Dehulling capacity and storability of naked oat

Anna-Maija Kirkkari

Work Efficiency Institute, Department of Agriculture, PO Box 13, FIN-05201 Rajamäki, Finland,
e-mail: anna-maija.kirkkari@tts.fi

Pirjo Peltonen-Sainio

MTT Agrifood Research Finland, Plant Production Research, FIN-31600 Jokioinen, Finland

Pekka Lehtinen

Helsinki University of Technology, Laboratory of Biochemistry and Microbiology, PO Box 6100,
FIN-02015 TKK, Finland

Harvested naked oat is not completely hulless. Hull content of various cultivars ranged between one and six percent. Genotype and environment control expression of nakedness. Using different threshing settings at different grain moisture contents, it was investigated whether grain moisture at threshing and combine harvester settings affected hull content and its relationship to germination capacity. Naked groats were stored at room temperature and analysed for protein content and fatty acid composition to determine storability. Grain moisture content at threshing had contrary effects on hull content and degree of hull retention in different years. Small grains tended to retain hulls more tightly during threshing. Grain filling capacity appears to be the dominant factor determining degree of nakedness rather than stage of maturity. The postulated protective nature of hulls was confirmed only for cultivar Lisbeth. Highly viable samples of grain of cv. Lisbeth, threshed at normal settings, contained a higher percentage of hulls than those with low germination capacity, while for cv. Bullion, a protective effect of the hulls was not evident. Grain moisture content at threshing did not affect protein content of naked cultivars, but some differences in fatty acid composition were recorded. Changes in lipid composition and volatile oxidation products during storage of groats were relatively moderate, indicating no major problems related to storage when naked oat was dried well.

Key words: *Avena sativa* L. nuda, germination, grain, grain moisture, groat, combine harvesters, hulls, naked oat, storage, threshing

Introduction

Oat (*Avena sativa* L.) florets are protected by two bracts or scales, the lemma on the outside and the palea on the inside (Bonnett 1961). Unlike conventional oat, the lemma of naked oat is thin and papery, containing only a little lignin, and from which the naked grain threshes free similarly to wheat and rye (Valentine 1995, Ougham et al. 1996). However, dehulling of naked oat is not complete. Experiments carried out with naked oat in Finland showed that the hull content of different cultivars generally ranged between one and six percent, although some cultivars had hull contents as high as 13 percent (Kangas et al. 2001). Variation in hull retention was reported to be substantial (Lawes 1971, Machan 1998). It is possible to increase the expression of nakedness through plant breeding. Modern cultivars can have less than one percent of hulled grains. Kangas et al. (2001) reported that the latest breeding lines of naked oat had a lower proportion of hulls in grains. This study aimed to compare dehulling capacity of different cultivars under Finnish growing conditions.

The single gene *N-1* controls the attachment of the hull to the groat. Three additional alleles (*N-2, N-3* and *N-4*) interact with *N-1*, and their combined effect contributes to the degree of nakedness of naked oat (Kibite 2002). There are four principal phenotypes of naked oat: completely naked, partially naked, partially hulled and completely hulled. Lawes and Boland (1974) reported that ten of 89 diverse naked genotypes grown in a field produced completely naked grains. The mosaic phenotype is a mixture of naked and covered kernels, in various proportions, depending on the alleles at the N-2 and N-3 loci (Kibite 2002).

The attachment of the hull is associated with factors including lignin content of the lemma, the multiflorous character and the length of the rachilla. In cultivars with mosaic expression of nakedness, the lignin content of the lemma varies greatly. Some groats retain the lemma while others thresh free from them (Valentine 1995).

The spikelet of naked oat is multiflorous, often bearing three or more florets per spikelet. Conventional oat usually has two fertile florets. The earlier the floret is set in the panicle, the more physiologically mature it is at threshing and the more probably it is also dehulled. Grains retaining hulls are often from the least mature spikelets.

In addition to genotype, environmental conditions markedly control the expression of nakedness (Boland and Lawes 1973). Lawes and Boland (1974) found that naked oat grown in the greenhouse regularly produced more naked groats than that grown in the field. They surmised that temperature has a major effect: at 25˚C, the expression of nakedness was complete in all cultivars studied, while at 20˚C some cultivars dehulled incompletely and at 15˚C only one cultivar expressed complete nakedness. Jenkins (1973) also reported that cool conditions prior to heading resulted in more hulled groats when compared with warm conditions. According to Lawes and Boland (1974), the degree of nakedness of early-sown naked oat was higher than that of late sown. One possible reason for this was that the late sown oat developed under conditions more prone to higher temperature. Moreover, the longer the light period, the higher the degree of nakedness. Furthermore, there are some indications that dry growing conditions increase hull retention (Cuddeford 1995). Thus, the aim of this study was to evaluate whether grain moisture at threshing and combine harvester settings affect hull content. As hulls are evidently important for successful germination and seedling establishment through protecting the groat from mechanical damage (Fulcher 1986, Peltonen-Sainio et al. 2001), the connection between the hull content and germination capacity was also investigated.

When the groat is damaged, lipase becomes active and breaks down fatty acids to produce a rancid flavour. Because naked oat is far more susceptible to mechanical damage than conventional oat (Valentine 1995, Thorton 1986, Kirkkari et al. 2001, Peltonen-Sainio et al. 2001), it has been assumed to be also more susceptible to

AGRICULTURAL AND FOOD SCIENCE

Kirkkari, A.-M. et al. Dehulling capacity and storability of naked oat

developing a distinctive rancid flavour associated with hydrolysis and oxidation of oat lipids. Our additional aim was to gauge the storability of naked oat.

Material and methods

Experiment 1

The Finnish naked oat cultivar Lisbeth and the British cultivar Bullion were grown in an experiment carried out at the research farm of the Work Efficiency Institute in Rajamäki, southern Finland, in 1998–2000. The experiment was sown at three different dates using standard farm machinery in spring to obtain grain samples from plants grown under different growing conditions and at different threshing moisture contents. The naked oat cultivars tested differed in their groat properties. A hectolitre of the seed were used each year in test weighed of cv. Bullion 68.6 kg and cv. Lisbeth 62.7 kg. Correspondingly, one thousand groats of cv. Bullion weighed 29.5 g and of cv. Lisbeth 27.8 g.

