

## Effects of grinding, pelleting and expanding on nutritive value of barley in pig diets

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Nutrient digestibility and protein utilization responses of growing pigs to different processes of barley were evaluated. The assayed treatments of barley were grinding methods: hammer milling (HM) and rolling (RM), pelleting (HP, RP), expanding (HE, RE) and their combination (HEP, REP). The study comprised a 8 x 8 Latin square designed digestibility and nitrogen balance trial with a 2 x 2 x 2 factorial arrangement of treatments. The average grist size of HM barley was smaller and wider than that of RM. Pelleting and expanding reduced the grist size and made the distribution wider compared to untreated ones. HM compared to RM achieved improved pellet quality, but expanding had no effect on pellet durability. Only small differences were found in the proximate composition or sugar content indicating a gelatinization degree of differently processed barleys. Grinding method had no effect on organic matter (OM) digestibility, whereas RM improved protein (CP) digestibility ( $P < 0.001$ ) but led to lower ether extract (EE) digestibility ( $P < 0.001$ ). Pelleting significantly improved digestibility of all barley constituents ( $P < 0.01$ ,  $0.001$ ), the magnitude being 0.02 compared to meal form barley. A significant interaction between the grinding method and pelleting was noticed in CP ( $P < 0.05$ ) and EE ( $P < 0.001$ ) digestibility. Except for the digestibility of crude fibre ( $P < 0.001$ ), there were no significant differences between the treatments in response to the expanding process of barley. Significant interactions in digestibilities were found between grinding methods and expanding. RM compared to HM achieved significantly higher N-retention ( $P < 0.001$ ) and protein utilization ( $P < 0.001$ ) and decreased urinary urea-N excretion ( $P < 0.001$ ). Pelleting significantly improved protein absorption ( $P < 0.001$ ) and tended to decrease urinary-N excretion, but N-retention was unaffected by the physical form of the barley. Expanding had no effect on protein absorption or N-retention, but achieved a small significant improvement in biological value of protein ( $P < 0.01$ ).

Key words: grinding, pelleting, expanding, digestibility, nitrogen balance, pig, barley

### Introduction

The major contribution of barley in pig diets has stimulated the development of various techniques for grain processing in order to increase the efficiency of utilization of dietary nutrients and pig performance. Barley has rather high total fibre con-

tent including both insoluble and soluble fibre (ÅMAN and HESSELMAN 1984). Thus, it is important to reduce particle size or by some other processing means to increase accessibility to the digestive enzymes of the pig.

Cereal grains are not all completely broken down during mastication and some may pass unutilized

through the alimentary tract. Fineness of grind will affect utilization of grain. It has been shown that screen sizes of up to five mm diameter are unlikely to impair utilization significantly, but screen size of nine mm or above will have a deleterious effect (LAWRENCE 1970, SIMONSSON 1978a). Compared with this, efficient rolling, so that each grain is throughout flattened, would appear capable of eliciting as efficient a response as any of the grinding procedures when using screen sizes up to five mm diameter (LAWRENCE 1978, SIMONSSON 1978b). There is evidence of a relationship between cereal particle size and ulceration, the finer the grinding the higher the incidence of ulceration in the oesophageal region of the pig (LAWRENCE 1972, SIMONSSON and BJÖRKLUND 1978, KIRCHGESSNER et al. 1985).

The use of pelleted feeds for pigs is associated with an improvement in feed utilization efficiency, due principally to reduced feed wastage and improved nutrient digestibility. It has been proposed that the following are the advantages of pelleted over meal feeds: reduced selective feeding, reduced segregation, increased bulk density and improved handling and flowability. A tendency for digestibility of nutrients and performance of pigs to improve has been noticed when the fibre content of the diet is increased (VANSCHOUBROEK et al. 1971, LAWRENCE 1983).

With the expander, it is possible to achieve higher temperatures and pressures compared to a conventional pellet mill. The advantages of a combination of expander and pellet mill are claimed to be: improved pellet quality, digestibility and reduction of bacteria (WETTSTEIN and WILD 1990).

Three of the more important production technologies in producing pig feeds will be dealt with here: grinding, pelleting and expanding and their combinations of treating barley. The objectives of the current study were to investigate the effects of various processes on nutrient digestibility and protein utilization in pigs fed barley based diets. A subsequent study where performance and oesophagogastric lesion responses of pigs to hammer milled and rolled barley diets were investigated will be published by ALAVIUHKOLA et al. (to be publ.)

