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Effects of Dietary Nutrient Density on Performance and Carcass Quality of Male Broilers Grown for Further Processing[1]

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Abstract: Two trials of identical design were conducted in floor pens to characterize the response of male broilers grown to heavy weights for further processing to dietary nutrient density levels. Nutrient density is defined as the metabolizable energy content of the diet with all essential nutrients maintained in proportion. Ten treatments were utilized with varying nutrient densities obtained by adding poultry oil from 0 to 9% in increments of 1%. Crude protein, amino acids, and other essential nutrients were maintained in proportion to dietary energy levels. Body weights, feed consumed and processing quality were obtained at different intervals up to 63 days of age. Body weight peaked with the diet containing 6% added fat (3267 ME Kcal/ kg, mean of starter, grower, and finisher ME values). Feed intake tended to decrease with increasing nutrient density, but not at a rate commensurate with the change in energy levels. Feed conversion (g gain per g feed) improved as dietary nutrient density increased. Dressing percentage tended to decrease as dietary nutrient density level increased. Abdominal fat and breast meat, both on an absolute weight or percentage of carcass weight basis, remained rather constant when protein was maintained in proportion to energy.

Key words: Broilers, nutrient density, body weight, processing quality

Introduction

Determining the level of energy of a diet is probably the most important decision to be made in formulating diets for poultry. Energy alone contributes to about 70% of the total cost of poultry diets (Skinner *et al.*, 1992); thus, choosing the proper level of energy that will optimize growth, carcass quality and feed efficiency, while still allowing for profitable production is a major concern to any integrator. For a number of years it has generally been assumed that chickens tend to eat to meet their energy needs, assuming that the diet is adequate in essential nutrients (Hill and Dansky, 1954). However, more recent research has consistently shown that if essential dietary nutrients are maintained in relationship to dietary energy, an increased growth rate and improved feed efficiency is observed with increasing levels of dietary energy (Farrell *et al.*, 1976; Waldroup, 1981; Jackson *et al.*, 1982; Sohn and Han, 1983a, 1983b; Bartov, 1992; Leeson *et al.*, 1996). This improvement in growth rate is due to the fact that the modern broiler has been primarily selected to consume feed at almost full capacity regardless of the dietary energy level.

Higher energy levels may allow for more rapid gains or for a greater quantity of meat to be produced in a given time so that capital costs of housing, equipment and labor may be reduced. It has been demonstrated (McDonald and Evans, 1977) that a higher dietary energy level may be more economical if it provides for more rapid rate of gain and subsequently a greater number of flocks per year. On the other hand, the ingredient and production costs of higher energy diets in contrast to diets of lower energy density may negate the benefits of improved performance (Waldroup, 1981). The major influence on the energy cost of diets is due the relative price differential between corn, soybean meal, and inedible fats (Brown and McCartney, 1982). The relative advantage or disadvantage of using diets higher in nutrient density has to be determined by the price of these ingredients at the time of use.

Controversy exists regarding the influence of dietary energy levels on carcass composition and quality. In general, carcass fatness will not change as long as the C:P (Calorie to protein) ratio remains constant; otherwise, carcass fatness increases as dietary energy level increases (Bartov *et al.*, 1974; Mabray and Waldroup, 1981; Skinner *et al.*, 1992). Mabray and Waldroup (1981) noted four general nutritional factors that influence the degree of fatness in broilers: First, narrowing the calorie-to-protein ratio has generally prevented excessive deposition of body fat; second, an imbalance of amino acids may cause an increase in body fat; third, the specific effect of dietary fat on carcass composition; and fourth, the effect of dietary energy levels on the degree of fatness of broilers.

[1]Published with the approval of the Director, Arkansas Agricultural Experiment Station. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the University of Arkansas and does not imply its approval to the exclusion of other products that may be suitable.

Pesti (1982) indicated that better estimates of the coefficients for the effects of protein and energy contents of diets on growth, feed utilization and carcass composition need to be determined for starting chicks and finishing broilers under field conditions before they can be added to the diet formulation models for maximum profitability. In order to estimate the proper energy (nutrient density) it is important to accurately estimate the degree of response to changes in dietary energy. Although previous reports (Fisher and Wilson, 1974; Waldroup *et al*., 1976) summarized research trials up to that time and offered information on response to energy, these studies were conducted using a broiler markedly different from that of today.