The naked oat cultivars were sown in 250 m² field plots, samples from which were threshed in three to seven different rounds at different grain moisture contents. The autumn weather conditions determined the number of threshing rounds each autumn to get as many samples as possible with different threshing moisture con-

tents. The threshing was carried out using standard farm machinery at three different threshing settings. The normal setting was used in 1998 with the cylinder (diameter 450 mm) speed at 1200 rpm (28 m s⁻¹) (recommended in the user manual for threshing conventional oat) and with the front concave clearance set at 18 mm and the rear concave clearance at 7 mm. In 1999, two cylinder speeds were used, 1200 rpm (28 m s⁻¹) and 900 rpm (21 m s⁻¹) and normal concave clearance set. In 2000, the concave clearance was reduced, with the front concave clearance setting at 15 mm and the rear at 5 mm and only one cylinder speed, 1200 rpm (28 m s⁻¹), was used. (Table 1).

After each threshing round, a sample of approximately 3 kg of grain was taken from the hopper of the combine harvester. To analyse the grain moisture, 10 g of whole grain was dried at 130˚C for 19 hours and weighed. After harvesting, the samples were dried with cold air and the germination analyses were carried out approximately four months after harvesting. Germination analyses (4 × 100 seeds on blotting paper) were made at the Plant Production Inspection Centre. Germination was classified from four replicates as being normal, abnormal or nonviable. Only normally germinating grains with undamaged radicles and hypocotyls were included in calculation of the germination percentage.

The samples from 1998–2000 were analysed for the proportion of hulls remaining attached to the groats as a percentage of the weight of three sub-samples of approximately 5 grams

Table 1. Threshing settings and moisture content at harvest.

Year	Threshing settings		
	Cylinder speed, rpm	Concave clearance, mm	Moisture content, %
1998	1200	18/7	20–44
1999	900	18/7	15–37
	1200	18/7	15–36
2000	1200	18/7	17–28
	1200	15/5	17–26

each. The hulled groats were separated from the sample, dehulled by hand and the proportion of the hulls of the total sample was weighed (termed hull content %). In addition, the number of hulled groats per one hundred groats was assessed for samples from 1999 and 2000 (termed degree of hull retention %). The impact of degree of nakedness on groat damage (germination damage), hull content and threshing moisture content was tested across threshing settings and cultivars.

Experiment 2

An additional set of experiments was arranged to study the association between grain size and hull content. The contribution of threshing moisture content induced variation in groat breakage and hull content to storability, in terms of effects on fatty acid composition and synthesis of volatile lipid oxidation products, was also investigated. Two replicate samples of grain (each ca. 250 grams) of five naked oat cultivars, Bullion, Lisbeth, Neon, Rhiannon and SW95926 were manually sorted into naked and hulled samples. The cultivars were grown at Viikki Experimental Farm of the University of Helsinki in 1999 and were harvested at grain moisture content of ca. 20%. The naked grains from each cultivar were weighed and sorted using sieve sizes of 1.7 and 2.0 mm. The grains > 2.0 mm, >1.7 mm and <1.7 mm were weighed and the grain size distribution (%) among these three size groups was determined. Grains retaining hulls of each cultivar were first dehulled by hand and the resulting naked yield was sorted into three size groups and the proportion of each size group was determined as described above. Expression of nakedness of cultivars SW95926 and Rhiannon was, however, complete in 1999 and hence, grain size distribution of unhulled grains was not possible.

Grain yield from the naked cultivars Bullion and Lisbeth grown in 1998 and 1999 at Viikki Experimental Farm and from a conventional reference cultivar Salo, were harvested at three or four moisture contents. Cultivar Bullion was harvested at grain moisture contents of 10.5,

23.0, 27.4 and 45.0% in 1998 and, 13.7, 19.9, 23.6 and 42.5% in 1999. Cultivar Lisbeth was harvested at 10.1, 20.2, 26.1 and 41.6% in 1998 and, 12.1, 19.1 and 30.9% in 1999. The conventional reference cultivar Salo was harvested at 10.1, 18.7, 26.7 and 37.6% in 1998 and, 12.4, 20.7, 24.9 and 35.2% in 1999. In 1999 additional control samples at grain moisture content of 19.9% for cv. Bullion, 19.1% for cv. Lisbeth and 16.5% for cv. Salo were manually threshed to avoid any mechanical stress induced grain damage caused by combine harvesting. Hull content (%) was measured by dehulling the grains retaining hulls by hand, weighing the hulls and groats and calculating the proportion of hulls from the total sample. Degree of hull retention (%) was measured as the number of grains retaining hulls in a sample of 100 grains. Hull content and degree of hull retention were analysed from three replicate samples. About 50 g of each sample (a total of 26), including only naked groats, was analysed for protein content (through Kjeltec Auto 1030 Analyzer) and fatty acid composition (through gas chromatography) after storage at room temperature (20˚C) until September 2000 (i.e., yield 1998 for two years and 1999 for one year). Grain composition was analysed at MTT Chemistry Laboratory using accredited, standardised methods.

Naked groat samples of cv. Bullion and cv. Lisbeth, representing different moisture contents at harvest, and those of conventional reference cultivar Salo were analysed for volatile lipid oxidation products. Volatile lipid oxidation products were determined essentially as described in Heiniö et al. (2002). Briefly, headspace composition of the sample was determined by static headspace measurement. Prior to the measurement, the sealed vials were equilibrated at 100˚C for 25 minutes. The headspace sample was then fed into a gas chromatograph equipped with a mass selective detector. The detector signals were calibrated using an external standard and all data were normalized so that for each compound, the maximum response was set to unity.

AGRICULTURAL AND FOOD SCIENCE

Kirkkari, A.-M. et al. Dehulling capacity and storability of naked oat

Results

Variation in hull content and degree of hull retention

In Experiment 1, the hull content (mass) for cultivar Lisbeth varied between 1.2 and 7.1%, with a mean of 3.9% depending on year. The hull content of cultivar Bullion was significantly lower, varying from 0.4 to 5.2%, the average being 1.6%. In 1999, when only 63 mm of precipitation accumulated from drilling to harvest, the hull percentage of naked oat was high, whereas under the favourable growing conditions of 2000, the hull content was lower.

