Utilization of metabolizable energy by ostrich (*Struthio camelus*) chicks at two different concentrations of dietary energy and crude fibre originating from lucerne[1]

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The effect of changing dietary energy and crude fibre concentrations on the utilization of metabolizable energy (ME) was investigated in four growing ostrich chicks by addition of lucerne meal to a maize–lucerne based diet. The experiment was carried out in an indirect open circuit calorimeter. When ME concentration was lowered by 7.5%, cell wall digestibility decreased by 9% and energy metabolizability (ME/GE) by 15% ($P < 0.05$). Energy loss as methane was negligible and was not influenced by dietary energy or crude fibre concentration. Maintenance energy requirement was 0.44 MJ/W, $kg^{0.75}$/day and the efficiency of ME utilization for growth was 0.32. The efficiency of ME utilization tended to deteriorate with decreasing energy or increasing crude fibre concentration in the diet. It was concluded that future research should be aimed at quantifying the influence of crude fibre on ME utilization over an extended range of dietary energy concentrations.

Die effek van 'n verandering in dieetenergie- en ruveselkonsentrasie op die doeltreffendheid van metaboliseerbare energie (ME)-benutting is by vier groeiende volstruiskuikens ondersoek deur 'n lusern–mielie-gebaseerde dieet met lusernmeel te verdun. Die proef is in 'n indirekte ope-baan kalorimeter uitgevoer. 'n Verlaging van 7.5% in ME-konsentrasie het die verteerbaarheid van selwande met 9% en die metaboliseerbaarheid van dieetenergie met 15% ($P <$ 0.05) verlaag. Verliese aan metaanenergie was onbeduidend en onafhanklik van energie- of ruveselkonsentrasie van die dieet. Die onderhoudsbehoefte was 0.44 MJ/W, $kg^{0.75}$/dag en die doeltreffendheid van ME-benutting vir groei was 0.32. Die doeltreffendheid van ME-benutting het geneig om te verswak met 'n afname in energie-konsentrasie of 'n toename in ruveselkonsentrasie van die dieet. 'n Finale gevolgtrekking was dat toekomstige navorsing gemik moet wees op die kwantifisering van die invloed van ruvesel op die benutting van ME oor 'n wyer reeks konsentrasies van dieetenergie.

Keywords: Calorimetry, efficiency, gas exchange.

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Introduction

Ostrich production on high concentrate meal diets is a new development with exceptional possibilities for the commercial ostrich farming industry in the Little Karoo of South Africa (Swart & Kemm, 1985).

Efficient diet formulation has accordingly become essential for profitable ostrich production. The nutritional value of feed constituents for ostriches is, however, still unknown, making effective least cost diet formulation and programming impossible. Present growth and finishing diets for ostriches are based on nutritional standards and energy values of ingredients derived for poultry (Blair *et al.*, 1983; Du Preez *et al.*, 1986) and pigs (Kemm & Ras, 1981; NRC, 1973; IAFMM, 1985). This approach may, however, result in unrealistic estimates of the nutritional value of feed constituents for ostriches (Swart *et al.*, 1993a), so that quantification of the nutritional value has consequently become necessary.

It was recently shown that ostriches digest plant fibre, and more specifically cellulose, effectively which could make a substantial contribution to the energy requirements of growing ostriches (Swart *et al.*, 1993a; 1993b). The objective of the present study was to investigate the effect of dietary energy concentration or crude fibre (CF), originating from lucerne, on the digestibility of gross energy (GE), the energy loss as methane, heat expenditure, as well as the effect on the efficiency of metabolizable energy (ME) utilization.

Materials and Methods

Animals and housing

Four ostrich chicks of 33.5 ± 0.9 kg initial live mass and between 42 and 210 days of age, were used. They were individually reared and housed in flat, deck-type metabolism cages (1.5 × 0.8 × 1.2 m high), fitted with non-skid rubber floors, height-adjustable water buckets and feeding troughs. The experiment was carried out in the open circuit indirect calorimeter at the Irene Animal Production Institute, as described by Viljoen (1985). Each metabolism cage was custom-made to fit inside both respiration chambers (A and B) of the calorimeter and could easily be wheeled in and out of the chambers in order to rotate birds between experiments. Prior to the experiments the birds were adapted to handling and confinement in the calorimeter chambers.