## Material and methods

The processing treatments of barley were two grinding methods, pelleting, expanding and their combination. The hammer milling was made with a peripherally fed mill, 1500 rpm to pass 3.5 mm sieve (HM) and the roll milling with a smooth roller (RM). Both of the ground barleys were divided into two batches, of which one was pelleted with a Bühler DPGC mill, to yield pellets of 4.5 mm diameter, at temperature of 65°C (HP, RP). Then, a part of each of the the bathes was either expanded (Kahl expander, temperature 95-100°C (HE, RE) or pelleted after expanding (HEP, REP). The grist spectrum of the barleys after different treatments is outlined in Table 1. They were measured with a test sieve shaker for 5 min after soaking 50 g feed in 250 ml water for 2 h and rinsing with water during sieving. Oversized feed on the sieves was kept at room temperature overnight and weighted. Quality of the pellets was measured by screening and counting the proportion of whole pellets retained on the

Table 1. Particle size distribution of differently treated barley.

Particle diameter, mm	HM	HP	HEP	HE	RM	RP	REP	RE
4.0 <	-	-	-	-	0.306	0.006	-	0.004
1.6 - 4.0	0.104	0.140	0.178	0.186	0.354	0.414	0.312	0.372
1.0 - 1.6	0.228	0.244	0.224	0.144	0.074	0.182	0.196	0.186
0.3 - 1.0	0.332	0.314	0.304	0.280	0.050	0.152	0.164	0.138
< 0.3	0.336	0.302	0.294	0.390	0.216	0.246	0.328	0.300

The treatments: hammer milling (HM), rolling (RM), pelleting of hammer milled and rolled (HP, RP), expanding of hammer milled and rolled (HE, RE) and the combination of expanding and pelleting of hammer milled and rolled (HEP, REP)

4 mm screen. The pellets were circulated for 1 min in a pneumatic transfer with a Holmen pellet tester.

A 8 x 8 balanced Latin square with growing pigs of castrated males (Landrace x Large White), initial weight of 28.6 (SE 1.85) kg and final weight of 97.4 (SE 3.75) kg with a 2 x 2 x 2 factorial arrangement of treatments, was carried out to determine the effects of grinding, pelleting and expanding and their combinations on nutrient digestibility and protein utilization of barley based diets. Eight dietary treatments were used and the diets consisted of treated barley 850 g/kg and soybean meal 150 g/kg. The pigs were fed twice daily according to a restricted feeding regime and their diets were adequately fortified with minerals and vitamins (SALO et al. 1990). The pigs were kept during the whole experiment in metal metabolism cages equipped with collection trays, allowing separate collection of faeces and urine. Each period comprised 5 days of adjustment and 5 days of total collection of faeces and urine. The details of the procedure are the same as described by NÄSI (1984). All animals completed the experiment successfully and the average daily weight gain during the entire experiment was 860 g. No differences in palatability of the variously treated barley diets were observed. Refusals of the diet were negligible.

The digestibilities of the barleys treated with different processes were calculated by difference method. Feed values of the ingredients were computed according to SALO et al. (1990) and ANDERSEN and JUST (1983). The data were analyzed by analysis of variance 8 x 8 Latin square with a 2 x 2 x 2 factorial arrangement of treatments. The sums of squares for treatment effect were further separated into single degrees of freedom for comparisons of the dietary treatments (SNEDECOR and COCHRAN 1967).

## Results and discussion

Barley ground in a roller mill had a considerably coarser average grist size. The particle distribution of rolled barley was more narrow compared to hammer milled, but pelleting and expanding reduced the grist size and made the distribution wider

(Table 1). Pellet durability was measured as a proportion of meal passing through a 4 mm sieve. The mealy proportions were 0.10, 0.12, 0.19 and 0.19 for treatments HP, HEP, RP and REP, respectively. Prior to pelleting, hammer milled compared to rolled barley achieved better pellet quality. The average particle size of the ground product has an influence on pellet quality. In many cases, pellet quality can be improved most economically by reducing the average particle size. With an expander the temperatures and pressures are higher than in pellet die, thus it could be expected that pellet durability is improving the pelleting followed after expanding. Here pellet quality was unaffected probably due to low process temperature and limited use of steam, which is in accordance with the gelatination degree judged from sugar content.

