

## Chemical composition of hulled, dehulled and naked oat grains

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### Abstract

The objective of the work was to evaluate the influence of genetic and mechanical removal of hulls from oat grains on their nutrient content. The studies included three cultivars and six lines of oat grains. In grain samples of hulled (5 samples), dehulled (5 samples) and naked (4 samples) oats, the following components were determined: chemical composition (ash, crude protein, crude fat, crude fibre and its components) and amino acids and fatty acid composition. The grain of naked and dehulled oats contained significantly more crude protein, crude fat and polyunsaturated fatty acids, and considerably less saturated fatty acids and crude fibre than hulled oats. In addition, the dietary fibre composition was more favourable than the naked oats. The coefficients of nutritional values of the protein (total essential amino acids, essential amino acid index and amino acids score) of naked oats were higher than hulled and dehulled oats. In all the tested oat grain samples, lysine was the most limiting amino acid. The study showed that genetic and mechanical reduction of the proportion of hulls in oat grains resulted in a significant decrease in dietary fibre content and a significant increase in nutrient content.

**Keywords:** Hulled and dehulled oat grains, naked oat grains, chemical composition

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### Introduction

Oat grains (*Avena sativa*) have multifunctional uses, including as animal feed, human food and in health care. However, the cultivation area of oats in the world is remarkably smaller than for other cereal crops such as maize, wheat and barley (Koehler & Wieser, 2013). This is probably owing to the lower yield of oats compared with the other cereals (Brand *et al.*, 2003). Oats tolerate wet weather and acidic soils far better than other cereals, are resistant to disease, and require less agro-chemical and fertilizer input (Givens *et al.*, 2004). As a consequence, their production costs may be similar to wheat or barley.

The nutritional value of oat grain makes it a very useful component of the diet for humans and animals. The amino acid composition of oat grains is superior to that of other cereals because its major storage protein is globulin (Klose & Arendt, 2012). Globulins have a higher concentration of lysine and other essential amino acids than prolamins, which are typical cereal storage proteins (Shewry & Halford, 2002). Oat also contains a high percentage of lipids, particularly unsaturated fatty acid (Welch, 1995; Peterson, 1998; Zhou *et al.*, 1998).

Increasing interest in oat utilization for human consumption has been stimulated by the need for soluble fibre, particularly  $\beta$ -glucans in diet, which have beneficial effects on health (Chen *et al.*, 2006; Wood, 2007; Hsueh *et al.*, 2011). For animal feed, however, low  $\beta$ -glucan concentration is desirable, particularly for poultry (Guenter, 1993).

The high-fibre content, which depresses the available energy of hulled oat grain, restricts its use as an animal feed, particularly for pigs and poultry (Morris, 1990). Genetic removal of the glumes from oat grain (naked oat) considerably improved its chemical composition and nutritional value (Brand *et al.*, 2003). Naked oat grain has a lower fibre and higher energy value, and contains more protein and lipids compared with hulled oat grain (Brand *et al.*, 2003; Givens *et al.*, 2004; Biel *et al.*, 2009). As an alternative to naked oat, hulls can be separated from groats by dehulling grain before being fed to animals.

The aim of this study was to evaluate the influence on the nutrient content of genetic and mechanical removal of hulls from oat grain.

## Materials and Methods

The research material comprised two cultivars (Krezus and Bingo) and three lines (STH 6106, STH 6108, STH 7105) of hulled and dehulled oat, and one cultivar (Polar) and three lines (STH 7202, STH 7205, STH 7206) of naked oat. Hulled and naked oat grain samples were derived from the plot trials carried out in 2011 on a sandy clay soil type at Lipnik Experimental Station (near Szczecin – 53°12'N; 14°27'E), Poland. The experiment was carried out on a light soil of the IVb botanical class, using 550 grains/m<sup>2</sup> and 90 kg N/ha. Hulled oat grains were dehulled with an impact laboratory oat dehuller (LH 5095, Codema, USA). The grain samples were stored in tightly closed glass jars at room temperature pending analysis.