Contrary to the recorded cultivar differences in hull content, the degree of hull retention was clearly higher in cultivar Lisbeth than in cv. Bullion. In cv. Lisbeth it ranged from 29.59% to 21.53%, whereas in cv. Bullion it was 12.11% to 9.84% (Table 2). Degree of hull retention of cv. Lisbeth was also higher under the dry conditions of 1999, while cultivar Bullion had slightly more hull retaining grains in 2000 than 1999.

Experiment 2 comprised five naked oat cultivars and results indicated that in both years cultivars Lisbeth and Bullion had low hull content ranging from less than 1 to 5% (Fig. 1). Cultivar Neon also had very low hull content, less than 3% at maximum. Cultivar Rhiannon and particularly cultivar SW95926 exhibited high hull contents, approaching 15%. Degree of hull retention changed in parallel with that of hull content (Figs. 2 and 3). In general, ten percentage units increase in degree of hull retention resulted in three percentage units increase in hull content.

Threshing moisture content and the hull content

High moisture contents at threshing increased hull content in cv. Bullion, but not in cv. Lisbeth when standard threshing settings were used. However, in 2000 the degree of hull retention decreased as grain moisture increased. Also in Experiment 2, contrary responses to grain moisture occurred. Namely, in 1998 hull content and degree of hull retention increased with increased grain moisture, while in 1999 they decreased. Cultivar Neon was the only exception to this tendency as its hull content and degree of hull retention always increased at increasing threshing moisture contents.

Table 2. Variation in the proportion of hull content (mass) and degree of hull retention (number) in cv. Lisbeth and cv. Bullion. Standard error of the mean (± SE) is given in parentheses.

| Cultivar Threshing settings	Year	Hull content %			Degree of hull retention (%)		
		Normal threshing	Low cylinder speed	Narrow concave clearance	Normal threshing	Low cylinder speed	Narrow concave clearance
Lisbeth	1998	2.85 (1.81)					
	1999	4.60 (1.52)	4.33 (0.96)		27.79 (4.91)	29.59 (5.01)	
	2000	4.44 (1.36)		4.67 (1.26)	21.53 (8.12)		23.96 (5.52)
Bullion	1998	1.51 (0.79)					
	1999	1.56 (1.39)	1.58 (0.97)		10.11 (6.21)	12.11 (7.70)	
	2000	2.27 (0.95)		1.90 (0.82)	10.12 (3.96)		9.84 (3.63)
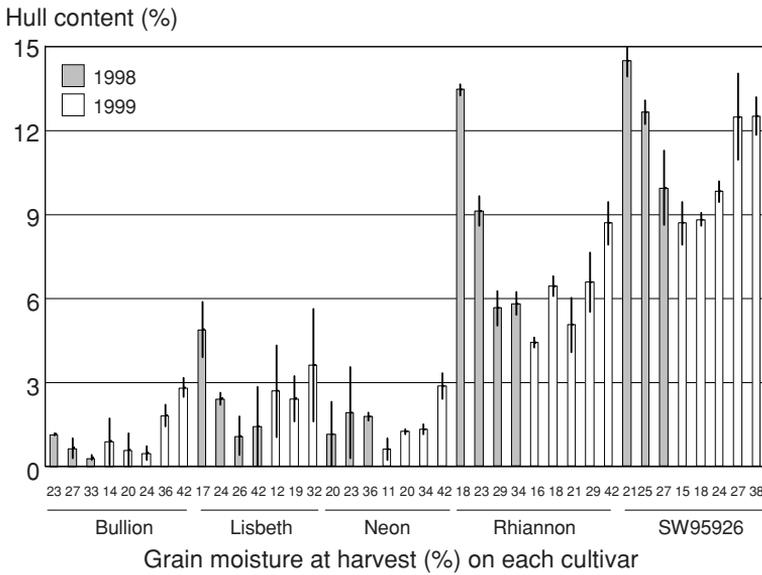
Hull content (%)

Fig. 1. Hull content of five naked oat cultivars at different threshing moisture content in 1998 and 1999. Error bars indicate standard error of mean.
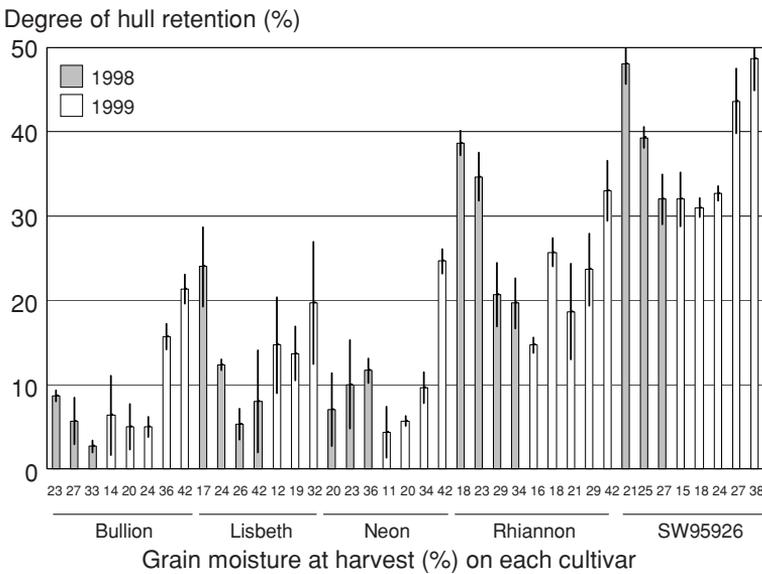
Degree of hull retention (%)

Fig. 2. Degree of hull retention of five naked oat cultivars at different threshing moisture contents in 1998 and 1999. Error bars indicate standard error of mean.

Threshing settings and the expression of nakedness

Low cylinder speeds, resulting in more gentle threshing and less mechanical stress, were asso-ciated with increased hull content in both culti-vars with increasing threshing moisture contents. Reduced concave clearance increased hull con-tent in cultivar Lisbeth and decreased in cv. Bul-lion as the threshing moisture content increased (Fig. 4).

