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EXPLOITATION OF THE GENETIC POTENTIAL OF OATS FOR USE IN FEED AND HUMAN NUTRITION (SECOND REPORT)

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by
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I Summary

Raising the level of oil, protein or beta-glucans would increase the value and marketability of oat grain. Genetic sources with very high oil content (up to 12.1% DM on a whole grain basis, 16.2% DM on a groat or kernel basis) have been identified and offer extremely promising prospects for increasing the value of oats for feed, in terms of high energy, and for extraction for industrial use. Genetic sources were confirmed as having high beta-glucan content in the groats (6.86% DM for Vedette compared to 5.67% DM for Melys and 5.51% DM for Dula, the current most widely grown variety). In the face of adverse negative correlations between grain yield and protein content, selection for high protein content derived from *Avena maroccana* does not, however, seem worthwhile.

II Introduction

In the final report of a three year project funded by H-GCA, Butler-Stoney and Valentine (1991) described the progress being made in selecting for high protein content from *A.maroccana*-derived winter and spring oats and high oil content from Pioneer in winter oats.

For protein content, spring sown winter oats and spring oats were identified with levels of up to 3% DM above Rollo and 4% above Dula on a whole grain basis, currently the most widely grown spring oat variety. On average, randomly drawn *A.maroccana* derived lines were taller, later maturing and lower yielding than Dula and Rollo and there were negative but incomplete associations between yield and protein content. It was concluded that further pre-competitive breeding was necessary in order to combine high protein content with other characteristics. The desirability of further transfer of genes from *A.maroccana* or the use of other genetic sources with different genetic factors was pointed out.

For oil content, winter oat lines were identified with levels up to 2% DM more oil in the grains, equivalent to Metabolisable Energy (ME) 0.5 MJ/kg DM above that of Image, currently the most widely grown winter oat variety. There were no adverse correlations between oil content and either yield or protein content but there was a positive, though incomplete, correlation between oil content and height. It was indicated that an important objective of further work would be to identify recombinants with high oil and reduced straw length.

Butler-Stoney and Valentine (1991) also indicated other opportunities for the exploitation of the genetic potential of oats in feed and human nutrition, one of them being the identification and incorporation of high beta-glucan ('soluble fibre') content.

Here, we report on the work carried out in a further year of extension of this project. Unless otherwise stated, results are presented on a whole grain, 12% moisture basis.

III Selection for high protein content in a second cycle of breeding

883 unreplicated micro-plots were established from 25-seed lots sown on 2-4 October 1989 using a plastic drain-pipe into furrows at 30 cm spacing. Micro-plots were arranged in 3.75 m rows, 30 cm apart, each row consisting of 10 micro-plots with single micro-plots at the end of each row acting as guard plots.

The genetic material consisted of 44 micro-plots of Solva and 45 of Image (NIAB Recommended Varieties) as controls sown adjacent at random positions throughout, 221 F3 families of two-way crosses made in 1987 between winter oats and *A.maroccana*-derived spring oats described by Butler-Stoney and Valentine (1991) and 573 F3 families of three-way crosses made in 1988, ie F1 (winter oats x *A.maroccana*-derived spring oats) x winter oats. The parentage of these crosses is shown in Appendix 1.

The crosses made in 1988 were rapidly advanced using supplementary glasshouse lighting and heat in order to sow unselected progenies in autumn 1989. The crosses made in 1987 proceeded as normal using a pedigree selection system, F2 ears with good agronomic characteristics but not selected for protein content being selected in the field in 1989. Micro-plots received 60 kg/ha N in two applications and were kept weed-free.

Plant height was recorded from soil level to the tip of panicles. Micro-plots were harvested using a sickle, dried to 12% moisture and samples of whole grain analysed for protein content using the Micro-Kjeldahl method. The factor 6.25 was used to convert nitrogen to protein content.

Due to the effect of the presence or absence of husk on grain yield, husked and naked oats will be considered separately. For crosses segregating for the degree of nakedness, the percentage of naked grain was estimated visually.

The characteristics of husked F3 progenies compared to controls are shown in Table 1, and for individual crosses in Appendix 2. There was a high recovery of genotypes with higher protein content than the control varieties Solva and Image. Overall, F3 progenies had a protein content +0.63% relative to controls. F3 progenies from two-way crosses which contained a greater proportion of high protein parental material had a protein content +1.64% relative to controls. F3 progenies from three-way crosses with proportionally more adapted germplasm had protein content only +0.38% relative to controls. There was a large range in protein content, particularly in two-way crosses between winter oats and *A.maroccana*-derived spring oats (Figure 1).

Table 1

Characteristics of winter oat F3 progenies involving *A.maroccana*-derived spring oats for crosses between husked oats

	Plant height (cm)	Yield (g/plot)	Protein (%)	Protein yield (g/plot)	r Protein/ yield
Solva					
mean (n=44)	109.4 ± 8.26	64.2 ± 12.84	10.59 ± 0.926	6.78 ± 1.402	-0.17 NS
range	97.0 - 128.0	34.5 - 92.7	8.81 - 13.06	4.18 - 9.96	
Image					
mean (n=45)	106.4 ± 9.03	57.8 ± 12.12	10.65 ± 0.933	6.15 ± 1.423	0.01 NS
range	90.0 - 126.0	26.3 - 90.5	8.44 - 14.19	2.89 - 9.42	
Solva & Image					
mean (n=89)	107.9 ± 8.73	61.0 ± 12.83	10.62 ± 0.925	6.46 ± 1.440	-0.09 NS
range	90.0 - 128.0	26.3 - 92.7	8.44 - 14.19	2.89 - 9.96	
Two-way crosses					
mean (n=142)	114.8 ± 9.16	35.6 ± 12.46	12.26 ± 1.647	4.27 ± 1.390	-0.45***
range	89.0 - 146.0	10.1 - 77.8	8.75 - 16.69	1.43 - 8.61	
Three-way crosses					
mean (n=573)	111.7 ± 12.34	46.2 ± 12.90	11.00 ± 1.351	5.02 ± 1.367	-0.32***
range	78.0 - 155.0	14.6 - 97.2	7.75 - 16.87	1.70 - 10.69	
Two- and three-way crosses					
mean (n=715)	112.3 ± 11.84	44.1 ± 13.48	11.25 ± 1.501	4.87 ± 1.403	-0.42***
range	78.0 - 155.0	10.1 - 97.2	7.75 - 16.87	1.43 - 10.69	

Protein content cannot, however, be considered in isolation. On average, F3 progenies were 4.4 cms taller than controls, 27.7% lower yielding and had 24.6% lower protein yields than controls. As expected, three-way crosses were, on average, superior to two-way crosses, for plant height +3.8 cms and +6.9 cms relative to controls respectively, for yield 24.3 % and 41.6% lower respectively and for protein yield 22.3% and 33.9% lower respectively. This was despite the fact that two-way crosses had received some selection in the F2 generation.