The chemical compositions of all grain samples were determined from the following AOAC (2006) procedures. The dry matter was established by drying the samples in an oven at 105 °C until a constant weight was obtained. Ash was ascertained by incineration in a muffle furnace at 580 °C for 8 h. Crude protein (N × 6.25) was obtained by the Kjeldahl method, using the Büchi Distillation Unit B-324 (Büchi Labortechnik AG, Switzerland). Ether extract was detected by Soxhlet extraction with diethyl ether. Crude fibre was determined with a fibre analyser, ANKOM 220 (ANKOM Technology, USA). Nitrogen-free extract was obtained by subtracting the sum of moisture, ash, crude protein, crude fat and crude fibre from 100. The fibre components were ascertained using the detergent method according to Van Soest *et al.* (1991), performed with a fibre analyser, ANKOM 220. Determination of neutral detergent fibre (NDF) was on an ash-free basis, and included sodium dodecyl sulphate (Merc 822050). Determination of acid detergent fibre (ADF) included hexadecyl-trimethyl-ammonium bromide (Merc 102342), while acid detergent lignin (ADL) was established by hydrolysis of an ADF sample in 72% sulphuric acid. Hemicellulose (HCEL) was calculated as the difference between NDF and ADF, and cellulose (CEL) as the difference between ADF and ADL. The content of  $\beta$ -glucans was determined enzymatically according to the ICC standard method (1998) using a Megazyme kit, K-BGLU (Megazyme International Ireland Ltd., Wicklow, Ireland). All components were expressed on a dry matter basis.

The free fatty acid analysis was performed on a VARIAN CP3800 gas chromatograph. Separation was performed in a capillary column, namely CPWAX 52 CB (60 m × 0.25 mm). The temperature of the injector and FID detector was 260 °C. The column temperature was 120 °C with a gradual increase to 210 °C. Helium was used as a carrier gas at a flow rate of 1.4 cm<sup>3</sup>/min.

Amino acids were determined using an AAA 400 automatic amino acid analyser (INGOS, Czech Republic). Samples were subjected to acid hydrolysis in the presence of 6 M HCl at 105 °C for 24 hours. Sulphur-containing amino acids were ascertained separately in 6 M HCl after oxidative hydrolysis using a mixture of formic acid and hydrogen peroxide at a ratio 9 : 1 v/v, for 20 h at 4 °C. Tryptophan was determined according to the method described in AOAC (2006). The amino acid composition was expressed in g/16 g N. Based on the amino acid composition in the protein of the oat grains, the following aspects were calculated: amino acids score (AAS) and essential amino acids index (EAAI) compared with egg white, used as the reference pattern (FAO/WHO/UNU, 1985). EAAI was calculated according to Oser (1951) as the geometric mean of the ratios of the essential amino acids in a protein to those of whole egg protein-reference pattern.

All the measurements were made in triplicate. Results were expressed as mean values. The data were subjected to a one-way analysis of variance (ANOVA). The significance of differences between means of the various forms of oats ( $\bar{x}_H$  – hulled oats,  $\bar{x}_{DH}$  – dehulled oats and  $\bar{x}_N$  – naked oats) was determined by Duncan's multiple range test using statistical computational software (Statistica PL, version 8.0).

## Results and Discussion

The chemical composition of dry matter of the oat grains is given in Table 1. The average contents of dry matter, ash and nitrogen free extract in grain of hulled ( $\bar{x}_H$ ), dehulled ( $\bar{x}_{DH}$ ) and naked oats ( $\bar{x}_N$ ) were not significantly different from one another. The mean contents of crude protein and ether extract in the grain of hulled oats (104.9 and 58.45 g/kg DM, respectively) were lower ( $P \leq 0.01$ ) than in the grain of dehulled (137.1 and 83.29 g/kg DM, respectively) and naked oats (126.7 and 84.09 g/kg DM, respectively). As expected, the crude fibre content in dehulled (13.49 g/kg DM) and naked oats (30.35 g/kg DM) was lower ( $P \leq 0.01$ ) than in hulled oats (104.80 g/kg DM). Dehulled oat, compared with naked oat, contained 8.2% more crude protein ( $P \leq 0.05$ ), with 2.2-fold less crude fibre ( $P \leq 0.01$ ). In this study, the mean crude protein values of hulled and naked oat were much lower than the values (143 and 159 g/kg DM, respectively) reported by Brand *et al.* (2003). In contrast, Givens *et al.* (2004) reported crude protein values of 93 g/kg DM for hulled oats and 120 g/kg DM for naked oats. Compared with other cereals, oat is unique in its high fat content (Frey & Holland, 1999). The results of the present study showed that the removal of hulls from oat grains significantly increased the fat content, which was confirmed by other authors (Brand *et al.*, 2003; Sykut-Domańska *et al.*, 2013). The oats Investigated differed considerably in crude fibre content, and for the dehulled and naked oat grains were comparable with wheat, maize and barley. Tamime *et al.* (1997) and