Kirkkari, A.-M. et al. Dehulling capacity and storability of naked oat

Hull content (%)

$$Y=0.0021X^2+0.19X1.171$$
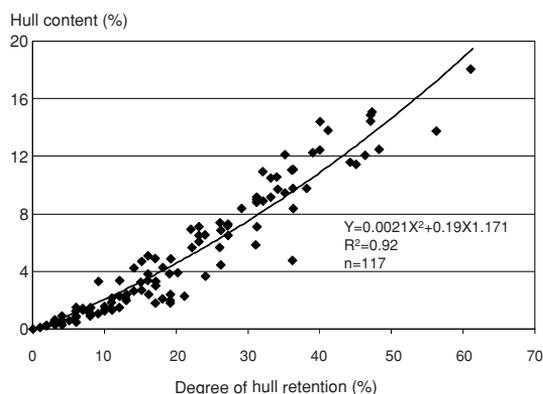$$R^2=0.92$$
$$n=117$$

Degree of hull retention (%)

Fig. 3. Association between degree of hull retention and hull content of five naked oat cultivars in 1998–1999.

Effect of degree of hull retention on germination damage

In these experiments, the seed batches of cv. Lisbeth that germinated well after normal threshing contained more hulls than the poorly germinating ones, but not in cv. Bullion. After threshing at a low cylinder speed, samples of cv. Bullion that germinated well contained fewer hulls than for those that germinated poorly. In cv. Lisbeth, at low cylinder speed, hull content was not associated with germination capacity (Fig. 5). For both cultivars, the samples that germinated well after threshing at a reduced concave clearance contained fewer hulls than those that germinated poorly.

Grain size distribution and hull content

Results from the experiment with five naked oat cultivars indicated that sorting groats liberated from hulls during threshing into three size groups resulted in 33 to 48% of groats > 2.0 mm depending on cultivar (Table 3). The small-grained cv. Lisbeth was, however, an exception, as only some 3% of its groats were > 2.0 mm. About 40 to 61% of naked groats were between 1.7 and 2.0 mm and only some 11–22% and 35% in size group ≤1.7 mm, in other naked cultivars and cv. Lisbeth respectively. When grains retaining hulls were manually dehulled and sorted, groat size distribution was contrary to that in groats liberated from hulls during threshing. Only 4–14% of dehulled grains were > 2.0 mm, while groat size groups 1.7–2.0 mm and ≤1.7 mm dominated.

Storage quality

When studying the effects of grain moisture content on grain composition after one (harvested in 1999) and two years (harvested in 1998) storage at room temperature, our results indicated that no threshing moisture content induced variation was associated with protein content of naked cultivars, Bullion and Lisbeth, or conventional cv. Salo (data not shown). However, some differences in fatty acid composition were recorded. Manually threshed control samples in particular had a higher proportion of polyunsaturated fatty acids in all cultivars independent of grain moisture content. The proportions of fatty acids were dependent on the year of harvest such that 1998 samples had lower linoleic acid concentrations compared with samples harvested in 1999 (Fig. 6). No systematic threshing moisture content effects on any of the measured fatty acid concentrations were recorded.

Major differences in production of volatile compounds were found between years, while there were far fewer among cultivars. Compared with groat samples stored for one year, the samples stored for two years clearly produced more volatile compounds known to result from oxidation of unsaturated fatty acids (Table 4). The presence of these volatile oxidation products was not systematically affected by the moisture content during threshing, but appears to reflect the fatty acid composition of the sample. The low content of polyunsaturated fatty acids in samples stored for two years was associated with a high level of volatile oxidation products. Thus,
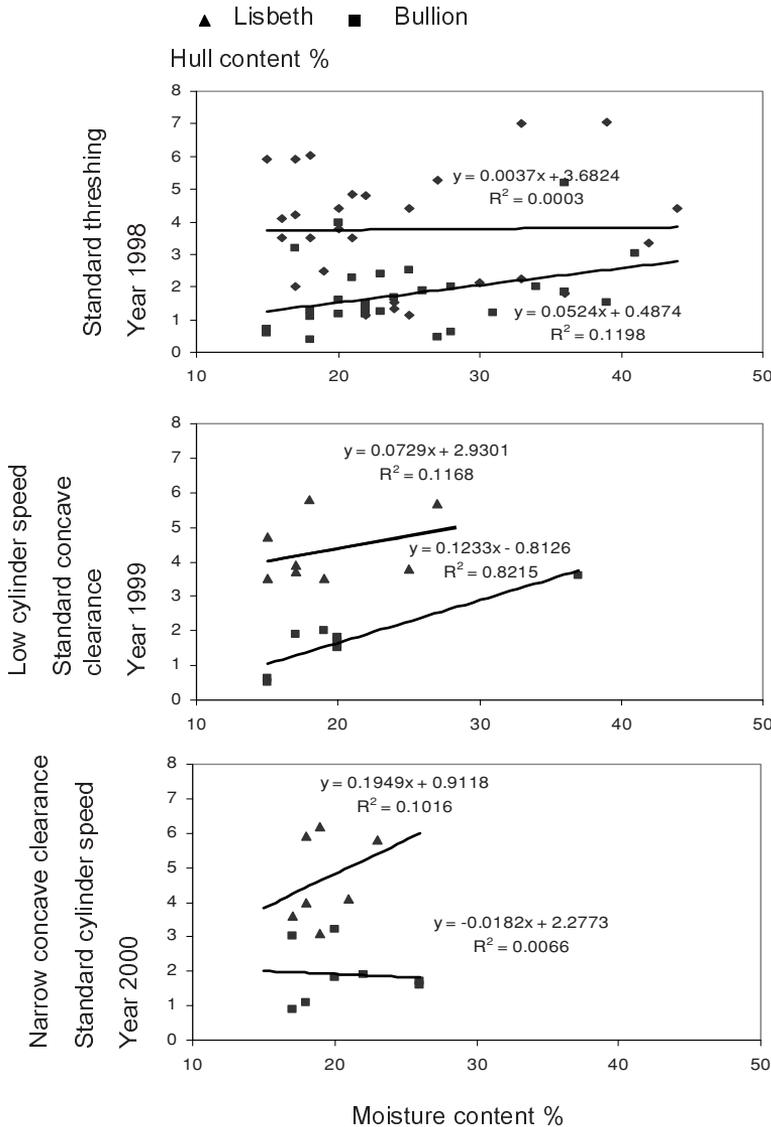
Fig. 4. Hull content and grain moisture at harvest in oat cultivars Lisbeth and Bullion in 1998–2000.

the variation of fatty acid content may be partly explained by the specific loss of unsaturated fatty acids due to oxidation.

