TABLE X

Effect of Linoleic Acid Content of Feed Grade Fats on Laying Hen Performance

Dietary treatment: Fat source	% Linoleic acid	ME (kcal/g)	% Production	Feed conversion (kg/doz)
Basal	---	2.73	78.1^{a}	1.78^{b}
Y.G., 3.0%	12.5	2.89	84.1^{b}	1.66^{a}
A, 3.0%	24.7	2.94	84.8^{b}	1.59^{c}
B, 3.0%	32.8	2.90	77.3^{a}	1.73^{b}
C, 3.0%	57.9	2.85	81.6^{b}	1.66^{a}

[a]Means not having common letter superscripts are significantly different at the 0.05 level of probability.

TABLE XI

Effect of Sulfur Amino Acid Level on Energy Utilization

	32 C		16 C	
Criteria	0.47	0.50	0.47	0.50
TSAA (mg/day)	449	465	517	598
ME (kcal/day)	281	279	330	359
ME above maintenance (kcal/day)	137	135	156	185
Energy balance (kcal/day)	81	90	107	133
Partial eff. of prod. (%)	59.1	66.7	68.6	71.9
Energetic efficiency (%)	53	62	58	64
Heat increment + activity (kcal/day)	132	106	139	129

higher temperature. The maximum energy balance obtained at 32 C was 90 kcal per day, while the maximum at 16 C was 133 kcal per day. Energetic efficiency was identical at the two temperatures with a maximum level of 61–64%. The feeding of diets deficient in methionine at the high environmental temperature resulted in an energetic efficiency of only 53%, whereas the lowest total sulfur amino acid intake at 16 C had 58% energetic efficiency (Table XI).

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Energy Levels for Broilers[1]

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ABSTRACT

One of the most important decisions to be made in feeding poultry is to determine the level of energy that will balance growth, carcass quality and efficiency of feed utilization with profitability of production. Strict adherence to measures of efficiency such as feed:gain ratios has caused many to overlook the potential benefits of modifying energy levels periodically to adjust to changes in price relationships among ingredients and in cost and quality of the finished product. It has been consistently shown that if an adequate quantity of essential nutrients is maintained in relationship to dietary energy, increasing levels of dietary energy for broilers results in a more rapid rate of gain and improvement in feed conversion efficiency. Controversy exists regarding the influence of dietary energy levels on carcass composition and quality, but in general, carcass fatness increases as dietary energy level increases. Selecting the optimum dietary energy level for broiler diets depends upon many factors, not all of which have been fully defined or quantitated. 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. 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.

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INTRODUCTION

Energy is supplied to the chick by most feed ingredients, and modifications to the dietary energy level can be made in a number of ways. Seldom does one see simple dietary changes that influence only the energy. For example, the introduction of more fibrous, lower energy materials may lead to changes in amino acid availability (usually poorer in fibrous materials), increased fiber content and reduced physical density (weight/volume) and levels of essential fatty acids. Although we would like to assume simple straight-line effects of dietary energy levels on broiler response, we cannot always do so, due to the complexity of other dietary interrelationships.

ENERGY:NUTRIENT INTERACTIONS

One of the most important developments in the use of high-energy diets for poultry was the concept of the calorie:protein ratio. This concept states that there is an optimum balance of energy and protein; excessive levels of energy reduce performance by limiting protein intake. Examples of this were observed in early research studies. Henderson and Irwin (1) reported that chicks tolerated as much as 10% added soybean oil in their diets, but higher levels caused a growth depression and an increased rate of feather shedding. Yacowitz (2) reported that 2.5–5% cottonseed oil improved growth and feed conversion of growing chicks, whereas 10–15% resulted in growth depression and poor feathering. Biely and March (3) found that the addition of fat to a 19% protein diet depressed growth and feed conversion in chicks, but had no adverse effects when added to diets with 24–28% protein.

Donaldson et al. (4) demonstrated that fat levels up to 31% could be fed to broiler chicks without adverse effects on performance if dietary protein levels were adjusted to maintain constant calorie:protein ratios. Baldini and Rosenberg (5) further refined this concept to consider the optimum ratio of calories to other essential nutrients. They demonstrated that the methionine requirement of the chick was influenced by the dietary energy level; as the energy level increased, a proportionate increase in the methionine requirement was observed.

It is unfortunate that many researchers studying dietary energy do not consider this important concept when formulating diets. This has led to some experimental results that have undoubtedly been highly influenced by imbalanced calorie:nutrient ratios, rather than by energy levels per se. This has been especially true in studies intended to determine the influence of dietary energy level in carcass composition.