Medel *et al.* (1999) reported the crude fibre content of wheat, maize and barley as 1.3 to 2.2%, 2.1 to 2.4% and 2.4 to 5.6%, respectively.

**Table 1** Chemical composition of hulled, dehulled and naked oat grains (g/kg dry matter)

Oats	Cultivar / line	Dry matter	Ash	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract
Hulled oat	Krezus	894.5	21.0	106.1	52.8	109.7	710.5
	Bingo	896.2	20.5	99.4	57.7	97.1	725.2
	STH 6106	913.0	22.7	105.0	63.0	110.7	698.6
	STH 6108	914.3	22.3	109.2	56.9	114.5	697.2
	STH 7105	894.4	19.2	104.7	62.0	92.0	722.1
	$\bar{x}_H$	<b>902.5<sup>a</sup></b>	<b>21.13<sup>a</sup></b>	<b>104.9<sup>A</sup></b>	<b>58.45<sup>A</sup></b>	<b>104.8<sup>A</sup></b>	<b>710.7<sup>a</sup></b>
	SEM	4.58	0.63	1.59	1.85	4.34	5.78
Dehulled oat	Krezus	893.7	20.8	139.1	75.7	15.3	749.2
	Bingo	888.2	20.1	129.7	75.9	18.8	755.6
	STH 6106	906.8	18.7	130.2	90.9	12.7	744.6
	STH 6108	907.1	19.9	148.0	93.0	10.4	728.8
	STH 7105	896.1	19.5	138.6	81.1	10.4	750.5
	$\bar{x}_{Dh}$	<b>898.4<sup>a</sup></b>	<b>19.78<sup>a</sup></b>	<b>137.1<sup>Ba</sup></b>	<b>83.29<sup>B</sup></b>	<b>13.49<sup>B</sup></b>	<b>745.7<sup>a</sup></b>
	SEM	3.73	0.35	3.37	3.67	1.59	4.58
Naked oat	Polar	891.5	19.9	136.5	90.0	22.8	730.8
	STH 7202	894.2	17.7	129.8	85.5	27.2	739.8
	STH 7205	896.3	17.3	119.5	81.8	36.4	745.0
	STH 7206	891.5	18.0	121.2	79.1	35.1	746.7
	$\bar{x}_N$	<b>893.4<sup>a</sup></b>	<b>18.21<sup>a</sup></b>	<b>126.7<sup>Bb</sup></b>	<b>84.09<sup>B</sup></b>	<b>30.35<sup>C</sup></b>	<b>740.6<sup>a</sup></b>
	SEM	1.16	0.58	3.96	2.37	3.24	3.57

<sup>A,B,C</sup> Means  $\bar{x}_H$ ,  $\bar{x}_{Dh}$  and  $\bar{x}_N$  in columns with different superscripts differ significantly at  $P \leq 0.01$ .

<sup>a,b</sup> Means  $\bar{x}_H$ ,  $\bar{x}_{Dh}$  and  $\bar{x}_N$  in columns with different superscripts differ significantly at  $P \leq 0.05$ .

SEM: standard error of mean.

