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Growth, feed intake and body composition of ostriches (*Struthio camelus*) between 10 and 30 kg live mass[1]

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Data on cumulative feed intake, growth rate and chemical body constituents of 24 ostrich chicks, from a comparative slaughter experiment, were utilized to describe patterns of efficiency of feed utilization, deposition rates of protein, fat and body energy, as well as patterns of energy intake over the live mass interval 10–30 kg, by employing the empirical, allometric autoregression growth model. The ratio of daily energy storage in protein accretion to that of fat accretion was 1.3:1 at 20 kg live mass and changed to 1:2 at 30 kg live mass. The change in energetic ratio coincided with a breaking-point in the log-linear relationship between live mass and cumulative metabolizable energy (ME) intake at 23 kg live mass, thus separating the growth curve into two different growth phases as reflected by different patterns of energy intake, growth rate, feed conversion ratio, body composition and the composition of growth. The relative apportionment of ME towards total body energy increased almost linearly across both phases and was closely related to deposition rate of body fat and inversely related to energy loss as heat expenditure. Gross efficiency of protein deposition remained constant within growth phases but decreased across phases. In terms of metabolic body size, the priority for the allocation of ME to the deposition of body energy in protein or fat, changes and is correlated with changes in heat production that would alter the maintenance needs of the growing animal.

Patrone van die doeltreffendheid van voerbenutting, neerleggingstempo's van proteïen-, vet- en liggaamsenergie, asook patrone van energie-inname is deur middel van data oor die kumulatiewe voerinname, groeitempo en chemiese liggaamsamestelling van 24 volstruiskuikens in 'n vergelykende slagproef met behulp van die empiriese, allometriese outoregressiemodel oor die massa-interval 10–30 kg beskryf. Die verhouding tussen energieneerlegging in daaglikse proteïen- en vetaanwas was 1.3:1 by 20 kg lewende massa en het verskuif na 1:2 by 30 kg lewende massa. Die verandering (1:1) het saamgeval met 'n breekpunt in die log-lineêre verwantskap tussen lewende massa en kumulatiewe metaboliseerbare energie(ME)-inname wat die groeikurwe by 23 kg lewende massa in twee groeifases verdeel het, elk met eiesoortige patrone van energie-inname, groeitempo, voeromsettingsdoeltreffendheid, liggaamsamestelling en samestelling van groei. Die proporsie van ME-inname wat in liggaamsenergie neergelê is, het lineêr oor beide groeifases toegeneem en was hooggekorreleerd met 'n toename in die neerleggingstempo van vetenergie en omgekeerd eweredig aan hitteproduksie. Die relatiewe benutting van ME-inname vir proteïendeponering het binne groeifases konstant gebly, maar afgeneem oor groeifases heen. In terme van metaboliese liggaamsgrootte ondergaan die toewysing van ME vir die deponering van liggaamsenergie in vet en proteïen gedurige verandering waarvolgens hitteproduksie, en waarskynlik die onderhoudsbehoefte van die groeiende dier, verander.

Keywords: Efficiency, energy deposition, feed conversion.

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Introduction

The objective of modern ostrich production is to convert feedstuffs such as lucerne meal and cereal grains to skin, meat and feathers in the growing ostrich (Swart & Kemm, 1985). Accurate descriptions of the metabolizable energy (ME) values of feeds are dependent on the efforts to relate ME intakes to product depositions (Bayley, 1982). ME must be either retained or dissipated as heat or waste products.

There is no quantitative information available on the effect of energy intake on the absolute and relative rates of protein and fat deposition in the growing ostrich. This study was conducted to quantify patterns of energy intake and the deposition of protein and fat in growing ostriches fed *ad libitum* on a diet formulated to contain an adequate protein and ME content. In this paper the emphasis is on patterns of efficiency of feed utilization for growth in ostriches, based on the use of longitudinal rather than cross-sectional data. The efficiency of conversion of feed to animal tissue is expressed as the ratio between output and input in energy units. Its reciprocal (input/output) is the feed conversion ratio (FCR), which is commonly used in practice (Meissner & Roux, 1984) and in this paper.

Materials and Methods

Animals and housing

Ostrich eggs (24) were hatched in a forced-air incubator (La Nationale Gascogne, Series C 2668: Briare, France) maintained at a dry bulb temperature of 24.0 ± 1.0°C. These temperature settings were determined from natural incubation parameters as reported by Swart *et al.* (1987) and Swart & Rahn (1988). The hatchability was 80% and the chicks weighed 0.86 ± 0.01 kg at 1 day of age. All eggs were obtained from the ostrich breeding flock of the Klein Karoo Agricultural Development Centre and were considered to be representative of South African domesticated ostriches (*Struthio camelus* var. *domesticus*) (Swart *et al.*, 1987).

The chicks were housed in flat deck-type metabolism cages, 1.6 × 1 m, fitted with expanded metal floors, height-adjustable water buckets and feeding troughs. An overhead infra-red heater fitted to each cage ensured temperatures above 23°C. The chicks were initially housed together in 6 groups of 4 chicks each and were subsequently allotted to 12 pairs, approximately equal in live mass.