Diets and treatments

Three dietary treatments, differing in daily energy supply (ME/day) and/or energy concentration (ME/kg DM), were fed consecutively to the four ostriches. The ostriches were randomly allotted in pairs and assigned to respiration chambers A and B, respectively.

The three dietary treatments were as follows:

1. Basal diet fed daily at 2% of live mass.
2. Basal diet fed daily at 3% of live mass, i.e. treatment 1 plus basal diet added at 1% of live mass.
3. Basal diet, diluted with 33% lucerne meal, fed daily at 3% of live mass, i.e. treatment 1 plus lucerne meal added at 1% of live mass.

The basal diet was formulated to contain *ca.* 19% crude protein and 13 MJ ME/kg DM (Table 1).

Each of the 12 trial periods (3 treatments × 4 ostriches) lasted 14 days; seven days adaptation in a non-functional or dummy respiration chamber and another seven days in the functional chambers of the calorimeter. The last four days were utilized for calorimetric and metabolic measurements.

Table 1 Composition of basal and lucerne-diluted meal diets

	DM intake of diets (g/W, $\text{kg}^{0.75}$)	
	Basal diet	Lucerne-diluted meal diet
Components (g/kg)		
Maize meal	530	398
Lucerne-meal (21% CP)	340	505
Fish-meal	84	63
Limestone powder	10	07
Monocalcium phosphate	26	20
Salt	10	07
Minerals and vitamins[a]	+	+
DM nutrient content (analysed)		
Protein (6.25 × N) (%)	19.4	19.6
Crude fibre (%)	13.0	17.0
NDF (%)	25.0	29.1
ME[b] (MJ/kg DM)	13.1	12.2

[a] Mineral-vitamin premix (Truka: Germiston, South Africa) added per kg mixed diet: 10000 IU Vit. A; 2000 IU Vit. D; 15 IU Vit. E; 2 mg Vit. K; 2 mg Thiamin; 8 mg Riboflavin; 4 mg Pyridoxine; 0.02 mg Vit. B^{12}; 1.5 mg Folic acid; 0.05 mg Biotin; 10 mg Pantothenic acid; 30 mg Niacin; 250 mg Manganese; 66 mg Zinc; 1 mg Iodine; 30 mg Iron; 11 mg Zinc Bacitracin.

[b] Values determined in the digestion trials (Table 3).

Digestibility and calorimeter trials

Special excreta bags were constructed from plastic bags to fit snugly over the entire tail end of the ostriches. The bag was taped to a 60–100 mm wide stomach girdle which in turn consisted of waterproof adhesive plaster taped around the abdomen of the ostrich (Figure 1). The open end of the excreta bag was folded back and sealed with tape and could be opened for each collection. At the beginning of each collection period, excreta collection bags were attached to the ostrich chicks. Prior to this, their tail feathers were washed, clipped and brushed to prevent contamination of excreta with scales and feathers.

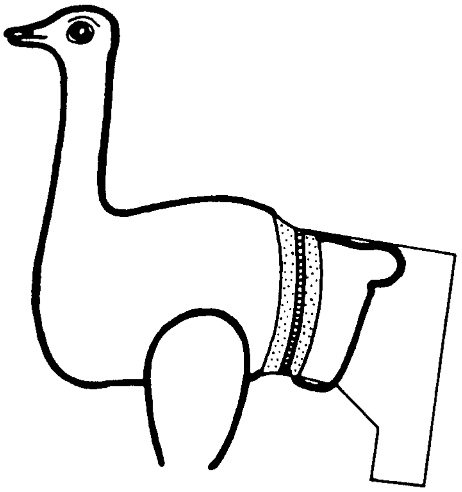

Figure 1 Illustration of ostrich chick with stomach girdle and excreta collection bag.

The total daily ration for each ostrich was accurately weighed and fed at 09:00, while total excreta and orts of the preceding 24 h were collected quantitatively. Daily excreta collections of each bird were weighed, bulked (4 days) and kept refrigerated (2 °C) in air-tight plastic containers until required for further analyses.

Sample preparation

At the end of each collection period, the pooled excreta of each bird was thoroughly blended. Approximately 2 g of each blend was then accurately weighed into porcelain crucibles in triplicate and dried at 100 °C in a convection oven for dry matter (DM) determination. A representative sample was concomitantly freeze-dried and ground (1-mm sieve) for further analyses. Representative dietary samples were also collected and stored for chemical analyses.

