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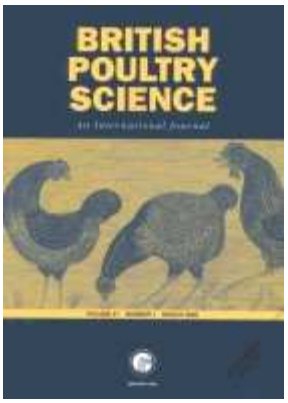

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Naked oats: metabolisable energy yield from a range of varieties in broilers, cockerels and turkeys

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Short title: NAKED OATS FOR POULTRY

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Abstract 1. Naked oats belong to the same species as "common oats", *Avena sativa*, but have a non-lignified husk which readily becomes detached during harvesting. The absence of the indigestible husk can be predicted to give an increased metabolisable energy (ME) content for poultry.

2. Measurements of true metabolisable energy (TME_N) were performed on 3-week-old broiler chicks (Cobb males), adult cockerels (IsaBrown, >1 year) and 7-week-old turkeys (BUT T8 males). The measurements were repeated in 2000, 2001 and 2002, with some measurements on a sub-set of varieties in 2004.

3. High-oil naked oat lines yielded 12% more energy (TME_N) than wheat. Naked oats, excluding the experimental high-oil lines, yielded 8.5% more energy than simultaneously assayed wheat samples.

4. In samples from the 2004 harvest, conventional oats gave TME_N values about 13% lower than those of wheat.

6. The addition of β-glucanase produced an increase of about 4% in the apparent metabolisable energy (AME) of oats for broiler chickens. This effect was associated with a 70% decrease in the jejunal viscosity of broilers receiving a 500 g/kg naked-oat diet.

7. The oil content of naked oats was about 5 times greater than that of wheat, with the high oil lines rising to more than 6 times greater. Naked oats had a lower starch content than wheat but not sufficiently lower to negate the energy benefits of the higher oil content. The crude protein (CP) contents of naked oats were similar to those of wheat, with the high-oil varieties tending to be higher in CP also.

INTRODUCTION

Naked oats are a cultivar of the same species as "common oats", *Avena sativa*, but have a dominant gene which gives rise to a phenotype with a non-lignified husk (Ougham *et al.*, 1996). This becomes detached during harvesting. The absence of the indigestible husk can

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be predicted to give increased metabolisable energy (ME) content for poultry; apart from the low intrinsic nutritional value of the husk, it is also a major source of variability among batches of grain. The potential of naked oats in poultry nutrition has been increased still further by selection for high oil content (Valentine *et al.*, 2003). The high oil lines used in the present work ("Chris" 91-229Cn234 and "Fatso" 91-229Cn253) resulted from a cross between Pendragon (a naked oat bred at IGER) and N313-2. N313-2 was obtained from a recurrent selection programme for high groat oil content based on germplasm from the wild relative *Avena sterilis* at the University of Iowa (Branson and Frey, 1989). Racoon (95-240 Cn) is a commercially-available naked oat combining an intermediate concentration of oil with higher yield than Chris or Fatso. It derives from a complex cross involving 12% of its genes from N 361-3, another selection from the same cycle of the Iowa recurrent selection programme. The present paper describes part of a collaborative project assessing the energy yield from a number of commercial and experimental lines originating from IGER and grown at ADAS, Rosemaund.

Oats are increasingly recognised as having a number of valuable nutritional and agronomic characteristics. Naked oats are higher in essential amino-acids than wheat or barley. This offers the possibility of replacing some imported soya and animal proteins over and above the value of oats an energy source. Further advantages of naked oats include a high concentration of polyunsaturated oils (40% of oil is monounsaturated, 40% polyunsaturated) and significant antioxidant activity. The latter two characteristics confer benefits on egg and meat quality. The health benefits of polyunsaturated fatty acids could make eggs and meat from oat-fed hens more attractive to consumers. The effects on meat quality have been shown to include enhanced sensory evaluation and properties such as low drip loss and longer shelf life (Lopez-Bote *et al.*, 1998*a*,*b*). Oats enhanced the oxidative stability of broiler meat and also reduced cholesterol oxidation during cooking.