Experimental diet

The diet was initially formulated according to poultry values (Du Preez *et al.*, 1984; Du Preez *et al.*, 1986) to contain 17% crude protein and 11 MJ ME/kg on an 'as is' basis (Table 1). Subsequently an ostrich ME value of 12.33 MJ/kg was determined on successive occasions in metabolism trials using 4 to 6 ostriches at different live masses. This requirement was higher than the previously suggested requirements for growth of juvenile ostriches (Swart & Kemm, 1985) and was higher than requirements for ostrich chicks reported by Flieg (1973) and Gandini *et al.* (1986). Protein content was, however, lower than the 24% suggested by Scott (1978) for growing ratites. The experimental chicks were fed *ad libitum* at all stages.

Table 1 Composition of the experimental diet (air-dry basis) fed to ostrich chicks from 5 to 36 kg live mass

Component (g/kg diet)	
Maize meal	530
Lucerne meal (21% crude protein)	340
Fish-meal	84
Limestone powder	10
Monocalcium phosphate	26
Salt	10
Minerals + vitamins[1]	+
Composition	
Metabolizable energy[2] (MJ/kg)	10.8
Protein (6.25 × N) (%)	17.3
Crude fibre (%)	11.6
Calcium (%)	1.7
Phosphorus (%)	1.0
Moisture (%)	10.0

[1] Mineral-vitamin premix (Truka: Germiston, South Africa) added per kg mixed diet: 10 000 IU Vit. A; 2 000 IU Vit. D; 15 IU Vit. E; 2 mg Vit. K; 2 mg Thiamin; 8 mg Riboflavin; 4 mg Pyridoxine; 0.02 mg Vit. B12; 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.

[2] Poultry values (Du Preez *et al.*, 1984; Du Preez *et al.*, 1986).

Procedures for the comparative slaughter experiment

Twelve chicks, one member of each pair, were sacrificed at 60 days of age and with live mass of 9.09 ± 0.69 kg. Live mass and cumulative feed intake measurements of the remaining 12 individually housed chicks were recorded every 3 days at 9:00. Six of the remaining chicks were sacrificed at 90 days of age (20.2 ± 1.1 kg live mass). A mathematical model was used in the present study to describe growth and body composition (see below). It is based on the discovery that ln(body-mass) and ln(cumulative feed intake) are linearly related and that cumulative feed intake, like body-mass, can be described over time (Roux, 1974). Furthermore, use was made of the fact that chemical body constituents are allometrically related to cumulative energy intake so that linear relationships exist in the logarithmic scale (Siebrits, 1986). A change in the pattern of feed intake and growth rate was observed for the ostriches in the present study. Consequently it was decided to slaughter a middle group of 6 ostriches between 20 and 24 kg live mass. The experiment ended when the last 6 ostriches were slaughtered at 120 days of age (30.57 ± 1.94 kg live mass). All slaughtered birds were analysed for chemical body constituents (see Appendix).

Body composition

The identical procedure was followed for all slaughtered birds. Warm body-mass was measured whereafter the abdominal cavity was opened, the entire intestinal tract removed, weighed, flushed with tap water and reweighed in order to determine empty body-mass (warm body-mass minus gut contents). The empty body, together with the emptied intestinal tract, was then sealed in a plastic bag and frozen.

The entire frozen carcasses were ground separately in a carcass grinder (Wolfking, Denmark), with a 5-mm sieve. The ground carcass was passed through the mincer six times to ensure proper mixing as described by Viljoen (1985), before a 1.5-kg sample was taken for dry matter (DM) determination and chemical analyses. DM content was determined by drying 300-g samples in triplicate at 100°C for 48 h in a convection drying oven.

A further 200-g sample was freeze-dried and milled through a 2-mm sieve in a laboratory mill, together with three times its volume of solid CO_2, as described by Siebrits (1984). The ground sample mixture was left in an open plastic bag untill all dry ice had sublimated, whereafter it was sealed and stored at −15°C for chemical analyses.

Chemical analyses

Protein content (N × 6.25) was determined according to the macro Kjeldahl method (AOAC, 1984). Fat content was determined by extraction with petroleum ether (boiling point 40–60°C), using the Tecator soxtec method (AOAC, 1984) and drying the extract at 105°C for 39 min, as recommended by Harris (1970). Total energy content was determined using an adiabatic bomb calorimeter (DDS 400: Digital Data Systems, Randburg, South Africa), calibrated with benzoic acid tablets. Ash content was determined using standard AOAC methods.

Biometrical analyses

The allometric autoregression (AA) growth model as described by Roux (1974) and substantiated in studies with sheep (Meissner, 1977; Roux *et al.*, 1982), cattle (Meissner & Roux, 1984; Roux & Meissner, 1984), pigs (Roux, 1981; Roux & Kemm, 1981; Siebrits 1979; 1984; 1986; Siebrits *et al.*, 1986) and boer goats (Viljoen, 1985) was employed to analyse and describe growth and body composition. In order to describe the 'average ostrich' as applied to the present study, the cumulative intakes and live masses of the six ostriches in the final slaughter group were averaged and utilized in the AA model.