Because little research emphasis has been placed on the response of broilers grown for further processing to changes in dietary nutrient density, the present studies were conducted. The objective of these studies was to determine the effects of dietary nutrient density on performance and carcass quality of broilers grown for heavy weights for deboning.

Materials and Methods

Birds and housing: Two trials with identical experimental design were conducted, each with four pens of 50 birds per treatment. Male chicks of a commercial stain (Ross[2]) were obtained from a local hatchery and randomly assigned to litter-floored pens with 50 birds per pen (4.65 m^2). The broiler house was a steel-truss house of commercial design with curtain sidewalls. The pens were equipped with two tube feeders and an automatic water font. Previously used softwood shavings with a top dressing of fresh shavings were used as litter over concrete floors. Thermostatically controlled brooder stoves, ventilation fans, and automatic sidewall curtains maintained house temperature and ventilation rates. Incandescent lamps supplemented natural daylight to provide 23 hr light daily.

Experimental treatments: Diets were formulated for starter (0 to 21 days), grower (21 to 42 days), and finisher (42 to 63 days) periods as suggested by NRC (1994). All diets were formulated to meet or exceed nutrient requirements for male broilers suggested by Thomas *et al*. (1992); minimum amino acid requirements were 105% of the suggested levels. All nutrients were maintained in relation to dietary energy. All diets contained 5% of a low-ash poultry by-product meal as a source of animal protein and were fortified with complete vitamin and trace mineral mixes obtained from a commercial poultry integrator.

Ten diets were formulated within each age period. These were obtained by increasing the amount of poultry oil from 0 to 9% in increments of 1% and formulated for optimum nutrient density (energy and associated nutrients). Starter diets ranged from 2985 to 3333 ME kcal/kg (Table 1), grower diets ranged from 3027 to 3079 ME kcal/kg (Table 2), and finisher diets ranged from 3078 to 3436 ME kcal/kg (Table 3). Calorie:protein ratios (ME kcal/kg ÷ % CP) remained constant across all diets within each age period. All diets were pelleted; starter diets were fed as crumbles. No attempt was made to evaluate pellet quality; however there was an obvious indirect relationship of pellet durability and level of supplemental poultry oil. Fat is viewed as creating pellet stability problems by reducing the formation of active binder and interfering with subsequent attachments between feed particles (Calet, 1965; Jensen and Falen, 1973; Elliasson *et al*., 1981a, b; Moran, 1989; Skinner *et al*., 1992).

Measurements: Body weight by pen and feed consumption were determined at 21, 42, 49, 56, and 63 days of age. Mortality was checked twice daily; birds that died were weighed for adjustment of feed utilization. Calorie conversion (ME kcal/kg gain) was calculated by multiplying consumption of starter, grower, and finisher diets by their respective caloric contents and dividing by the sum of the weight of live and dead birds. At 63 days of age, sample birds were processed in a pilot plant to determine the influence of dietary treatments on processing characteristics and breast meat yields as described by Izat *et al*. (1990). Leg scoring as described by Ferket and Sell (1989) was performed on all birds at day 63. Birds were individually scored at day 63 for incidence and severity of leg disorders, ranging from 1 (none) to 4 (severe). Data were subjected to the analysis of variance using the General Linear Models procedure of SAS (SAS Institute, 1988). When significant differences among treatments were found, means were separated by repeated t-tests using probabilities generated by the Lsmeans option of the GLM procedure. Pen means were the experimental unit and main effects of mean dietary nutrient density were examined. Mortality data were transformed to $\sqrt{n+1}$ while dressing percentage, breast meat, and abdominal fat were converted to arc sine. All transformed data are presented as natural numbers.

Results and Discussion

In order to simplify discussion of the results, a mean dietary energy (MDE) level was calculated as the average energy content of starter, grower, and finisher diets. There was no significant treatment by trial interaction; thus, the data from the two experiments were pooled for statistical analysis. The results of feeding

[2]Ross Breeders, Huntsville AL 35805

Table 1: Ingredient composition (%) and calculated nutrient content of diets fed 0 to 21 days of age