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Evidence is accumulating on the suitability of naked oats for inclusion in poultry diets up to a high concentration (Cave and Burrows, 1993; Hsun and Maurice, 1992; MacLean *et al.*, 1993) with or without enzyme supplementation (Brenes *et al.*, 1993). Oats are high in β-glucans, which are seen as a negative feature of barley. However, β-glucans vary in properties such as degree of branching and molecular weight, both of which influence anti-nutritive effects. Realisation of the beneficial nutritional qualities of oat products is already increasing demand for oats in human nutrition and knowledge on the biologically-active constituents is increasing rapidly (Lasztity, 1998).

Metabolisable energy (ME = gross energy - [faecal + urinary energy]) is a key measurement when including an ingredient in commercial diets. Accurate measurement of ME is necessary for formulating a diet with the appropriate energy concentration. It is also essential for determining the concentration of other diet components, since they should be included in proportion to energy content. This is because food intake by weight is governed largely by energy content, so the intake of other nutrients is determined by their ratio to energy content. Early in the analysis of results, it became clear that the values for conventional oats were higher than expected. Our hypothesis to explain this was that some oat hulls may have been retained in the gizzard beyond the end of the experimental period, since particles do not leave the gizzard until they are ground below a certain size. This would have the effect of reducing the measurement of total faecal energy, which would give an elevated ME estimate. The test of this hypothesis is described in the Materials and Methods section.

MATERIALS AND METHODS

Measurements of TME were performed in each of three harvest years (2000, 2001, 2002) on 3-week-old broiler chicks (Cobb males), adult cockerels (IsaBrown, >1 year) and 7-week-old turkeys (BUT T8 males). Each year, the evaluations were performed within 6

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months of harvest. The grain samples were stored at room temperature in natural-fibre bags. The varieties labelled "Chris" and "Fatso" are experimental high-oil lines. Two feed wheats were built into a randomised-block experimental design to give simultaneous comparison with the oat varieties. A feed wheat (Consort) was assayed every year, for comparison with the oat varieties. Annual measurements on a subset of varieties recommenced in 2004 and are expected to continue until 2009; some results from 2004 are included for comparison.

Slightly different bioassay techniques (McNab and Blair, 1988; MacLeod *et al.*, 1997) were adopted for each class of stock (Tables 1, 2, 3). All materials were ground through a 2.5 mm screen before feeding. The bioassays were done as soon as possible after each harvest. Results were corrected to zero nitrogen retention, which makes the simplification that the feedingstuff evaluated is used entirely as an energy source. The justification for this correction is that ME is purely an energy evaluation system, so materials should be assessed only for their energy value. The correction involves calculating (by the following equation) the additional energy which would appear in the excreta if any nitrogen retained were instead to be catabolised and excreted:

$$([\text{faecal+urinary}]\ \text{energy})_N = ([\text{faecal+urinary}]\ \text{energy}) + 34.4(\text{N intake} - [\text{faecal+urinary}]\text{N})$$

where 34.4 kJ/g is the mean gross energy of the nitrogenous excretory products.

Nitrogen correction was applied to endogenous energy losses (EEL) also. Becaause the "glucose control" birds used to measure EEL are temporarily on on a nitrogen-free diet, nitrogenous matter makes up a large proportion of endogenous losses. EEL_N is, therefore, lower than EEL (McNab and Blair, 1988).

Six replicate cockerels and 8 replicate broilers and turkeys were used for each raw material. Results were analysed by GENSTAT, using a REML method.

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Test for effect of hull retention

A separate experiment was carried out to test whether any oat hulls from hulled varieties were retained in the gut beyond the 48 h collection period and the effect of this on the TME estimate. A conventional oat (Gerald), a thin-hulled oat (Millennium) and a naked oat (Grafton) were compared. Each variety was precision-fed to 5 replicate cockerels in a randomised-block design. After the TME measurement procedure shown in Table 1, the birds were killed by intravenous pentabarbitone injection and the contents of the gizzard, ileum, caeca and rectum were collected in pre-weighed containers. The container and contents were then weighed, frozen and vacuum dried. The proportions of hulls retained were calculated from measurements of the hull content of representative samples of the corresponding oat variety.