Practical application of the AA model to growth data of pigs was demonstrated by Siebrits (1986). Briefly, live mass is allometrically related to cumulative energy intake. Hence the relationship between cumulative energy intake and time can be described by the equation:

$$x_t = \alpha + \rho^t(\mu - \alpha)$$

where x_t = ln (cumulative energy intake) at time t,
μ = ln (cumulative energy intake) at time t_0,
ρ = the slope of the autoregression of ln (cumulative energy intake),
α = intercept of the autoregression of ln (cumulative energy intake) / $(1 - \rho)$.

An autoregression of ln (cumulative ME intake) was calculated by means of a linear regression between the ln of the mean cumulative ME intake at time $(t - 1)$ as x, and ln (mean cumulative ME intake) at time t as y. The linear relationship of ln (cumulative ME intake) and ln (mass) was then used to calculate growth rate, intake and feed conversion ratio at different live masses within the experimental limits, i.e. between 10 and 30 kg live mass. A graphical plot of the raw data in the latter relationship was also used to identify different phases (or so-called breaking-points) in the growth curve as indicated by a change in the slope of the linear relationship between ln (intake) and ln (live mass), as was previously observed for cattle (Roux & Meissner, 1984), sheep (Searle *et al.*, 1972), boer goats (Viljoen, 1985), pigs (Roux & Kemm, 1981; Siebrits, 1984) and rats (Scholtz & Roux, 1981; 1984).

Linear regressions between ln (cumulative ME intake) and ln (body protein, fat, moisture, ash and energy, respectively) were also calculated for the 24 slaughtered ostriches. Growth rates, rates of deposition and feed intake were then calculated by differentiation as described by Siebrits (1979; 1986). Corresponding rates of heat production were calculated as ME intake minus energy deposition rates.

Results

Mass gain

Despite their somewhat wild nature and troop instinct, all ostriches adapted well to their single-cage environment and all the birds remained in good health during the experimental period. They gained live mass at an overall mean rate of 340 g/day, with a corresponding average feed conversion rate of 3 kg feed per kg live mass gain during the live mass interval 10–30 kg. This was well within the expected limits, in agreement with the performance of ostrich chickens in commercial feedlots (Swart, unpublished data) and well above rates reported by Gandini *et al.* (1986).

Growth patterns

The overall mean growth rate does, however, not reveal the dramatic change in the growth pattern after attainment of 23 kg live mass. The alteration of the growth pattern is recognizable as a distinct break in the slope of the allometric log-relationship between cumulative energy intake and live mass (Figure 1), indicating a change in energy conversion rate between 23 and 24 kg live mass. If such a breaking-point was ignored, this would lead to an erroneous description of the growth pattern and its composition (Siebrits, 1984; 1986).

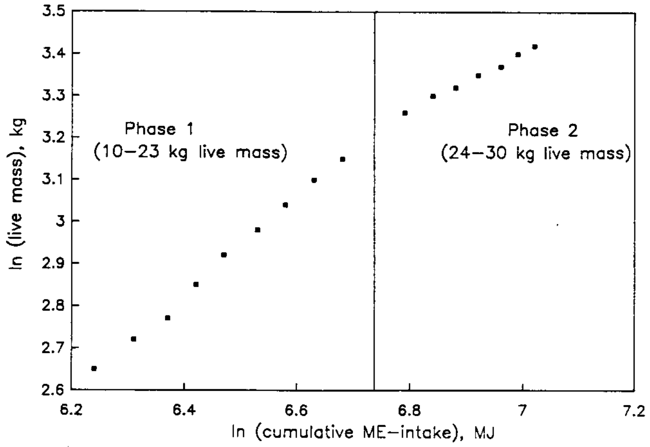

Figure 1 Allometric log-relationship between cumulative energy (ME) intake and live mass indicating a breaking-point between 23 and 24 kg live mass.

Growth parameters

A separate set of growth parameters was calculated according to the AA model for each of the two growth phases, viz. 10–23 kg (Phase 1) and 24–30 kg live mass (Phase 2), respectively. The mean growth parameters are presented in Table 2. The coefficients of determination (r^2) indicate that practically all of the variations in live mass can be accounted for by corresponding variations in feed intake for both phases. The different sets of statistical parameters suggest different growth patterns within each growth phase.

Regression equations

The regression equations describing the allometric relationships between each of the different chemical body components of the total body and cumulative ME intake are presented in Table 3. The r^2 value was highest for body energy (r^2 = 0.9996, Phase 2) and lowest for body fat (r^2 = 0.8981, Phase 1). All r^2 values are in agreement with values reported for pigs (Siebrits, 1984) and goats (Viljoen, 1985). Again, each phase had a different set of statistical parameters, indicating different patterns of body composition and composition of growth.

