

Relationships between physical and chemical characteristics and calculated metabolizable energy values in barley and oats with highly variable volume weights

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Abstract. 61 samples of barley with a volume weight of 38–75 kg/hl, and 49 oat samples with a volume weight of 40–65 kg/hl were analyzed for physical and chemical characteristics. The approximate metabolizable energy (ME) value was calculated from the composition.

The physical characteristics varied more, but the starch content less, in barley than in oats. There was also a negative correlation between starch and crude protein, and ether extract level in barley, but not in oats. Therefore the difference between the ME values of the best and the poorest samples was only 12 % for barley, but 27 % for oats.

Both the starch and the crude protein content predicted the ME value well: R^2 of starch was 78–94 %, and that of crude fibre 55–84 %. The volume weight still gave a good indication for barley, but not at all for oats.

Introduction

Barley is known to have a very constant feeding value: its net energy content is only slightly or not at all affected by the stage of ripeness, the location or the year (MADSEN et al. 1972, THOMKE 1972), nor even by its variety (SCHULZ and OSLAGE 1969, PEERS and TAYLOR 1977). However, if the volume weight is very low, the F.U. value for pigs (SUNDSTØL 1970) and the Mcal.-value for chickens (SIBBALD and PRICE 1976) is slightly reduced. The crude protein content varies more than the energy value, being influenced by the variety, climatic conditions and nitrogen fertilization (REKUNEN 1969, SCHULZ and OSLAGE 1969, GAARBO THOMSEN 1977, PEERS and TAYLOR 1977).

Oats, instead, are more inconsistent. Their high and variable hull content reflects in the feeding value causing variation (THOMKE 1961, SIBBALD and PRICE 1977). This fact has been taken into account in the Feed Tables.

Barley and oats are the main cereals cultivated in Finland. If the summer is cold, the crops do not get to the full-ripeness stage. They can still be damaged by frost or even a fall of snow. Such grains are not of full value.

The motive for this study was the low weight of cereals after the cold and rainy summer of 1977. The purpose was to evaluate the variation scale of the

physical and chemical characteristics of barley and oats, the relationships between them, and to establish the parameters, which would most suitably characterize the nutritive value of these crops.

Materials and methods

61 samples of barley from 14 different varieties, and 49 samples of oats, from 10 varieties were collected from various parts of Finland. The area ranged from a latitude 60° to 64°. The majority of the samples were from the summer of 1977, but a small proportion were from earlier, climatically normal years.

Analytical methods

The volume weight and the 1000-kernel weight were measured using apparatus and methods of the Research Laboratory of Finnish State Granary. A slight precleaning of the grain was included the method. The results were corrected to 85 % grain DM content. The hull content of the oats was determined from five gram samples. The moisture of the grains was determined by drying for 48 h at 103° C.

The chemical analyses were made on the same batch of grains as were used for the volume weight measurements. The grains were ground using a 0.5 mm sieve.

The common feed analyses were made according to standard methods. The starch was determined by the amyloglucosidase method but without ethanol extraction in order to include the sugars (SALO and SALMI 1968). The sugar content of these grains is only 1–2 %.

Calculation of metabolizable energy value

A metabolizable energy (ME) value, even an approximate one, was necessary for the comparison of various grain samples. The ME value for pigs was calculated on the basis of starch, ether extract and crude protein contents as follows: For the starch the gross energy value, 4.1 kcal/g, was used, because the starch of cereals is totally digested by pigs (SALO 1965, 1971). The contents of ether extract and crude protein were multiplied with factors which were calculated according to average digestion coefficients from Feed Tables for pigs, and the Mcal values of digestible nutrients. The coefficients used for the ether extract were 5.0 for barley and 7.1 for oats and those for crude protein 3.7 and 3.3, respectively.

The ME values thus obtained were too low, because the pig is capable of digesting a great deal of the hemicellulose of the kernel; only the hulls are of no value. The digestibility of the hemicellulose of the wheat bran is nearly 50 % (SALO 1965). To correct the figures to correspond to the normal ME level, they were multiplied by a factor, which was obtained by comparing them with the ME values from the Feed Tables for grains with a similar composition (ERIKSSON et al. 1972). The corrected values, expressed as MJ, are presented in Tables 1 and 2. The corresponding F. U. values, corrected to 87 % DM

content of grains are also presented (kg/F.U.). The ratio Mcal./F. U. was taken from NJF's Feed Tables (ANON. 1969).

Although the calculated ME values are not exact and the level for oats perhaps is a little too high, they agree with each other.