Enzyme (β-glucanase) effects

An apparent metabolisable energy (AME_N) technique was used to measure the effect of β-glucanase on energy yield from naked oats (variety *Harpoon*) (Table 4). Jejunal viscosity was also measured. A commercial enzyme preparation, produced by the fungus *Trichoderma longibrachiatum* (ATCC 74 252), was used. It was added to the test diet to provide the following activities per kg of diet, based on the manufacturer's declared specification: endo-1,4-β-glucanase, 400 U; endo-1,3(4)-β-glucanase, 900 U; endo-1,4-β-xylanase, 1300 U. To permit stabilisation of the gut environment, the birds were kept on the test diets for 16 d before measurements were performed. The oats were substituted for 50% of a basal diet based on maize and soya (Table 5) and the AME of oats estimated by comparison of the 50% oat diet with the basal diet. Maize was used in the basal diet to give the most similar nutrient:energy ratio to the oat test material. A total of 4 diets were tested: basal diet control; basal diet + β-glucanase; mixed diet (50% oats) control; mixed diet + β-glucanase. The 4 diets were each given to 8 replicate groups of 3 Ross broiler

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males. On d 1-4, the birds were fed on a standard broiler starter diet. The experimental diets were given from d 5-21. Droppings were collected for analysis from d 18-21. Titanium dioxide was added to allow the use of a marker ratio technique in estimating AME. In this technique, apparent metabolisability is calculated from the equation below and multiplied by the gross energy of the diet to give AME.

$$\text{Apparent metabolisability} = 1 - (GE_{droppings} / TiO_{2\ droppings})/(GE_{feed} / TiO_{2\ feed})$$

The substitution method uses the equation below for calculation of the AME of the test ingredient (oats) from the AME of the basal diet and the AME of the diet made up of 50% oats and 50% basal diet.

$$AME_{oats} = AME_{basal} + (AME_{test} - AME_{basal})/(\text{proportion of oats in test diet})$$

Chemical analysis

Sub-samples of each variety were analysed for crude protein, oil (acid ether extract), starch and β-glucan by Eurofins Laboratories Ltd (Wolverhampton, England), using standard AOAC methods.

RESULTS

ME values are summarised in Tables 6 and 7. TME_N is true metabolisable energy adjusted to zero nitrogen balance. A dry matter basis gives a better standard of comparison but an as-fed basis is typically used in commercial feed formulation. The coefficients of variation in TME were low, typically about 3%. Excluding the experimental high-oil lines, naked oats on average yielded a TME_N 8.5% higher than that of wheat assayed simultaneously. The high-oil lines yielded 12% more energy than wheat. These relative differences have been repeated in grain from the 2004 harvest (Table 8). In the 2004 samples, conventional oats gave TME values about 13% lower than those of wheat. Naked oats and the high-oil naked oats gave values respectively 9% and 13% higher than wheat. There was a highly significant interaction between cereal species and bird species, turkeys appearing to extract

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more TME from oats (especially husked oats) than did broilers, although there was no difference between bird species in the amount of TME obtained from wheat. The oil contents (acid ether extract) of the cereal samples were as follows (g/kg): wheats, 30; Gerald, 90; Millennium, 70; Expression, 120; 95-240-Cn, 150.

Comparison of bird types

There were significant and consistent differences between bird types, with the mature cockerels giving the highest value (17.7 MJ/kg dry matter), the broilers lowest (17.0 MJ/kg) and the turkeys intermediate (17.2 MJ/kg). There was a close linear relationship between TME_N measured in broilers and cockerels, although there was a tendency for broiler TME_N to be about 3% lower. Broiler and turkey values were in closer agreement.

Comparison of harvest years

There were significant differences between years (2000, 17.0 MJ/kg dry matter; 2001, 17.3 MJ/kg; 2002, 17.6 MJ/kg).

Relationships between TME and chemical composition

There was a significant positive relationship between TME_N and acid ether extract in all types of poultry examined. The relationships were as follows:

Broilers: $TME_N = 15.7$ (*SEM 0.36*) + 0.11 (*SEM 0.030****) (% fat)

Cockerels: $TME_N = 16.3$ (*SEM 0.41*) + 0.12 (*SEM 0.034****) (% fat)

Turkeys: $TME_N = 15.9$ (*SEM 0.40*) + 0.11 (*SEM 0.033****) (% fat)

There was a significant negative relationship between TME_N and β-glucan in all types of poultry examined. This is likely to have been due to the increased gut viscosity produced by soluble non-starch polysaccharides. The relationships were as follows:

Broilers: $TME_N = 18.9$ (*SEM 0.42*) – 0.46 (*SEM 0.10****) (% β-glucan)

Cockerels: $TME_N = 18.9$ (*SEM 0.48*) – 0.28 (*SEM 0.12**) (% β-glucan)

Turkeys: $TME_N = 18.1$ (*SEM 0.45*) – 0.22 (*SEM 0.11**) (% β-glucan)