Gas exchange and calorimetry

Immediately after feeding and collection of excreta at 09:00 each day, the ostrich chicks were confined to the respiration chambers of the animal calorimeter for measurement of oxygen consumption, carbon dioxide production and methane production over the following 24 h as described by Viljoen (1985). The results of measurements taken over four consecutive days were then utilized to calculate the mean daily heat expenditure (HP) after the method of Brouwer (1958), according to the formula proposed by Blaxter (1970). Ostriches void faeces and urine together as total excreta, as in poultry. Uric acid-N (Romijn & Lockhorst, 1961) instead of urine-N, was therefore needed to correct the observed values of O_2 and CO_2 for protein degradation. The following formula was used:

$$HP\ (kJ) = 16.18(O_2) + 5.02(CO_2) - 2.17(CH_4) - 5.99(N) \quad (1)$$

where O_2 = oxygen consumed (l/day); CO_2 = carbon dioxide produced (l/day); CH_4 = methane produced (l/day); and N = uric acid-N (g/day).

By definition, the difference between ME and HP provides values for retained energy (RE).

Chemical analyses

CF was analysed according to standard AOAC (1984) procedures. Neutral detergent fibre (NDF) or cell wall contents was determined using a Tecator Fibretec hot extraction apparatus after removal of starch with α-amylase (Robertson & Van Soest, 1981).

GE was determined by combustion of samples in an adiabatic bomb calorimeter (DDS 400: Digital Data Systems, Randburg, South Africa). Apparent ME of the diets was calculated using the following relationship:

$$ME\ (MJ) = GE - (FE + UE) - CH_4E \quad (2)$$

where GE = gross energy or ingested energy; (FE + UE) = faecal plus urinary energy voided as total excreta (Sibbald, 1982), and CH_4E = energy in methane. Daily methane production was measured as 1/24 h and converted to CH_4-energy (0.0395 MJ/l CH_4; Blaxter, 1970).

Uric acid-N was determined in samples of total excreta according to the method of Ekman (1948).

Statistical analyses

Linear contrasts between treatment means, expressed per $W, kg^{0.75}$, were calculated according to *t*-test procedures (Snedecor & Cochran, 1980). Calculation by regression was only performed between data sets of treatments 1 and 2 owing to the significant difference between efficiency of ME utilization for growth (kg) from treatments 1 and 2, versus treatment 3. Fitting a linear regression equation to the data sets of treatments 1 and 2 provided estimates of the maintenance energy requirements (ME_m) and the efficiency of ME utilization (kg) for live mass gain (Bayley, 1982). The mean metabolic mass of each ostrich chick ($W, kg^{0.75}$) was estimated from live mass measured at the beginning and end (14 days) of each experiment.

Results and Discussion

Feed intake

Despite their susceptibility to stress and wild nature, the health of the ostrich chicks in the metabolism and calorimetric experiments was good. Although rations were not completely consumed, the variation in feed intake, expressed per $W, kg^{0.75}$, within treatments was small (CV < 10%). Furthermore, the calculated additional DM intake on treatment 3 (added lucerne), which was higher than that of treatment 1 (low-level basal ration), consisted almost entirely of lucerne. The increased DM intake on treatment 2 (high-level basal ration), which was higher than that of treatment 1, was only slightly higher than the additional lucerne intake on treatment 3 (Table 2).

Table 2 Dry-matter intake by ostriches on the three dietary treatments

	DM intake of diets ($g/W, kg^{0.75}$)			
Dietary treatment	Basal ration	Additional basal ration	Additional lucerne	Total ration
(1) Basal (low level)	39.5 ± 0.79	–	–	39.5 ± 0.79
(2) Basal + basal	39.5 ± 1.51	14.7 ± 1.42	–	54.2 ± 1.70
(3) Basal + lucerne	40.5 ± 1.43	–	12.8 ± 1.11	53.3 ± 0.33