INGREDIENT	A	B	C	D	E	F	G	H	I	J
Yellow corn	66.20	64.23	62.27	60.30	58.33	56.37	54.40	52.43	50.46	48.50
Soybean meal (47%)	25.05	25.98	26.90	27.83	28.76	29.68	30.61	31.54	32.47	33.39
Poultry byproduct (60%)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Poultry oil	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
Iodized salt	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.46	0.47	0.48
Limestone	0.93	0.94	0.95	0.95	0.96	0.97	0.98	0.99	1.00	1.00
Dicalcium phosphate	1.38	1.41	1.43	1.46	1.49	1.52	1.55	1.58	1.61	1.64
DL Methionine (98%)	0.17	0.18	0.18	0.19	0.19	0.20	0.20	0.21	0.21	0.22
L-Lysine HCl (98%)	0.11	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02
Common supplements[A]	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
ME, kcal/kg	2993	3032	3070	3109	3147	3186	3225	3263	3302	3341
Crude protein, %	20.70	21.01	21.22	21.53	21.84	22.00	22.32	22.61	22.84	23.10
Lysine, %	1.15	1.17	1.18	1.20	1.21	1.23	1.24	1.26	1.27	1.29
Methionine, %	0.51	0.51	0.52	0.53	0.54	0.55	0.55	0.56	0.57	0.58
TSAA, %	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95
Threonine, %	0.77	0.78	0.79	0.80	0.82	0.83	0.84	0.85	0.86	0.87
ME kcal/%CP	144.58	144.31	144.67	144.40	144.09	144.82	144.48	144.34	144.57	144.63

[A]Includes trace mineral mix to supply per kg of diet: Mn 100 mg; Zn 100 mg; Fe 50 mg; Cu 10 mg; I , 1 mg; vitamin premix to provide per kg of diet: vitamin A 7714 IU; cholecalciferol 2204 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; choline 1040 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.066 mg; ethoxyquin 125 mg; Se 0.1 mg; BMD-50 (Alpharma, Inc., Ft. Lee, NJ 07024) to provide 50 g/ton bacitracin activity; Coban 60 (Elanco Animal Health division of Eli Lilly & Co., Indianapolis, IN 46825) to provide 90 g/ton monensin.

starter, grower, and finisher diets with varying dietary nutrient density on body weight are shown in Table 4. Body weight at Day 21, 42, and 49 was significantly improved by increasing dietary nutrient density (P<0.05), and peaked at a MDE of 3276 ME kcal/kg (diet with 6% added fat). After this level, BW started to decline but remained higher than body weight of birds on MDE lower than 3267 ME kcal/kg. Although body weight at Day 56 followed a trend similar to that of Day 21, 42, and 49, the difference in the values was not statistically different among treatments. Body weight at Day 63 was significantly improved by increased dietary nutrient density, and peaked at a MDE of 3267 ME kcal/kg, remained constant up to 3304 ME kcal/kg and then declined at higher ME levels. Other researchers have demonstrated the same reduction in performance at higher energy levels (Farrell, 1974; Farrell *et al.*, 1973).

On a relative basis, it may be seen that at 21 d, the BW increased at a rate approximately commensurate with the increase in dietary nutrient density (Table 4). The increase in BW at older ages was not as great as the increase in dietary nutrient density and appeared to diminish in magnitude of increase as the birds aged.

Feed conversion at Day 21 was significantly improved as MDE increased (P<0.05), and demonstrated a quadratic response to MDE by reaching a plateau at approximately 3267 ME kcal/kg or 6% added poultry oil (Table 5). Feed conversion at Day 42, 49, 56, and 63 followed the same trend by improving significantly as MDE increased, and then reaching a plateau at approximately 3304 ME kcal/kg. On a relative basis, feed conversion at 21 d appeared to be improve slightly greater than the change in nutrient density; but at older ages this trend disappeared. Feed conversion at 56 and 63 d did not improve commensurate with the rate of increase in nutrient density.

The effects of dietary nutrient density on feed intake are shown in Table 6. Up to 42 d of age, feed consumption tended to remain the same up to an MDE of 3148 ME kcal/kg, and tended to decline thereafter, in agreement with Waldroup *et al.* (1976). However, this decline in feed intake was not proportional to

Table 2: Ingredient composition (%) and calculated nutrient content of diets fed 21 to 42 days of age