Results and discussion

Composition and nutritive value

As examples of the composition, Tables 1 and 2 present the physical and chemical characteristics and the calculated energy values of the most common varieties of both cereals, and further, the averages of the whole materials. Nine samples of barley belonged to two-rowed varieties and the rest to multi-rowed ones, but there were no clear differences in composition attributable to this property or, on the whole, between different varieties of barley and of oats.

The variation ranges over the whole materials, 61 barley samples and 49 oat samples, were as follows:

Volume weight (87 % DM), kg/hl	barley 38.4 -75.3,	oats 39.8 -64.9
1000-kernel w. (87 % DM), g	22.2 -50.7	22.7 -42.1
Hulls, %		20.4 -43.3
Starch + sugars, % of DM	51.5 -61.7	37.5 -52.6
Crude protein, % of DM	9.9 -15.5	9.7 -15.8
Ether extract, % of DM	1.7 - 2.8	4.8 - 7.8
Crude fibre, % of DM	4.1 - 7.4	7.2 -15.0
Ash % of DM	2.4 - 3.4	2.5 - 4.2
MJ ME/kg DM	12.61-14.22	10.42-14.29
Kg grain/F.U. (87 % DM)	1.02- 1.15	1.03- 1.41
Pepsin solubility of CP, %	73.2-84.4	74.9 -87.6

The physical characteristics varied more, but the starch content less, in barley than in oats. This is one reason for the fact that the difference between the highest and lowest ME values over 61 barley samples was only 12 %, whereas over 49 oat samples it was 27 %. The result is in agreement with the finding that barley reaches its full nutritive value many weeks before the full-ripeness stage (MADSEN et al. 1972, THOMKE 1972). This does not appear to be true with the oats. One has of course, to bear in mind, that oats require a somewhat longer growth period than barley. However, the conclusion can be drawn that even in a bad year the nutritive value of barley is fairly normal, even when its volume weight is low. The oats however, though grown in the same conditions, may possess only three fourths of their normal feeding value.

The variation of crude protein content was the same for both cereals. A part of samples were also analyzed for pepsin soluble crude protein. On average, the high pepsin solubility appeared to be related to the high level of crude protein. The solubility of oat protein was a little higher than that of barley, irrespective of the fact, that about 6 % of oat protein arises from the low-soluble protein of hulls. The hulls contain 3.0 % crude protein of DM with a pepsin solubility of 39 %.

Table 1. The physical and chemical characteristics of the barley variety *Otra* (16 samples), and the averages of all 61 barley samples.

Volume weight kg/hl ¹)	1000-kernel w.g. ¹)	% of DM					MJ /kg DM 2)	ME of CP 3)	kg/F.U. (87 % DM) 4)	
		Starch and sugars	Crude protein	Ether extract	Crude fibre	Ash				
72.2	50.7	59.2	13.7	2.2	4.1	2.7	14.12	82.5	1.03	
70.5	40.4	57.3	13.6	2.3	5.0	2.7	13.77		1.05	
68.1	40.0	55.6	13.9	2.3	5.2	2.7	13.49	82.1	1.07	
66.6	34.5	61.4	10.0	2.1	5.5	2.5	13.88	77.0	1.04	
61.3	33.2	59.5	11.1	2.4	5.4	2.6	13.78	80.2	1.05	
61.2	30.7	55.7	13.7	2.2	5.9	2.7	13.45	80.1	1.08	
60.7	33.7	60.0	11.7	2.2	5.3	2.5	13.93		1.04	
60.2	31.7	60.6	9.9	2.4	5.7	3.0	13.78	73.2	1.05	
58.7	34.0	57.2	13.0	2.2	5.8	2.7	13.62	78.5	1.06	
57.9	34.9	57.3	12.5	2.2	5.8	2.6	13.55		1.07	
55.2	34.1	58.1	12.9	2.4	5.7	2.7	13.82	79.7	1.05	
54.5	35.4	58.3	11.9	2.4	5.5	2.8	13.69	77.0	1.06	
53.4	30.5	56.0	11.0	2.6	6.8	2.8	13.14	79.2	1.10	
53.3	30.7	56.4	12.3	2.2	6.1	2.8	13.48	76.4	1.08	
52.6	31.9	55.5	12.6	2.2	5.9	3.1	13.23		1.10	
38.4	26.6	51.5	12.8	2.8	7.4	2.6	12.64	75.9	1.15	
Averages	59.1	34.6	57.5	12.3	2.3	5.7	2.7	13.58	78.5	1.07
S.D	±8.3	±5.5	±2.4	±1.3	±0.2	±0.7	±0.2	±0.36		
Averages	60.2	33.2	57.4	12.7	2.2	5.6	2.8	13.60	79.6	1.07
and S.D.	±7.5	±5.6	±2.5	±1.3	±0.2	±0.7	±0.2	±0.40		
of all 61 samples										

¹) Calculated to 87 % DM; ²) Calculated from the starch, crude protein and ether extract contents, see text; ³) Pepsin solubility of CP; ⁴) F. U. = 0.7 x starch units.