Table 2 Mean growth parameters using the allometric model

Growth model parameters[1]	Growth phase Phase 1 (10–23 kg live mass)	 Phase 2 (24–30 kg live mass)
ρ	0.97289	0.91693
α	8.48214	7.36379
a	–4.57430	–1.42647
b	1.15623	0.69031
μ	6.24244	6.78707
$*r^2$	0.9972	0.9941
$**r^2$	0.9995	0.9982

[1] ρ = slope of autoregression; α = asymptote of cumulative ME intake; a = intercept of ln(live mass) – ln(cumulative ME intake) regressions; b = slope of ln(live mass) – ln(cumulative ME intake) regressions; μ = initial ln(cumulative ME intake) value; $*r^2$ = coefficients of determination of the ln(cumulative ME intake) – ln(live mass) regressions; $**r^2$ = coefficients of determination of the autoregressions.

Table 3 Regression equations describing the relationship between ln(cumulative ME intake) as independent variable (x) and ln(body protein, fat, moisture, ash and energy of the total body, respectively) as dependent variable (y)

Group	n	Dependent variable	Regression equation	r^2
Phase 1	17	Protein	$y = -6.88027 + 1.21786x$	0.9919
		Fat	$y = -10.52105 + 1.64230x$	0.8981
		Moisture	$y = -4.11205 + 1.00841x$	0.9867
		Ash	$y = -8.23626 + 1.19992x$	0.9784
		Energy	$y = -3.85175 + 1.32264x$	0.9782
Phase 2	5	Protein	$y = -3.84783 + 0.78328x$	0.9900
		Fat	$y = -10.25045 + 1.62187x$	0.9837
		Moisture	$y = -1.58758 + 0.64069x$	0.9856
		Ash	$y = -5.31164 + 0.78769x$	0.9266
		Energy	$y = -3.10531 + 1.22994x$	0.9996

The values in Tables 2 and 3 were used to calculate the data presented in Tables 4–6 and Figures 2 and 3.

Feed intake, growth and feed conversion rate

The data presented in Table 4 show that intake gradually increased at a declining rate from 721 g/day (8.89 MJ ME/day) to 1 060 g/day (13.08 MJ ME/day) during Phase 1 (10–23 kg live mass). Over the following 1-kg gain (23–24 kg live mass) intake increased markedly by more than 200 g/day and then decreased at an accelerating rate to 946 g/day at 30 kg live mass. Within the two growth phases, changes in growth rate closely followed changes in feed intake. However, feed intake could not account for differences in growth rate between phases. The average feed conversion ratio changed from 2.52 in Phase 1 to 4.07 in Phase 2. This was the result of an increase of 24% in intake with a concomitant 23% decrease in growth rate. Feed conversion rate surprisingly showed a slight improvement from 2.7 to 2.4 kg feed/kg gain during Phase 1. Thereafter it deteriorated almost twofold to 4.3 kg feed/kg gain at 30 kg live mass.

Composition of growth

Body protein

The mean contents and relative composition of the empty body at different live masses are presented in Table 5. Relative to total body components (or empty body-mass), protein content (%) was fairly constant, increasing from 16.3% at 10 kg live mass to 18.7% at 30 kg live mass. Relative to empty body mass gain, protein content of gain (%) showed a small initial increase (1.3 percentage units), reached a maximum of 19.6% at 23 kg live mass, and then remained practically constant during the following growth phase (Table 6).

Body fat

The relative fat content (%) of the empty body doubled to 10.9% during the experimental period (Table 5), so that fat content of gain increased by 12.4 percentage units from 8.1 to 22.6%, thus exceeding that of protein deposition (Table 6). Similar patterns exist for other farm animals such as different types of poultry (Du Preez *et al.*, 1967; Du Preez *et al.*, 1971), obese as well as lean type pigs (Siebrits, 1984) and boer goats (Viljoen, 1985).

Body moisture

Relative accretion rates decreased from 74.6% at 10 kg live mass to 66.0% at 30 kg live mass. Body moisture was thus replaced by fat.

Body ash

Total energy content of the empty body increased from 5.54 MJ/kg to 8.13 MJ/kg of live mass over the experimental period. Energy deposition rates (Table 6) followed the same pattern as ME intake (see Table 4). Linear regression analyses of the data in Table 6 reveal that the total energy content of empty body-mass gain was closely related to fat deposition rates (r^2 = 0.999) across both growth phases. This was not the case with protein deposition (r^2 = 0.076). However, within phases, both protein and fat deposition were linearly related to energy accretion.

Energy allocation

The theoretical energy values for protein (23.9 MJ/kg) and fat (39.8 MJ/kg) suggested by Brouwer (1965) were used to calculate the deposition rates of protein and fat energy. By definition, ME intake minus energy deposition supplies the corresponding rates of heat production. The results are graphically presented in Figure 2. ME intake per $W^{0.75}$ declined while heat production rate closely followed the pattern of ME intake and accounted for 72–80% of ME intake (see Figure 3) during the 10–30 kg live mass interval. On the other hand, energy retained as live mass gain remained constant (0.3 MJ/$W^{0.75}$/day) between 10 and 23 kg live mass as a result of a decrease in protein deposition rate which was negatively correlated (r = –0.98) to the inrease in fat deposition rate.

