cn3/2 continued to do well with valuable characters as described previously – exceptional resistance to lodging and to mildew respectively - and were entered into 2004 National List trials in autumn 2003.

97-4Cn18 yielded 105 relative to Gerald 100. It is 14cms taller than Gerald, appealing to those such as livestock farmers who value straw. It was earmarked for further development and possible entry to 2005 NL trials.

The dwarf 97-119Cn5/2 continued to yield well (99 compared to 95 for Buffalo, 99 for Penderi and 103 for Gerald). The variety has an unusually high level of oil (9.3%) which may make it valuable as premium feed for ruminants. It showed 2 per cent points above Buffalo for kernel content based on 2002 samples. It was a candidate for NL in 2005 though later results (2004 winter analyses of quality samples) show it to have kernel content 2% per cent points less than

Buffalo in 2003. This variation is possibly related to poor extrusion of the panicle from the flag leaf in 2003, extrusion being poorer in warmer seasons and under glasshouse conditions.

Effort was continued in 2003 to identify high-yielding lodging resistant lines with improved kernel content and resistance to mildew. Height is only one component of lodging. In order to get more information on lodging, a special lodging trial in which additional nitrogen was applied to standard size unreplicated trial plots. The advanced line 97-106Cn6 would probably have gone forward to 2005 NL trials if this trial had not highlighted its weakness (literally) in this area. The trial is also proving valuable in providing higher levels of mildew induced by higher N applications.

2003-04

There were 53 conventional lines and 1 dwarf line sown in autumn 2003 for first year in trials and 14 conventional and 5 dwarf entries from 73 for second year trials. Two lines 97-4Cn18 (high yielding conventional) and 97-119Cn5 (dwarf) have been selected for seed production (pre NL) which have better yield and disease resistance than Gerald. Trials are on-going.

Development of oat germplasm leading to varieties of naked oats for poultry feed and other premium feed

2001-02

In trials of winter naked oats, 120 entries were 'conventional' naked (compared to 55 in 2000), 20 were dwarf naked (2 in 2000) and 31 were high oil naked oats (1 in 2000). There was a major increase in effort in naked oats in this year. This is partly as a result of industry pull and partly as the excellent progress that has been made in two cycles of hybridisation and selection of high oil naked oats. Both the concentration of oil, by conferring high energy well above that of wheat, and high grain yield is important to the economic production of naked oats and their inclusion in least cost formulated poultry diets. The genetic sources of the high oil lines were unadapted husked spring oats derived from *A.sativa* x *A.sterilis* hybrids obtained from the Iowa recurrent selection programme with groat oil content up to 16.2% g/kg DM. In trials at 3 locations, one line, which in the 2000 breeding nursery had 29% higher oil content than Grafton, yielded broadly similar to Grafton, making it on the basis of these preliminary results highly suitable for use by the poultry industry. This line has been advanced to further trials and will also be tested within the AFENO project. Another trial, in which seed availability was limiting, was sown in January (due to the wet autumn) at Gogerddan. Although results must be treated with caution, a line that in the 2000 breeding nursery had 43% higher oil content than

Grafton, yielded 12% above Grafton. At this level, this line could be of interest to the emerging oat fractionation industry.

At earlier stages, 1500 selections from F2 2001 of high oil crosses made in 1999 and from accelerated lines of 2000 crosses were assessed in F3 clumps in 2002.

2002-03

Seventeen naked advanced winter oats, 2 F1s and 5 new high oil genetic sources from Iowa from the 2001 programme were selected as parents for the 2002 winter oat crossing programme for the development of germplasm and screening of useful traits for potential new varieties of naked oats for poultry feed. The 17 advanced winter oats included 6 conventional height lines selected for high yielding ability (including Expression), 3 naked dwarf lines (including Hendon), 7 lines (including 96-140Cn1 and 95-240Cn3/1 and 5 lines from a January 2002 sown high oil trial) from the second cycle of introgression of high oil into high yielding naked winter oats) and a short rachilla dwarf line. The F1s were three-way crosses with a new spring oat dwarf line, CROA59. In addition, crosses were made with husked advanced winter oats (to increase economic competitiveness) and with sources of disease resistance. A cross between a high oil naked line and the naked dwarf variety Hendon was accelerated. (cbreeding/wo2002/list of crosses2002/ list of 02 crosses worksheet).

In F2, 80 naked oat populations from crosses made in 2000 and grown as F1s in 2001 were sown with the Monosem precision drill. These included crosses between high yielding naked and husked oats (including Expression), crosses between high yielding and second cycle high oil lines, two crosses with 13087Cn (a promising naked spring oat), crosses to sources of resistance to crown rust involving PC 68 and a line from Illinois containing several genes for resistance. Dwarf crosses included crosses between high yielding naked oats and dwarf oats (particularly Hendon), crosses involving APR 122, the source of resistance to mildew from *A. pilosa*, crosses with F495-100Cn1/1 (Krypton x 90-299Cn1/2), an early line. (F2 2001/2002 F2 winter oat field book and winter oat nursery F3 2002/03 Naked Material field book 4).