INGREDIENT	A	B	C	D	E	F	G	H	I	J
Yellow corn	70.33	68.36	66.47	64.56	62.66	60.75	58.85	56.94	55.02	53.10
Soybean meal (47%)	21.19	22.06	22.92	23.79	24.65	25.52	26.38	27.25	28.12	28.99
Poultry byproduct (60%)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Poultry oil	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
Iodized salt	0.42	0.43	0.44	0.44	0.45	0.46	0.46	0.47	0.48	0.49
Limestone	0.85	0.86	0.87	0.88	0.88	0.89	0.90	0.91	0.91	0.92
Dicalcium phosphate	1.29	1.32	1.34	1.37	1.40	1.43	1.46	1.48	1.51	1.54
DL Methionine (98%)	0.16	0.17	0.17	0.18	0.19	0.19	0.20	0.20	0.21	0.21
L-Lysine HCl (98%)	0.01	0.05	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00
Common supplements[A]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
ME, kcal/kg	3033	3072	3112	3151	3190	3229	3269	3308	3347	3386
Crude protein, %	19.17	19.41	19.65	19.90	20.14	20.38	20.63	20.88	21.13	21.38
Lysine, %	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.11	1.13	1.15
Methionine, %	0.48	0.49	0.50	0.50	0.51	0.52	0.53	0.53	0.54	0.55
TSAA, %	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90
Threonine, %	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79	0.81
ME kcal/%CP	158.21	158.26	158.37	158.34	1 58.39	158.43	158.45	158.43	158.40	158.37

[A]As given in Table 1.

Table 3: Ingredient composition (%) and calculated nutrient content of diets fed 42 to 63 days of age

Ingredient	A	B	C	D	E	F	G	H	I	J
Yellow corn	75.59	73.76	71.91	70.09	68.24	66.40	64.57	62.74	60.90	59.06
Soybean meal (47%)	16.19	16.98	17.77	18.57	19.36	20.15	20.94	21.73	22.52	23.31
Poultry byproduct (60%)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Poultry oil	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
Iodized salt	0.43	0.44	0.45	0.45	0.46	0.47	0.47	0.48	0.49	0.50
Limestone	0.82	0.83	0.84	0.84	0.85	0.86	0.87	0.87	0.88	0.89
Dicalcium phosphate	1.14	1.16	1.19	1.21	1.24	1.27	1.29	1.32	1.34	1.37
D-L Methionine (98%)	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.11	0.12	0.12
Common supplements[A]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
ME, kcal/kg	3084	3124	3164	3204	3244	3284	3324	3364	3404	3444
Crude protein, %	17.14	17.36	17.58	17.80	18.03	18.28	18.47	18.69	18.92	19.14
Lysine, %	0.83	0.85	0.87	0.89	0.91	0.92	0.94	0.96	0.98	1.00
Methionine, %	0.37	0.38	0.39	0.39	0.40	0.41	0.41	0.42	0.43	0.43
TSAA, %	0.68	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.75	0.75
Threonine, %	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72
ME kcal/%CP	179.92	179.95	179.97	180.00	179.92	179.65	179.96	179.98	179.91	179.94

[A]As given in Table 1.

Table 4: Effect of dietary nutrient density on absolute and relative body weight of male broilers (mean of two trials with four replicate pens of 50 male broilers per trial)

Mean Dietary Energy (ME kcal/kg)[1]	Poultry Oil (%)	Body weight (g) 21d	42 d	49 d	56 d	63 d	Relative Energy Content[2]	Body weight (relative) 21 d	42 d	49 d	56 d	63 d
3023	0	681^{d}	2119^{c}	2652^{e}	3149	3625^{b}	100.0	100.0	100.0	100.0	100.0	100.0
3069	1	692^{cd}	2128^{bc}	2679de	3132	3604^{b}	101.5	101.6	100.4	101.0	99.5	99.4
3109	2	718^{ab}	2179^{abc}	2702^{cde}	3194	3651^{b}	102.8	105.4	102.8	101.9	101.4	100.7
3148	3	713^{bc}	2158^{abc}	2698^{cde}	3170	3664^{ab}	104.1	104.7	101.8	101.7	100.7	101.0
3188	4	726^{ab}	2187^{abc}	2757^{abc}	3222	3738^{ab}	105.5	106.6	103.2	103.9	102.3	103.1
3227	5	708^{bc}	2201^{ab}	2720^{bcde}	3156	3717^{ab}	106.7	103.9	103.8	102.5	100.2	102.5
3267	6	740^{a}	2224^{a}	2816^{a}	3277	3778^{a}	108.1	108.7	104.9	106.1	104.1	104.2
3304	7	722^{ab}	2204^{a}	2780^{ab}	3248	3736^{ab}	109.3	106.0	104.0	104.8	103.1	103.1
3344	8	724^{ab}	2208	2741^{bcd}	3185	3624^{b}	110.6	106.3	104.2	103.3	101.1	99.9
3383	9	729^{ab}	2200^{ab}	2727^{bcd}	3207	3628^{b}	111.9	107.0	103.8	102.8	101.8	100. 1
Probability > F			0.0009	0.05	0.0005	0.27	0.07					
SEM			8	24	23	38	41					

[1]Mean dietary energy level (ME kcal/kg) of diets fed 0 to 21d, 21 to 42 d, and 42 to 63 d. [2]Diet energy relative to treatments with no added poultry oil. ^{abcde}Means in column with common superscript do not differ significantly (P < 0.05).