The correlations between protein content and yield were non-significant ($r = -0.09$) for controls, but were negative, though incomplete, for F3 progenies ($r = -0.42$, $P<0.001$).

From a selection viewpoint, it is rare or infrequent genotypes breaking adverse associations which are of most interest. While it is clear that the cost, on average, of additional protein content was a significant reduction in yield, inspection of the results (not presented for the sake of brevity) indicated some progenies for possible further evaluation.

For crosses containing naked oat parents, the situation is complicated by variation in the proportion of naked grains. Naked expression can range from completely naked types through a range of intermediate types containing both husked and naked grains to completely husked types. In Table 2, comparisons are made between near-complete husked lines, defined as having 95-100% husked grains and near-complete naked lines, defined as having 95-100% naked grains. Thirty-two of 53 husked lines had 100% husked grains, the remainder having varying proportions of grain presumed de-husked during threshing as opposed to being genetically naked. 138 of 193 naked lines were categorised as being 100% naked. Both 100% classes had characteristics extremely similar to those of the 95-100% classes and while progenies of 100% or nearly so naked grain are of most interest, results for the latter are presented in view of larger sample sizes. Two crosses, 88-169ACn and 87-213Cn, proved to be mainly husked (Appendix 3) and have been omitted from further analyses.

Table 2

Characteristics of winter oat F3 progenies involving *A.maroccana*-derived spring oats with one or more naked oat parents

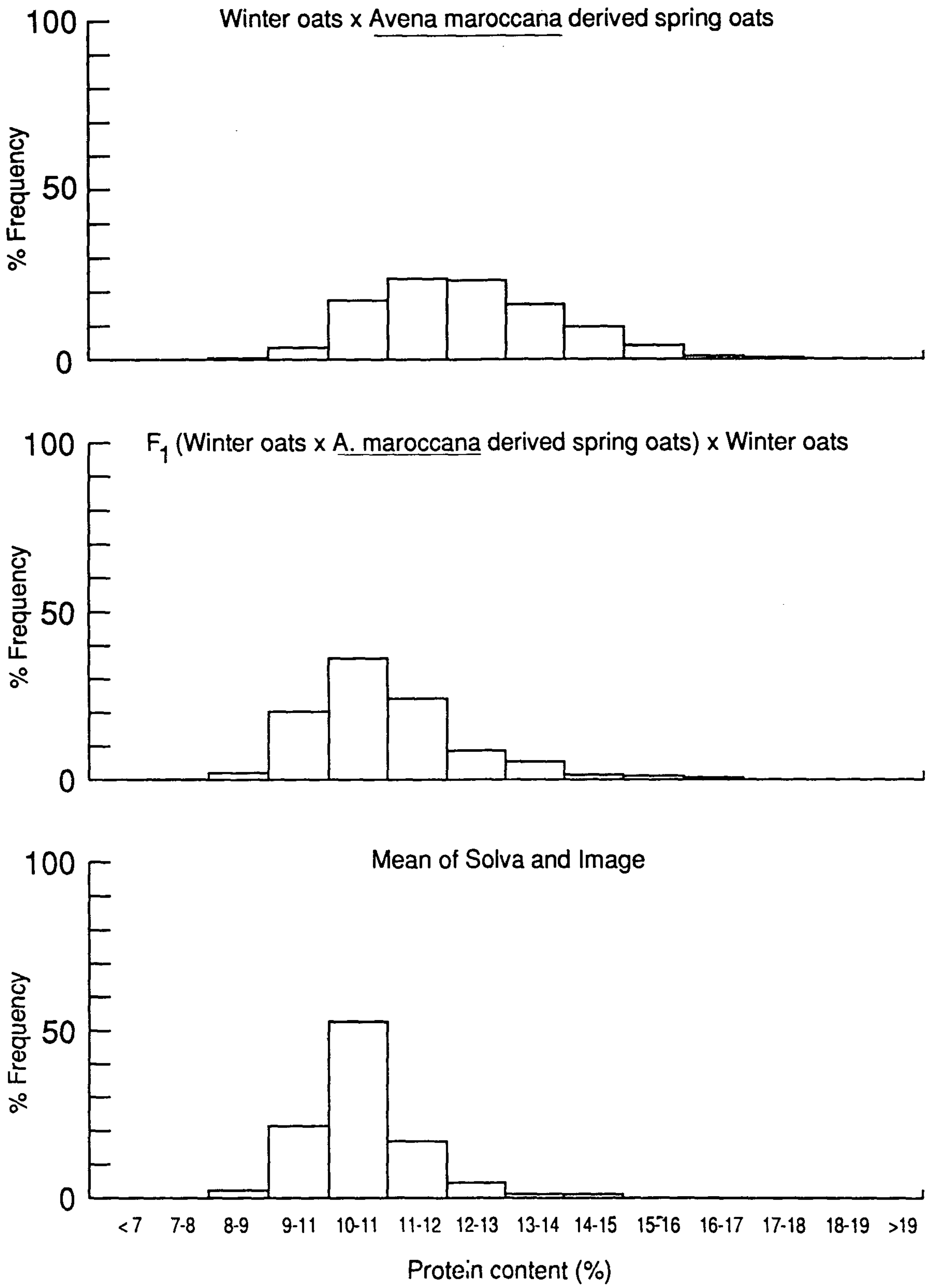
	Plant height (cm)	Yield (g/plot)	Protein (%)	Protein yield (g/plot)	Naked grains (%)	r Protein/ yield
Two-way crosses						
All progenies (n=210)	117.3 ± 10.26	33.3 ± 11.84	12.99 ± 2.002	4.19 ± 1.244	79.8	0.61***
95-100% husked (n=22)	122.5 ± 9.65	42.4 ± 16.85	11.27 ± 0.990	4.72 ± 1.770	2.5	-0.39 NS
95-100% naked (n=131)	115.2 ± 8.91	31.5 ± 10.46	13.60 ± 1.998	4.14 ± 1.161	98.5	-0.65***
Naked vs husked[1]	-7.3	74.3	120.7	87.7	-	-
Three-way crosses						
All progenies (n=150)	113.8 ± 10.90	38.8 ± 12.78	12.74 ± 1.833	4.84 ± 1.410	63.2	-0.48***
95-100% husked (n=31)	115.9 ± 10.41	46.5 ± 13.37	11.00 ± 1.135	5.04 ± 1.372	1.6	-0.32 NS
95-100% naked (n=62)	115.7 ± 10.94	32.9 ± 8.58	13.77 ± 1.683	4.48 ± 1.188	98.8	-0.29*
Naked vs husked	+0.2	70.7	125.2	88.9	-	-
Two- and three-way crosses						
All progenies (n=360)	115.9 ± 10.66	35.6 ± 12.52	12.88 ± 1.935	4.46 ± 1.352	72.9	-0.55***
95-100% husked (n=53)	118.7 ± 10.54	44.8 ± 14.90	11.11 ± 1.078	4.91 ± 1.540	2.0	-0.44***
95-100% naked (n=193)	115.3 ± 9.58	31.9 ± 9.90	13.66 ± 1.900	4.25 ± 1.178	98.6	-0.56***
Naked vs husked	-3.4	71.2	122.9	86.5	-	-