Reducing the proportion of hulls in grain oats decreased the concentration of the dietary fibre significantly (Table 2). Dehulled and naked oats contained less NDF (3.3- and 2.7-fold, respectively,  $P \leq 0.01$ ), ADF (7.7- and 3.4-fold, respectively,  $P \leq 0.01$ ), ADL (3.5- and 2.2-fold, respectively,  $P \leq 0.01$ ), HCEL (2.1- and 2.3-fold, respectively,  $P \leq 0.01$ ) and CEL (10.6 and 3.8-fold, respectively,  $P \leq 0.01$ ) than hulled oat. Dehulled oats, compared with naked oats contained higher concentrations of ADF ( $P \leq 0.01$ ), ADL ( $P \leq 0.01$ ), CEL ( $P \leq 0.01$ ) and NDF ( $P \leq 0.05$ ). The concentrations of NDF, ADF and HCEL in hulled and naked oats in our study are broadly in line with results reported by Givens *et al.* (2004).

Oats contains 26% hull (Todorov, 1988), which is one of the main reasons for the higher fibre content. The oat hull contains 386 g ADF/kg and 718 g NDF/kg (Van der Merwe & Smith, 1991). This demonstrates that the lower crude fibre content and favourable composition of dietary fibre in grains of dehulled oats than naked oats are mainly the result of lower proportions of hulls on the dehulled oat grains. The hull has a lower digestibility relative to the groat, and because of this, the proportion of hull in oats largely determines the energy value of the grain (Givens *et al.*, 2004). Dehulling oat grains increases the nutritive value and concentration of metabolizable energy (9% - 10%) for poultry and pigs, which results mainly from a marked reduction in fibre content in dehulled grains (Peltonen-Sainio *et al.*, 2004). A much higher content of digestible energy for pigs in the naked oats than in the hulled oats was reported by Brand *et al.* (2003) and Givens *et al.* (2004).

The average content of  $\beta$ -glucans in the tested hulled oat grain (31.24 g/kg DM) was lower ( $P \leq 0.01$ ) than in the grain of naked (by 41.4%) and dehulled oats (by 52.5%) (Table 2). The husk contains negligible amounts of  $\beta$ -glucans compared with the endosperm of the grain; thus naked oats contains a higher

percentage of  $\beta$ -glucans (range, 3.6% - 4.7%) compared with hulled oats (range, 2.9% - 3.5%) (Zute *et al.*, 2011).  $\beta$ -glucans decreases serum cholesterol, glucose and insulin levels in humans (Welch, 1995; Wood, 2007). However, for animal feed low  $\beta$ -glucans concentration is desirable, particularly for monogastric animals. Increased levels of  $\beta$ -glucans lead to decreased nutrient digestion and absorption in poultry (Burrows *et al.*, 1992) and, to an extent, in pigs (Van Barneveld & Hughes, 1994).  $\beta$ -glucans increase the viscosity of the digesta, leading to changes in the physiology and ecosystem of the gut (Choct *et al.*, 1996).

**Table 2** Components of dietary fibre of tested oat grains (g/kg dry matter)

Oats	Cultivar / line	NDF	ADF	ADL	HCEL	CEL	$\beta$ -glucans
Hulled oat	Krezus	380.3	183.7	33.65	196.6	150.1	27.5
	Bingo	329.5	156.2	36.10	173.3	120.1	34.7
	STH 6106	314.6	156.5	27.25	158.2	129.2	32.0
	STH 6108	306.9	141.3	27.80	165.6	113.5	33.2
	STH 7105	297.2	154.1	26.30	143.1	127.8	28.9
	$\bar{x}_H$	<b>325.7<sup>A</sup></b>	<b>158.4<sup>A</sup></b>	<b>30.22<sup>A</sup></b>	<b>167.4<sup>A</sup></b>	<b>128.1<sup>A</sup></b>	<b>31.24<sup>A</sup></b>
	SEM	14.64	6.93	1.95	8.85	6.17	1.34
Dehulled oat	Krezus	114.9	25.5	10.10	89.5	15.4	43.9
	Bingo	81.5	18.7	8.25	66.8	10.5	48.8
	STH 6106	112.1	21.9	8.85	90.2	13.0	49.7
	STH 6108	88.4	17.0	7.70	71.4	9.5	50.6
	STH 7105	92.7	19.9	7.95	72.8	12.0	45.3
	$\bar{x}_{Dh}$	<b>97.9<sup>Ba</sup></b>	<b>20.6<sup>B</sup></b>	<b>8.57<sup>B</sup></b>	<b>78.12<sup>B</sup></b>	<b>12.04<sup>B</sup></b>	<b>47.64<sup>B</sup></b>
	SEM	6.63	1.45	0.43	4.89	1.03	1.29
Naked oat	Polar	144.6	47.8	12.00	96.8	35.8	42.4
	STH 7202	108.8	51.2	13.80	57.7	37.4	46.3
	STH 7205	111.8	45.3	13.45	66.6	31.8	39.2
	STH 7206	110.9	43.7	14.75	67.2	29.0	48.9
	$\bar{x}_N$	<b>119.0<sup>Bb</sup></b>	<b>47.0<sup>C</sup></b>	<b>13.50<sup>C</sup></b>	<b>72.05<sup>B</sup></b>	<b>33.48<sup>C</sup></b>	<b>44.18<sup>B</sup></b>
	SEM	8.55	1.63	0.57	8.53	1.91	2.12