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The oil content of naked oats was about 5 times greater than that of wheat (Table 9), with the high oil varieties more than 6 times greater. Oats had a lower starch content but not sufficiently lower to negate the energy benefits of the higher oil content. Crude protein (CP) contents of naked oats were broadly similar to those of wheat, with the high oil varieties tending to be high in CP also. The proportions by weight of the major energy-yielding nutrients are shown in Table 10. The proportions in terms of energy contribution were estimated from the coefficients of the EU ME equation for oil, starch and CP. The proportional contribution of oil varied from 6% in wheat to 30% in high-oil naked oat varieties, with the proportion from starch decreasing from 80% in wheat to 57% in high-oil naked oats. If dietary energy were to be expressed in terms of net energy, naked oats would have an added advantage over wheat in energy yield.

Chemical composition

Table 9 shows key ME-related chemical analyses (g/kg dry matter) of oats from the 2000, 2001 and 2002 harvests and wheats from the 2002 harvest. The most noticeable difference in terms of energy yield is that naked oats had about 4 times as much oil as wheat, rising to 6-7 times as much in the high-oil naked oat lines. The crude protein content of most naked oat varieties was similar to that of wheat, with high-oil varieties tending to have a greater crude protein content also. The relative contributions of oil, starch and crude protein in terms of energy yield (Table 10) were calculated from the EC equation estimating AME from a multiple regression on protein, oil, starch and sugars:

AME_N (MJ/kg) = 0.34 (%fat) + 0.16 (%CP) + 0.13 (% total sugar [expressed as sucrose]) + 0.17 (%starch).

The proportion of energy contribution as oil was 4-5 times that in wheat, with the contribution as protein quite similar between species and the contribution as starch being about 20% less in oats

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Enzyme effects

The addition of β-glucanase produced an increase of about 4% in the apparent metabolisable energy (AME) of oats for broilers (Tables 11 and 12). β-glucanase had a very large effect on jejunal viscosity in broilers fed on a high-oat diet (Table 13) but the relatively modest effect on AME is typical of enzyme effects on metabolisability.

Technical error with hulled oats

Dissection of cockerels 48 h after feeding on Gerald conventional oats indicated that enough oat hulls were retained in the gizzard to give an overestimate of about 1 kJ/g or about 7.4% (Table 14). There was insufficient material in other parts of the gut to give a large enough sample for energy determination and the amount was also similar between all varieties, suggesting that the material in the lower gut could not be ascribed only to hulled varieties. In the thin-hulled variety, Millennium, retained hulls gave an overestimate of 6.3%. In the naked oat, Grafton, the corresponding overestimate was only 0.7%.

DISCUSSION

Excluding the experimental high-oil lines, naked oats on average yielded a TME_N 8.5% higher than that of wheat assayed simultaneously. The high-oil lines yielded 12% more energy than wheat. These relative differences in TME were been repeated in the 2004 harvest. The ME yield from naked oats was comparable with that of maize rather than wheat. The values obtained for wheat may be seen as high by some commercial users but it is important to note that our values are TME, which can be up to 5% higher than AME. It should also be noted that wheat has been included in each year and gives similar values from year to year. If there are doubts about absolute TME values, the oat varieties can accordingly be assessed relatively to the simultaneous measurements for wheat. The high ME results largely from the combined effects of the absence of husks and the high oil content. Digestibilities of the major nutrients are similar to those found in wheat. TME

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increased by about 0.11 MJ for every 1% increase in oil content; this is the increase that would be expected if oil is replacing other energy-yielding materials such as starch. Unpublished work by McNab (1987) gave dry matter TME_N values of 16.5 MJ/kg (about 14.5 MJ/kg as fed) for the first naked oat varieties, the spring variety Rhiannon and the winter variety Kynon, released by IGER. The winter naked oat Expression and the winter dwarf naked oat Hendon, from two further cycles of hybridisation and selection, were used in the present study. These contain about 30% more oil than the Rhiannon and Kynon, which helps to explain their increased mean dry matter TME_N values of 17.1 MJ/kg (about 15.0 MJ/kg as fed). Continuity between the techniques used in 1987 and in 2000-2003 was assured in that one of the authors of the present paper (Bernard) also assisted with the 1987 work.