[1] For plant height, the difference in cms; for other characters as percentage.

While naked progenies of three-way crosses yielded 74.3% of husked progenies, a difference which can be attributed to the removal of the husk, naked progenies of two-way crosses for some unknown reason yielded only 70.7% of husked progenies. Likewise, no explanation can be given for the lower protein content (11.27%) of husked lines from two-way crosses involving naked parents than for the husked lines from husked crosses (12.26%), particularly since the protein contents of corresponding three-way crosses exactly coincide (11.00%).

Naked progenies from both two-way and three-way crosses had high protein (13.60% and 13.77% respectively, with maximum levels of 18.00% and 18.50%

Figure 1 Variation in protein content in A.maroccana derived material compared to controls



respectively). Corresponding protein yields of naked progenies were 87.7% and 88.9% of husked progenies. Welch, Hayward and Jones (1983) found that 10 *A.sativa* genotypes had 23.9 to 32.8% husk content and 2.0 to 3.3% protein in the husk, from which husk protein yields of 0.52 to 1.059 g/plot can be calculated. It is possible that the differences found between the protein yield of husked and naked oats can be entirely explained by the loss of protein located in the husk, and similar protein yields would be obtained if groat protein had been examined.

IV Selection for high oil content in a second cycle of breeding

One hundred and three unreplicated micro-plots were established as in the previous section. Seed was sown on 8 October 1990. Micro-plots received 135 kg/ha N in three applications and were kept weed-free. Oil (lipid) content of freshly ground samples of whole grains was determined using the 'Soxtec' HT6 system.

The genetic material consisted of (a) controls as follows: Solva (3 micro-plots), Image (1), Pendragon (1) and 83-87CnII/1/1, an advanced generation naked oat line (1), (b) 26 F3 families of 88-128Cn (82-170Cn14 x Solva), (c) 29 F3 families of 88-129Cn (Solva x 82-170Cn14), the reciprocal cross of 88-128Cn, (d) 39 naked F3 families of 89-137Cn (83-87CnII/1/1 naked x 84-84Cn1 naked), (e) advanced F5 lines of 86-141Cn (78-34Cn5 x 79-77Cn9/2/3 naked). The parentage of 82-170Cn14 is Pioneer (high oil) x Image, while 84-84Cn1 resulted from the cross of Image and F1 (Ky 78-443 x Branwen) originally made in order to increase winter-hardiness, but this particular selection had above average oil content. 79-77Cn9/2/3 was a sister selection of Pendragon which was added to the UK Descriptive List of Cereals for 1993 (Anon, 1993a).

88-128Cn and 88-129Cn families were obtained by selecting for good agronomic types in the F2 generation grown in the previous year. 89-137Cn were unselected except for the naked character derived by accelerated generation procedures using supplementary glasshouse lighting and heat during the 1989-90 winter. The 86-141Cn lines were naked oats from the conventional pedigree breeding method, ie no early generation selection for high oil content was exerted.

A summary of variation in oil content is presented in Table 3. In husked oats, F3 families had higher oil content than Solva or Image. Five lines had an oil content above 7%. One line, 88-128CnI/1/17, had an oil content of 9.2% (67% above Solva).

In naked oats, one line (89-137CnXXI/1/1) had an oil content of 9.4%, eight lines had oil content above 8% and thirty-two lines had oil content above 7%. As expected, the oil content of the three naked oats derived by pedigree selection was lower, but the lines had generally good agronomic characteristics. In comparison, Pendragon and 83-87CnII/1/1 had oil contents of 6.5 and 6.9% respectively.

These results are based on an as received rather than DM basis. In order to convert from a moisture content of 12%, all values should be multiplied by 1.14. This equates to an oil content of 7.41% DM for Pendragon and 10.7% DM for the best F3 family.

It is possible that the 'Soxtec' HT6 method of oil analysis did not fully extract all the oil (particularly bound lipids) and therefore underestimated the amount of total oil in this material. The lines with oil content above 9% were used as parents of crosses initiating a third cycle of selection.

Table 3

Variation in oil content in winter oat micro-plots

	n	Mean	Range
Husked oats			
88-128Cn	26	6.53 ± 0.69	5.6 - 9.2
88-129Cn	29	6.01 ± 0.46	5.4 - 7.2
Solva	3	5.38 ± 0.36	5.1 - 5.8
Image	1	5.93	-
Naked oats			
89-137Cn	39	7.58 ± 0.67	5.6 - 9.4
86-141Cn	3	6.98 ± 0.45	6.7 - 7.5
Pendragon	1	6.52	-
83-87CnII/1/1	1	6.95	-

V Characterisation of genetic sources varying in beta-glucan and protein content

Fourteen diverse genotypes of spring oats were sown in a randomised block experiment. There were three blocks. The unit of assessment was a micro-plot established using 25 seed lots as in the previous experiments. The experiment was sown on 27 March 1991 and 88 kg/ha nitrogen was applied.