In addition, 8 crosses made in 2001 were accelerated in 2002. These included three-way crosses with the new spring oat dwarf line, CROA59 and crosses between 93-180Cn1/1 (a high oil line) on the one hand and Expression and Penderi (husked 'tall dwarf') on the other hand. Random F3 rows were sown in October 2002. In F3, crosses involved 93-122Cn5 (progenitor of Expression), Grafton, Hendon, Krypton (with Buffalo) and a number of advanced lines.

The 1500 selections from F2 2001 of high oil crosses made in 1999 and from accelerated lines of 2000 crosses assessed in 2002 were harvested and analysed during the 2002-2003 winter for oil content using NIR based on the rapid cold soxhet method. 94 lines were selected to be sown for multiplication in spring 2003 capitalising on the fact that winter oats have a low vernalisation requirement. The selected lines had oil content greater than 10.5% compared to 7.6% for Grafton. The genetic sources of the high oil lines were unadapted husked spring oats derived from *A. sativa* x *A. sterilis* hybrids obtained from the Iowa recurrent selection programme with groat oil content up to 16.2% g/kg DM. (F3 oil clumps 2001-02 book and F4 selections spring multiplications book).

Apart from the lines mentioned above, parents in F4 aimed at increasing economic competitiveness and reducing plant height included Grafton, Lexicon, Millennium, 90-199Cn9/1 (a Harpoon derivative) and a 91-88Cn (Pendragon derivative), (F4 12's 2001-2002 Books 4 and 5).

2002-03

There were 29 conventional and 23 dwarf lines entered for first year yield trials and disease nurseries. 10 conventional lines selected from 109 for second year trials in 2002. Preliminary results show 95-240Cn3/1/1 had yield 4.2% and oil content 30% above Grafton (6.02t/ha and 6.94% oil). This line was identified as of high interest, if confirmed, to the poultry feed industry and to an emerging oat fractionation industry.

There were 52 conventional and 9 dwarf winter oat lines entered into autumn 2002 first year trials and 12 conventional and 12 dwarf lines selected from 52 entered into autumn 2002 second year trials.

Parallel to the genetic improvement of naked oats in terms of high yield and oil, further promising results were obtained in the related AFENO project. A paper presented by Cark Maunsell in October 2003 entitled *Vertically Integrated Crop Production* showed that from the value of naked oats in least cost formulations and inclusion rates calculated by Roche Vitamins, the potential annual use of oats in integrated poultry units was approximately 750,000 tonnes annually. Short-chain contracted production was proposed. This further encouraged us in the seeking of genetic gains in economic competitiveness and/or oil content necessary to consolidate the entry of naked oats into this large market.

In the dissection of components of feed quality, oat groats contained relatively low levels of NDF and ADF. Higher than expected levels of lignin were obtained, but the absolute values

should be treated with caution. Groats were highly digestible with NCGD in a relatively narrow range of 94.7 to 95.8. There were significant differences between oil content of varieties, with Assiniboia having lower oil content than other varieties. Nevertheless, predicted MEs were also in a narrow range probably reflecting the greater weighting of NCGD compared to oil in the prediction equation. Autumn sowing increased oil content and predicted ME.

The much higher fibre content of oat husks was clearly observed. Significantly, Assiniboia had less than a third of the lignin content of other varieties irrespective of whether it was autumn or spring sown. This was reflected in much higher NCGD and predicted ME values. Although values for husk oil content were low, there were clear variety differences, with Kingfisher having twice as much oil as Gerald, Millennium and Assiniboia.

We have used the predicted MEs of groat and husk and the proportion of groat (groat%) to determine the predicted ME of whole grain. The two naked varieties Hendon and Expression had the highest ME values, with Assiniboia having significantly higher ME than the other husked varieties.

We have predicted what improvements could be attained by incorporating the low lignin husk trait into varieties with different oil levels. Assuming a high groat content of 77% and husk oil of 1.2% with a husk NCGD of 59% and groat NCGD of 95%, then increasing the groat oil content to 11% and 14% would result in predicted MEs of 14.3 and 14.9, respectively. If the groat content was increased from 77% to 79% with the same levels of oil this would result in predicted MEs of 14.5 and 15.1 respectively.