Only small differences were found in the proximate composition of differently processed barleys (Table 2). HM-barley had a little higher crude protein content compared to the others. The preliminary samples taken after processing were similar, thus higher content is caused by some contamination when transported. Rolled barleys showed a little higher fibre content compared to milled ones. Only a small variation is shown in sugar or starch contents of treated barleys, indicating only a minor gelatinization effect from heating in pelleting or expanding processes. The gelatinization temperature of barley starch is relative low 59 - 64°C (DOGGETT 1970), but here the actual hydrothermal stage of the processing was rather short and the moisture content was quite low for higher gelatinization.

Grinding method had no effect on organic matter or carbohydrate digestibility (Tables 3 and 4). However, rolling led to better crude protein digestibility ( $P < 0.001$ ), although resulting in lower ether extract digestibility ( $P < 0.001$ ). This is supported by the observation that larger grist sizes of barley, ground by roller milling, has been utilized to the same extent as the smaller grist sizes, resulting from a peripherally fed hammer mill (SIMONSSON 1978a). Neither did LAWRENCE (1970) find differences in performance of pigs given diets containing

Table 2. The chemical composition of the experimental feeds.

Treatment of feed Composition, g/kg DM	HM	HP	HEP	HE	RM	RP	REP	RE	Soy bean meal
Dry matter	868	864	861	853	862	860	859	849	871
Ash	32	27	26	28	29	27	26	27	70
Crude protein	133	120	116	116	121	119	119	119	491
Ether extract	39	37	36	36	37	37	36	37	33
Crude fibre	49	44	47	52	50	49	44	45	55
Nitrogen free extract	747	772	775	769	764	767	774	773	352
NDF	180	177	181	194	197	197	179	183	114
ADF	42	39	42	48	45	47	41	41	47
Hemicellulose	138	138	139	146	152	150	139	142	67
Starch	539	602	597	581	555	555	567	583	-
Sugars	43	45	42	41	44	43	41	42	-

The treatments: hammer milling (HM), rolling (RM), pelleting of hammer milled and rolled (HP, RP), expanding of hammer milled and rolled (HE, RE) and the combination of expanding and pelleting of hammer milled and rolled (HEP, REP)

barley which had been either rolled or ground to widely different degrees. Efficient rolling may overcome most of the problems caused by fine grind eg. dusty, unpalatable, sticky and pasty in the mouth of a pig, and gastric lesions. The rolling mill has been found to achieve rolled grain pores which are made up of fissures and cavities in the particle. These pores increase the surface area of a particle. Pore size distribution of HM- and RM-barleys was measured with a Hg-porosimeter, and the preliminary observations showed RM-barley to have very many small pores (Unpubl.). Total pore volume and pore size distribution can also be determined from gas absorption isotherms. External and pore surfaces may have a significant effect over a wide range of phenomena, particularly ad- and absorption of liquids and enzymes, which determines digestibility as well as particle size.

Pelleting significantly improved ( $P < 0.01$ ,  $0.001$ ) digestibility of all the organic constituents, the magnitude being approximately 0.02 compared to meal form barley. A significant interaction between the grinding method and pelleting was noticed in CP ( $P < 0.05$ ) and EE ( $P < 0.001$ ) digestibility. In the pelleting process, cereals are subjected to pressure of being forced through the die of the pelleter. There is a frictional heating effect and excess, but prior to this, the grain is steam heated. Pelleting

appears to modify molecular fractions of the feed. This is suggested from the fact that when pellets have been ground into meal before being fed, the beneficial effect of pelleting has still been obtained. Both chemical and physical changes are indicated which are involved in improving digestibility (LAWRENCE 1978).

The extensive review prepared by VANSCHOU-BROEK et al. (1971) indicated that feeding of pelleted rations results in significant responses in the performance and food utilization in growing pigs. Present results are in accordance with data presented by LAWRENCE (1970) who found pelleting to improve dry matter and energy digestibility. The physical form of the diet, however, had only a small non-significant effect on the digestibility of energy and ME/DE ratio according to the data of PATTERSON (1989). The digestibility of nitrogen was significantly improved by pelleting, and nitrogen retention was also increased but not significantly (PATTERSON 1989). Furthermore, YEN et al. (1971) found improved amino acid digestibility, which is in accordance with present results. Rarely is the cereal component subjected to pelleting alone. The effects of pelleting on the complete diet could be different, as here, when barley was alone. The effect of pelleting varies according to the method, pelleting cold versus steam. SKOCH et al. (1983)

Table 3. Digestibility of nutrients in pigs on diets based on differently treated barley.