<sup>A,B,C</sup> Means  $\bar{x}_H$ ,  $\bar{x}_{Dh}$  and  $\bar{x}_N$  in columns with different superscripts differ significantly at  $P \leq 0.01$ .

<sup>a,b</sup> Means  $\bar{x}_H$ ,  $\bar{x}_{Dh}$  and  $\bar{x}_N$  in columns with different superscripts differ significantly at  $P \leq 0.05$ .

NDF: neutral detergent fibre; ADF: acid detergent fibre; ADL: acid detergent lignin; HCEL: hemicellulose; CEL: cellulose. SEM: standard error of mean.

Compared with the hulled oats, dehulled and naked oat fat contained less saturated fatty acids (SFAs) ( $P \leq 0.05$ ), including C16:0 ( $P \leq 0.05$ ) and C14:0 ( $P \leq 0.05$ ) (Table 3). The fat in the dehulled and naked oats contained about 79% unsaturated fatty acids (UFAs), compared to 74% in the hulled oats. One of the main UFAs was oleic acid, which is highly positively correlated with total fat content (Zhou *et al.*, 1998). Lipids in the naked and dehulled oats contained more ( $P \leq 0.05$ ) oleic acid than in the hulled oat. Zhou *et al.* (1998) reported that, compared with other cereals, naked oat has considerably more UFAs. Oats are rich in polyunsaturated fatty acids (PUFAs), including essential fatty acids in mammalian nutrition, such as linoleic acid (C18: 2n-6) and linolenic acid (C18: 3n-3). The dehulled and naked oat fat contained more PUFAs ( $P \leq 0.05$ ), including C18:2 and C18:3 ( $P \leq 0.05$ ) compared with the hulled oat. Givens *et al.* (2004) reported a linoleic acid content in naked and hulled oats of 37.4% to 38.9% and a total fatty acid content of 36.2% to 37.1%, respectively. The differences in the proportion of fatty acids (expressed as g/kg oat), between the hull-less and hulled oats will be much larger owing to the significantly higher ( $P \leq 0.01$ ; Table 1) crude fat content in the dehulled and naked oats compared with hulled oats. UFAs of oat are regarded as nutritionally important owing to the high content of essential fatty acids (Youngs, 1986).