Threshing moisture content affected the concentrations of another groups of volatile compounds that probably indicate degradation of amino acids or microbe and/or enzyme activity (Table 5). In this case differences between years were modest. The higher the grain moisture at harvest, the higher the concentration of isobutanal in cv. Bullion in 1998 and cv. Salo in 1999, isopentanal and 3-pentanon in cv. Salo in 1999, and fenylacetaldehyde in cultivars Bullion and Salo in 1999.
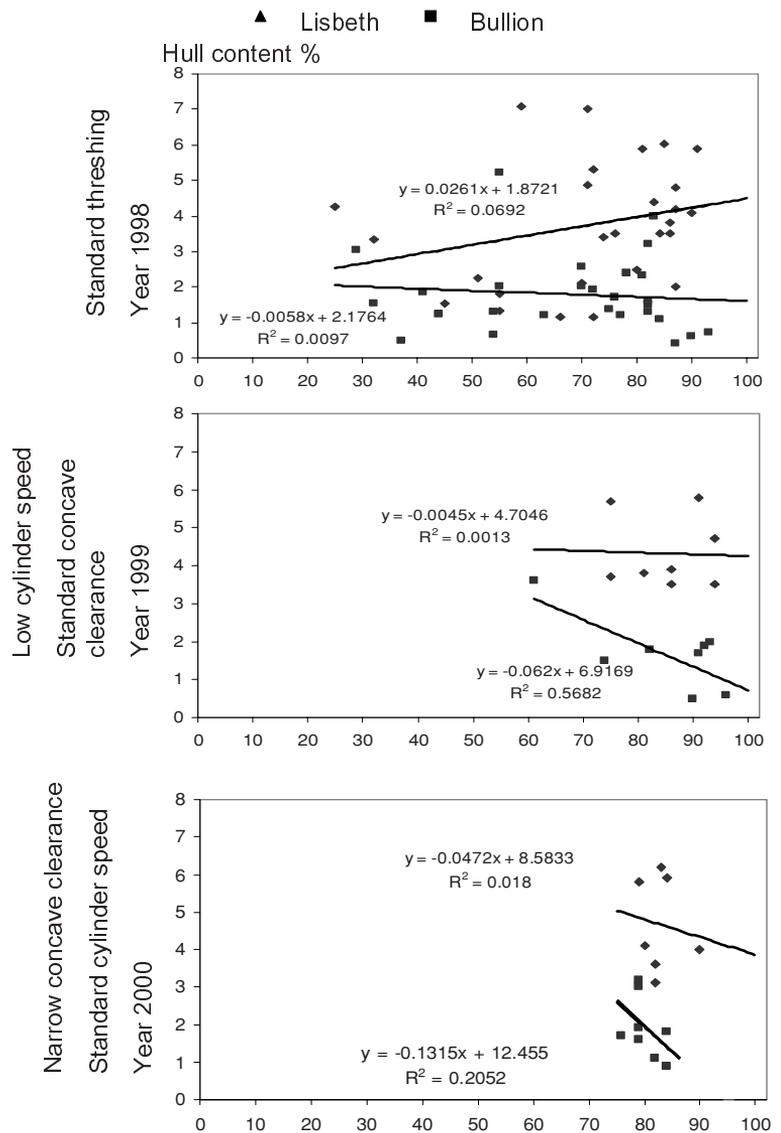
Kirkkari, A.-M. et al. Dehulling capacity and storability of naked oat

Fig. 5. Hull content and germination capacity in oat cultivars Lisbeth and Bullion in 1998–2000.

Discussion

Expression of nakedness

Grain moisture content at threshing had contrary effects on hull content and degree of hull retention in different years. The hull content was at its highest in 2000 at the same time as the proportion of hull-retaining grains was as its lowest in Experiment 1. Growing conditions in 2000 probably favoured full and relatively slow ripening better than in 1999 when severe drought occurred, improving dehulling capacity. This indicates that the hulls remaining attached to the grains must have been heavy, which could also

Table 3. Proportion of different groat size groups (%) dehulled during threshing and grains retaining hulls after manual dehulling. Standard error of mean (± SE) is given in parentheses.

Cultivar	Groats dehulled during threshing[1]			Grains retaining hulls after dehulling[2]		
	> 2.0 mm	1.7–2.0 mm	< 1.7 mm	> 2.0 mm	1.7–2.0 mm	< 1.7 mm
Bullion	47.2 (1.5)	39.7 (1.2)	13.2 (0.3)	11.5 (0.8)	42.8 (2.4)	45.8 (3.1)
Lisbeth	3.4 (0.1)	61.5 (0.1)	35.2 (0.1)	3.8 (0.2)	44.2 (1.2)	52.1 (1.0)
Neon	33.2 (0.4)	45.0 (0.4)	21.9 (0.8)	14.1 (1.3)	43.9 (1.8)	42.1 (0.6)
Rhiannon	46.8 (0.2)	41.7 (0.4)	11.5 (0.5)	–	–	–
SW95926	47.7 (0.4)	41.1 (0.8)	11.3 (0.4)	–	–	–

[1] Results shown earlier in Peltonen-Sainio et al. (2001).

[2] Due to almost complete expression of nakedness when threshed, no data available for cultivars Rhiannon and SW95926

result from contamination of naked oat by conventional oat. For Experiment 2, high grain moisture at harvest resulted in decreased hull content and degree of hull retention in 1998 when the growing season was rainy and oat matured late. The opposite response was registered in 1999 under constant drought (Fig. 2), although in both cases the aim was to harvest grains only when they were physiologically fully mature. Only the cultivar Neon expressed similar trends in both years: the lower the moisture content, the fewer grains retaining their hulls. Strong correlation ($R^2 = 0.92$) between degree of hull retention and hull content in Experiment 2 (Fig. 3) suggested that there was no marked growing-condition dependent difference in hull weight and no mixing of hulled and naked oat. As there were contrasting results for grain moisture effects on dehulling capacity, there was no recommended range established for threshing moistures favouring dehulling. Peltonen-Sainio et al. (2004) concluded that when an impact dehuller was used, the lower moisture contents resulted in higher dehulling capacity. Threshing settings had only limited effects on hull content and degree of hull retention, contrary to our postulation that gentle threshing increases the hull percentage.

Fig. 6. Effect of harvest moisture on contents of saturated, monounsaturated and polyunsaturated fatty acids in naked oat cultivars Bullion and Lisbeth and conventional Salo in 1998 and 1999.