Digestibility	HM	HP	HEP	HE	RM	RP	REP	RE	SEM	M	P	M*P	E	M*E	P*E	M*P*E
Dry matter	0.808	0.823	0.815	0.804	0.798	0.816	0.829	0.816	0.002	NS	***	NS	**	***	NS	NS
Organic matter	0.834	0.848	0.840	0.829	0.823	0.839	0.853	0.842	0.002	NS	***	NS	**	***	NS	NS
Ash	0.290	0.287	0.274	0.259	0.276	0.320	0.303	0.271	0.011	NS	**	NS	NS	NS	NS	NS
Crude protein	0.797	0.806	0.802	0.793	0.792	0.825	0.829	0.815	0.005	***	***	*	NS	*	NS	NS
Ether extract	0.503	0.538	0.528	0.519	0.411	0.527	0.506	0.465	0.008	***	***	***	***	NS	***	*
Crude fibre	0.201	0.220	0.217	0.203	0.162	0.202	0.264	0.227	0.012	NS	**	NS	***	***	NS	NS
NFE	0.908	0.914	0.907	0.900	0.899	0.904	0.914	0.908	0.002	NS	***	NS	NS	***	NS	NS
NDF	0.478	0.512	0.476	0.466	0.463	0.489	0.513	0.492	0.009	NS	**	NS	NS	***	NS	NS
ADF	0.075	0.083	0.065	0.098	0.022	0.074	0.103	0.123	0.014	NS	*	***	NS	NS	NS	NS
Hemicellulose	0.612	0.651	0.614	0.598	0.607	0.621	0.640	0.626	0.008	NS	***	NS	NS	***	NS	NS

The treatments: hammer milling (HM), rolling (RM), pelleting of hammer milled and rolled (HP, RP), expanding of hammer milled and rolled (HE, RE) and the combination of expanding and pelleting of hammer milled and rolled (HEP, REP)

M = grinding method, P = pelleting and E = expanding

SEM = standard error of the means; significance: NS = non-significant, \* P<0.05, \*\* P<0.01, \*\*\*P<0.001

Table 4. Digestibility of nutrients of differently treated barley in pigs.

Digestibility	HM	HP	HEP	HE	RM	RP	REP	RE	SEM	M	P	M*P	E	M*E	P*E	M*P*E
Dry matter	0.803	0.822	0.812	0.798	0.792	0.813	0.829	0.814	0.003	NS	***	NS	**	***	NS	NS
Organic matter	0.834	0.850	0.841	0.828	0.821	0.840	0.856	0.843	0.003	NS	***	NS	**	***	NS	NS
Ash	0.091	0.048	0.007	-0.004	0.035	0.115	0.073	0.005	0.002	NS	NS	**	**	NS	NS	NS
Crude protein	0.769	0.780	0.772	0.756	0.757	0.815	0.822	0.796	0.009	***	***	*	NS	**	NS	NS
Ether extract	0.480	0.520	0.508	0.498	0.371	0.508	0.482	0.433	0.010	***	***	***	NS	NS	***	*
Crude fibre	0.194	0.217	0.214	0.197	0.145	0.195	0.272	0.226	0.014	NS	**	NS	***	***	NS	NS
NFE	0.906	0.914	0.905	0.898	0.897	0.912	0.913	0.907	0.002	NS	***	NS	NS	***	NS	NS

The treatments: hammer milling (HM), rolling (RM), pelleting of hammer milled and rolled (HP, RP), expanding of hammer milled and rolled (HE, RE) and the combination of expanding and pelleting of hammer milled and rolled (HEP, REP)

M = grinding method, P = pelleting and E = expanding

SEM = standard error of the means; significance: NS = non-significant, \* P<0.05, \*\* P<0.01, \*\*\*P<0.001

reported improvements in FCR of 0.071 and 0.055 of cold and steam-press pellets, respectively, in comparison to meal with increases in energy of 0.018 and 0.016.

Except for the digestibility of crude fibre ( $P<0.001$ ), there were no significant differences between the treatments in response of other nutrients to expanding process of barley. Significant interactions in digestibilities of CP ( $P<0.01$ ), CF and NFE ( $P<0.001$ ) were found between grinding methods and expanding. Pigs fed extruded barley diet have had higher ileal digestibility for dry matter, energy and starch, but no significant differences in faecal digestibility were found (FADEL et al. 1988), which is in accordance with the present data. Extrusion of yellow corn or corn and wheat middling diet has been found to improve energy and DM digestibility, but has not affected the digestibility of lysine or N at the terminal ileum (SKOCH et al. 1983, HERKELMAN et al. 1990). Expanding and extrusion are rather similar processes, despite stronger hydrothermal effect in the extruder. An improvement of 0.13 over the controls in daily gain of piglets fed expanded diet has been reported by BOLDUAN and PEISKER (1992), but product temperature of 115°C was higher than in present treatment. The thermal processing of the present expanding treatment proved to be quite slight, so that the effect on nutrient digestibilities was weak.