**Table 3** Fatty acid composition of the tested oat grains (% of total fatty acids)

Oats	Cultivar / line	C14:0	C16:0	C18:0	C20:0	C16:1	C18:1	C20:1	C22:1	C18:2	C18:3	SFA	UFA	MUFA	PUFA
Hulled oat	Krezus	0.39	21.13	1.87	0.14	0.20	41.63	0.99	0.25	30.54	0.52	23.53	74.1	43.1	31.1
	Bingo	0.29	20.63	2.57	0.19	0.18	42.71	1.00	0.37	29.32	0.50	23.68	74.1	44.3	29.8
	STH 6106	0.36	20.57	2.39	0.21	0.31	44.06	0.99	0.53	27.67	0.73	23.53	74.3	45.9	28.4
	STH 6108	0.34	21.25	2.03	0.15	0.19	43.61	0.96	0.62	27.81	0.86	23.77	74.1	45.4	28.7
	STH 7105	0.39	21.39	1.86	0.16	0.18	43.31	1.00	0.53	28.30	0.94	23.80	74.3	45.0	29.2
	$\bar{x}_H$	<b>0.35<sup>a</sup></b>	<b>20.99<sup>a</sup></b>	<b>2.14</b>	<b>0.17</b>	<b>0.21<sup>a</sup></b>	<b>43.06</b>	<b>0.99<sup>a</sup></b>	<b>0.46</b>	<b>28.73<sup>a</sup></b>	<b>0.71<sup>a</sup></b>	<b>23.66<sup>a</sup></b>	<b>74.16</b>	<b>44.72</b>	<b>29.44<sup>a</sup></b>
	SEM	0.02	0.17	0.14	0.01	0.03	0.42	0.01	0.07	0.54	0.09	0.06	0.05	0.49	0.47
Dehulled oat	Krezus	0.24	19.51	2.02	0.16	0.17	42.94	0.82	0.27	32.20	0.91	21.93	77.3	44.2	33.1
	Bingo	0.23	18.67	1.92	0.17	0.16	43.01	1.12	0.36	32.94	0.64	20.99	78.2	44.7	33.6
	STH 6106	0.30	18.01	2.03	0.22	0.26	43.63	1.01	0.59	32.52	0.86	20.56	78.9	45.5	33.4
	STH 6108	0.31	17.78	1.68	0.14	0.20	42.84	0.98	0.63	33.62	0.96	19.91	79.3	44.7	34.6
	STH 7105	0.26	19.06	1.75	0.15	0.16	43.01	0.99	0.53	32.54	0.99	21.22	78.3	44.7	33.5
	$\bar{x}_{Dh}$	<b>0.27<sup>b</sup></b>	<b>18.61<sup>b</sup></b>	<b>1.88</b>	<b>0.17</b>	<b>0.19<sup>b</sup></b>	<b>43.09</b>	<b>0.98<sup>a</sup></b>	<b>0.48</b>	<b>32.76<sup>b</sup></b>	<b>0.87<sup>b</sup></b>	<b>20.92<sup>b</sup></b>	<b>78.39</b>	<b>44.75</b>	<b>33.63<sup>b</sup></b>
	SEM	0.02	0.32	0.07	0.01	0.02	0.14	0.05	0.09	0.24	0.06	0.34	0.34	0.23	0.25
Naked oat	Polar	0.20	17.57	1.74	0.16	0.14	44.34	0.77	0.27	33.21	0.95	19.71	79.5	45.4	34.2
	STH 7202	0.23	15.94	1.85	0.17	0.23	43.92	0.85	0.47	34.11	0.75	18.15	80.3	45.5	34.9
	STH 7205	0.25	17.51	2.09	0.10	0.18	41.31	0.70	0.40	35.04	0.90	19.75	78.5	42.6	35.9
	STH 7206	0.23	16.77	1.87	0.15	0.18	42.35	0.82	0.48	34.90	1.01	18.83	79.8	43.9	35.9
	$\bar{x}_N$	<b>0.23<sup>b</sup></b>	<b>17.00<sup>b</sup></b>	<b>1.89</b>	<b>0.15</b>	<b>0.18<sup>b</sup></b>	<b>42.98</b>	<b>0.78<sup>b</sup></b>	<b>0.41</b>	<b>34.32<sup>b</sup></b>	<b>0.90<sup>b</sup></b>	<b>19.09<sup>b</sup></b>	<b>79.55</b>	<b>44.33</b>	<b>35.21<sup>b</sup></b>
	SEM	0.01	0.29	0.05	0.02	0.01	0.75	0.03	0.04	0.42	0.06	0.33	0.36	0.74	0.45

<sup>a, b</sup> Means  $\bar{x}_H$ ,  $\bar{x}_{Dh}$  and  $\bar{x}_N$  in columns with different superscripts differ significantly at  $P \leq 0.05$ .

SEM: standard error of mean.