Technical error with hulled oats

The positive error of 6% in the ME value obtained for hulled oats would be of significant practical importance in feed formulation. Dissecting the birds in order to measure the retention of material in the gizzard would not be the method of choice for dealing with this error. Later work (MacLeod *et al.*, 2006) has shown that the error became negligible when the hulls were ground through a 1 mm screen. Even where it does occur, the error is one of evaluation only, because the passage of hulls through the gizzard would reach a steady state under normal feeding conditions.

Future research and commercial implications

The nutritional profiles obtained for oats and naked oats demonstrated that earlier published nutritional data significantly under-estimated the value of oats and naked oats in poultry diets. Further research is needed to assess any beneficial effects of oat hulls (MacLeod and Bernard, 2005). The development of higher yielding 'high oil' varieties, of which Racoon is the first example, should enhance the use of naked oats in poultry rations.

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Naked oats have been demonstrated to be nutritionally viable as a wheat alternative within poultry rations. The values measured for Harpoon and Grafton were used to formulate diets by the commercial partners and gave the predicted results in terms of bird performance.

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REFERENCES

BRANSON, C.V. & FREY, K.J. (1989). Recurrent selection for groat oil content in oats. *Crop Science* **29:** 1382-1387.

BRENES, A., GUENTER, W., MARQUARDT, R.R. & ROTTER, B.A. (1993). Effect of beta-glucanase pentosanase enzyme supplementation on the performance of chickens and laying hens fed wheat, barley, naked oats and rye diets. *Canadian Journal of Animal Science,* **73:** 941-951.

CAVE, N.A. & BURROWS, V.D. (1993). Evaluation of naked oat (*Avena nuda*) in the broiler chicken diet. *Canadian Journal of Animal Science,* **73:** 393-399.

HSUN, C.L. & MAURICE, D.V. (1992). Nutritional value of naked oats (*Avena nuda*) in laying hen diets. *British Poultry Science,* **33:** 355-361.

LASZTITY, R. (1998). Oat grain – a wonderful reservoir of natural nutrients and biologically active substances. *Food Reviews International* **14:** 99-119.

For Peer Review Only

LOPEZ-BOTE, C.J., SANZ, M., REY, A., CASTANO, A. & THOS, J. (1998*a*). Lower lipid oxidation in the muscle of rabbits fed diets containing oats. *Animal Feed Science and Technology* **70:** 1-9.

LOPEZ-BOTE, C.J., GRAY, J.I., GOMAA, E.A. & FLEGAL, C.J. (1998*b*). Effect of dietary oat administration on lipid stability in broiler meat. *British Poultry Science* **39:** 57-61.

MACLEAN, J., WEBSTER, A.B. & ANDERSON, D.M. (1993). Naked oats in grower and finisher diets for male chicken and female turkey broilers**.** *Canadian Journal of Animal Science,* **74:** 135-140.

MACLEOD, M.G., BERNARD, K. & KNOWLES, H. (1997). A comparison of the true metabolisable energy of wheat and soya bean meal in 28-day-old turkeys and broilers**.** *British Poultry Science,* **38:** S32-33.

MACLEOD, M.G., MCNEILL, L., BERNARD, K & VALENTINE, J. (2006). Oats: metabolisable energy yield from husked and naked varieties and an experimental naked high-oil line compared with wheat in broilers and turkeys. *British Poultry Abstracts* **2:** 10-11.

MCNAB, J.M. & BLAIR, J.C. (1988). Modified assay for true and apparent metabolisable energy based on tube feeding**.** *British Poultry Science,* **29:** 697-707.

OUGHAM, H.J., LATIPOVA, G. & VALENTINE, J. (1996). Morphological and biochemical characterization of spikelet development in naked oats (*Avena sativa*). *New Phytologist*, **134**: 5-12.

VALENTINE, J., COWAN, S., HOWARTH, C. & LANGDON, T. (2003). One hundred years of progress in cereal breeding from Mendel to molecular selection. *Proceedings of the EUCARPIA Cereal Section Meeting "From Biodiversity to Genomics: Breeding Strategies for Small Grain Cereals in the Third Millennium"* (Eds: Faccioli, P; Marè, C; Stanca, A M), Salsomaggiore, Italy, 21-25 November, 2002 .