Table 5: Effect of dietary nutrient density on absolute and relative feed conversion by male broilers (mean of two trials with four replicate pens of 50 male broilers per trial)

Mean Dietary Energy (ME kcal.kg)[1]	Poultry Oil %	Feed conversion (g gain ÷ g feed) 0-21 d	0-42 d	0-49 d	0-56 d	0-63 d	Relative Energy Content[2]	Feed conversion (relative) 0-21 d	0-42 d	0-49 d	0-56 d	0-63 d
3023	0	0.693^{a}	0.550^{a}	0.512^{a}	0.482^{a}	0.456^{a}	100.0	100.0	100.0	100.0	100.0	100.0
3069	1	0.713^{b}	0.554^{ab}	0.515^{ab}	0.487^{a}	0.457^{ab}	101.5	102.8	100.7	100.6	101.0	100.2
3109	2	0.727^{bc}	0.557^{ab}	0.519^{abc}	0.487^{a}	0.460^{ab}	102.8	104.9	101.3	101.4	101.0	100.8
3148	3	0.738^{cd}	0.564^{bc}	0.524^{bc}	0.488^{a}	0.462^{ab}	104.1	106.4	102.5	102.3	101.2	101.3
3188	4	0.753^{de}	0.571^{c}	0.527^{cd}	0.488^{a}	0.463^{abc}	105.5	108.6	103.8	102.9	101.2	101.5
3227	5	0.754^{de}	0.573^{cd}	0.528^{cde}	0.487^{a}	0.468^{abcd}	106.7	108.8	104.2	103.1	101.0	102.6
3267	6	0.772^{ef}	0.572^{cd}	0.536^{def}	0.501^{b}	0.468^{abcd}	108.1	111.4	104.0	104.7	103.9	102.6
3304	7	0.762^{ef}	0.582^{de}	0.542^{fe}	0.504^{b}	0.475^{cd}	109.3	109.9	105.8	105.8	104.5	104.2
3344	8	0.781^{f}	0.594^{f}	0.538^{efg}	0.504^{b}	0.468^{bcd}	110.6	112.7	108.0	105.0	104.5	102.6
3383	9	0.784^{f}	0.590^{ef}	0.548^{g}	0.511^{b}	0.478^{d}	111.9	113.1	107.2	107.0	106.0	104.8
Probability > F		0.0001	0.0001	0.0001	0.0001	0.0142						
SEM		0.013	0.011	0.012	0.014	0.019						

[1]Mean dietary energy level (ME kcal/kg) of diets fed 0 to 21d, 21 to 42 d, and 42 to 63 d. [2]Diet energy relative to treatments with no added poultry oil. ^{abcdefg}Means in column with common superscript do not differ significantly (P < 0.05).

Table 6: Effect of dietary nutrient density on absolute and relative feed consumption by male broilers (mean of two trials with four replicate pens of 50 male broilers per trial)