Total beta-glucan % of groats (de-husked oats) was assessed in the Department of Biological and Biomedical Sciences, University of Ulster, using an enzymic method (McCleary and Glennie-Holmes, 1985). Vedette, Greta, Shearer, Sorbo and Hinoat were putative sources of high beta-glucan identified by Welch and Lloyd (1989). Cc6501 is a line derived from *A.sterilis* containing high protein. Av1893/2, Av3290/2/13 and Av3281/2/1/1 were *A.maroccana* high protein derivatives described by Butler-Stoney and Valentine (1991). Sv874225 and Sv874229 are *A.maroccana*-derived lines produced in Svalof, Sweden. The lines originated from the WPBS *A.maroccana*-derived line 2330/4/18/19/14 (Maris Oberon x (*A.maroccana* Cc4911 x Sun II^2)) crossed with Vital, a high yielding stiff-strawed Swedish variety. Selection was made for good agronomic characters and high protein content. Svalof trials indicated the lines to have grain yield 80-85% of Vital and 16% protein (+2% more than Vital) (Hagberg, personal communication). Dula, Rollo and Melys are spring oat varieties included as controls.

Results (Table 4) indicate the eleven putative genetic sources of high beta-glucan and protein content to have protein contents above controls. All were substantially lower yielding and had lower protein yields than Melys. Hinoat and Cc6501, from Canada and USA respectively, were particularly low yielding, had very early ear emergence and short straw, probably reflecting too rapid development. Putative sources of high beta-glucan were very susceptible to mildew. Grain size was acceptable for all entries except Av3281/2/1/1. There was a wide range of variation in kernel content with Greta and the two Svalof lines having particularly unacceptable values (66.4 - 69.7%) although differences were not statistically significant. The two Svalof lines had higher protein (21.0 - 21.3%) than the WPBS *A.maroccana*-derived lines (16.3 - 18.9%) but were lower yielding, generally more susceptible to mildew and had poorer kernel contents.

Total beta-glucan levels of the five genetic sources from the set identified by Welch and Lloyd (1989) ranged from 6.17% to 6.86% on a groat/DM basis. These are higher values than those obtained for controls (Dula 5.51%, Rollo 5.14%, Melys 5.67%) or putative high protein genetic sources (4.67-5.98%). In terms of proportion, Vedette had 21% more beta-glucan than Melys. Despite having a beta-glucan content very similar to the mean of all genotypes (5.71%), Melys had the highest beta-glucan yield (and protein yield) by virtue of having the highest yield in this experiment. Yield was negatively correlated with protein content ($r = -0.67$, $P<0.001$), although this may partly reflect the fact that some of the high protein genetic sources (Cc 6501 and Hinoat in particular) were very poorly adapted to UK conditions. Total beta-glucan was not correlated with protein % ($r = 0.13$, NS) nor yield ($r = -0.05$, NS).

Table 4 Characteristics of genetic sources varying in beta-glucan and protein

	Yield/plot (g)	Ear emergence (days after 1 May)	Plant height (cm)	Mildew (%)	1000 Grain weight (g)	1000 Kernel weight	Kernel (%)	Protein (%)	Protein yield (g)	Beta-glucan % (DM) (groats)	Beta-glucan yield (g) (groats)
Vedette	27.2	22.7	117	60.0	38.7	27.3	70.8	17.1	465	6.86	186
Greta	19.8	22.7	100	70.0	36.4	25.2	69.5	16.1	312	6.46	124
Shearer	23.3	23.7	117	63.3	40.0	30.4	76.2	19.5	453	6.17	146
Sorbo	20.8	27.3	107	70.0	37.4	26.9	72.4	14.4	299	6.03	125
Hinoat	18.0	19.3	95	66.7	37.6	26.8	71.5	19.8	342	6.29	106
Cc6501	10.9	18.7	83	76.7	38.4	27.7	72.1	21.5	236	5.65	62
Av1893/2	22.3	27.0	107	63.3	38.0	27.3	72.0	18.9	426	5.98	132
Av3290/2/13/1	22.5	20.3	115	33.3	36.4	28.0	77.4	17.1	383	5.60	126
Av3281/2/1/1	24.2	28.0	103	43.3	30.4	23.4	76.8	16.3	397	5.07	117
Sv874225	20.7	27.0	115	53.3	40.4	26.9	66.4	21.3	441	4.88	101
Sv874229	21.1	27.0	117	53.3	39.8	27.7	69.7	21.0	443	4.67	99
Dula	37.8	24.3	105	56.7	40.5	29.5	72.6	12.3	468	5.51	211
Rollo	27.2	21.7	98	56.7	39.4	28.4	72.3	14.2	387	5.14	140
Melys	48.4	26.7	107	50.0	37.1	26.2	70.7	14.5	709	5.67	278
Mean	24.6	24.02	106	58.3	37.9	27.3	72.2	17.4	411	5.71	140
s.e.d.	6.13	0.653	3.4	5.49	2.26	1.56	3.57	0.82	96.6	0.517	36.7
Prob.	<0.001	<0.001	<0.001	<0.001	0.019	0.028	0.218	<0.001	0.018	0.009	<0.001

VI Characterisation of spring-sown winter and spring oats varying in oil content

The object of this experiment was to quantify the oil content of ten high oil accessions in order to identify their value for use in the UK breeding programmes and to compare them with existing sources and selections for high oil content and also with existing husked and naked winter and spring oat varieties and advanced lines.

The ten high oil accessions (prefixed by N in Table 5) came from the C6 cycle of an experimental recurrent selection experiment in Iowa described by Thro and Frey (1985), Branson and Frey (1989) and Schipper and Frey (1991).

Pioneer is an old North American variety resulting from the cross between Winter Fulghum and Winter Turf, with high oil content (Welch *et al*, 1983). The breeding line 78-34Cn5 is a high oil selection from an initial cross between Pioneer and Oyster made in 1978. The two 82-170Cn (Pioneer x Image) lines are also Pioneer-derived selections identified by Butler-Stoney and Valentine (1991), while the two 82-52Cn (Image x 78-34Cn5) lines are the products of a second cycle of hybridisation and selection also identified by earlier H-GCA funded work (Butler-Stoney and Valentine, 1991). 41/5 is an Australian dwarf accession.