The function of hulls is to protect the groat (Welch 1995). In an experiment by Thorton (1986), naked oat that retained hulls was not damaged to a similar extent as dehulled oat during threshing. The embryo of naked oat protrudes from the groat, which has been presumed to be a reason for sensitivity to damage, in addition to the softness of the groat (Valentine 1995). However, the experiments of Thorton (1986) and Peltonen-Sainio et al. (2001) showed no constant
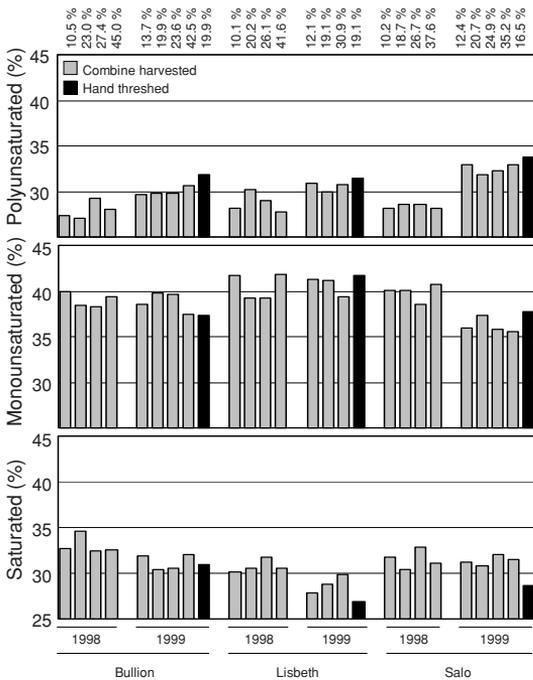
A G R I C U L T U R A L   A N D   F O O D   S C I E N C E

Kirkkari, A.-M. et al. Dehulling capacity and storability of naked oat

Table 4. Normalised concentrations of volatile compounds associated with oxidation of unsaturated fatty acids. Standard error of mean ($\pm$ SE) is given in parentheses ($\pm$ SE of 0.01 indicates that $\pm$ SE is < 0.01).

Moisture content (%)	Pentanal	1-Pentanol	Hexanal	1-Hexanol	Pentylfuran	Nonanal
cv. Bullion 1998						
10.5	0.57 (0.03)	1.00 (0.08)	0.93 (0.04)	0.88 (0.01)	1.00 (0.03)	0.73 (0.10)
23.0	0.38 (0.05)	0.47 (0.05)	0.43 (0.02)	0.65 (0.05)	0.35 (0.01)	0.31 (0.03)
27.4	0.32 (0.02)	0.51 (0.03)	0.48 (0.02)	0.65 (0.05)	0.37 (0.01)	0.28 (0.01)
45.0	0.47 (0.01)	0.43 (0.03)	0.60 (0.02)	0.43 (0.06)	0.45 (0.02)	0.34 (0.01)
cv. Bullion 1999						
13.7	0.22 (0.01)	0.28 (0.03)	0.32 (0.02)	0.39 (0.04)	0.48 (0.02)	0.48 (0.18)
19.9	0.15 (0.01)	0.28 (0.02)	0.16 (0.01)	0.29 (0.12)	0.19 (0.00)	0.19 (0.03)
23.6	0.27 (0.02)	0.29 (0.03)	0.29 (0.01)	0.35 (0.03)	0.42 (0.01)	0.32 (0.04)
42.5	0.35 (0.02)	0.26 (0.03)	0.37 (0.01)	0.19 (0.09)	0.40 (0.01)	0.25 (0.05)
Control (19.9)	0.13 (0.02)	0.19 (0.01)	0.14 (0.01)	0.39 (0.04)	0.14 (0.01)	0.15 (0.02)
cv. Lisbeth 1998						
10.1	0.55 (0.05)	0.66 (0.05)	0.83 (0.06)	0.71 (0.01)	0.74 (0.03)	1.00 (0.07)
20.2	0.27 (0.01)	0.32 (0.03)	0.36 (0.03)	0.45 (0.03)	0.34 (0.01)	0.26 (0.03)
26.1	0.28 (0.01)	0.38 (0.04)	0.37 (0.04)	0.54 (0.06)	0.32 (0.02)	0.36 (0.08)
41.6	0.42 (0.02)	0.29 (0.02)	0.51 (0.02)	0.26 (0.06)	0.46 (0.01)	0.39 (0.05)
cv. Lisbeth 1999						
12.1	0.32 (0.02)	0.37 (0.03)	0.41 (0.01)	0.30 (0.03)	0.53 (0.01)	0.45 (0.05)
19.1	0.16 (0.01)	0.20 (0.02)	0.18 (0.01)	0.38 (0.02)	0.17 (0.01)	0.20 (0.01)
30.9	0.24 (0.01)	0.20 (0.02)	0.24 (0.01)	0.20 (0.01)	0.34 (0.01)	0.47 (0.01)
Control (19.1)	0.16 (0.01)	0.10 (0.01)	0.12 (0.01)	0.33 (0.02)	0.15 (0.01)	0.15 (0.02)
cv. Salo 1998						
10.1	1.00 (0.07)	0.8 (0.05)	1.00 (0.03)	1.00 (0.02)	0.82 (0.04)	0.89 (0.06)
18.7	0.99 (0.05)	0.69 (0.02)	0.92 (0.03)	0.75 (0.06)	0.78 (0.02)	0.79 (0.03)
26.7	0.90 (0.02)	0.67 (0.04)	0.91 (0.01)	0.80 (0.04)	0.88 (0.01)	0.95 (0.03)
37.6	0.85 (0.01)	0.54 (0.04)	0.74 (0.02)	0.40 (0.03)	0.64 (0.01)	0.64 (0.02)
cv. Salo 1999						
12.4	0.41 (0.01)	0.24 (0.01)	0.23 (0.01)	0.37 (0.03)	0.23 (0.01)	0.31 (0.07)
20.7	0.42 (0.03)	0.24 (0.01)	0.24 (0.01)	0.42 (0.05)	0.21 (0.01)	0.32 (0.06)
24.9	0.51 (0.03)	0.28 (0.01)	0.34 (0.01)	0.36 (0.03)	0.38 (0.01)	0.32 (0.11)
35.2	0.71 (0.01)	0.35 (0.02)	0.45 (0.01)	0.41 (0.01)	0.51 (0.01)	0.42 (0.15)
Control (16.5)	0.44 (0.02)	0.28 (0.02)	0.35 (0.01)	0.39 (0.05)	0.50 (0.01)	0.78 (0.31)

association between protrusion of embryo and sensitivity to groat damage. Groat damage was not associated with groat weight, length, roundness or diameter (Peltonen-Sainio et al. 2001). The postulated protective nature of hulls was confirmed only for cultivar Lisbeth. Highly viable samples of cv. Lisbeth, threshed at normal settings, had a higher hull percentage than those with low germination ability, while for cv. Bullion, there was no evident protective effect of the hulls. As reduced concave clearance did not

decrease hull content, it likewise did not affect germination capacity.