TABLE I

Regression Coefficients Related to Change in Performance Associated with Metabolizable Energy Changes of + 1 kcal/g (6)

Response	Sex	1 to 28 d	29 to 56 d
A. Live-weight gain (ΔW, g/day)	M	5.11	6.06
	F	3.29	4.24
	M/F	4.20	5.15
B. Food intake (F,g/day)	M	1.64	15.35
	F	3.02	16.73
	M/F	2.33	16.04
C. Food conversion efficiency (FCE, ΔW/F)	M	0.21	0.15
	F	0.17	0.12
	M/F	0.19	0.13

TABLE II

Effects of Feeding Broiler Chicks Diets Varying in Metabolizable Energy to 56 Days of Age (7)

ME (kcal/kg)	Body wt (g)[1]	Feed:gain ratio[1]	Feed/ bird (g)[1]	Mcal/ bird[1]	Calories per gram of gain[1]
2970	1409^{a}	2.17^{e}	3055^{c}	9.07^{a}	6.45^{a}
3080	1478^{b}	2.10^{d}	3095^{c}	9.53^{b}	6.46^{ab}
3190	1500^{bc}	2.02^{c}	3019^{bc}	9.63^{bc}	6.44^{a}
3300	1554^{cd}	1.94^{b}	3002^{abc}	9.91^{c}	6.40^{a}
3410	1521^{bcd}	1.92^{b}	2916^{ab}	9.94^{cd}	6.54^{ab}
3520	1569^{de}	1.86^{a}	2919^{ab}	10.27^{de}	6.55^{ab}
3630	1580^{de}	1.83^{a}	2895^{a}	10.51^{e}	6.66^{bc}
3740	1626^{e}	1.81^{a}	2938^{ab}	10.99^{f}	6.77^{c}

[1]Means having the same superscript do not differ significantly ($P<.05$).

BROILER RESPONSE TO ENERGY

Fisher and Wilson (6) conducted an excellent survey, lasting over 20 years, of poultry research on the response of broilers to dietary energy levels. By combining the results of 51 experiments, they were able to estimate the influence of dietary energy on various production parameters. The regression coefficients related to a dietary metabolizable energy change of +1 kcal/g are shown in Table I for various production factors. Live weight gains were increased, feed intake was reduced, and food conversion efficiency was improved as dietary energy level increased. Although total feed intake would be reduced, a greater energy intake would be expected with increasing dietary intake.

Waldroup et al. (7) conducted trials to determine the response of broiler chicks to diets varying in energy level. A series of diets was formulated to contain from 2970 to 3740 ME kcal/kg. All essential nutrients were maintained in proportion to the energy level so as to have equal ratios of amino acids, calcium, phosphorus and other nutrients to energy.

Body weight gains increased as the dietary energy level increased, while the amount of feed required to support the gain was reduced (Table II). The amount of feed consumed per bird declined, but by only a small amount. For example, increasing the energy content from 2970 to 3740 ME kcal/kg, an increase of over 25%, caused only a 4% reduction in food intake. As a result, the total consumption of energy and other nutrients was increased. Energy utilization efficiency, measured as calories needed per gram of gain, was relatively constant from 2970 to 3520 kcal/kg, well within the normal energy use range.

The birds were processed and evaluated to determine the effects of dietary energy on carcass quality. As the energy level increased, the birds had a higher fleshing score and carcass finish score, which reflected their greater body weight (Table III). No significant differences were observed in body conformation. Birds fed the higher energy levels were judged visually to have the most abdominal fat, but the score did not indicate an excessive amount. Overall carcass appearance scores did not indicate a problem with greasy appearance, even though very high levels of supplemental soybean oil was used to provide the high energy levels.

DeGroote (8,9) has extensively researched the response of broilers to dietary energy levels. His data indicate that increasing the dietary energy level results in improvement in weight gains, a slight decline in feed consumption with a concomitant increase in energy consumption, and improved feed conversion efficiency without impairment of energy utilization (Tables IV and V).

Although it has been conclusively demonstrated that increasing the dietary energy level results in more rapid body weight gains and improved efficiency of feed conversion, this does not imply endorsement of the use of high-energy diets. The cost of producing high-energy diets must be weighed against the potential returns.