Mean dietary Energy (kcal/kg)[1]	Poultry Oil(%)	Feed consumed (g/bird)					Relative Energy Content[2]	Feed consumed (relative)				
		0-21 d	0-42 d	0-49 d	0-56 d	0-63 d		0-21 d	0-42 d	0-49 d	0-56 d	0-63 d
3023	0	978^{ab}	3864^{ab}	5257^{a}	6612^{a}	8033^{ab}	100.0	100.0	100.0	100.0	100.0	100.0
3069	1	983^{ab}	3829^{abcd}	5138^{abc}	6393^{abc}	7796^{bcd}	101.5	100.5	99.1	97.7	96.7	97.0
3109	2	993^{a}	3909^{a}	5257^{a}	6553^{ab}	7933^{abc}	102.8	101.5	101.2	100.0	99.1	98.8
3148	3	966^{abc}	3825^{abcd}	5154^{abc}	6491^{abc}	7927^{abc}	104.1	98.8	99.0	98.0	98.2	98.7
3188	4	947^{bcd}	3832^{abcd}	5230^{ab}	6600^{a}	8174^{a}	105.5	96.8	99.2	99.4	99.8	101.8
3227	5	936^{cd}	3841^{abc}	5146^{abc}	6469^{abc}	7937^{abc}	106.7	95.7	99.4	97.9	97.8	98.8
3267	6	956^{bcd}	3884^{ab}	5247^{ab}	6590^{a}	8062^{ab}	108.1	97.8	100.5	99.8	99.7	100.4
3304	7	947^{bcd}	3788^{bcd}	5214^{abc}	6490^{abc}	7941^{abc}	109.3	96.8	98.0	99.2	98.2	98.8
3344	8	925^{d}	3719^{d}	5072^{bc}	6328^{bc}	7672^{cd}	110.6	94.6	96.2	96.4	95.7	95.5
3383	9	926^{d}	3727^{cd}	4979^{c}	6268^{c}	7584^{d}	111.9	94.7	96.4	94.7	94.8	94. 4
Probability > F		0.0001	0.0001	0.0001	0.0001	0.0001						
SEM		11	42	62	86	116						

[1]Mean dietary energy level (ME kcal/kg) of diets fed 0 to 21d, 21 to 42 d, and 42 to 63 d. [2]Diet energy relative to treatments with no added poultry oil. [abcde]Means in column with common superscript do not differ significantly (P < 0.05).

Table 7: Effect of dietary energy level on absolute and relative energy utilization by male broilers (mean of two trials with four replicate pens of 50 male broilers)

Mean dietary Energy (kcal/kg)[1]	Poultry Oil%	Calorie utilization (ME kcal/kg gain)					Relative Energy Content[2]	Calorie utilization (relative)[2]				
		0-21 d	0-42 d	0-49 d	0-56 d	0-63 d		0-21 d	0-42 d	0-49 d	0-56 d	0-63 d
3023	0	4312	5499^{d}	5930^{d}	6341^{f}	6828^{d}	100.0	100.0	100.0	100.0	100.0	100.0
3069	1	4241	5535^{d}	5955^{d}	6425^{ef}	6883^{bcd}	101.5	98.4	100.6	100.4	101.3	100.8
3109	2	4212	5549^{d}	6048^{bcd}	6479^{de}	6875^{cd}	102.8	97.6	100.9	101.9	102.2	100.7
3148	3	4204	5550^{d}	6014^{cd}	6519^{cde}	6911^{bcd}	104.1	97.5	100.9	101.4	102.8	101.2
3188	4	4171	5556^{cd}	6046^{bcd}	6567^{bcd}	6833^{d}	105.5	96.7	101.0	101.9	103.6	100.0
3227	5	4211	5603^{bcd}	6107^{abc}	6644^{ab}	6944^{bcd}	106.7	97.6	101.9	102.9	104.7	101.7
3267	6	4164	5676^{ab}	6088^{abc}	6600^{bc}	7049^{ab}	108.1	96.5	103.2	102.7	104.1	103.2
3304	7	4270	5653^{abc}	6073^{abc}	6618^{bc}	7021^{abc}	109.3	99.0	102.8	102.4	104.4	102.8
3344	8	4216	5604^{bcd}	6143^{ab}	6732^{a}	7181^{a}	110.6	97.8	101.9	94.5	106.2	105.2
3383	9	4245	5706^{a}	6182^{a}	6666^{ab}	7179^{a}	111.9	98.4	103.7	96.2	105.1	105.1
Probability > F		0.41	0.001	0.005	0.0001	0.0002						
SEM		42	35	42	38	61						

[1]Mean dietary energy level (ME kcal/kg) of diets fed 0 to 21d, 21 to 42 d, and 42 to 63 d. [2]Diet energy relative to treatments with no added poultry oil. [abcde]Means in column with common superscript do not differ significantly (P < 0.05).