The hull content and degree of hull retention varied among cultivars. On the basis of the results for Lisbeth, one could assume that it is a mosaic cultivar, in which the lignin content of hulls varies greatly and, thus, makes its hull content non-responsive to even rough handling. An alternative is that hull retention of cultivar Lisbeth is associated with its exceptional grain size distribution compared with other tested cultivars.

Table 5. Normalised concentrations of volatile compounds possibly associated with degradation of amino acids that could indicate microbe or enzyme activity.

Moisture content (%)	Isobutanal	Isopentanal*	3-Pentanon*	Fenylacetaldehyde
cv. Bullion 19981				
0.5	0.061 (0.003)	–	–	0.145 (0.008)
23.0	0.072 (0.003)	–	–	0.107 (0.002)
27.4	0.076 (0.003)	–	–	0.152 (0.014)
45.0	0.228 (0.012)	0.304 (0.019)	0.285 (0.015)	0.430 (0.028)
cv. Bullion 1999				
13.7	0.129 (0.005)	0.125 (0.001)	0.118 (0.013)	0.128 (0.010)
19.9	0.103 (0.003)	0.254 (0.002)	0.222 (0.003)	0.135 (0.033)
23.6	0.162 (0.006)	0.171 (0.007)	0.199 (0.006)	0.230 (0.035)
42.5	0.390 (0.075)	0.350 (0.006)	0.350 (0.006)	0.320 (0.058)
Control (19.9)	0.113 (0.004)	0.088 (0.001)	–	0.109 (0.021)
cv. Lisbeth 1998				
10.1	0.069 (0.002)	–	–	0.148 (0.008)
20.2	0.127 (0.046)	–	–	0.138 (0.015)
26.1	0.092 (0.005)	–	–	0.169 (0.006)
41.6	0.370 (0.069)	0.450 (0.011)	0.360 (0.006)	0.660 (0.012)
cv. Lisbeth 1999				
12.1	0.127 (0.008)	0.116 (0.001)	–	0.117 (0.020)
19.1	0.106 (0.005)	0.109 (0.002)	–	0.100 (0.001)
30.9	0.192 (0.007)	0.180 (0.043)	0.211 (0.027)	0.200 (0.015)
Control (19.1)	0.080 (0.007)	–	–	0.126 (0.020)
cv. Salo 1998				
10.1	0.208 (0.006)	0.226 (0.015)	0.253 (0.016)	0.340 (0.012)
18.7	0.163 (0.005)	0.191 (0.006)	0.225 (0.016)	0.340 (0.041)
26.7	0.156 (0.004)	0.184 (0.014)	0.230 (0.007)	0.287 (0.009)
37.6	1.000 (0.127)	1.000 (0.017)	1.000 (0.023)	1.000 (0.017)
cv. Salo 1999				
12.4	0.169 (0.001)	0.180 (0.009)	0.194 (0.017)	0.218 (0.027)
20.7	0.212 (0.012)	0.190 (0.012)	0.212 (0.027)	0.265 (0.082)
24.9	0.390 (0.035)	0.298 (0.019)	0.285 (0.019)	0.370 (0.064)
35.2	0.520 (0.011)	0.35 (0.006)	0.430 (0.006)	0.490 (0.052)
Control (16.5)	0.340 (0.064)	0.247 (0.006)	0.245 (0.002)	0.380 (0.081)

–, not detectable

In general, as in convention oat, sorting and pre-cleaning aim at even size distribution for better dehulling properties in industry (Deane and Commers 1986). In this study, we noted that cv. Lisbeth had very small grains, but it had also very high hull content. Hence, in cultivars other than Lisbeth and Bullion, small grains tended to retain hulls more tightly during threshing (Table 3). This may indicate that the most advanced grains were more completely filled and mature and therefore, also better able to dehull. This, together with our finding of growing condition effects on dehulling capacity, may emphasise that grain filling capacity is the dominant factor in determination of degree of nakedness rather than stage of ripening.

AGRICULTURAL AND FOOD SCIENCE

Kirkkari, A.-M. et al. Dehulling capacity and storability of naked oat

Storability

The changes in lipid composition and in the volatile oxidation products during storage of oat groats were relatively moderate. The most obvious change was the slight oxidation of linoleic acid during storage over 1–2 years. This was probably due to groat breakage in the combine harvester as oxidation was minimal in the manually threshed groats. The moisture content during harvesting was however not critical in determining the stability of unsaturated fatty acids. Compared with conventional oat, all the naked oat cultivars studied were of similar storage stability.

The presence of degradation products of amino acids in the oats harvested at high moisture content, especially in conventional cultivar Salo, may be explained by the germination prior to harvesting. As these compounds are associated with positive flavour parameters, the moisture content prior to harvesting probably has a large effect on groat properties (Heiniö et al. 2002).

References

Boland, P. & Lawes, D.A. 1973. The inheritance of naked grain character in oats studied in a cross between the naked variety Caesar and the husked variety BO 1/11. *Euphytica* 22: 582–591.

Bonnett, O.T. 1961. The oat plant: Its histology and development. *Bulletin* 672. University of Illinois, Agricultural Experiment Station. 112 p.

Cuddeford, D. 1995. Oats for animal feed. In: Welch, R.W. (ed.). *The oat crop, production and utilization*. Chapman & Hall, London, UK. p. 321–368.

Deane, D. & Commers, E. 1986. Oat cleaning and processing. In: Webster, F.H. (ed.). *Oats: chemistry and technology*. American Association of Cereal Chemists, St Paul, MN. p. 371–412.