TABLE III

Effects on Carcass Characteristics of Feeding Broiler Chicks Varying in Metabolizable Energy to 56 Days of Age (7)

ME (kcal/kg)	Carcass fleshing score[1,3]	Carcass finish score[1,4]	Body conformation score[2,5]	Abdominal fat score[1,6]	Carcass appearance score[1,7]
2970	3.23^{a}	3.13^{a}	3.29	3.69^{c}	3.46^{b}
3080	3.22^{a}	3.06^{a}	3.08	3.24^{c}	3.38^{b}
3190	3.22^{a}	3.31^{ab}	3.19	3.07^{b}	3.17^{ab}
3300	3.62^{ab}	3.28^{ab}	3.42	3.10^{b}	3.34^{b}
3410	3.62^{ab}	3.63^{abc}	3.51	2.48^{a}	3.17^{ab}
3520	4.07^{b}	3.86^{c}	3.81	2.87^{ab}	3.42^{ab}
3630	3.35^{a}	3.45^{abc}	3.27	2.99^{ab}	3.28^{ab}
3740	3.65^{ab}	3.41^{ab}	3.33	2.89^{ab}	3.05^{a}

[1] Means having the same superscript do not differ significantly ($P < .05$).
[2] No significant differences between treatment means.
[3] 1 = poorly fleshed; 5 = very well fleshed.
[4] 1 = poorly finished; 5 = good fat covering.
[5] 1 = poorly formed; 5 = good conformation.
[6] 1 = excessive amount; 5 = minimum amount.
[7] 1 = excessive greasiness; 5 = dry, firm skin.

TABLE IV

Influence of Dietary Energy Levels on Performance of Broilers (9)

ME (kcal/kg)	56-day weight (g)	Feed/ day (g)	Feed: gain	Mcal/ bird	Calories per gram of gain
3000	1706	66.1	2.216	11.10	6.65
3100	1758	63.2	2.058	10.97	6.38
3200	1789	66.1	2.113	11.85	6.76
3300	1835	66.1	2.060	12.22	6.80
3400	1860	63.4	1.945	12.07	6.61

TABLE V

Influence of Nutrient Density on the Nutritional Efficiency of Broiler Production (8)

ME (kcal/kg)	56-day weight (g)	Feed/ day (g)	Mcal/ bird	Feed: gain	Calories per gram of gain
3000	1836	71.2	11.95	2.17	6.51
3115	1880	71.4	12.46	2.13	6.63
3207	1918	71.3	12.79	2.08	6.67
3488	2047	69.5	13.56	1.90	6.63

TABLE VI

Broiler Profits per Square Meter of Floor Space As Influenced by Dietary Energy Level and Various Production Assumptions (10)

	Assume M.E. does not affect growth rate		Assume M.E. affects growth rate	
M.E. of starter diets	Slaughter at age of maximum profit	Slaughter at 2 kg body weight	Slaughter at age of maximum profit	Slaughter at 2 kg body weight
	(Profit/M^2/year)			
2.7	3.28	2.87	3.33	2.88
2.75	3.86	3.47	4.18	3.81
2.8	4.06	3.78	4.76	4.45
2.85	4.38	4.00	5.26	4.99
2.9	4.67	4.26	5.77	5.57
2.95	4.79	4.39	6.15	6.02
3.0	4.87[1]	4.47[1]	6.50	6.40
3.05	4.77	4.36	6.69	6.62
3.1	4.63	4.24	6.81	6.78
3.15	4.50	4.12	6.94	6.96
3.2	4.39	4.00	7.09[1]	7.13[1]
3.25	3.64	3.21	6.91	6.97

[1] Point of maximum profitability.

McDonald and Evans (10) used a computer simulation model to examine the effects of feeding least-cost diets containing ME levels varying from 2.7 to 3.25 kcal/g in the starter diet and 2.79 to 3.39 kcal/g in the finisher diet on profitability in a broiler operation. Using a series of alternative conditions and influences, they determined that the effect of dietary metabolizable energy on growth rate would influence the selection of the most profitable energy level. Higher energy levels could be justified if broilers responded with a more rapid growth rate, regardless of whether the decision was based on maximum profits per meter of floor space per year (Table VI) or on minimum cost to produce a kilogram of meat (Table VII).

Farrell and associates (11) compared the performance of broilers fed a range of dietary energy levels, from 9.3 to 14.3 MJ kg^{-1} (about 2225 to 3421 ME kcal/kg). As the energy level increased, the birds grew faster and required less food (in terms of both total weight and total energy) to reach specific live weights. These effects were not marked, however, when the dietary ME concentration was above 13.5 MJ kg^{-1} (3230 ME kcal/kg). Dressing percentage increased with increases in dietary ME concentration for males but tended to decline for females. Equations were presented to estimate response to dietary energy.