Table 4 Feed intake, energy intake, growth rate and feed conversion ratio (FCR) at different live masses

Growth phase	Live mass (kg)	Age (days)	Feed intake (g/day)	ME intake rate (MJ/day)	Growth rate (g/day)	FCR (kg/kg)	FCR (MJ/kg)
1	10.00	57.17	720.99	8.89	268.47	2.693	33.11
	11.00	60.78	757.48	9.34	285.71	2.653	32.69
	12.00	64.19	791.61	9.76	302.12	2.623	32.31
	13.00	67.41	823.65	10.16	317.76	2.593	31.96
	14.00	70.49	853.78	10.53	332.70	2.573	31.64
	15.00	73.43	822.17	10.88	346.98	2.543	31.35
	16.00	76.26	908.97	11.21	360.65	2.523	31.08
	17.00	78.98	934.29	11.52	373.75	2.503	30.82
	18.00	81.61	958.26	11.82	386.31	2.483	30.59
	19.00	84.16	980.96	12.10	398.36	2.463	30.36
	20.00	86.63	1002.47	12.36	409.93	2.453	30.15
	21.00	89.04	1022.88	12.61	421.04	2.432	29.95
	22.00	91.39	1042.24	12.85	431.72	2.412	29.77
	23.00	93.67	1060.61	13.08	441.97	2.402	29.59
2	24.00	94.29	1282.29	15.81	322.17	3.864	47.60
	25.00	97.37	1244.41	15.34	316.51	3.934	48.48
	26.00	100.62	1199.20	14.79	299.69	4.004	49.34
	27.00	104.06	1146.70	14.14	281.76	4.075	50.18
	28.00	107.73	1086.96	13.40	262.76	4.145	51.01
	29.00	111.69	1020.02	12.58	242.72	4.205	51.82
	30.00	115.69	945.92	11.66	221.69	4.275	52.61

Table 5 Mean contents and relative composition of the empty body (total body components) at different live masses. Percentage values denote the fraction of total body components or empty body mass

Growth phase	Live mass (kg)	Protein		Fat		Moisture		Ash		Energy (MJ)
		kg	%	kg	%	kg	%	kg	%	
1	10.00	1.44	16.31	0.47	5.32	6.59	74.63	0.33	3.74	55.42
	11.00	1.59	16.46	0.54	5.59	7.16	74.12	0.37	3.83	61.80
	12.00	1.74	16.60	0.61	5.82	7.73	73.76	0.40	3.82	68.27
	13.00	1.90	16.80	0.68	6.01	8.29	73.30	0.44	3.89	74.81
	14.00	2.05	16.91	0.76	6.27	8.84	72.94	0.47	3.88	81.43
	15.00	2.20	17.00	0.84	6.49	9.39	72.57	0.51	3.94	88.12
	16.00	2.36	17.16	0.92	6.69	9.93	72.22	0.54	3.93	94.87
	17.00	2.51	17.24	1.00	6.87	10.47	71.91	0.58	3.98	101.69
	18.00	2.67	17.37	1.09	7.09	11.00	71.57	0.61	3.97	108.56
	19.00	2.83	17.48	1.17	7.23	11.54	71.28	0.65	4.01	115.49
	20.00	2.98	17.55	1.26	7.42	12.06	71.02	0.68	4.00	122.46
	21.00	3.14	17.64	1.35	7.58	12.59	70.73	0.72	4.04	129.49
	22.00	3.30	17.74	1.44	7.74	13.11	70.48	0.75	4.03	136.57
	23.00	3.46	17.82	1.54	7.93	13.63	70.19	0.79	4.07	143.69
2	24.00	3.96	18.57	1.76	8.25	14.67	68.78	0.94	4.41	163.80
	25.00	4.15	18.59	1.94	8.69	15.24	68.28	0.99	4.44	176.16
	26.00	4.34	18.63	2.13	9.14	15.80	67.81	1.03	4.42	188.91
	27.00	4.53	18.63	2.33	9.58	16.37	67.34	1.08	4.44	202.05
	28.00	4.72	18.65	2.53	10.00	16.93	66.89	1.13	4.46	215.58
	29.00	4.91	18.66	2.75	10.45	17.49	66.45	1.17	4.45	229.49
	30.00	5.10	18.65	2.98	10.90	18.05	66.00	1.22	4.46	243.78

Table 6 Mean (g/day) and relative accretion rates (%) of body components and body energy at different live masses. Percentage values denote deposition rates relative to that of total body components or empty body mass