Nutrient digestion and energy metabolism

The effect of increasing ME intake and decreasing dietary energy concentration on nutrient digestion and energy metabolism is presented in Table 3. When the intake of DM was increased without changing energy or CF concentration of the diet (treatment 1 vs. 2), the CF and NDF digestibilities ($P < 0.01$) were depressed by 19.0% and 9.5%, respectively. Energy metabolizability decreased by 3.3% ($P < 0.05$). When DM intake was increased to the same level, but at a lower energy concentration (treatment 1 vs. 3), however, DM, CF and NDF digestibilities were depressed by 8.6%, 23.8% and 18% ($P < 0.01$), respectively. Energy metabolizability decreased by 17.9% ($P < 0.01$). On the other hand, when the intake of CF from lucerne was increased by 30% (constant DM intake, treatment 2 vs. 3), it tended to decrease CF digestibility, and decreased NDF digestibility by 5.9% and 9.4% ($P < 0.05$), respectively. DM digestibility and energy metabolizability decreased ($P < 0.01$) by 5.0% and 15.0%, respectively.

Various experiments on different animal species show that the possibility exists that high proportions of CF in the diet result in a faster rate of passage (Warner, 1981). Furthermore, when energy concentration decreases or as CF concentration increases, more nutrients are likely to pass through the small intestine and a large proportion of protein and carbohydrates are fermented to ammonia, amines and volatile fatty acids (VFA) in the hindgut (Holmes *et al*, 1973; Just, 1979; Sambrook, 1979; Low, 1980; Just, 1982a; 1982b; 1982c; 1982d; Just *et al.*, 1982; 1983). In this respect it was recently demonstrated that ostriches are also effective hindgut fermenters, utilizing microbial fermentation to digest plant fibre (Swart *et al*, 1987; Swart *et al.*, 1993a; 1993b). Thus, an increase in the rate of passage owing to increasing dietary CF might reduce the time that individual components of digesta are retained in the small intestine and are subsequently subjected to microbial fermentation in the hindgut.

Swart *et al.* (1993b) indicated that fermentative digestion of carbohydrates (more specifically hemicellulose and cellulose) in the capacious hindgut of ostriches could make a significant contribution to the energy requirements of the growing ostrich. However, the influence of energy concentration of the diet on

Table 3 Digestion and metabolism data (mean ± *SE*) for four ostrich chicks fed diets differing in daily ME supply and/or energy concentration

	Treatment		
Measurement	1	2	3
Nutrient intake (g/W, $kg^{0.75}$/day)			
DM	39.5 ± 0.79	54.2^{b} ± 3.25	53.3^{b} ± 2.33
Crude fibre	5.1^{a} ± 0.10	7.0^{b} ± 0.35	9.1^{c} ± 0.40
NDF	10.1^{a} ± 0.20	13.9^{b} ± 0.69	16.0^{c} ± 0.70
Energy intake (MJ/W, $kg^{0.75}$/day)			
GE	0.71^{a} ± 0.02	0.96^{b} ± 0.05	0.94^{b} ± 0.04
ME	0.53^{a} ± 0.01	0.71^{b} ± 0.04	0.65^{c} ± 0.04
Nutrient digestibility (%)			
DM	72.3^{a} ± 1.03	69.6^{a} ± 0.24	66.1^{b} ± 0.92
Crude fibre	46.2^{a} ± 2.01	37.4^{b} ± 2.50	35.2^{b} ± 2.22
NDF	55.0^{a} ± 0.01	49.8^{b} ± 0.01	45.1^{c} ± 1.85
Energy metabolism			
ME (% of GE)	75.9^{a} ± 0.92	73.4^{b} ± 0.24	69.6^{c} ± 0.75
HP (MJ/W, $kg^{0.75}$/day)	0.504^{a} ± 0.0	0.624^{b} ± 0.03	0.612^{b} ± 0.02
RE (MJ/W, $kg^{0.75}$/day)	0.030^{a} ± 0.03	0.084^{b} ± 0.02	0.040^{ab} ± 0.03
Dietary ME content (MJ/kg DM)	13.56^{a} ± 0.08	13.11^{b} ± 0.01	12.12^{c} ± 0.18
ME utilization (Δ RE/Δ ME)		0.311 ± 0.11	0.084 ± 0.06

$^{a-c}$ Denote significance in rows ($P < 0.05$).

efficiency of ME utilization has not been studied in ostriches. Several studies with pigs (Just, 1979; 1982b; Böhme *et al.*, 1982; Just *et al.*, 1982; 1983; Müller & Kirchgessner, 1982) indicated that the utilization of ME decreases with increasing CF or decreasing energy concentration. This finding also applies to ruminants (ARC, 1980; Meissner & Roux, 1984) but not to poultry, as is evident from results reported by Sibbald & Morse (1984).