Solva, Image and Gerald are WPBS-bred winter oat varieties on the H-GCA funded UK Recommended List of cereals for 1993 (Anon, 1993a). Kynon and Pendragon are WPBS-bred winter naked oats on the UK Descriptive List for 1993, there being no UK Recommended List for naked oats as yet. 83-111Cn9/1 is an advanced naked winter oat currently (1993) in NL2. The WPBS bred Rhiannon is the only spring naked oat on the UK Descriptive List for 1993. Dula and Keeper are on the UK Recommended List of spring oats for 1993 (Anon, 1993), Wenol is a now discontinued husked spring oat from WPBS and 10448Cn and 10455Cn are advanced lines of naked spring oats. Exeter is an unadapted spring oat variety with very low oil content (Welch, 1974).

The thirty varieties were sown in a randomised block experiment. Experimental details were as for the previous experiment. Oil (lipid) content was determined on freshly ground samples using the 'Soxtec' HT6 system. In this experiment, both protein and oil contents were converted from a 12% moisture basis to a DM basis and have also been expressed as % of groat (kernel), assuming the kernel content of husked grains to be 75%.

Results indicate that the ten putative high oil lines have a mean oil content of 10.8% DM (whole grains) equivalent to 14.3% DM (groats). N326-7 had the highest level, 12.1% DM (whole grains) equivalent to 16.2% DM (groats). The Australian dwarf line 41/5 had an oil content of 12.4% DM (groats). These levels are substantially more than those obtained for Pioneer, 10.4% DM (groats) previously used as a source of high oil content (Butler-Stoney and Valentine, 1991) and well above levels of oil found for husked and naked winter and spring naked oats. As expected, Exeter had a low oil level.

The Iowa high oil lines were short, early but low yielding and more susceptible to mildew than commercially available UK lines. Negative correlations between groat oil % and yield (r = -0.80***) and between groat protein % and yield (r = -0.78***) reflect the lack of adaptedness of the Iowa high oil lines rather than an inherent inverse association between oil content and yield. This is borne out by more recent work (Surek, 1993) carried out under glasshouse conditions which found grain yield of single plants and groat oil content in two crosses (N327-6 x 78-34Cn5 and N313-2 x Pendragon) to be positively correlated (r = 0.39** and r = 0.48***) while in two other crosses (N313-2 x Exeter and N313-2 x 78-34Cn5) there were no associations between grain yield and groat oil content (r = 0.07 and r = 0.18 respectively).

Table 5 Characteristics of genetic sources varying in oil content

	Yield/plot (g)	Ear emergence (days after 31 May)	Plant height (cm)	Mildew (%)	Naked grains (%)	Protein % (DM)	Groat protein % (DM)	Oil % (DM)	Groat oil % (DM)
N305-1	5.90	17.3	87	53.3	0	17.6	23.5	11.3	15.0
N313-2	10.3	15.0	87	70.0	5.0	17.5	23.0	10.6	13.9
N326-7	9.5	14.0	92	60.0	0	18.1	24.1	12.1	16.2
N327-6	11.2	13.7	85	70.0	0	18.4	24.5	10.6	14.1
N337-4	5.2	13.7	88	70.0	5.0	17.3	22.8	10.3	13.6
N361-3	7.4	12.7	80	70.0	0	16.6	22.1	10.4	13.8
N375-6	6.7	12.7	83	70.0	0	18.1	24.2	10.4	13.9
N383-6	10.2	12.7	80	70.0	0	19.0	25.3	10.3	13.7
N399-8	8.4	12.3	82	70.0	5.0	17.2	22.6	10.3	13.6
N401-6	7.1	12.7	80	70.0	0	18.3	24.4	11.3	15.1
41/5	2.9	17.3	42	73.3	0	20.3	27.0	9.3	12.4
Pioneer	18.9	25.0	108	57.0	0	14.8	19.7	7.8	10.4
78-34Cn5	31.3	30.7	103	60.0	0	14.8	19.7	7.4	9.9
82-170Cn14	18.7	30.0	95	57.7	0	16.5	22.0	8.2	10.9
82-170Cn62	25.3	32.3	102	50.0	0	16.0	21.3	8.9	11.8
82-52Cn72	21.6	32.7	98	50.0	0	14.1	18.8	7.4	9.9
82-52Cn10	31.0	32.3	100	33.3	0	16.0	21.3	7.1	9.5
Solva	29.1	33.7	87	43.3	0	14.1	18.8	6.4	8.5
Image	30.6	33.0	92	36.7	0	14.9	19.9	7.1	9.4
Gerald	32.2	34.5	85	63.3	0	13.8	18.4	6.3	8.4
Kynon	14.2	33.7	92	60.0	99.0	18.6	18.7	8.4	8.4
Pendragon	23.4	32.3	88	53.3	92.7	17.1	17.7	9.5	9.7
83-111Cn9/1/1	19.9	33.0	90	43.3	73.3	16.3	17.8	8.2	8.9
Rhiannon	20.8	26.3	93	60.0	92.7	18.4	18.9	8.2	8.4
Dula	35.7	23.3	95	70.0	0	13.0	17.3	4.3	5.7
Keeper	28.3	22.0	92	70.0	0	14.1	18.8	4.3	5.8
Wenol	33.5	25.3	92	63.3	0	14.5	19.4	5.8	7.7
10448Cn	25.4	21.3	102	70.0	97.7	19.4	19.5	8.7	8.7
10455Cn	23.2	20.7	102	63.3	95.0	19.1	19.5	8.7	8.9
Exeter	24.9	27.3	105	56.7	0	15.8	21.1	2.6	3.5
Mean	19.1	23.5	90	60.2	18.8	16.7		8.4	10.7
s.e.d.	3.90	1.14	4.5	3.95	2.44	0.77		0.37	0.48
Prob.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

VII Characterisation of commercially available winter oats for total beta-glucan content

Sub-samples were extracted from grain harvested from 1991 yield trials for seven varieties of winter oats (two naked and five husked). Yield trials were established in October 1990 at three diverse locations: Berriew (Powys), Winterbourne Stoke (Wiltshire) and Dundee (Tayside). Each trial had three replicates, received standard rates of nitrogen and was kept weed-free.