Growth phase	Live mass (kg)	Protein g/day	Protein %	Fat g/day	Fat %	Moisture g/day	Moisture %	Ash g/day	Ash %	Energy (MJ/day)
1	10.00	40.66	18.30	17.96	8.08	154.32	69.44	9.28	4.18	1.70
	11.00	43.49	18.46	19.89	8.44	162.24	68.88	9.91	4.21	1.84
	12.00	46.20	18.61	21.82	8.79	169.66	68.36	10.51	4.23	1.97
	13.00	48.80	18.75	23.73	9.12	176.63	67.87	11.09	4.26	2.09
	14.00	51.30	18.88	25.63	9.43	183.18	67.41	11.65	4.29	2.21
	15.00	53.70	18.99	27.52	9.73	189.37	66.97	12.18	4.31	2.33
	16.00	56.01	19.10	29.39	10.02	195.22	66.56	12.69	4.33	2.45
	17.00	58.23	19.19	31.24	10.30	200.74	66.17	13.18	4.34	2.56
	18.00	60.37	19.28	33.08	10.57	205.98	65.79	13.65	4.36	2.67
	19.00	62.43	19.37	34.90	10.83	210.94	65.43	14.11	4.38	2.77
	20.00	64.42	19.44	36.69	11.07	215.65	65.09	14.54	4.39	2.87
	21.00	66.34	19.52	38.47	11.32	220.12	64.76	14.97	4.40	2.97
	22.00	68.19	19.59	40.22	11.55	224.36	64.45	15.37	4.41	3.07
	23.00	69.98	19.65	41.95	11.78	228.39	64.14	15.76	4.43	3.16
2	24.00	62.23	19.27	57.37	17.76	188.48	58.35	14.91	4.62	4.04
	25.00	59.62	19.19	57.76	18.59	179.06	57.63	14.29	4.60	3.97
	26.00	56.75	19.10	57.67	19.41	169.07	56.91	13.60	4.58	3.88
	27.00	53.63	19.01	57.05	20.23	158.52	56.20	12.86	4.56	3.76
	28.00	50.26	18.92	55.88	21.04	147.45	55.51	12.05	4.54	3.60
	29.00	46.64	18.82	54.12	21.84	135.86	54.82	11.19	4.52	3.42
	30.00	42.80	18.72	51.75	22.64	123.79	54.15	10.27	4.49	3.21

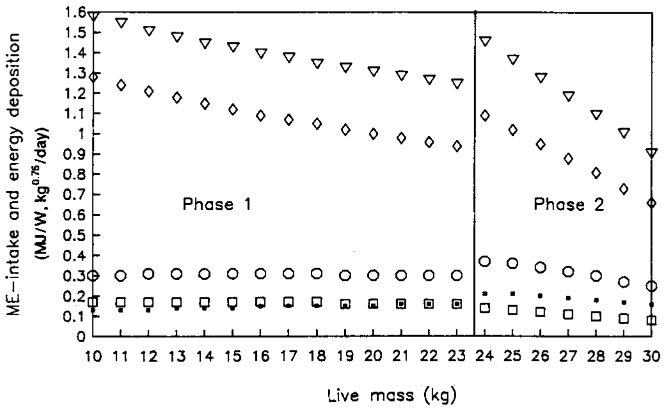

Figure 2 Dietary ME intake (Δ) and the allocation thereof to body energy (○), body fat (■), body protein (□), and heat production (◇) for the live mass interval 10–30 kg.

The breaking-point separating the two growth phases coincided with an increase in dietary ME intake, as reported for rats and cattle by Scholtz & Roux (1981) and Roux & Meissner (1984), respectively, together with a corresponding increase in heat production and energy deposition rate. However, most relevant and probably most important was the sudden increase in the deposition rate of fat energy while the rate of energy deposition as protein decreased, resulting in a change in deposition rates in favour of fat deposition between the two phases. Although dietary ME intake from 24 to 30 kg live mass averaged well below that of the first phase, energy retention rates were well above those of the first phase. This can be explained by a corresponding increase in mean fat deposition rate. During Phase 2 the pattern of energy deposition as fat was a decreasing one, being positively correlated (r = 0.995) to protein deposition, in contrast to the preceding phase.

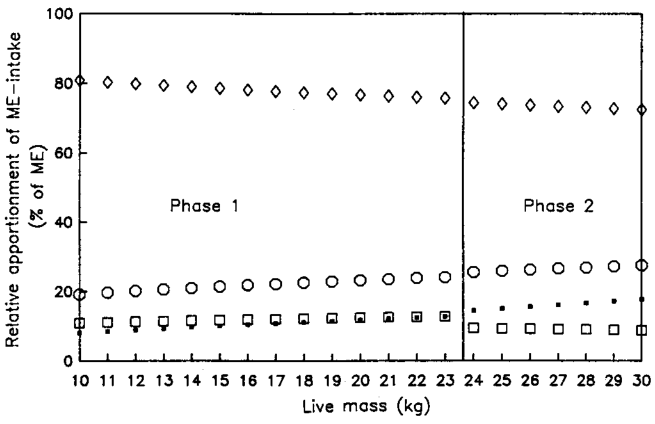

Figure 3 The relative apportionment of ME energy intake (% of ME) towards total body energy (○), fat energy (■), protein energy (□), and heat production (◇) for the live mass interval 10–30 kg.

Relative apportionment of dietary ME

Patterns of the relative apportionment of dietary ME to body protein, fat and heat production against live mass are presented in Figure 3. Regardless of the breaking-point, the partitioning of dietary ME to energy in fat increased almost linearly from 8% at 10 kg live mass to 17.6% at 30 kg live mass. The fraction of dietary ME allocated to heat production was inversely proportional to that of fat deposition. On the other hand, the relative deposition rate of energy in protein increased only slightly (10.9–12.8%) to reach a point where the apportionment of dietary ME to protein and energy deposited as fat was equal. This point coincided with the breaking-point. During Phase 2 the fraction of dietary ME allocated to protein energy decreased from 9.4 to 8.8%, which is well below that of fat deposition.