Although the current price of tallow or other fat supplements generally is in excess of their calorie value, there are instances when fat supplements become the least-cost source of energy and when high usage levels may be justified. Some concern has been expressed about possible reduction in the utilization of dietary fats at high usage levels. However, Farrell (12) conducted studies on the efficiency of utilization of energy from diets with a wide range of levels of corn oil and tallow (up to 14.1%), and found no significant differences between diets in the regression equations relating ME intake to energy retention. Energy retention was actually greatest at the highest concentration of tallow in the diet. Therefore, if higher fat levels are economical, the chick is able to use the added fat economically.

ENERGY AND HEAT STRESS

Since fats have a lower heat increment than proteins and carbohydrates, it has often been suggested that under extreme heat stress conditions, a greater portion of the dietary energy for broilers should be supplied by supplemental fats. However, research work to support this theory is not con-

TABLE VII

Broiler Production Costs As Influenced by Dietary Energy Level and Various Production Assumptions (10)

	Assume M.E. does not affect growth rate		Assume M.E. affects growth rate	
	Slaughter at age of maximum profit	Slaughter at 2 kg body weight	Slaughter at age of maximum profit	Slaughter at 2 kg body weight
	Cost/kg of chicken			
2.7	51.47	51.68	51.45	51.67
2.75	51.02	51.2	50.79	50.94
2.8	50.78	50.94	50.34	50.45
2.85	50.61	50.76	49.96	50.04
2.9	50.41	50.55	49.56	49.61
2.95	50.31	50.45	49.27	49.30
3.0	50.25[1]	50.39[1]	49.01	49.03
3.05	50.33	50.47	48.90	48.90
3.1	50.42	50.58	48.80	48.80
3.15	50.52	50.67	48.70	48.70
3.2	50.60	50.77	48.60[1]	48.60[1]
3.25	51.20	51.4	48.79	48.78

[1] Point of least cost of meat production.

clusive. Kubena and associates (13,14) conducted two studies in environmental chambers. Broilers were fed the test diets from 4 to 8 weeks of age at 21 C. At 8 weeks of age, the broilers were subjected to 40 C.

In the first study, fat levels of 1 and 7% added fat were compared in isocaloric diets. The broilers given isocaloric diets with 7% added fat had higher mortality during the first 90 minutes of exposure to heat stress than those with 1% added fat in their diets (Table VIII). Mortality during the total heat stress episode was significantly greater for the birds fed the diets with 7% added fat.

In the second study, added fat levels ranged from 1 to 10%; however, in this instance the dietary energy level was allowed to increase as the fat levels increased. The ratio of essential nutrients to energy was maintained constant. In this study there was no influence of dietary fat level on heat stress-induced mortality (Table IX).

In both the experiments, the birds that died were weighed. These birds were larger than the surviving birds, reinforcing the commonly held belief that larger birds are more susceptible to heat stress. The results of these studies do not support the idea that high-energy diets should be used in extremely hot weather to minimize mortality.

Dale and Fuller (15) observed that broiler chicks fed diets with a constant dietary energy, but also with an increased portion of the calories coming from supplemental fat, had less depression in performance due to heat stress during either constant high temperatures (Table X) or cyclic high temperatures (Table XI). They also pointed out that factors other than reduced feed intake contribute to the growth depression associated with high temperature.

TABLE VIII

Effect of Added Fat in Isocaloric Diets on Response to Heat Stress (40 C) by Broilers (13)

	% added fat[1,2]	
Effects	7.0 (3175)	1.0 (3168)
	(Number)	
Mortality from heat		
0- 30 min	0^{a}	0^{a}
31- 60 min	23^{a}	10^{b}
61- 90 min	64^{a}	38^{b}
91- 120 min	52^{a}	50^{a}
121- 150 min	31^{a}	33^{a}
151-1080 min	20^{a}	23^{a}
Total	$190/360^{a}$	$154/360^{b}$
Survivor weights (g)	1661^{b}	1682^{ab}
Mortality weights (g)	1709^{a}	1698^{ab}
Mean weights (g)	1686	1689

[1]Figure in parentheses is ME kcal/kg.

[2]Means having the same superscript do not differ significantly ($P < .05$).

TABLE IX

Influence of Dietary Fat and Energy Levels on Response to Heat Stress (40 C) by Broilers (14)

ME (kcal/kg)	% Added fat	Mortality (number)[1]	8-week body weight (g)[1] Survivors	Mortality
3042	1.00	$76/180^{a}$	1837^{a}	1919^{ab}
3207	3.00	$80/180^{a}$	1924^{bc}	1909^{a}
3372	7.00	$65/180^{a}$	1965^{c}	2047^{c}
3461	10.00	$74/180^{a}$	1912^{b}	1957^{b}

[1]Means having the same superscript do not differ significantly ($P < .05$).