The results of the N balance and various calculated parameters of protein utilization are shown in Table 5. Rolling of barley compared to hammer milling achieved significantly higher N-absorption ( $P<0.001$ ) and lower urinary-N and urea-N excretion ( $P<0.01$ ). A rolled barley diet gave significantly higher N-retention (22.4 vs. 23.7 g/d,  $P<0.001$ ) and proportions of N-retention in relation to intake of N were improved by 0.03 ( $P<0.001$ ). Biological value is significantly higher on the rolled barley diet, which was in accordance with the tendency of improved daily gain.

Pelleting of barley improved diet N-digestibility ( $P<0.001$ ) and tended to decrease urinary-N excretion ( $P<0.1$ ). N-retention was unaffected by the

Table 5. Nitrogen balance and protein metabolism in pigs fed differently treated barley based diets.

Nitrogen balance	Nitrogen balance and protein metabolism															
	HM	HP	HEP	HE	RM	RP	REP	RE	SEM	M	P	M*P	E	M*E	P*E	M*
N intake, g/d	57.7	53.8	53.0	52.1	54.2	53.8	52.0	53.3	0.53	*	**	NS	***	*	NS	***
N in faeces, g/d	11.6	10.2	10.2	10.6	10.8	9.3	8.7	9.6	0.29	***	***	NS	**	NS	NS	NS
N absorbed, g/d	46.1	43.6	42.8	41.5	43.3	44.5	43.3	43.7	0.52	NS	NS	NS	***	**	NS	***
N digestibility	0.797	0.806	0.802	0.793	0.792	0.825	0.829	0.815	0.0050	***	***	*	NS	*	NS	NS
N in urine, g/d	24.1	20.7	20.4	19.1	19.8	20.3	19.8	19.9	0.48	**	NS	NS	***	***	**	***
N retained, g/d	22.0	22.9	22.3	22.4	23.5	24.2	23.4	23.8	0.50	***	NS	NS	NS	NS	NS	NS
- of intake	0.389	0.434	0.429	0.435	0.440	0.456	0.458	0.455	0.0066	***	**	NS	***	NS	***	*
- of absorption	0.489	0.541	0.537	0.550	0.559	0.553	0.554	0.560	0.0081	***	NS	*	*	*	**	**
- g/kg W <sup>0.75</sup>	1.054	1.105	1.056	1.056	1.111	1.139	1.124	1.141	0.0208	***	NS	NS	NS	NS	NS	NS
Urea N, g/d	20.8	17.2	17.3	15.9	15.0	17.1	16.7	17.1	0.64	**	NS	*	NS	***	NS	***
Urea N, g/W <sup>0.75</sup>	0.939	0.766	0.763	0.714	0.684	0.769	0.755	0.755	0.0242	**	NS	**	*	***	NS	***
Biological value	0.562	0.615	0.613	0.627	0.633	0.625	0.626	0.633	0.0076	***	NS	*	**	***	**	***
Daily gain, g/d	853	791	886	801	881	913	830	833	40.7	NS	NS	NS	NS	NS	NS	NS

The treatments: hammer milling (HM), rolling (RM), pelleting of hammer milled and rolled (HP, RP), expanding of hammer milled and rolled (HE, RE) and the combination of expanding and pelleting of hammer milled and rolled (HEP, REP)

M = grinding method, P = pelleting and E = expanding

SEM = standard error of the means; significance: NS = non-significant, \*  $P<0.05$ , \*\*  $P<0.01$ , \*\*\*  $P<0.001$

Table 6. Calculated feed values of the differently treated barleys.