The relative apportionment of dietary ME to total body energy increased almost linearly from 19% to 17.5% and was more dependent on the deposition of fat energy than on that of protein energy (see Table 6). This is in accordance with results obtained for pigs by Thorbek (1967) and Leroy (1965), who also concluded that the greater the daily fat storage the smaller the energy loss per unit of intake. Webster (1980) reported an inverse relationship between the proportion of dietary ME lost as heat, and the efficiency of fat deposition. This is in agreement with the results of this study.

The net energy value per kg of the diet was calculated to increase from 2.34 to 3.39 MJ while ME (12.33 MJ/kg feed) remained constant, as reported by Swart *et al.* (1993).

Discussion

Feed conversion and energetic efficiency

The poor feed conversion rate during the second growth phase (23–30 kg live mass) was caused by a relatively high feed intake, together with an unexpected poor growth performance and high deposition rate of body fat (see Table 6 & Figure 2). Differences in growth rate may be explained by differences in feed conversion rate which in turn may be explained by differences in the composition of growth and heat production (Hofmeyr *et al.*, 1974; Meissner & Pretorius, 1980; Siebrits, 1984). The sudden changes observed in these variables between successive growth phases (this study) is, however, not easily explained. It is suggested that these sudden changes or so-called breaks in the growth curve correspond to physiological changes in the animal (Scholtz & Roux, 1981).

Energy conversion (MJ ME/MJ deposited; calculated from Tables 4 & 6) improved from 5.23 in Phase 1 (10 kg live mass) to 3.63 in Phase 2 (30 kg live mass), indicating that the ostrich in fact becomes energetically more efficient, while feed conversion rate (Table 4) deteriorates. This was caused by a shift in the composition of growth, characterized by an increase in the relative fat content per kg gain and a concomitant decrease in heat production rate.

Growth patterns

The change in the ratio of the rate at which protein: fat is deposited (calculated from Table 6), from 2.3 :1 at 10 kg live mass to a 1:1 ratio at 26 kg like mass, was of particular interest. The tendency towards equality coincided with the break in the slope of the allometric log-relationship (Figure 1) between energy intake and live mass. Similar deposition patterns exist for growing pigs (calculated from data of Siebrits, 1984) and growing boer goat does (calculated from data of Viljoen, 1985). The change in the ratio of protein: fat deposition also corresponds with a break in the allometric relationship at 30 and 20 kg live mass for pigs and goats, respectively.

Regression analyses of the data in Table 6 revealed that a 1.1 percentage unit increase in percentage fat deposition contributed to a one percentage unit decrease in moisture content of the daily empty body-mass gain ($r^2 = 0.996$). Body moisture was thus replaced by body fat as reported by Siebrits (1984) and Viljoen (1985), and by deposited body protein (Van Es, 1982). Consequently energetic efficiency improved while feed conversion rate deteriorated.

Protein deposition is the main factor which determines live mass gain owing to its relationship with water deposition (Van Es, 1982), while heat loss is positively related to protein deposition (Bickel & Durrer, 1973; Ørskov & McDonald, 1970; Webster, 1980). Furthermore, it was indicated that the gross efficiency of protein deposition might be somewhat higher than that of fat deposition during the first growth phase, in the present study. Thus, the slight improvement in feed conversion rate observed from 10 to 23 kg live mass (Table 4), may be explained by an almost constant protein deposition rate accompanied by an increasing rate of fat deposition, below that of protein. Johnson & Crownover (1976) explained the increased maintenance requirement by an increasing rate of protein synthesis and not body composition as such. This is in accordance with results obtained by Pullar & Webster (1973) who showed that changes in the proportion of energy used for protein synthesis are inevitably accompanied by changes in the maintenance requirement of the growing (maturing) animal. Thus energy cost of protein accretion is greater than that of fat accretion, but is still subject to marked auto-correlation because the partitioning of energy between fat and protein is altered during growth.

Efficiency of energy deposition

The efficiency whereby consumed dietary ME is deposited as body energy in ostriches was found to compare favourably with values obtained for growing pigs (Thorbek *et al.*, 1982), poultry (Kirchgessner, 1982; Guilluame, 1976), sheep (Bickel & Durrer, 1973) and quail (Farrell *et al.*, 1982). Much higher values have, however, been reported by other research workers for pigs (Hofsetter & Wenk, 1982), broiler chickens (Leclercq & Saadoun, 1982), chickens and ducklings (Farrell & Siregar, 1979) and boer goats (Viljoen, 1985). Viljoen (1985) pointed out that these differences may be explained by a continuously changing pattern of growth composition depending on the physiological growth phase of the animal under consideration, because the gross efficiency of ME utilization depends on differences in the energy cost of protein and fat synthesis, as well as on the ME content of the diet.