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TABLE 1. *Protocol for cockerel TME measurement*

Day 1	Birds to individual cages, no food, free access to water
Day 2	50 ml of 50% glucose solution administered to all birds
Day 3	50 g of test material or 50 g of glucose tube fed to birds
	Clean tray placed under each cage
	Feeding time recorded
Day 4	50ml of water administered to all birds
Day 5	Excreta collected 48 h after feeding

TABLE 2. *Protocol for broiler chicken TME. Birds used when 21 d old*

Day 1	Birds to individual cages, no food, free access to water
Day 2	No procedures
Day 3	9 g of test material or 9 g of glucose tube fed to birds (am)
	Clean tray placed under each cage
	9 g of test material or 9 g of glucose tube fed to birds (pm)
Day 4	9 g of test material or 9 g of glucose tube fed to birds (am)
	9 g of test material or 9 g of glucose tube fed to birds (pm)
	Feeding time recorded
Day 5	10 ml of water administered to all birds
	If necessary, water again pm
Day 6	Excreta collected 48 h after last feeding

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TABLE 3. *Protocol for turkey TME measurement. Birds used when 7 weeks old*

Day 1	Birds to individual cages, no food, free access to water
Day 2	No procedures
Day 3	50 g of test material or 50 g of glucose tube fed to birds
	Clean tray placed under each cage
	Feeding time recorded
Day 4	50 ml of water administered to all birds
Day 5	Excreta collected 48 h after feeding

TABLE 4. *Protocol for 14-d AME measurement*

Day 1	Wing band and weigh birds
	Allocate 5 one-d-old birds per brooder section
Days 1- 4	Standard diet
Day 5	Remove standard diet and replace with experimental diets
Day 7	Weigh birds and food
Day 14	Weigh birds and food
Day 18	Clean paper on trays
Day 21	Weigh birds and food
	Collect excreta sample
	Kill birds, collect ileal contents

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TABLE 5. *Diets for enzyme trial*

	Test diet (g/kg)	Basal diet (g/kg)
Naked oats (meal)	**500.0**	**0.0**
Maize meal	228.0	456.0
Soya bean meal	216.0	432.0
Fish meal	22.0	44.0
Soya oil	0.8	1.6
DL-methionine	1.0	2.0
Sodium chloride	3.5	3.5
Dicalcium phosphate	13.4	13.4
Limestone flour	10.0	10.0
Choline chloride	0.3	0.3
Vitamins and minerals[1]	5.0	5.0
Cellulose	0.0	32.2

[1]Vitamins and minerals were provided to meet or exceed NRC recommendations for broiler diets.

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TABLE 6. *Metabolisable energy values (TME_N MJ/kg* ***dry matter****) of oats and reference wheat in cockerels, growing chicks and growing turkeys (2000, 2001, 2002 harvests)*

Variety	Bird type	2000	2001	2002	Mean across harvests and bird types
"Chris"	cockerel	17.78*	18.07	18.60	17.85
91-229Cn234	chick	17.28	16.85	18.34	
(high oil)	turkey	17.18	18.08	18.41	
"Fatso"	cockerel	18.04	17.97	*	17.65
91-229Cn253	chick	16.85	17.13	*	
(high oil)	turkey	17.18	18.03	*	
Hendon	cockerel	17.39	17.53	18.14	17.23
(dwarf)	chick	16.78	16.27	17.78	
	turkey	16.55	17.97	16.97	
Icon	cockerel	17.03	16.97	*	17.06
(dwarf)	chick	16.62	16.39	*	
	turkey	16.64	17.88	*	
Grafton	cockerel	17.37	17.78	17.89	17.05
	chick	16.35	16.62	16.74	
	turkey	16.46	17.61	17.04	
Harpoon	cockerel	17.17	17.17	*	17.00
	chick	16.54	16.57	*	
	turkey	16.33	17.39	*	
Krypton	cockerel	17.45	18.24	18.27	17.78
	chick	18.10	17.27	18.29	
	turkey	16.46	18.15	17.50	
Lexicon	cockerel	17.45	17.79	17.92	17.38
	chick	17.05	16.40	17.76	
	turkey	16.61	18.83	16.99	
Expression	cockerel	*	17.27	17.78	16.92
	chick	*	16.51	17.56	
	turkey	*	17.13	16.40	
Consort	*cockerel*	*16.19*	*15.56*	*16.83*	*15.91*
(feed wheat)	*chick*	*15.55*	*14.67*	*16.11*	
	turkey	*15.55*	*16.06*	*16.53*	
Equinox	*cockerel*	*	*15.26*	*16.80*	*15.81*
(feed wheat)	*chick*	*	*14.73*	*16.42*	
	turkey	*	*15.88*	*15.78*	