Since Assiniboia is not adapted to UK conditions, concentrated breeding effort is being made at IGER to incorporate the trait into UK oats. We believe that

- this would represent a quantum leap in the value of the oat crop for feeding to ruminants (and possibly monogastrics),
- with high ME (higher than wheat) and their nutritional benefits, oats would be incorporated at much greater levels than at present in feed compounds
- the greater demand for oats would be beneficial to sustainable agriculture as indicated in the introduction of this paper.

2003-04

There were 52 conventional and 9 dwarf lines entered for first year trials and 12 conventional and 12 dwarf lines selected from 52 for second year trials. Preliminary results showed 95-

240Cn3/1/1 had yield 4.2% and oil content 30% above Grafton (6.02t/ha and 6.94% oil) and has been entered into NL trials 2004.

The 2002 high oil selections were multiplied in 2003. Two oil trials have been sown comprising 41 new entries to assess agronomic characteristics, all entries had oil content greater than 10.5% compared to 7.6% for Grafton (NIR calibration against cold Soxhlet method). An additional 53 entries were sown as six 18m drills due to insufficient seed for trialling.

In relation to the selection of low lignin from Assiniboia, from a cross made in 2001 and accelerated (01-165Cn) between Assiniboia and ((Gerald x Chamois) x Emperor), 4 out of 164 F3 rows were selected as having sufficient merit to be sown in F4 multiple 12's. One of these proved to not possess the gene (or was possibly heterozygous) when stained with phloroglucinol. The other lines had low lignin and are being multiplied up to give sufficient seed for in vitro and in vivo feeding trials; two of the lines have been used in crossing in 2004 to introgress the gene further into an adapted background.

Investigation of oat germplasm leading to varieties with new properties for possible new food and industrial markets.

As a preliminary step to the selection of oats with low oil we sent a low oil variety, Exeter, (c2% oil), to Quaker Oats in USA in 2001. It was thought that low oil is desirable from a low fat viewpoint and for extrusion, but may impair flavour development.

Quaker Oats reported back in April 2003. Lab scale thermal processing used prior to chemical analyses. The low fat oat variety contained Maillard Reaction Products significantly higher than the normal fat oat variety. According to Quaker, this would give the nutty flavour that they are looking for, although there could be issues such as uniformity.

From this result, we accelerated two crosses made in 2002 aimed at incorporating low oil (for low fat markets). These were grown under lights as F1s between July 2002 and December 2002 and F2s between January and July 2003. However, we have decided to store the material, given that this area is not a priority for the future LINK project, given the knowledge from previous work that levels as low as the low parent are very difficult to recover, and the long timescale and several cycles of breeding that would be necessary to incorporate the character in an agronomically acceptable background.

We attained two HGCA bursary students to develop methods for rapid screening of lines for beta glucan analysis and calibrating NIR. This calibration proved difficult to fully validate and this is consistent with reports from industry on the accuracy of beta glucan determination in oats.

Assessment of segregating material involving a high antioxidant parent identified two genotypes with exceptional levels of antioxidants above that of the high expression line. These lines could be of very high interest to the food industry. They have been further used in the breeding programme.

A discussion with Talbott's, UK Manufacturers of Biomass and Waste to Energy Systems – 29 June 2003, indicating possible use of oat husk/hair (100,000t available) as an energy source was brought to attention of Alan Meikle, Chairman of BOBMA.

Work in the six-month extension

With regard to the milestones in the six- month extension from 1 October 2003 – 31 March 2004, we sowed 19793 winter oat rows and clumps in the breeding nursery and in mildew, crown rust, OMV and winter-hardiness tests in Gogerddan and Tynpynfarch (excluding borders) on 9th October 04 and 2190 trial plots at Gogerddan, Lydbury, Balgonie, Fulbourn and ADAS Rosemaund (excluding discards, NL and RL trials). We grew sufficient parental material for 160 crosses aimed at human consumption and 85 aimed at premium feed markets, in both cases also addressing the needs of sustainable agriculture. We recorded winter-hardiness and plant habit during this period and completed quality assessments according to the IGER protocol.

Conclusions and Implications

The benefits for HGCA levy payers are clear in terms of improved economic competitiveness and enhanced end use characteristics of the lines produced by the programme at IGER.

As a result of the naked oats produced in this project and the demonstration that naked oats can be utilised in poultry diets, short chain production contracts are being offered by two major seed traders to commercially assess their inclusion in poultry diets. Their benefits lie in an alternative starch-based raw material and in their high oil content which is able to substitute for oil from tallow or recovered from deep fat frying which are being outlawed by the EU.

For naked oats for poultry production, a line 95-240Cn3/1/1 combining high yield and high oil was entered into 2004 NL trials. The advances made are in sharp contrast to selection for high protein in the 1980's which proved unachievable.

Additionally there has been increasing interest in using naked oats for feeding to pigs. This is potentially another large market. It is thought that naked oats would compliment lupins very well.