The ME content of lucerne as such was estimated as described by Schneider & Flatt (1975), using the ME values of diets 2 and 3 in Table 3. Assuming that the ME fraction from lucerne is independent of that of the basal diet, a value of 8.99 MJ/kg DM was calculated. Similarly, the digestibility of NDF in lucerne was calculated to be 0.365.

Table 4 Data on gas exchange and uric acid-N for four ostrich chicks (mean ± *SE*) fed diets differing in energy concentration and daily energy supply. Values expressed per W, $kg^{0.75}$/day

	Treatment (MJ ME/kg DM)		
Measurement	1 (13.56 MJ)	2 (13.11 MJ)	3 (12.29 MJ)
O_2 consumption (l/day)	25.2 ± 1.38	29.4 ± 2.09	30.7 ± 3.54
CO_2 production (l/day)	20.0 ± 0.94	25.1 ± 2.09	26.2 ± 2.95
RQ	0.79	0.85	0.85
CH_4 production (l/day)	0.04 ± 0.02	0.02 ± 0.01	0.01 ± 0.00
Uric acid-N (g/day)	0.45 ± 0.04	0.63 ± 0.04	0.64 ± 0.07

Gas exchange and uric acid-N

Results on gas exchange and uric acid-N, for the calculation of heat expenditure and correction of ME for energy loss in methane, are presented in Table 4. Uric acid-N was not affected by increased dietary CF ($P > 0.05$). On average, CH_4 production amounted to only 0.1% of GE and can therefore be neglected in the determination and application of ME.

This result is surprising, considering the extensive fermentative digestion of carbohydrates in the hindgut of ostriches (Swart *et al.*, 1987; Swart *et al.*, 1993a; 1993b). However, the loss of energy in methane is also negligible (< 2% of GE) and unaffected by the composition of balanced diets in pigs (Bowland *et al.*, 1970; Müller & Kirchgessner, 1982; Just, 1982d; Seerly & Ewan, 1983). Müller & Kirchgessner (1982) recently reported CH_4 production in pigs amounting to 10% of energy released during cellulose digestion. This is similar to the range found in ruminal fermentation. Very low CH_4 production has also been reported by Hoppe (1984) for the dik-dik. To what extent these low methane levels are due to dietary inhibitors (e.g. high levels of NH_3), microbes (e.g. lack of methanogenic micro-organisms) or the host, is still unknown.

The site of absorption plays an important role where the effect of energy concentration on the net energy value of pig diets is concerned, as does the difference in chemical composition of the nutrients absorbed from the small intestine and from the hindgut, which in turn depends on the chemical composition of the diets (Holmes *et al.*, 1973; Just, 1979; Sambrook, 1979; Low, 1980; Just, 1982a; 1982b; 1982c; 1982d; Just *et al.*, 1982; 1983). As dietary CF increases and energy concentration decreases, nutrients that are more readily digested are most likely to pass to the hindgut, which results in a greater contribution from fermentative digestion. Since ostriches are successful hindgut fermenters (Swart *et al.*, 1987), a large proportion of nutrients could also be fermented by the microflora to VFA, which could have a lower metabolic efficiency as compared to carbohydrates absorbed from the small intestine.

Maintenance energy requirements

When retained energy (RE) (Y, MJ/W,kg$^{0.75}$/day) was regressed against ME intake (X, MJ/W,kg$^{0.75}$/day) the equation obtained (Figure 2) was:

$$Y = 0.318X - 0.141; \quad n = 8, r^2 = 0.78$$

The efficiency of utilization of ME for tissue synthesis was 0.32 and maintenance energy (ME$_m$) requirement was 0.44 MJ/W,kg$^{0.75}$/day. The maintenance energy requirements were in agreement with values found in laying hens (0.36 – 0.49 MJ/W,kg$^{0.75}$/day; Chwalibog, 1982; Johnson & Farrell, 1982; Kirchgessner, 1982) but were much lower than that found for ducks and geese (0.79 – 0.88 MJ/W,kg$^{0.75}$/day; Bayley *et al.*, 1982), quail (1.14 MJ/W,kg$^{0.75}$/day; Farrel *et al.*, 1982) and budgerigars (0.88 MJ/W,kg$^{0.75}$/day; Wachter-Vormann *et al.*, 1982). The efficiency of ME utilization (0.32) was much lower than that reported for the above-mentioned bird species (ranging from 0.63 to 6.85). This may have been due to a lower utilization efficiency of VFA energy which has also been reported in studies with rats (Eggum & Chwalibog, 1982). In addition, heat production caused by stress and activity of the ostrich chicks would have resulted in underestimated ME$_m$ values (if activity was included in ME maintenance). Therefore underestimated ME$_m$ values and low energy retention (RE = ME – HP) would result in low efficiency of ME utilization values.

Utilization of ME

A higher intake of basal diet (treatment 2) increased ME intake and RE by 0.180 MJ/W,kg$^{0.75}$ (34%) and 0.054 MJ/W,kg$^{0.75}$ (180%), respectively. The corresponding heat expenditure increased by 23.8% (Table 3). On the other hand, addition of lucerne to the basal ration (treatment 3) increased ME intake by only 0.120 MJ/W,kg$^{0.75}$ (22.6%), while the corresponding heat expenditure increased by 21.4% and the gain in RE was only 0.01 MJ/W,kg$^{0.75}$ and not significant ($P > 0.05$). Although the variation within treatments was large, most likely due to behavioural differences of the ostriches under stressful experimental conditions, the efficiency of the utilization of ME from the lucerne-diluted diet (8.4%) tended to be inferior ($P < 0.10$) compared to that of diet 2 (31.1%).

Conclusions

Although the variation of the calorimetric measurements was large, the supplementation of dietary energy at an increased concentration of CF tended to have a negative effect on the utilization of ME in growing ostriches. The efficiency of nutrient digestion did not only deteriorate, but also had a marked depressive effect on energy metabolizability. Furthermore, energy loss as methane was small and can be neglected in the application of the ME system to ostriches.

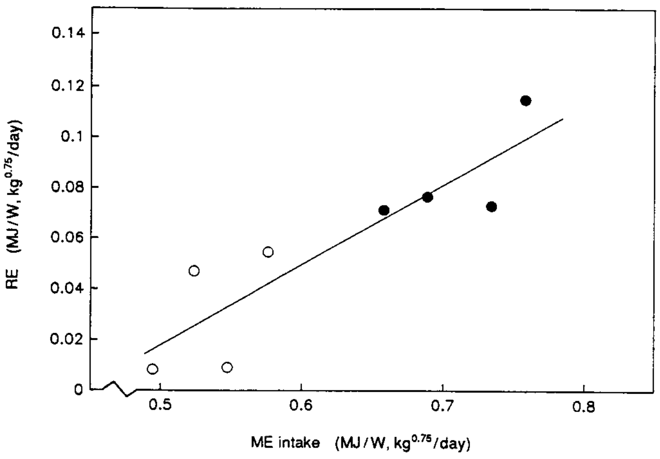

Figure 2 Relationship between ME intake and ME retention in ostrich chicks fed the same diet at two levels of intake (○ low, ● high, —— $y = 0.318x - 0.141$; $r^2 = 0.78$).

Finally, the use of ME as a criterion to evaluate feedstuffs and the formulation of balanced diets for ostrich production requires further research before it can be fully employed. With the design of similar experiments in future, cognizance should be taken of the wild nature and stress susceptibility of ostrich chicks that can lead to large variation in heat production. Future research should be aimed at quantifying the influence of CF on ME utilization over an extended range of dietary energy concentrations. Meanwhile, the probability of different efficiencies of ME utilization for diets differing significantly in their fibre content or energy concentration, should be considered in future ostrich feeding programmes.

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References

AOAC, 1984. Official methods of analyses (14th edn.). Association of Official Analytical Chemists, Washington DC.

ARC, 1980. The nutrient requirements of ruminant livestock. Commonwealth Agricultural Bureaux, Farnham Royal, England.

BAYLEY, H.S., 1982. Energy metabolism in birds. *Proc. 9th Symp. Energy Metab.*, Lillehamer, Norway. *EAAP* 29, 309.