Table 8: Effect of dietary energy level on mortality rates of male broilers (mean of two trials with four replicate pens of 50 male broilers per trial)

Mean dietary Energy (kcal/kg)[1]	Poultry Oil (%)	% Mortality				
		0-21 d	0-42 d	0-49 d	0-56 d	0-63 d
3023	0	4.62	8.43	12.27^{a}	13.20^{a}	15.17^{a}
3069	1	4.26	7.78	8.79^{ab}	11.06^{ab}	11.82^{ab}
3109	2	3.47	6.72	7.73^{bc}	9.47^{abc}	10.93^{abc}
3148	3	1.49	3.74	4.99^{c}	6.24^{c}	7.74^{bc}
3188	4	2.95	6.98	8.16^{bc}	8.76^{bc}	9.28^{bc}
3227	5	2.52	5.84	6.35^{bc}	6.60^{c}	8.37^{bc}
3267	6	3.01	6.34	6.35^{bc}	7.39^{bc}	8.45^{bc}
3304	7	3.01	4.77	5.53^{bc}	6.53^{c}	7.31^{c}
3344	8	2.49	4.48	5.23^{c}	6.72^{c}	7.72^{bc}
3383	9	2.51	4.52	5.27^{c}	7.03^{c}	8.28^{bc}
Probability > F		0.49	0.11	0.003	0.02	0.01
SEM		0.92	1.16	1.18	1.41	1.45

[1]Mean dietary energy level (ME kcal/kg) of diets fed 0 to 21d, 21 to 42 d, and 42 to 63 d. [abcde]Means in column with common superscript do not differ significantly ($P < 0.05$).

Table 9: Effects of dietary energy level on incidence of leg disorders and carcass characteristics of 63 d old male broilers (mean of two trials with four pens of 50 male broilers per trial. Five birds per pen were processed for carcass measurements).

Measurement[2]	Mean dietary energy, ME kcal/kg[1]										SEM	Prob>F
	3023	3069	3109	3148	3188	3227	3267	3304	3344	3383		
Normal gait, %	82.99	85.18	81.52	80.57	81.34	78.95	79.23	80.13	86.25	85.56	3.63	0.96
Visible lameness, %	12.11	11.64	14.72	13.96	14.85	16.62	15.34	15.64	9.91	10.16	3.35	0.98
Severe lameness, %	3.69	2.90	2.87	4.10	3.51	2.51	4.60	2.74	3.01	2.63	0.95	0.39
Unable to walk, %	1.19^{ab}	0.28^{b}	0.88^{ab}	1.37^{ab}	0.29^{b}	1.91^{a}	0.82^{ab}	0.59^{ab}	0.83^{ab}	1.64^{ab}	0.54	0.03
Mean leg score[3]	1.23	1.18	1.23	1.26	1.23	1.27	1.27	1.23	1.18	1.20	0.04	0.70
Carcass weight (CW), g	2813^{bcd}	2788^{cd}	2846^{bcd}	2859^{a-d}	2940^{a}	2899^{ab}	2874^{abc}	2882^{ab}	2774^{d}	2785^{d}	31.91	0.001
Dressing percent	72.36^{abc}	72.35^{abc}	72.62^{ab}	72.97^{a}	72.76^{ab}	72.12^{bcd}	71.79^{cd}	71.79^{cd}	71.84^{cd}	71.44^{d}	0.27	0.01
Breast weight, g	649^{bcd}	630^{d}	653^{bcd}	667^{ab}	692^{a}	670^{ab}	668^{ab}	659^{bc}	834^{cd}	637^{cd}	10.32	0.001
Breast, % of CW	23.07^{abc}	22.56^{c}	22.91^{abc}	23.29^{ab}	23.53^{a}	23.09^{abc}	23.25^{ab}	22.88^{bc}	22.88^{bc}	22.87^{bc}	0.23	0.04
Abdominal fat, g	98.9^{abc}	101.5^{ab}	95.9^{bc}	107.9^{a}	103.5^{ab}	100.7^{ab}	101.7^{ab}	102.7^{ab}	95.2^{c}	101.2^{ab}	3.82	0.005
Abdominal fat % of CW	3.52	3.64	3.37	3.77	3.51	3.46	3.52	3.55	3.30	3.63	0.12	0.08

[1]Mean dietary energy level (ME kcal/kg) of diets fed 0 to 21d, 21 to 42 d, and 42 to 63 d. [2]Leg scores assigned as described by Ferket and Sell, 1989. [3]Based on 1 = normal gait; 2 = visible lameness; 3 = severe lameness; 4 = unable to walk. [abcd]Means in column with common superscript do not differ significantly ($P < 0.05$).

changes in MDE. For example, increasing MDE from 3023 to 3304 ME kcal/kg represents an increase of 9.3 percent. The 0 to 63 d feed consumption of birds fed an MDE of 3304 decreased only 1.12 percent as compared to those fed an MDE of 3023. Even though relative feed intake declined at MDE levels greater than 3304 ME kcal/kg, the reduction was not commensurate with the change in nutrient density. Thus, it is apparent that the modern broiler does not regulate feed intake by maintaining isocaloric consumption.