Relationships between characteristics

Correlation coefficients between physical and chemical characteristics and calculated ME values are presented for all samples in Tables 3 and 5, and for the most common varieties in Tables 4 and 6.

Some differences appeared between the whole material and one variety, but for most the correlation coefficients accorded. Highly significant positive correlations ($P < 0.001$), uniformly in both matrixes, proved to be between starch and ME values in both cereals, and in barley also between volume weight and 1000-kernel weight, and ME value. Highly negative ones appeared between crude fibre and many characteristics in both cereals, in oats also between hulls and many characteristics. Most relationships found for barley are in agreement with those presented by SIBBALD and PRICE (1976). In oats the agreement is lower, perhaps because their material contained some naked varieties.

The correlation matrixes show that starch has very significant effect on the ME value, the finding of which is not surprising because starch is the main

Table 2. The physical and chemical characteristics of the oat variety *Ryhti* (21 samples), and the averages of all 49 oat samples.

Volume weight kg/hl ¹)	1000-kernel w.g. ¹)	Hulls %	% of DM				Ash	MJ /kg ²)	ME DM ³)	PS-% of CP ³)	kg/F. U. (87 % DM) ⁴)
			Starch and sugar	Crude protein	Ether extract	Crude fibre					
64.9	36.2	20.4	48.6	14.8	5.9	8.3	3.1	13.29	84.6	1.11	
60.0	38.0	22.8	43.6	14.2	5.5	11.6	2.9	12.11		1.21	
57.2	34.4	20.6	44.1	13.9	5.3	11.6	4.2	12.11		1.21	
56.1	36.3	25.4	42.4	11.8	5.5	13.7	3.4	11.54	84.3	1.27	
55.7	34.0	23.9	49.0	12.3	6.6	10.6	3.0	13.22	83.6	1.11	
54.0	38.4	23.4	41.9	10.9	6.0	13.7	3.3	11.48	80.9	1.28	
53.7	33.9	23.0	50.5	12.1	5.2	10.5	3.1	13.01	82.1	1.13	
53.5	37.1	24.4	43.0	10.6	5.9	13.9	3.2	11.61	80.2	1.27	
53.2	30.1	22.9	48.4	14.7	5.6	10.2	3.0	13.14	87.6	1.12	
51.9	37.0	23.9	47.4	10.7	6.0	11.8	3.6	12.48	81.7	1.18	
51.9	42.1	22.0	45.4	12.5	6.2	11.2	3.6	12.44		1.18	
51.6	32.9	22.9	49.4	15.6	5.4	9.1	2.9	13.40		1.10	
51.1	35.1	25.0	44.0	12.1	6.7	12.5	3.4	12.28	83.2	1.20	
51.0	35.3	25.4	42.5	11.4	5.9	13.8	3.8	11.64	80.8	1.26	
49.8	37.2	23.0	44.4	12.5	5.4	12.3	3.8	11.99		1.23	
48.5	32.2	25.5	44.5	11.1	5.4	12.9	4.1	11.80	81.3	1.25	
48.1	33.6	26.9	47.3	12.2	6.8	11.7	3.1	12.95	80.0	1.14	
47.1	25.7	35.1	40.6	10.8	4.8	14.0	3.8	10.83	78.6	1.36	
46.8	36.0	24.7	49.7	10.7	5.5	11.4	3.3	12.75		1.15	
43.8	31.5	26.5	47.9	11.3	5.6	12.6	3.3	12.53	78.9	1.17	
40.2	29.8	33.5	39.9	11.4	5.9	14.9	4.2	11.15	81.9	1.32	
Averages	51.9	34.6	24.8	45.4	12.3	5.8	12.0	12.27	81.9	1.20	
S.D.	±5.4	±3.5	+3.6	±3.2	±1.5	±0.5	±1.7	±0.4	±0.74		
Averages	52.3	33.5	25.6	45.5	12.5	5.9	11.9	12.35	82.5	1.19	
and S.D.	±5.7	+4.4	±4.3	±3.4	+1.6	±0.5	±1.7	+0.4	±0.79		
of all 49 samples											

1-4) See footnotes, Table 1.

source of energy in grains. On the volume weight starch has a lesser effect, especially in the case of oats.