Feed value	HM	HP	HEP	HE	RM	RP	REP	RE
FU/kg DM	1.118	1.147	1.135	1.116	1.098	1.132	1.152	1.133
FU/kg	0.97	0.99	0.97	0.95	0.95	0.97	0.99	0.96
DCP g/kg DM	103	94	89	87	91	97	98	95
DCP g/FU	92	82	79	78	83	86	85	83
ME MJ/kg DM	14.70	15.03	14.84	14.59	14.39	14.85	15.11	14.84
NE MJ/kg DM	9.14	9.39	9.25	9.06	8.91	9.26	9.45	9.25
FE <sub>s</sub>	1.184	1.216	1.198	1.174	1.154	1.199	1.225	1.19

The treatments: hammer milling (HM), rolling (RM), pelleting of hammer milled and rolled (HP, RP), expanding of hammer milled and rolled (HE, RE) and the combination of expanding and pelleting of hammer milled and rolled (HEP, REP)

FU = feed units, 0.7 kg starch equivalent, DCP = digestible crude protein, ME = metabolizable energy, NE = net energy, FE<sub>s</sub> = Danish net energy system for pigs

physical form of the barley. Protein utilization was improved by pelleting to a small degree. The observation is similar to that of PATTERSON (1989). Daily gain of the pigs fed on a pelleted diet improved 842 vs 855 g/d, being consistent with earlier results given in the literature. The better performance of pigs fed a pelleted diet over meal form has obviously resulted from the higher digestibility of energy yielding components and from avoiding most of the feed wastage rather than improved protein utilization.

Expanding had no effect on N-digestibility or N-retention. Urinary-N excretion ( $P < 0.001$ ) and parameters indicating protein utilization ( $P < 0.01, 0.05$ ) were improved by using an expander as a treatment. In contrast to this, the daily gain was slightly inferior in pigs fed expanded barley compared to untreated ones. There was a small difference in the N-intake which may have had an effect on the parameters measured. Hydrothermal processes are directed to rupture cell wall matrix and modify the chemical structure of cereal constituents. These processes are aimed at rendering nutrients more susceptible to enzyme degradation in the small

intestine, thus improving the digestibility and utilization, especially amino acids. Two explanations for the lack of response could be either that the expanding process was too mild or that no further improvement can be achieved in the endogenous enzymes of barley or intestinal bacteria which can sufficiently degrade cell structure (GRAHAM et al. 1986) (Table 6).

In conclusion, rolled barley showed higher nutritive value compared to hammer milled and if the incidence of gastric lesions caused by small grit size could be depressed by using rolled cereal, then it is preferable from the nutritional point of view. Pelleting improved feed value of barley over the milled form. Expanding had no beneficial effect on pellet quality or nutritive value of barley.

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## SELOSTUS

**Jauhatustavan, rakeistuksen ja ekspanderkäsittelyn vaikutus  
ohran rehuarvoon lihasian ruokinnassa**

MATTI NÄSI

Helsingin yliopisto

Tutkimuksessa selvitettiin vasaramyllyjauhatuksen ja litistuksen, rakeistuksen sekä ekspanderkäsittelyn vaikutusta lihasioille syötettävän ohran ravintoaineiden sulavuuteen ja valkuaisen hyväksikäyttöön. Tutkimus tehtiin 2\*2\*2 faktoriokkeena 8\*8 latinalaisen mallin mukaan 29 - 97 kg elopainoisilla lihasioilla. Litistetyn ohran partikkelikoko oli keskimäärin suurempaa kuin vasaramyllyjauhetun. Rakeistus ja ekspanderkäsittely pienensivät partikkelikokoa. Litistettyä ohraa käytettäessä rakeiden laatu oli heikompi kuin vasaramyllyjauhettua käytettäessä. Ekspanderkäsittelyllä ei ollut parantavaa vaikutusta rakeiden kestävyYTEEN. Litistetyn

ohran raakaproteiinin sulavuus oli parempi kuin jauhetun. Rakeistus paransi ohran kaikkien ravintoaineiden sulavuuk-  
sia keskimäärin 0.02. Ekspanderkäsittely paransi raaka-  
kuidun sulavuutta. Rakeistuksen ja ekspanderkäsittelyn sekä  
jauhamistavan välillä oli sulavuudessa yhdysvaikutuksia.  
Litistettyä ohraa saaneet siat pidättivät enemmän typpeä ja  
valkuaisen hyväksikäyttö oli tehokkaampaa kuin vasaramyl-  
lyjauhettua saaneilla. Rakeistus paransi valkuaisen imeyty-  
mistä, mutta sillä ei ollut vaikutusta typen pidättymiseen.  
Ekspanderkäsittely ei vaikuttanut valkuaisen imeytymiseen  
eikä typen pidättymiseen.