* SEM of individual values = 0.248

Statistical differences (oats only)		
	SEM	*P*
Variety effect	0.119	<0.001
Bird type effect	0.063	<0.001
Year effect	0.067	<0.001
Variety x bird		<0.002

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TABLE 7. *Metabolisable energy values (TME_N MJ/kg* ***adjusted to 88% dry matter*** *) of oats and reference wheat in cockerels, growing chicks and growing turkeys (2000, 2001, 2002 harvests)*

Variety	Bird type	2000	2001	2002	Mean across harvests and bird types
"Chris"	cockerel	15.65*	15.90	16.37	15.71
91-229Cn234	chick	15.21	14.83	16.14	
(high oil)	turkey	15.12	15.91	16.20	
"Fatso"	cockerel	15.88	15.81	*	15.53
91-229Cn253	chick	14.83	15.07	*	
(high oil)	turkey	15.12	15.87	*	
Hendon	cockerel	15.30	15.43	15.96	15.16
(dwarf)	chick	14.77	14.32	15.65	
	turkey	14.56	15.81	14.93	
Icon	cockerel	14.99	14.93	*	15.01
(dwarf)	chick	14.63	14.42	*	
	turkey	14.64	15.73	*	
Grafton	cockerel	15.29	15.65	15.74	15.00
	chick	14.39	14.63	14.73	
	turkey	14.48	15.50	15.00	
Harpoon	cockerel	15.11	15.11	*	14.96
	chick	14.56	14.58	*	
	turkey	14.37	15.30	*	
Krypton	cockerel	15.36	16.05	16.08	15.65
	chick	15.93	15.20	16.10	
	turkey	14.48	15.97	15.40	
Lexicon	cockerel	15.36	15.66	15.77	15.29
	chick	15.00	14.43	15.63	
	turkey	14.62	16.57	14.95	
Expression	cockerel	*	15.20	15.65	14.89
	chick	*	14.53	15.45	
	turkey	*	15.07	14.43	
Consort	*cockerel*	*14.25*	*13.69*	*14.81*	*14.00*
(feed wheat)	*chick*	*13.68*	*12.90*	*14.18*	
	turkey	*13.68*	*14.13*	*14.55*	
Equinox	*cockerel*	*	*13.43*	*14.78*	*13.91*
(feed wheat)	*chick*	*	*12.96*	*14.45*	
	turkey	*	*13.97*	*13.89*	

* SEM of individual values = 0.218

Statistical differences (oats only)		
	SEM	*P*
Variety effect	0.105	<0.001
Bird type effect	0.055	<0.001
Year effect	0.059	<0.001
Variety x bird		<0.002

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TABLE 8. *Metabolisable energy values of oats and reference wheats (2004 harvest) in growing broilers and growing turkeys*

Variety	Bird species	TME_N MJ/kg as fed		TME_N MJ/kg dry matter (DM)	
		Mean	Standard deviation	Mean	Standard deviation
Expression	broiler	15.6	0.40	17.7	0.46
(naked oat)	turkey	15.5	0.64	17.6	0.72
Hendon	broiler	15.7	0.37	17.8	0.42
(dwarf naked oat)	turkey	16.5	0.26	18.5	0.08
95-240-Cn	broiler	16.1	0.38	18.5	0.44
(high oil naked oat)	turkey	16.8	0.45	19.0	0.52
Gerald	broiler	12.4	0.42	14.1	0.48
(covered oat)	turkey	14.0	0.46	15.9	0.53
Millennium	broiler	12.4	0.49	14.2	0.56
(thin husk covered oat)	turkey	14.0	0.70	16.0	0.80
Consort	broiler	14.3	0.41	16.5	0.47
(wheat)	turkey	14.1	1.06	16.3	1.23
Robigus	broiler	14.2	0.37	16.1	0.42
(wheat)	turkey	14.5	1.09	16.4	1.24

Source of variation	Degrees of freedom	*P*
Cereal "species"	2	< 0.001
Cereal variety	6	< 0.004
Bird species	1	< 0.001
Cereal*bird	2	< 0.001
Variety*bird	6	NS

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TABLE 9. *Selected chemical analyses (g/kg dry matter) of oats from 2000, 2001 and 2002 harvests and wheats from 2002. The analyses were carried out on duplicate samples each year.*