SFA: saturated fatty acids; UFA: unsaturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

**Table 4** Essential amino acid composition of protein of the tested oat grains (g/16 g N)

Item	Cultivar / line	Lys	Met	Met+Cys	Thr	Ile	Trp	Val	Leu	His	Phe	Phe+Tyr
Hulled oat	Krezus	3.37	1.77	4.44	2.68	2.73	1.52	4.64	6.43	2.54	4.23	6.14
	Bingo	3.45	1.62	4.26	2.91	2.91	1.47	4.57	6.74	2.70	4.28	6.25
	STH 6106	3.02	1.51	4.23	2.92	2.66	1.35	4.13	5.95	1.63	4.08	5.64
	STH 6108	3.21	1.65	4.54	2.98	2.73	1.14	4.33	6.68	1.83	3.99	5.37
	STH 7105	3.71	1.82	4.53	3.02	3.11	1.20	5.12	7.21	2.60	4.65	6.85
	$\bar{x}_H$	<b>3.35<sup>a</sup></b>	<b>1.67</b>	<b>4.40</b>	<b>2.90<sup>a</sup></b>	<b>2.83<sup>a</sup></b>	<b>1.32</b>	<b>4.56</b>	<b>6.60</b>	<b>2.26</b>	<b>4.25</b>	<b>6.09</b>
	SEM	0.12	0.05	0.07	0.06	0.08	0.11	0.17	0.21	0.22	0.11	0.31
Dehulled oat	Krezus	3.35	1.73	4.45	2.92	3.08	1.22	4.24	6.24	2.87	4.38	6.31
	Bingo	3.29	1.76	4.44	2.69	3.16	1.08	4.20	6.36	3.06	4.09	5.98
	STH 6106	3.55	1.69	4.48	3.05	2.77	1.22	4.46	6.51	1.83	4.41	5.65
	STH 6108	3.50	1.62	4.19	2.94	2.76	1.14	4.25	6.24	1.83	4.37	6.18
	STH 7105	3.39	1.98	4.86	2.84	3.20	1.27	4.82	6.53	2.08	4.54	6.96
	$\bar{x}_{Dh}$	<b>3.42<sup>a</sup></b>	<b>1.76</b>	<b>4.48</b>	<b>2.89<sup>a</sup></b>	<b>2.99<sup>a</sup></b>	<b>1.19</b>	<b>4.39</b>	<b>6.38</b>	<b>2.33</b>	<b>4.36</b>	<b>6.23</b>
	SEM	0.05	0.06	0.11	0.06	0.10	0.03	0.12	0.06	0.26	0.07	0.20
Naked oat	Polar	3.52	1.67	4.20	2.99	3.19	1.15	4.73	6.71	3.09	4.46	6.11
	STH 7202	3.66	1.83	4.60	3.02	3.19	1.26	4.71	6.54	2.13	4.69	7.44
	STH 7205	4.10	1.89	4.69	3.70	3.73	1.21	4.92	7.54	3.09	5.06	7.20
	STH 7206	3.84	1.79	4.61	3.80	3.51	1.12	4.85	7.79	2.94	5.11	7.04
	$\bar{x}_N$	<b>3.78<sup>b</sup></b>	<b>1.80</b>	<b>4.53</b>	<b>3.38<sup>b</sup></b>	<b>3.41<sup>b</sup></b>	<b>1.19</b>	<b>4.80</b>	<b>7.15</b>	<b>2.81</b>	<b>4.83</b>	<b>6.90</b>
	SEM	0.12	0.05	0.11	0.22	0.13	0.03	0.05	0.31	0.23	0.15	0.37

<sup>a, b</sup> Means  $\bar{x}_H$ ,  $\bar{x}_{Dh}$  and  $\bar{x}_N$  in columns with different superscripts differ significantly at  $P \leq 0.05$ .

SEM: standard error of mean.