Crude protein is the other main nutrient, but it has a positive influence upon the magnitudes of ME value and volume weight only in oats because, in barley, there is a high negative correlation between the protein and starch contents. This finding confirms the results of SIBBALD and PRICE (1976).

The crude fat content of barley is low and negatively related to the starch and protein. Oats contain more fat, and it is slightly positively correlated with starch. Consequently, the fat level has a positive influence upon the ME value of oats, whereas the reverse is true in the case of barley.

The negative correlations between the three main nutrients, together with the fairly stable starch content, explain the constant energy value of barley:

Table 3. Correlation coefficients between physical and chemical characteristics of barley, all samples n = 61.

Characteristics	1	2	3	4	5	6	7	8
1. Volume w.	1.00							
2. 1000-kr. W.	+.67 ³	1.00						
3. Starch + sugars	+.48 ³	+.50 ³	1.00					
4. Ether extract	-.26 ¹	-.05	-.10	1.00				
4. Crude protein	+.12	+.16	-.49 ³	-.10	1.00			
6. Crude fibre	-.58 ³	-.57 ³	-.65 ³	-.01	-.08	1.00		
7. Ash	-.39 ²	-.47 ³	-.57 ³	-.28 ¹	+.18	+.40 ²	1.00	
8. MJ ME/kg DM	+.59 ³	+.66 ³	+.88 ³	-.05	-.04	-.80 ³	-.60 ³	1.00

¹ = P < 0.05 ² = P < 0.01 ³ = P < 0.001.

Table 4. Correlation coefficients between physical and chemical characteristics of barley variety *Otra*, n = 16.

Characteristics	1	2	3	4	5	6	7	8
1. Volume w.	1.00							
2. 1000-kr. w.	+.79 ³	1.00						
3. Starch + sugars	+.61 ¹	+.35	1.00					
4. Ether extract	-.64 ²	-.41	-.54 ¹	1.00				
5. Crude protein	+.13	+.40	-.56 ¹	-.10	1.00			
6. Crude fibre	-.89 ³	-.88 ³	-.64 ²	+.65 ²	-.21	1.00		
7. Ash	-.19	-.12	-.15	+.06	-.05	+.10	1.00	
8. MJ ME/kg DM	+.79 ³	+.65 ²	+.89 ³	-.65 ²	-.12	-.88 ³	-.21	1.00

Table 5. Correlation coefficients between physical and chemical characteristics of oats, all samples, n = 49.

Characteristics	1	2	3	4	5	6	7	8	9
1. Volume w.	1.00								
2. 1000-kr. w.	+.53 ³	1.00							
3. Hulls	-.61 ³	-.77 ³	1.00						
4. Starch + sugars	+.29 ¹	+.50 ³	-.71 ³	1.00					
5. Ether extracts	-.07	-.07	-.10	+.15	1.00				
6. Crude protein	+.44 ²	+.33 ¹	-.46 ³	+.38 ²	-.20	1.00			
7. Crude fibre	-.57 ³	-.42 ²	+.67 ³	-.71 ³	-.06	-.51 ³	1.00		
8. Ash	-.32 ¹	+.10	+.06	-.03	-.06	-.26	+.32 ¹	1.00	
9. MJ ME/kg DM	+.35 ¹	+.56 ³	-.73 ³	+.97 ³	+.25	+.53 ³	-.74 ³	-.10	1.00

¹ = P < 0.05, ² = P < 0.01, ³ = P < 0.001

when the starch content is low, the other two, to some degree, compensate for it. The negative correlations also explain the generally known fact that barley with a low energy value has a high content of crude protein. In oats on the contrary, the low starch content is associated with low protein and fat contents.

Table 6. Correlation coefficients between physical and chemical characteristics of oat variety *Ryhti*, n = 21.