BAYLEY, H.S., SOMERS, J. & ATKINSON, J.L., 1982. Energy metabolism in ducks and geese. *Proc. 9th Symp. Energy Metab.*, Lillehamer, Norway. *EAAP* 29, 286.

BLAIR, R., DAGHIR, N.J., MORIMOTO, H., PETER, V. & TAYLOR, T.G., 1983. International nutrition standards for poultry. *Nutr. Abstr. Rev.*, Ser. B 53, 11.

BLAXTER, K.L., 1970. Energy units: proposals for change from the calorie to the joule. *Proc. 5th Symp. Energy Metab.* Vitznau, Switzerland. *EAAP* 13, 9.

BÖHME, H., GÄDEKEN, D. & OSLAGE, H.J., 1982. Efficiency of utilization of metabolizable energy as influenced by different energy concentrations in rations for growing fattening pigs. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 29, 206.

BOWLAND, J.P., BICKEL, H., PFIRTER, H.P., WENK, C.P. & SCHÜRCH, A., 1970. Respiration calorimetry studies with growing pigs fed diets containing three to twelve per cent crude fibre. *J. Anim. Sci.* 31, 494.

BROUWER, E., 1958. On simple formulae for calculating the heat expenditure and the quantities of carbohydrate and fat metabolized in ruminants, from data on gaseous exchange and urine-N. *Proc. 1st Symp. Energy Metab.* Copenhagen, Denmark. *EAAP* 8, 182.

CHWALIBOG, A., 1982. Energy efficiency for egg production. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 29, 270.

DU PREEZ, J.J., DUCKITT, J.S. & PAULSE, M.J., 1986. A rapid method to evaluate metabolizable energy and availability of amino acids without fasting and force feeding experimental animals. *S. Afr. J. Anim. Sci.* 16, 47.

EGGUM, B.O. & CHWALIBOG, A., 1982. Energy metabolism in rats with normal and reduced gut flora. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 29, 164.

EKMAN, P., 1948. A new chemical method for separating faecal nitrogen from urinary nitrogen in poultry excreta. *8th World's Poult. Congr.* (Copenhagen) *Official Report* 1, 220.

FARRELL, D.J., ATMAMIHARDJA, S.I. & PYM, R.A.E., 1982. Calorimetric measurements on Japanese quail selected for increased bodyweight on high or low nutrient density diets. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 29, 301.

HOLMES, J.H.G., BAYLEY, H.S. & HORNEY, F.D., 1973. Digestion and absorption of dry matter and high moisture diets in the small and large intestine of the pig. *Br. J. Nutr.* 30, 401.

HOPPE, P.P., 1984. Strategies of digestion in African herbivores. In: Herbivore nutrition in the Subtropics and Tropics. Eds. Gilchrist, F.M.C. & Mackie, R.I., The Science Press (Pty) Ltd., Craighall, South Africa. pp. 223—243.

IAFMM, 1985. Digestible energy content of fish meal fed to growing/finishing pigs. *Fish Meal Flyer* Project 82.1.5.

JOHNSON, R.J. & FARRELL, D.J., 1982. The effects of restricted feedings on the energy metabolism of layers. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway, *EAAP* 29, 258.

JUST, A., 1979. Influence of dietary composition on site of absorption and efficiency of utilization of metabolizable energy in growing pigs. *Proc. 8th Symp. Energy Metab.* Cambridge. *EAAP* 26, 27.

JUST, A., 1982a. The net energy value of balanced diets for growing pigs. *Livestk. Prod. Sci.* 8, 541.

JUST, A., 1982b. The net energy value of crude fat for growth in pigs. *Livestk. Prod. Sci.* 9, 501.

JUST, A., 1982c. The influence of crude fibre from cereals on the net energy value of diets for growth in pigs. *Livestk. Prod. Sci.* 9, 569.

JUST, A., 1982d. The influence of ground barley straw on the net energy value of diets for growth in pigs. *Livestk. Prod. Sci.* 9, 717.

JUST, A., FERNANDEZ, J.A. & JORGENSEN, H., 1982. The relationship between the absorption of energy yielding nutrients from the hindgut and the efficiency of utilization of metabolizable energy in growing pigs. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 2, 214.