When determining responses to changes in energy intake it is important to distinguish between situations of protein adequacy and those in which protein is limiting. Dunkin & Campbell (1982) pointed out that the relative apportionment of dietary ME to body protein and fat, and the efficiency of its utilization for these purposes are materially affected by the protein status of the diet. However, in this study it is most unlikely that the change in the ratio of protein: fat deposition efficiencies can be ascribed to a limited protein intake. Firstly, the ostriches were fed *ad libitum* at all stages with a diet containing 17% crude protein. Secondly, protein intake must have been adequate to maintain an increasing protein deposition rate during Phase 1 and thirdly, similar patterns were also found for growing pigs (Siebrits, 1984) and goats (Viljoen, 1985) fed *ad libitum* on balanced growth diets. On the other hand, amino acids, vitamins, trace elements or minerals can each be limiting nutrients. Swart & Kemm (1985) previously reported deposition of excessive amounts of subcutaneous fat in growing ostriches even when they were fed diets high in protein and low in energy.

The net energy value of the diet increased from 2.4 MJ/kg feed to 3.4 MJ/kg feed during the experimental growth period while ME (12.33 MJ/kg feed) remained constant (Swart *et al.*, 1993).

It can be concluded that the patterns of body and growth composition of the growing ostrich chick agree with those of other growing animals. Although normal growth and thus live mass gain is dependent on a mandatory rate of protein deposition, accompanied by water deposition, it is inevitably subject to an increasing rate of fat storage which apparently commences at the onset of growth. At some stage the deposition of protein and fat will approach equality, resulting in a subsequent change in the ratio of protein:fat deposition. The results of this study provide evidence that these sudden changes in body and growth composition coincide with a corresponding break in the growth curve, which in turn may correspond to physiological changes in the animal (Scholtz & Roux, 1981; Roux & Meissner, 1984), such as the onset of puberty and sexual maturity. These often correspond with changes in rates of feed intake between different growth phases as previously reported by several authors for different animal species (Meissner *et al.*, 1975; Meissner, 1977; Roux & Kemm, 1981; Scholtz & Roux, 1981; Scholtz & Roux, 1984; Siebrits, 1984; Viljoen, 1985).

Thus, in terms of metabolic body size ($W^{0.75}$), the priority for the allocation of ME to the deposition of body energy in protein or in fat undergoes change and is correlated with changes in heat production of the growing animals (Figures 2 & 3). This must inevitably alter the maintenance needs of the growing animal that is in accordance with results of Thorbek *et al.* (1982), who found that ME for maintenance is not related to $W^{0.75}$, but to a linear function thereof: $a + b\ W^{0.75}$. Finally, the gross efficiency of ME utilization for the deposition of body energy changes as the apportionment of energy towards protein and fat accretion changes in the growing (maturing) animal.

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Appendix Measured body composition of ostriches slaughtered at different live masses

Live mass (kg)	Age (days)	Empty body mass (kg)	Cumulative feed intake (kg)	Moisture (kg)	Ash (kg)	Protein (kg)	Fat (kg)	Energy (MJ)	Cumulative ME intake (MJ)
5.40	62	4.46	16.64	3.41	0.14	0.72	0.16	23.90	205.17
7.35	62	6.24	21.96	4.62	0.23	0.96	0.37	37.79	270.79
7.76	63	6.42	23.04	4.76	0.25	0.95	0.34	35.13	284.04
7.76	62	6.64	23.05	4.91	0.23	1.02	0.39	40.64	284.21
7.95	62	6.44	23.55	4.78	0.27	1.02	0.21	35.15	290.39
8.34	63	7.04	24.57	5.24	0.25	1.11	0.27	39.08	303.01
8.68	63	7.30	25.48	5.41	0.24	1.02	0.36	44.92	314.16
9.76	63	8.09	28.31	6.06	0.28	1.25	0.30	44.06	349.07
11.18	65	9.50	31.98	6.95	0.37	1.50	0.40	55.49	394.34
11.64	65	9.84	33.14	7.20	0.37	1.53	0.49	59.91	408.66
12.42	62	10.62	35.14	7.62	0.40	1.66	0.59	70.89	433.28
13.82	64	11.68	38.66	8.29	0.41	1.86	0.69	78.22	476.65
17.62	92	15.45	48.81	11.03	0.58	2.60	0.95	97.91	601.84
18.97	92	15.99	47.29	11.16	0.56	2.62	1.50	115.42	583.10
19.09	108	17.11	60.72	11.52	0.65	3.17	1.50	136.37	748.73
19.17	91	17.07	56.26	11.88	0.72	2.69	1.20	118.49	693.71
19.94	105	18.51	62.48	12.80	0.79	3.31	1.24	123.67	770.33
25.24	107	22.81	67.97	15.36	0.96	4.10	1.96	175.72	838.05
26.03	120	23.64	71.27	15.65	1.08	4.31	2.15	188.91	878.78
26.06	119	23.93	73.03	15.85	1.02	4.45	2.15	191.92	900.47
27.45	118	24.90	72.15	–	–	–	–	–	889.58
31.67	117	29.39	99.61	–	–	–	–	–	1228.23
35.94	119	32.24	102.98	20.45	1.46	5.89	3.56	294.70	1269.74
36.26	119	33.30	111.61	20.53	1.39	6.00	4.62	324.45	1376.20