Characteristics	1	2	3	4	5	6	7	8	9
1. Volume w.	1.00								
2. 1000-kr. w.	+ .47 ¹	1.00							
3. Hulls	- .71 ³	- .69 ³	1.00						
4. Starch + sugars	+ .20	+ .07	- .52 ¹	1.00					
5. Ether extract	+ .03	+ .36	- .14	+ .10	1.00				
6. Crude protein	+ .54 ²	+ .02	- .51 ¹	+ .37	- .08	1.00			
7. Crude fibre	- .54 ²	- .16	+ .65 ²	- .84 ³	- .05	- .75 ³	1.00		
8. Ash	- .41	- .16	+ .38	- .63 ²	- .23	- .43 ¹	+ .62 ²	1.00	
9. MJ ME/kg DM	+ .33	+ .14	- .61 ²	+ .94 ³	+ .28	+ .59 ²	- .92 ²	- .69 ³	1.00

Table 7. Relationships between ME values (MJ/kg DM) (y) and three characteristics (x).

Characteristics	Regression line	T value	R ² %
<i>Volume weight (87 % DM)</i>			
Barley, n 61	$y = 11.70 + 0.032 X_1$	+ 5.61***	35
Barley, n 16	$y = 11.57 + 0.034 X_1$	+ 4.81***	62
Oats, n 49	$y = 9.14 + 0.061 X_1$	+ 2.52*	12
Oats, n 21	$y = 9.91 + 0.046 X_1$	+ 1.54	11
<i>Crude fibre (% of DM)</i>			
Barley, n 61	$y = 16.25 - 0.470 X_2$	- 10.35***	65
Barley, n 16	$y = 16.04 - 0.432 X_2$	- 6.95***	78
Oats, n 49	$y = 17.46 - 0.429 X_2$	- 7.57***	55
Oats, n 21	$y = 17.10 - 0.402 X_2$	- 9.92***	84
<i>Starch + sugars (% of DM)</i>			
Barley, n 61	$y = 5.28 + 0.145 X_3$	+ 14.56***	78
Barley, n 16	$y = 6.05 + 0.131 X_3$	+ 7.25***	79
Oats, n 49	$y = 2.69 + 0.212 X_3$	+ 28.10***	94
Oats, n 21	$y = 2.32 + 0.219 X_3$	+ 12.08***	88

* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$

The crude fibre content is a characteristic which has a highly negative effect on the level of volume weight and ME value in both cereals. And, because a great deal of the crude fibre arises from the hulls which contain 40 % crude fibre of DM, these behave as the crude fibre. This adverse influence of crude fibre has been stated by many scientists (e.g. NORDFELDT et al. 1954, THOMKE 1960, 1961, SUNDSTØL 1970).

The regression equations (Table 7) further reveal that both starch and crude fibre values gave a good indication of the ME value of barley and oats. The

starch was a little better than the crude fibre, however, the calculation pattern which was used for the computing of the ME value, might have slightly overestimated the proportion of starch. Regarding analyses, the starch is a little quicker to determine, and the repeatability of results is better than in the case of crude fibre.

The volume weight also gave a good indication for barley, especially within varieties, but for oats it was quite unreliable.

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Eri koostumustekijäin ja energia-arvon välisistä vuorosuhteista ohrassa ja kaurassa, kun hehtoliträn paino huomattavasti vaihtelee

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Tutkimuksessa analysoitiin 61 ohra- ja 49 kauranäytettä, joiden hl-painot vaihtelivat 38—75 ja 40—65 kg/hl väleillä. Koostumuksesta laskettiin muuntokelpoisen energian (ME) ja nettoenergian likimääräiset arvot.

Vaikka ohran hl-paino ja 1000 jyvän paino vaihteli enemmän kuin kauran, sen ME-arvo vaihteli vähemmän: parhaan ja huonoimman näytteen ME-arvon ero oli ohrassa vain 12 %, kaurassa sen sijaan 27 %. Viljojen erilaisuus johtui lähinnä siitä, että tärkkelyspitoisuus vaihteli ohrassa vähemmän kuin kaurassa ja lisäksi tärkkelys oli ohrassa negatiivisessa vuorosuhteessa proteiiniin ja rasvaan, mutta kaurassa positiivisessa vuorosuhteessa kumpaankin.

ME-arvoa kuvasivat yksityisistä tekijöistä parhaiten tärkkelys- ja raakakuitupitoisuudet. Tärkkelyksen selitysaste oli ohrassa koko aineiston osalta 78 % ja yleisimmän Otra-lajikkeen näytteissä 79 % sekä kaurassa 94 % ja yleisimmän Ryhti-lajikkeen näytteissä 88 % ja raakakuidun selitysaste vastaavasti 65—78 ja 55—84 %. Myös hl-paino ilmaisi ohran ME-arvon varsin hyvin (koko aineistossa 35 ja Otra-näytteissä 62 %), mutta kauran arvon hyvin huonosti (koko aineistossa 12 ja Ryhti-näytteissä 11 %).