JUST, A., FERNANDEZ, J.A. & JORGENSEN, H., 1983. The net energy value of diets for growth in pigs in relation to the fermentative processes in the digestive tract and site of absorption of the nutrients. *Livestk. Prod. Sci.* 10, 171.

KEMM, E.H. & RAS, M.N., 1981. Die effek van snystadium op die waarde van gedehidreerde lusernmeel in varkgroeidiëte. *S.-Afr. Tydskr. Veek.* 11, 285.

KIRCHGESSNER, M., 1982. Efficiency of utilization of dietary energy by the laying hen in relation to different energy and protein supply. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 29, 270.

LOW, A.G., 1980. Nutrient absorption in pigs. *J. Sci. Fd Agric.* 31, 1087.

MEISSNER, H.H. & ROUX, C.Z., 1984. Growth and feed intake patterns: 2. Application to feed efficiency. In: Herbivore nutrition in the Subtropics and Tropics. Eds. Gilchrist, F.M.C. & Mackie, R.I., The Science Press, Craighall, South Africa. pp. 691—705.

MÜLLER, H.L. & KIRCHGESSNER, M., 1982. Effect of straw and cellulose on heat production and energy utilization in pigs. *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 29, 229.

NRC, 1973. Nutrient requirements of swine. National Academy of Sciences, Washington DC.

ROBERTSON, J.B. & VAN SOEST, P.J., 1981. In: The analysis of dietary fibre. Eds. James, W.P.T. & Theander, O., Dekker, New York. pp. 123—158.

ROMIJN, C. & LOCKHORST, W., 1961. Some aspects of energy metabolism in birds. *Proc. 2nd Symp. Energy Metab.* Wageningen, The Netherlands. *EAAP* 10, 49.

SAMBROOK, I.E., 1979. Studies on digestion and absorption in the intestines of growing pigs. 7. Measurements of the flow of total carbohydrate, total reducing substances and glucose. *Br. J. Nutr.* 42, 267.

SEERLY, R.W. & EWAN, R.C., 1983. An overview of energy utilization in swine nutrition. *J. Anim. Sci., Suppl.* 57, 300.

SCHNEIDER, B.H. & FLATT, W.P., 1975. The evaluation of feeds through digestibility experiments. The University of Georgia Press, Athens.

SIBBALD, I.R., 1982. Measurement of bio-available energy in poultry feedingstuffs: A review. *Can. J. Anim. Sci.* 62, 983.

SIBBALD, I.R. & MORSE, P.M., 1984. A preliminary investigation of the utilization of true metabolizable energy by chicks. *Poult. Sci.* 63, 954.

SNEDECOR, G.W. & COCHRAN, W.G., 1980. Statistical methods (7th edn). Iowa State University Press, Ames, Iowa, USA.

SWART, D. & KEMM, E.H., 1985. Die invloed van dieetproteïen- en energiepeil op die groeiprestasie en veerproduksie van slagvolstruise onder voerkraaltoestande. *S.-Afr. Tydskr. Veek.* 15, 146.

SWART, D., MACKIE, R.I. & HAYES, J.P., 1987. For feathers and leathers. *Nucl. Active* 36, 2.

SWART, D., MACKIE, R.I. & HAYES, J.P, 1993a. Influence of live mass, rate of passage and site of digestion on energy metabolism and fibre digestion in the ostrich (*Struthio camelus* var. *domesticus*). *S. Afr. J. Anim. Sci.* 23, 119.

SWART, D., MACKIE R.I. & HAYES, J.P., 1993b. Fermentative digestion in the ostrich (*Struthio camelus* var. *domesticus*), a large avian species which utilizes cellulose. *S. Afr. J. Anim. Sci.* 23, 127.

VILJOEN, J., 1985. Die energiehuishouding van die boerbokooi tydens groei, dragtigheid en laktasie. M.Sc.(Agric.)-tesis, Universiteit van Pretoria, Pretoria.

WACHTER-VORMANN, U., SCHNEIDER, W. & MENKE, K.H., 1982. Energy exchange and maintenance requirement of budgerigars (*Melopsittacus undulatus*). *Proc. 9th Symp. Energy Metab.* Lillehamer, Norway. *EAAP* 29, 305.

WARNER, A.C.I., 1981. Rate of passage of digesta through the gut of mammals and birds. *Nutr. Abstr. Rev., Ser. B* 51, 789.