Total beta-glucan levels on a groat/DM basis were assessed as in Section V. Results (Table 6) indicate statistically significant differences between locations, with Berriew (mean = 5.17%) having consistently higher beta-glucans than Dundee (by 9%) or Winterbourne Stoke (by 11%). The factor or factors responsible for this variation are not known. Aintree (5.36%), Craig (5.22%) and Mirabel (5.11%) had higher beta-glucan than Kynon (4.84%), Image (4.76%) and Pendragon (4.22%), with Solva (3.96%) having relatively low beta-glucans. Differences were not great however: the best variety being only 5% better than the mean of all varieties though nearly 36% better than Solva. In this series of samples, a statistically significant interaction between varieties and locations was found. In this respect, Pendragon and, to a lesser extent Kynon, had lower than expected beta-glucan values at Winterbourne Stoke in Wiltshire.

Table 6
Levels of total beta-glucans (% groat DM) in commercial varieties of winter oats at three locations in 1991

	Berriew	Winterbourne Stoke	Dundee	Mean
Solva	3.92	4.17	3.80	3.96
Image	5.11	4.67	4.51	4.76
Craig	5.66	4.97	5.01	5.22
Aintree	5.35	5.55	5.23	5.37
Mirabel	5.42	5.13	4.78	5.11
Kynon (naked)	5.33	4.36	4.85	4.84
Pendragon (naked)	5.36	3.79	5.01	4.72
Mean	5.17	4.66	4.74	4.86

Availability levels with standard errors of differences are

(a) between locations = $P<0.001$; 0.103
(b) between varieties = $P<0.001$; 0.157
(c) varieties x locations = $P<0.001$; 0.273

In a separate study, Longland and Valentine (1993) reported values of insoluble, soluble and total beta-glucans for the same set of varieties grown at the same locations in 1991 determined using a modification of the enzymic method of Aman and Graham (1987). For total beta-glucans, similar differences between sites were found (Berriew = 5.45, Winterbourne Stoke = 4.06, Dundee = 4.44) and the range of varietal differences was similar to that presented in Table 6. There were, however, differences in the ranking of varieties. In that study, the naked oat Pendragon had the highest total beta-glucan concentration. Differences are probably due to differences in methodology, for instance the solvent used to extract the soluble beta-glucan fraction.

VII <u>Characterisation of commercially available spring oats for total beta-glucan content</u>

Sub-samples were extracted from grain harvested from 1991 yield trials for five varieties of spring oats including the naked oat variety Rhiannon. Yield trials were established at two locations, Morfa Mawr in Dyfed and Sarn in Powys. Each trial had three replicates, received standard rates of nitrogen and was kept weed-free.

Total beta-glucan levels were assessed as in Section V. Results (Table 7) indicate the differences between locations to be relatively small. Differences between varieties were small, in the range 4.95-5.17% over the two locations with the exception of Melys, with a beta-glucan content of 5.76%. There was no evidence of differential values of beta-glucans for varieties at different locations.

Table 7
Levels of total beta-glucans (% groat DM) in commercial varieties of spring oats at two locations in 1991

	Morfa Mawr	Sarn	Mean
Dula	5.34	5.00	5.17
Rollo	4.99	4.91	4.95
Valiant	5.15	5.19	5.17
Melys	5.86	5.66	5.76
Rhiannon	5.16	4.87	5.02
Mean	5.30	5.13	5.21

Probability levels with standard errors of difference are

(a) between locations = NS; 0.153
(b) between varieties = 0.05; 0.241
(c) varieties x locations = NS; 0.342

IX Conclusions

Valuable broad conclusions can be drawn from the further year of extension of this project.

Since the initial report of the production of stable BC1 F3 and BC2 F2 *A.maroccana* x *A.sativa* families with the *A.sativa* chromosome number of 42 (Thomas, Haki and Arangzeb, 1980), concerted effort has been spent on combining high protein from these families (lines) with high yield and good agronomic characteristics. Some useful progenies were identified which could be evaluated further, but in general, it has not proved possible to combine high levels of protein and yield in the face of negative, although incomplete, associations between protein and yield. It is possible that the protein genes from *A.maroccana* are linked with genes conferring low yield or that the bio-energetic cost of increasing protein is too great. It is proposed that a better route to the production of high protein oats is by the development of dwarf varieties in which late applications of nitrogen fertiliser can be channelled into high protein levels.

In contrast, selection for high oil content seems more promising. Whereas limited progress was being made using the genetic source Pioneer (Section IV), lines derived from *A.sterilis* (Section VI) have been confirmed to have very high oil content (up to 16.2%). A negative correlation between groat oil % and yield of genetic resources reflect the lack of adaptedness of the high oil lines relative to UK varieties rather than an inherent inverse association between oil content and yield, since more recent work (Surek, 1993) has shown positive or zero rather than negative associations between oil content and grain yield.

The significance of increased oil levels lies in the increased energy value of the grain for animal feed and a greatly increased potential for industrial extraction of oil. As far as the former is concerned, on the basis that an increase of 1% DM oil gives an increase of about 0.25 MJ/DM (ADAS, 1986), the predicted effect of increased levels of oil on ME is shown in Table 8.

Table 8

The predicted effect of increased levels of oil in winter naked and husked oats compared to other cereals

	Winter Naked Oats				Winter Husked Oats				Wheat[1]	Barley[1]
	Present[2]	Predicted			Present[3]	Predicted				
Oil (% DM)	10	12	14	16	6	8	10	12	1.9	1.3
Metabolisable energy (MJ/kg DM)	14.7	15.2	15.7	16.2	12.4	12.9	13.4	13.7	13.6	12.8

Source of data: [1] MAFF (1986), [2] Everington (1989), [3] Anon (1988)

The commercial viability of potential applications of oat oil in the cosmetic, confectionery and pharmaceutical industries is currently being assessed (Green, 1992; Mason, 1992). The economic attractiveness of extraction will, however, undoubtedly improve with the development of commercially acceptable varieties containing higher levels of oil. Oat oil has a good perception in the cosmetic industry and also contains natural tocols which have antioxidant and vitamin properties. Under current EC rules, crops grown for industrial use can be grown on land receiving set-aside payments and are therefore very attractive to UK farmers.

In the final extension year of the project, variation in beta-glucans was examined. Beta-glucan, the main component of soluble fibre, is associated with major health benefits such as lowering blood cholesterol and regulating blood glucose (Ripsin *et al*, 1992). These findings have resulted in a number of new oat products and oat soluble fibre may also have a role as a fat replacer in cereal products such as cakes and biscuits (Anon, 1993b); enriching the beta-glucan fraction would be of obvious benefit to processors and consumers.