High oil oats make industrial fractionation a more attractive prospect. In strategic terms, green chemistry is likely to become much more important as change from reliance on petrochemicals is enforced by shortage of supply.

For human consumption, two superior genotypes were selected. These were 96-21Cn7, as an extremely lodging resistant oat with thick straw (from an unadapted Pennsylvania line) and 96-41Cn 3 as a stiff mildew resistant line from initial trialling to entry to 2004 NL trials. Their main advantage over other varieties lies in their extremely high resistance to lodging and mildew respectively, and in the light of concerns of millers and the increasing calls for sustainable agriculture, for production with reduced plant growth regulators and fungicides.

Very high-yielding dwarf winter oats have been released in the period of the report but the project has not been able to improve the kernel content of dwarf husked oats.

We have shown in the project that major gains in metabolisable energy of oats could be made by selecting for thin low lignin husks and high oil groats. Concentrated breeding effort is being made at IGER to incorporate the low lignin trait from an unadapted source into UK oats. We believe that

- this would represent a quantum leap in the value of the oat crop for feeding to ruminants (and possibly monogastrics),
- with high ME (higher than wheat) and their nutritional benefits, oats would be incorporated at much greater levels than at present in feed compounds
- the greater demand for oats would be beneficial to sustainable agriculture

Future plans for oat breeding research at IGER Oatlink 1/4/04 to 31/3/09

Defra and SEERAD have sponsored a new 5 year Sustainable Arable LINK proposal at IGER in which HGCA, SW Seed Ltd, BOBMA, Bernard Matthews Foods Ltd, British United Turkeys, British Poultry Council, GB Seeds Ltd, Svalof Weibull Ab, Roslin Institute, ADAS, Oat Services, and Elm Farm Research Centre are partners, which will maintain the integrity of the programme and has also clearly identified the targets of each funding bodies. OatLink seeks to incorporate important traits underlying sustainable development of the oat crop through combining “conventional” phenotypic selection with molecular technologies.

This project seeks to maintain and increase the value of oats as a profitable component of conventional and organic production for human and livestock consumption, delivering benefits to sustainable agriculture. Although conventional farmers, organic farmers, millers and poultry producers have different aims, there is also much in common in terms of the need for economic competitiveness, good agronomic and disease characteristics and the sharing of molecular markers. We will develop and assess new oats using ‘conventional’ and marker-assisted selection for the milling and poultry industry. The scientific justification is that the use of molecular markers in conjunction with phenotype assessments will allow more effective selection for more key traits (particularly those associated with differentiated quality) within the context of a real breeding programme. This innovative approach will be more effective than simply expanding a conventional breeding programme, through achieving better understanding of the inheritance of traits, through more effectively selecting for high trait expression using rapid and precise marker-assisted selection and by identifying and bringing together multiple interacting factors from genotypes of similar phenotypic value). Although the project is targeted at the whole UK, there is a strong cross-cutting Scottish dimension. Oats are an important product in Scotland from farming, milling and export of premium product viewpoints.

Considerable opportunities also exist for developing oats for sustainable agricultural systems including organic and integrated systems, for developing premium quality oats for ruminants and for developing oats for functional foods. There is considerable scope for the use of biotechnology e.g. marker assisted selection and genomics as part of underpinning BBSRC work to add to our understanding of the genetic control of sustainable traits, including introgression from wild primary and secondary gene pools, from which strategies can be developed to enhance the oat crop and open up new markets.

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Sue Lister NIR results for oil and protein

Outputs from project HGCA 2383 2000-2004

New Varieties

Varieties added to UK Recommended List 2003

Hendon (93-85ACn5/2/2) the first dwarf naked UK winter oat. High resistance to lodging with high energy content and good levels of essential fatty acids and amino acids

Buffalo (93-76Cn)- the first dwarf husked UK winter oat. High yield with lodging resistance with specific recommendation (2003 RL) for growing with plant growth regulators. Low kernel content

Varieties added to UK Recommended List 2004

Mascani (95-56ACn3) High yielding husked oat with good milling quality

Expression (93-122Cn5/1) Very high yielding naked oat with good naked expression.

Shows

Joint demonstration exhibition with Semundo at Cereals 2001, 2002, 2003 These included demonstration plots of Millennium and Hendon and Buffalo.

Stand at HGCA stand 2002 with demonstration of oat varieties including Millennium.

Presence at the ADAS Rosemaund open day on June. 2003

Part of IGER stand at Royal Welsh Show 2001, 2002, 2003

Technical Presentations

Presentations at ABIPO, AFENO meetings 2000-2003

Technical articles/publications

Oat forward look meeting, MRC 11 August 2000

[A meeting was convened bringing all sides of oat users, growers, researchers, millers and processors, together to identify ways ahead.]

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