Protein in naked oat grains contained more ( $P \leq 0.05$ ) lysine (Lys), threonine (Thr) and isoleucine (Ile) than in the dehulled and hulled oats (Table 4). The levels of the remaining amino acids in all oat grain (g/16 g N) are similar, but if expressed as g/kg of oat, there will be significant differences between the hull-less and the hulled oats, owing to the significantly higher crude protein content in the dehulled and naked oats than in the hulled oats. The content of sulphur-containing amino acids in the protein of the analysed oat lines was high, in the range of 4.40 - 4.53 g/16 g N, which makes oats a good complementary protein source to legumes (Pedó *et al.*, 1999). The content of essential amino acids in protein of naked and dehulled oats was comparable with the level in naked oats reported by Zarkadas *et al.* (1995) and dehulled oats reported by Pedó *et al.* (1999).

Total content of essential amino acids (EAAs) in the protein of naked oats was 12% higher ( $P \leq 0.05$ ) than in dehulled and hulled oats (Table 5). The content of EAAs was reflected in the essential amino acid index (EAAI) values, which in relation to the reference pattern (egg white) in naked oats (73.19) was higher ( $P \leq 0.05$ ) than in dehulled (67.12) and hulled oats (67.90). Comparisons with the reference pattern (egg white) revealed that lysine was the most limited amino acid in all analysed oat grains in the range: 54.0% (naked oat), 48.8% (dehulled oat) and 48.1% (hulled oat) of the reference pattern. The amino acids score (AAS) value for naked oats was higher ( $P \leq 0.05$ ) than that for dehulled and hulled oats. Other authors found that lysine is the most limited amino acid in naked and dehulled oat grains (Zarkadas *et al.*, 1995; Pedó *et al.*, 1999).

**Table 5** Coefficients of nutritive value of tested oat grain protein

Item	Cultivar / line	EAAs (g/16 g N)	EAAI	AAS <sub>Lys</sub> (%)
Hulled oat	Krezus	34.7	69.4	48.2
	Bingo	35.1	70.0	49.2
	STH 6106	31.3	62.6	43.2
	STH 6108	32.5	64.2	46.8
	STH 7105	37.4	73.3	52.9
	$\bar{x}_H$	<b>34.21<sup>a</sup></b>	<b>67.90<sup>a</sup></b>	<b>48.12<sup>a</sup></b>
	SEM	1.06	2.07	1.39
Dehulled oat	Krezus	34.5	68.5	48.0
	Bingo	34.2	65.8	46.9
	STH 6106	33.3	65.9	50.7
	STH 6108	33.1	64.8	50.0
	STH 7105	35.7	70.2	48.1
	$\bar{x}_{Dh}$	<b>34.13<sup>a</sup></b>	<b>67.12<sup>a</sup></b>	<b>48.82<sup>a</sup></b>
	SEM	0.46	0.89	0.59
Naked oat	Polar	35.7	68.8	50.3
	STH 7202	37.0	72.0	52.3
	STH 7205	40.4	76.4	58.6
	STH 7206	39.7	75.5	54.9
	$\bar{x}_N$	<b>38.18<sup>b</sup></b>	<b>73.19<sup>b</sup></b>	<b>54.03<sup>b</sup></b>
	SEM	1.11	2.13	1.24

<sup>a, b</sup> Means  $\bar{x}_H$ ,  $\bar{x}_{Dh}$  and  $\bar{x}_N$  in columns with different superscripts differ significantly at  $P \leq 0.05$ .

EAA: essential amino acids; EAAI: essential amino acid index; AAS<sub>Lys</sub>: Amino acids score (Lys).

SEM: standard error of mean.

The amino acid composition and biological value of oat protein are better than that of other cereals such as wheat, barley or maize (McMullen, 2000). In these cereals, the biological value of the protein declines markedly in the grain with increasing crude protein content. The major storage proteins of oats are

globulins, which have a higher concentration of lysine and other essential amino acids than prolamins, which are typical cereal storage proteins (Shewry & Halford, 2002).

Owing to its composition, especially low fibre content, naked and dehulled oat can be a valuable component of diet for monogastric animals. Naked oat can be a substitute for maize and wheat in grower-finisher pig diets (Brand & Van der Merwe, 1996; Flis *et al.*, 2005).

## Conclusion

The results of this study indicated that reducing the proportion of hulls in oat grains resulted in a significant decrease in dietary fibre content and a significant increase in nutrient content. Such changes can be achieved by the cultivation of naked oats or separation by dehulling grain prior to feeding to animals.

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