Limited variation was found for beta-glucan content in the groats (kernels) of commercially available winter and spring oats (Sections V, VII and VIII). Variation was probably insufficient to be a major factor governing varietal choice. Further work, however, would be justified in order to partition varietal, site and year effects. As far as future genetic improvement is concerned, it is necessary to turn to unadapted genetic sources. In particular, Vedette had a beta-glucan content 21% above Melys. Genetic improvements of this order would be economically significant. The existence of lines containing up to 60.7% more beta-glucans than average has recently been reported (Peterson, 1992).

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XII Appendices

Appendix 1

Parentage of crosses used in Section III

Three-way crosses (includes three F1 x F1 crosses)

88-156ACn	(*Av3260Cn1/15/1* x Solva) x Solva
88-157ACn	80-30Cn31 x (Av3260Cn1/15/1 x *79-77Cn5/2*)
88-169ACn	80-30Cn31 x (Av3290Cn1/3/1 x *79-77Cn5/2*)
88-174ACn	(Av3336 x Solva) x *Pendragon*
88-175ACn	*79-77Cn5* x (Av3336 x Solva)
88-176ACn	Solva x (Av1893/2 x Solva)
88-177ACn	80-30Cn31 x (Av1893/2 x Solva)
88-178ACn	81-110Cn9 x (Av1893/2 x Solva)
88-179ACn	(Av1893/2 x Solva) x (Av3290Cn2/13/1 x Solva)
88-180ACn	(Av3336 x Solva) x (Av1893/2 x Solva)
88-181ACn	(Av1893/2 x 81-24CnA/10) x 81-110Cn9
88-185ACn	81-110Cn9 x (Av1893/2 x *79-77Cn5/2*)
88-186ACn	Solva x (Av1893/4 x Solva)
88-187ACn	(Av1893/4 x Solva) x 82-3CnACn3/2
88-188ACn	(Av1893/4 x *79-77Cn5/2*) x *79-77Cn5*
88-189ACn	(Av1893/4 x *79-77Cn5/2*) x (Av3336 x Solva)

Two-way crosses

87-185Cn	*Av3260Cn1/15/1* x Solva
87-186Cn	*Av3260Cn1/15/1* x Craig
87-187Cn	*Av3260Cn1/15/1* x *79-77Cn5/2*
87-193Cn	*Av3281Cn2/1/1* x Solva
87-197Cn	Av3290Cn1/3/1 x 78-53Cn4
87-199Cn	Av3290Cn2/13/1 x Solva
87-200Cn	Av3290Cn2/13/1 x Craig
87-202Cn	*Av3336* x Solva
87-207Cn	Av1893/2 x Solva (putative)
87-208Cn	Av1893/2 x Solva
87-209Cn	Av1893/2 x 81-24ACn10
87-211Cn	Av1893/4 x Solva
87-213Cn	Av1893/4 x *79-77Cn5/2* (putative)

Lines in italics are naked oats.

Appendix 2

Characteristics of winter oat F3 progenies involving *A.maroccana*-derived spring oats for crosses between husked oats - individual cross results

		Height (cm)	Yield (g/plot)	Protein (%)	Protein yield (g/plot)	r Protein/ yield
88-176ACn	mean	122.7 ± 10.51	52.6 ± 15.56	10.67 ± 1.366	4.49 ± 1.448	-0.57***
(n = 61)	range	103 - 155	17.6 - 86.5	8.69 - 15.37	2.25 - 8.56	
88-177ACn	mean	127.8 ± 10.58	48.3 ± 14.97	11.72 ± 1.679	5.53 ± 1.484	-0.55*
(n = 19)	range	108 - 147	27.6 - 69.7	9.37 - 14.56	3.02 - 8.92	
88-178ACn	mean	109.0 ± 10.02	47.4 ± 12.31	11.36 ± 1.493	5.32 ± 1.343	-0.34***
(n = 231)	range	85 - 134	18.6 - 97.2	8.75 - 16.87	2.16 - 10.69	
88-179ACn	mean	116.8 ± 10.35	44.9 ± 14.34	11.30 ± 0.682	5.02 ± 1.477	-0.62 NS
(n = 8)	range	100 - 134	20.0 - 67.8	10.12 - 12.37	2.59 - 7.25	
88-181ACn	mean	91.8 ± 6.63	45.5 ± 11.34	10.88 ± 1.002	4.92 ± 1.150	-0.33*
(n = 47)	range	78-110	23.6 - 71.2	9.19 - 13.25	2.65 - 7.59	
88-186ACn	mean	106.5 ± 7.15	50.2 ± 9.02	10.97 ± 0.844	5.50 ± 1.026	-0.08 NS
(n = 27)	range	93 - 120	37.5 - 76.0	9.12 - 12.69	3.48 - 8.17	
88-187ACn	mean	115.6 ± 9.18	41.6 ± 11.92	10.60 ± 1.123	4.39 ± 1.123	-0.37***
(n = 179)	range	88 - 140	14.6 - 81.9	7.75 - 15.31	1.70 - 10.17	
87-197Cn	mean	117.7 ± 7.33	37.7 ± 18.27	12.11 ± 1.83	4.33 ± 1.80	-0.72***
(n = 21)	range	105 - 132	10.1 - 77.8	9.19 - 15.1	1.43 - 8.61	
87-199Cn	mean	122.8 ± 11.04	29.5 ± 12.44	12.68 ± 1.41	3.65 ± 1.37	-0.50*
(n = 18)	range	97 - 143	13.9 - 63.1	11.00 - 15.31	2.07 - 7.26	
87-200Cn	mean	117.3 ± 6.50	25.5 ± 8.40	13.73 ± 1.461	3.49 ± 1.218	-0.09 NS
(n = 16)	range	107 - 132	11.8 - 46.7	10.69 - 16.69	1.75 - 6.54	
87-208Cn	mean	111.6 ± 8.60	39.0 ± 10.17	11.44 ± 1.362	4.43 ± 1.138	- 0.25 NS
(n = 25)	range	98 - 127	22.3 - 65.0	8.75 - 14.31	2.73 - 7.56	
87-209Cn	mean	111.6 ± 7.57	39.9 ± 10.47	11.88 ± 1.472	4.74 ± 1.379	-0.09 NS
(n = 39)	range	89 - 123	17.4 - 58.1	9.56 - 15.13	1.95 - 8.39	
87-211Cn	mean	113.2 ± 9.46	34.3 ± 8.07	12.59 ± 1.639	4.29 ± 1.057	-0.23 NS
(n = 23)	range	100 - 146	19.9 - 46.6	9.69 - 16.69	2.60 - 6.38	