	Harvest	Dry matter	Crude protein (6.25 N)	Oil (acid ether extract)	Starch	β-glucan
"Chris"	**2000**	890	158	156	557	46.1
91-229Cn234	**2001**	884	134	152	637	41.1
(high oil)	**2002**	861	140	158	545	39.0
	Mean	878	144	155	580	42.1
"Fatso"	**2000**	900	150	146	645	53.3
91-229Cn253	**2001**	885	129	162	608	41.1
(high oil)	**2002**	-	-	-	-	-
	Mean	893	140	154	627	47.2
Hendon	**2000**	886	130	104	635	49.9
(dwarf)	**2001**	880	114	109	727	40.6
	2002	857	111	97	554	24.6
	Mean	874	118	103	639	38.4
Icon	**2000**	896	135	109	634	46.4
(dwarf)	**2001**	879	112	105	697	45.5
	2002	-	-	-	-	-
	Mean	888	124	107	666	46.5
Grafton	**2000**	893	136	102	591	49.0
	2001	878	116	115	649	46.0
	2002	853	119	108	504	36.5
	Mean	875	124	108	581	43.8
Harpoon	**2000**	889	143	105	627	39.4
	2001	876	121	86	648	40.0
	2002	-	-	-	-	-
	Mean	883	132	96	638	39.7
Krypton	**2000**	885	124	112	569	37.0
	2001	882	103	117	748	32.8
	2002	858	103	118	630	36.2
	Mean	875	110	116	649	35.3
Lexicon	**2000**	891	140	110	634	39.6
	2001	876	115	102	700	37.9
	2002	856	116	121	576	37.0
	Mean	874	124	111	637	38.2
Expression	**2000**	-	-	-	-	-
	2001	874	114	108	751	44.1
	2002	856	122	130	611	47.0
	Mean	865	118	119	681	45.6
Wheats						
Charger	**2002**	871	140	23	691	-
Claire	**2002**	882	123	23	703	-
Consort	**2002**	870	129	24	693	-
Equinox	**2002**	870	126	25	672	-
Savannah	**2002**	872	125	23	703	-

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TABLE 10. *Oil, starch and crude protein (CP); relative proportions of total (oil+starch+CP) in terms of weight and energy yield*

	Proportions by weight			Proportions by energy contribution		
	Oil	Starch	CP	Oil	Starch	CP
High-oil naked oats	0.16	0.67	0.16	0.30	0.57	0.13
Naked oats	0.13	0.74	0.14	0.23	0.66	0.12
Wheat	0.03	0.82	0.15	0.06	0.80	0.14

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TABLE 11. *Effects of a commercial beta-glucanase preparation on AME (kJ/g as fed; n=8)*

	Control diet		Oat-containing diet		Oat result	
	mean	sem	mean	sem	mean	sem
No enzyme	10.64	0.12	11.55	0.13	12.46	0.13
β-glucanase	10.80	0.10	11.86	0.17	12.92	0.17

TABLE 12. *Effects of a commercial beta-glucanase preparation on AME_N (kJ/g as fed; n=8)*

	Control diet		Oat-containing diet		Oat result	
	mean	sem	mean	sem	mean	sem
No enzyme	9.83	0.09	10.48	0.12	11.13	0.12
β-glucanase	10.01	0.09	10.74	0.16	11.47	0.16

TABLE 13. *Enzyme effects on jejunal viscosity (centipoise; n=8)*

	Control diet (maize-soya)	Oat diet (50% oats)
No enzyme	2.62	11.70
β-glucanase	2.30	3.26
Significance of effects		
Oats	$P<0.001$	
Enzyme	$P=0.01$	
Interaction	$P=0.02$	
SEM	1.391	
Least significant difference ($P<0.05$)	3.980	

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TABLE 14. *Covered oats with naked oat (Grafton) for comparison: error due to hulls remaining in gizzard 48 h after feeding (mean ± SD; n=5)*

	% hulls retained in gizzard after 48h	TME_N kJ/kg as fed (standard method)	TME_N kJ/kg as fed (corrected for gizzard contents)	Error kJ/g	Error %
Gerald *(conventional)*	24.8 ± 14.8	14.6 ± 0.89	13.6 ± 0.50	1.0	+7.4
Millennium *(thin-hulled)*	30.6 ± 8.89	15.3 ± 0.88	14.4 ± 1.09	0.9	+6.3
Grafton *(naked)*	0.0 ± 0.00	15.3 ± 0.53	15.2 ± 0.45	0.1	+0.7*

*Other residues in gizzard

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