It must be noted that a dramatic decline in the physical quality of the feed pellets occurred with poultry oil at levels above 5% of the diet. Others have demonstrated that the poor pellet quality might be the reason for depressed feed consumption at higher energy levels because of the associated work of prehension (Auckland and Fulton, 1972; Jensen and Falen, 1973; Waldroup, 1981; Moran, 1989; Skinner *et al.*, 1992).

The effects of dietary nutrient density on calorie conversion (ME kcal per g of gain) are shown in Table 7. As a result of the decline in body weight gain at the higher MDE levels, coupled with the rather constant feed intake, energy utilization (ME kcal/kg of gain) was constant up to an MDE of about 3267 ME kcal/ kg. At all ages (except day 56), the birds were significantly less efficient in utilizing the caloric intake at higher MDE levels. These results are in agreement with Waldroup *et al.* (1976) who reported that calorie conversion was essentially equal from 2970 to 3300 ME Kcal/kg with a reduction in the calorie utilization when the energy levels were higher than 3300 ME Kcal/kg.

The reduction in caloric efficiency as broilers age is interesting in light of research that suggests that the ability to utilize supplemental fats improves as birds grow older (Renner and Hill, 1960; Fedde *et al.*, 1960; Young, 1961; Carew *et al.*, 1972; Katongole and March, 1980; Polin and Hussein, 1982; Lessire *et al.*, 1982; Sell *et al.*, 1986). However, in most of these studies the primary effect of age was upon the utilization of more saturated fats such as tallow with minimal effect on utilization of highly unsaturated fats such as corn oil or animal-vegetable blends. Poultry oil is highly unsaturated and thus should not be as subject to age-associated changes in absorption but little research exists on absorption of poultry oil at various ages.

One of the frequently expressed concerns regarding the use of high dietary energy levels is the potential impact upon mortality and incidence of leg disorders. Mortality was not adversely affected as MDE increased (Table 8), and, in fact, appeared to be inversely related to MDE. Birds were individually scored at Day 63 for incidence and severity of leg disorders, ranging from 1 (none) to 4 (severe) as described by Ferket and Sell (1989). Percentage and mean leg scores are shown in Table 9. There were no significant differences among MDE levels for scores of none, slight, and moderate leg disorders. Although there were significant differences among treatments for birds scored as severe leg disorders, there was no consistent relationship to MDE levels.

The effects of MDE on carcass characteristics are given in Table 9. Carcass weight was significantly improved as MDE was increased, peaked at 3188 ME kcal/ kg, and then declined at very high energy levels (3344 and 3383 ME kcal/kg). Dressing percentage was relatively constant up to an MDE of 3188 ME kcal/kg and then began to decline. Breast meat yield as percentage of carcass weight showed significant differences among MDE levels ($P<0.05$), however, it did not follow any specific trend among the dietary treatments. Breast meat weight increased as MDE increased and was heaviest at MDE of 3188 ME kcal/kg, then declined as MDE exceeded 3304 ME kcal/kg.

High energy levels are often blamed for excessive abdominal fat accumulation, but there was no consistent relationship of MDE to abdominal fat weight or percentage of carcass. It must be noted that in these trials a constant C:P ratio was maintained; this has been shown in numerous studies to have more effect on carcass fat than dietary energy per se (Donaldson *et al.*, 1956; Bartov *et al.*, 1974; Griffiths *et al.*, 1977; Bartov, 1977; Mabray and Waldroup, 1981). Bartov *et al.* (1974) and Bartov (1977) reported that an increase in energy content of the diet through the addition of fat without altering the C:P ratio had no effect on carcass fat content of the broilers.

Conclusions: Body weight gain and feed conversion of broilers grown to large weights for further processing tended to improve as dietary nutrient density increased. However, feed intake did not decrease at the same rate at which the nutrient density level increased; thus, caloric efficiency tended to decline. There was no adverse effect on mortality or leg disorders resulting from increased dietary nutrient density. Abdominal fat was not adversely affected by increasing nutrient density when protein was maintained in ratio to energy. Breast meat yield and percentage remained rather constant as dietary nutrient density changed. When establishing the proper dietary nutrient density the economics of selection of nutrient density levels needs to be considered in addition to its effects on production parameters.

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