Fulcher, R.G. 1986. Morphological and chemical organization of the oat kernel. In: Webster, F.H. (ed.). *Oats: chemistry and technology*. American Association of Cereal Chemists, St Paul, MN. p. 47–71.

Heiniö, R.-L., Lehtinen, P., Oksman-Caldentey, K.-M. & Poutanen, K. 2002. Differences between sensory profiles and development of rancidity during long-term storage of native and processed oat. *Cereal Chemistry* 79: 367–375.

Jenkins, G. 1973. The effect of sowing date and photoperiod on panicle morphology in naked oats. *Annals of Applied Biology* 73: 85–94.

Kangas, A., Salo, Y. & Vuorinen, M. 2001. Paljasjyväisten kauralajikkeiden satoisuus. (The yield of naked oat). In: Kaurasta elinvoimaa. *EKT-sarja* 1221. Helsinki, Finland. p. 77–83. (In Finnish).

Kibite, S. 2002. An isozyme marker linked to the *N-1* gene coverning nakedness in oat. *Oat Newsletter* v. 48. Updated 2 Oct 2002. Cited 1 Apr 2003. Available on the Internet: http://wheat.pw.usda.gov/ggpages/newsletter/v48/Isozyme.htm

Kirkkari, A.-M., Peltonen-Sainio, P. & Rita, H. 2001. Reducing grain damage in naked oat through gentle harvesting. *Agricultural and Food Science in Finland* 10: 223–229.

Lawes, D.A. 1971. Oat improvement – recent research and developments. *Field Crop Abstracts* 24: 203–215.

Lawes, D.A. & Boland, P. 1974. Effect of temperature on the expression of the naked grain character in oats. *Euphytica* 23: 101–104.

Machan, F. 1998. Performance and quality of naked oat cultivars of the world collection, Czech Republik, 1995–1997. Updated 2 Aug 1998. Cited 3 Oct 1999. Available on the Internet: http://wheat.pw.usda.gov/ggpages/oatnewsletter/oatnews_main.html

Ougham, H.J., Lapitova, G. & Valentine, J. 1996. Morphological and biochemical characterization of spikelet development in naked oats (*Avena sativa*). *New Phytologist* 134: 5–12.

Peltonen-Sainio, P., Kontturi, M., Rajala, A. & Kirkkari, A.-M. 2004. Impact dehulling oat grain to improve quality of on-farm produced feed. I Hullability and associated changes in nutritive value and energy content. *Agricultural and Food Science* 13: 18–28.

Peltonen-Sainio, P., Muurinen, S., Vilppu, M., Rajala, A., Gates, F. & Kirkkari, A.-M. 2001. Germination and grain vigour of naked oat in response to grain moisture at harvest. *Journal of Agriculture Science, Cambridge* 137: 147–156.

Thorton, M.S. 1986. *Investigations into the problems associated with the development of naked oats as a crop*. PhD. Thesis: University of Wales, Aberystwyth.

Valentine, J. 1995. Naked oats. In: Welch, R.W. (ed.). *The oat crop, production and utilization*. Chapman & Hall, London, UK. p. 504–527.

Welch, R.W. 1995. Naked oats. In: Welch, R.W. (ed.). *The oat crop, production and utilization*. Chapman & Hall, London, UK. p. 279–320.

SELOSTUS

Paljasjyväisen kauran kuoriutuvuus ja säilyvyys

Anna-Maija Kirkkari, Pirjo Peltonen-Sainio ja Pekka Lehtinen
Työtehoseura ry., MTT (Maa- ja elintarviketalouden tutkimuskeskus) ja Teknillinen Korkeakoulu

Paljasjyväisen kauran kuoriutuminen puinnissa ei ole täydellistä, vaan kuorta jää jyviin 1–6 % lajikkeesta ja ympäristöoloista johtuen. Vaikka paljasjyväisen kauran kuoriksi sanotut helpeet ovat paperiset ja hauraat ja kuoripitoisuus on pieni, toisin kuin tavanomaisella kauralla, vähäisetkin määrät kuoria alentavat paljasjyväisen kauran käyttömahdollisuuksia. Siksi loppukäyttäjän tavoitteena onkin mahdollisimman hyvin kuoriutunut paljasjyväinen kaura. Tässä tutkimuksessa selvitettiin paljasjyväisten kauralajikkeiden kuoriutumista erilaisissa puintikosteuksissa ja erilaisilla puintisäädöillä. Lisäksi tutkittiin paljasjyväisen kauran jyvän kokojakauman, itävyyden ja säilyvyyden yhteyttä kuoriutuvuuteen. Kokeet tehtiin Työtehoseuran, Helsingin yliopiston Viikin ja MTT:n Jokioisten koetiloilla sekä säilyvyysanalyysit Teknillisessä korkeakoulussa.

Puintikosteus vaikutti eri tavalla kuoripitoisuuteen ja kuorellisten jyvien määrään eri vuosina. Kasvuoloiltaan suotuisana vuonna 2000 kuorellisten jyvien määrä oli alhaisimmillaan, vaikka kuoriprosentti olikin korkeampi kuin kuivana vuonna 1999. Sateisena vuonna 1998 korkea puintikosteus vähensi kuoripitoisuutta ja kuorellisten jyvien määrää, kun vaikutus oli päinvastainen kuivana vuonna 1999. Puintisäädöillä oli vain vähäinen vaikutus paljasjyväisen kauran kuoriutuvuuteen. Kuoripitoisuudessa ja kuorellisten jyvien määrässä oli eroja lajikkeiden välillä. Myös jyvän koolla oli vaikutusta kuoriutuvuuteen, sillä pienet jyvät kuoriutuivat huonoimmin. Tästä voisi päätellä, että suurempien jyvien jyvän täyttyminen on ollut täydellisempää, mikä näin edistäisi kuoriutuvuutta. Tulosten mukaan jyvän täyttymisolosuhteet vaikuttavat kuoriutumiseen enemmän kuin jyvän valmistumisaste.

Kuorien suojaava vaikutus tuli esille vain Lisbeth-lajikkeella, sillä sen hyvin itävissä jyvänäytteissä oli enemmän kuorta kuin huonosti itävissä. Sen sijaan Bullion-lajikkeella tätä vaikutusta ei havaittu. Puintikosteus ei olennaisesti vaikuttanut kauran säilyvyyteen.