Appendix 3

Characteristics of winter oat F3 progenies involving *A.maroccana*-derived spring oats with one or more naked oat parents - individual cross results

	Height (cm)	Yield (g/plot)	Protein (%)	Protein yield (g/plot)	Naked grains (%)	r Protein/ yield
88-156ACn (n=30)	110.7 ± 8.22	42.1 ± 14.33	12.34 ± 1.736	5.08 ± 1.510	61.1	-0.47**
Husked (n=2)	117.5 ± 0.71	42.9 ± 15.49	11.03 ± 0.486	4.70 ± 1.499	2.5	-
Naked (n=7)	111.0 ± 9.22	37.5 ± 6.78	13.61 ± 1.367	5.05 ± 0.706	99.7	-0.62 NS
88-157ACn (n=45)	116.0 ± 8.53	41.3 ± 12.52	12.71 ± 1.577	5.20 ± 1.474	43.8	-0.30*
Husked (n=16)	113.2 ± 9.66	42.6 ± 15.64	11.71 ± 0.864	4.96 ± 1.791	1.2	-0.27 NS
Naked (n=10)	117.7 ± 7.45	34.5 ± 4.89	14.42 ± 1.534	4.97 ± 0.811	100.0	-0.15 NS
88-169ACn (n=30)	128.4 ± 7.771	43.8 ± 11.77	11.99 ± 1.044	5.22 ± 1.404	4.5	-0.29 NS
Husked (n=30)	128.4 ± 7.771	43.8 ± 11.77	11.99 ± 1.044	5.22 ± 1.404	4.5	-0.29 NS
88-174ACn (n=5)	134.4 ± 7.64	27.0 ± 6.01	16.26 ± 0.67	4.38 ± 0.934	99.0	-0.27 NS
Naked (n=5)	134.4 ± 7.64	27.0 ± 6.01	16.26 ± 0.67	4.38 ± 0.934	99.0	-0.27 NS
88-175ACn (n=23)	122.0 ± 7.87	41.6 ± 12.62	10.77 ± 1.02	4.40 ± 1.100	48.7	-0.64***
Husked (n=11)	122.5 ± 7.41	52.1 ± 8.07	9.94 ± 0.428	5.16 ± 0.718	1.8	-0.38 NS
Naked (n=11)	122.0 ± 8.92	31.0 ± 6.50	11.61 ± 0.769	3.63 ± 0.915	99.1	0.46 NS
88-185ACn (n=35)	104.5 ± 9.82	35.8 ± 10.49	13.43 ± 1.240	4.76 ± 1.360	83.0	-0.33*
Husked (n=2)	100.0 ± 14.14	50.4 ± 12.87	11.1 ± 2.210	5.43 ± 0.310	2.5	-
Naked (n=20)	107.8 ± 8.73	35.1 ± 9.52	13.70 ± 0.993	4.78 ± 1.266	97.5	-0.31 NS
88-189Cn (n=12)	116.3	29.8 ± 11.0	14.12 ± 1.70	4.10 ± 1.420	96.7	-0.66**
Naked (n=9)	116.7 ± 4.47	28.0 ± 11.29	14.58 ± 1.617	3.97 ± 1.498	98.9	-0.73*
87-185Cn (n=47)	128.7 ± 9.71	38.7 ± 12.98	11.30 ± 1.170	4.33 ± 1.390	40.0	-0.29*
Husked (n=19)	124.1 ± 9.26	41.3 ± 17.74	11.35 ± 0.994	4.63 ± 1.883	2.4	-0.36 NS
Naked (n=9)	132.1 ± 9.05	37.4 ± 7.56	11.79 ± 1.422	4.39 ± 0.929	96.1	-0.24 NS
87-186Cn (n=14)	110.2 ± 5.32	23.9 ± 3.52	13.53 ± 0.872	3.23 ± 0.490	82.5	-0.18 NS
Naked (n= 5)	114.4 ± 4.28	25.0 ± 2.56	13.55 ± 0.835	3.38 ± 0.345	97.0	-0.26 NS
87-187Cn (n=30)	112.4 ± 6.99	33.5 ± 10.41	13.81 ± 1.760	4.56 ± 1.177	91.7	-0.55**
Husked (n=2)	109.5 ± 4.95	53.7 ± 3.61	10.25 ± 0.619	5.52 ± 0.702	2.5	-
Naked (n=26)	112.3 ± 7.32	31.7 ± 9.04	14.30 ± 1.447	4.49 ± 1.205	98.6	-0.31 NS
87-193Cn (n=36)	115.1 ± 7.16	35.2 ± 8.82	12.72 ± 1.175	4.44 ± 1.071	88.6	-0.32 NS
Husked (n=1)	120.0	39.50	11.94	4.71	5.0	-
Naked (n=24)	115.2 ± 7.56	32.71 ± 8.07	12.93 ± 1.305	4.20 ± 1.305	99.0	-0.30 NS
87-202Cn (n=40)	119.9 ± 7.71	25.1 ± 2.46	15.05 ± 2.255	3.54 ± 1.231	89.6	-0.85***
Naked (n=30)	118.7 ± 7.53	23.82 ± 12.68	15.46 ± 2.250	3.44 ± 1.257	98.2	-0.88***
87-207Cn (n=43)	110.1 ± 6.18	36.6 ± 9.25	12.34 ± 1.352	4.48 ± 1.106	97.6	-0.35*
Naked (n=37)	110.2 ± 5.78	36.1 ± 8.21	12.49 ± 1.29	4.48 ± 1.01	99.3	-0.30 NS
87-213Cn (n=7)	113.7 ± 7.610	39.0 ± 3.74	12.40 ± 1.880	4.82 ± 0.882	4.3	-0.07 NS
Husked (n=7)	113.7 ± 7.610	39.0 ± 3.74	12.40 ± 1.880	4.82 ± 0.882	4.3	-0.07 NS