TABLE X

Influence of Dietary Fat on Response of Broiler Chicks to Heat Stress (Constant Temperatures) (15)

	A	B	C
Calculated analysis			
ME (kcal/kg)	3190	3190	3530
Protein (%)	22.0	22.0	24.3
Fat calories (%)	12.6	33.6	33.2
Nutrient density (%)	100	100	111
Body weight gain (g)[1,2]			
14 C	1151^{b} (100)	1198^{bc} (104)	1263^{c} (110)
31 C	942^{a} (100)	988^{a} (106)	1010^{a} (107)
Feed/gain[1]			
14 C	2.15^{d}	2.09^{cd}	1.83^{ab}
31 C	2.04^{c}	1.89^{b}	1.77^{a}
Carcass lipid (%)[1]			
14 C	9.99^{a}	12.37^{bc}	13.72^{cd}
31 C	11.23^{ab}	13.19^{c}	14.84^{d}

[1]Means having the same superscript do not differ significantly ($P < .05$).

[2]Values in parentheses are relative to that of treatment A at corresponding temperatures.

ENERGY AND LINOLEIC ACID NEEDS

Another factor that may contribute to the variable response to dietary energy level is the essential fatty acid content of the diet. The National Research Council (16) suggests a minimum linoleic acid requirement of 1% for chicks up to 8 weeks of age. However, some research studies have suggested that the needs are considerably higher, especially for the rapidly growing male. Menge (17) suggested that the linoleic acid requirement of the male broiler was 1.2% of the diet, or 3.6% of the total metabolizable calories. His data, however, suggest a positive response to even higher linoleate levels (Table XII).

Carew and Foss (18) reported that the linoleic acid requirement of the male broiler chick for maximum growth to 4 weeks of age was 1.9% of the diet, or 5.3% of the dietary calories (Table XIII). Again, the data suggest that even higher levels give continued growth response. Edwards et al. (19) suggested that the chick required approximately 2.5% linoleic acid in the diet for maximum growth rate.

TABLE XI

Influence of Dietary Fat on Response of Broiler Chick to Heat Stress (Cyclic Temperatures) (15)

	D	E
Calculated analysis		
ME (kcal/kg)	3170	3170
Protein (%)	21.8	21.8
Fat calories (%)	14.5	27.5
Body weight gain (g)[1,2]		
17 to 23 C	1159^{b} (100)	1286^{c} (111)
24 to 23 C	994^{a} (100)	1188^{bc} (120)
% Growth depression from heat stress	14.2	7.6
Feed intake (kg/chick)[1,2]		
17 to 23 C	2.643^{c} (100)	2.778^{c} (105)
24 to 23 C	2.237^{a} (100)	2.483^{b} (111)

[1]Means having the same superscript do not differ significantly ($P < .05$).

[2]Values in parentheses are relative to that of treatment D at corresponding temperatures.

TABLE XII

Effect of Different Levels of Linoleate on the Growth of Male and Female Chicks (17)

Dietary linoleate %	% Calories as linoleate	6-week body weights[1] Males	Females
0.0	0.0	362^{a}	363^{a}
0.15	0.5	392^{bc}	359^{a}
0.3	0.9	423^{cde}	378^{ab}
0.6	1.8	453^{ef}	409^{bcd}
1.2	3.6	479^{fg}	439de
2.4	7.3	509^{g}	439de

[1]Means having the same superscript do not differ significantly (P<.01).

Since increased dietary energy is usually accomplished by substituting corn (rich in linoleic acid) for other cereal grains or fibrous byproducts (usually low in linoleic acid), or through the increased addition of supplemental fats (which may range from low-linoleic acid sources such as tallow to high-linoleic acid sources such as the vegetable oils), it becomes apparent that at least a portion of the response to increased dietary energy levels may be the result of increased levels of linoleic acid *per se*. Further studies are needed to determine the extent of this response in broilers to market age.

TABLE XIII

Effect of Level of Dietary Linoleate on Growth of Male Broiler Chicks (18)

Dietary source of linoleate	Added dietary linoleate % of diet	% of calories	Weight gain (g)
None	0	0	496^{a}
Safflower oil	0.7	2.1	540^{b}
↓	1.5	4.2	465^{bc}
	2.9	8.1	586^{cd}
	4.4	11.7	591^{cd}
	5.8	15.2	601^{d}
	11.7	27.1	594^{d}
Corn oil	1.7	4.8	587^{cd}
↓	3.4	9.2	584^{cd}
	5.2	13.2	610^{d}
	6.9	16.9	604^{d}

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Soybean Meal in Calf Milk Replacers

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ABSTRACT

Major research efforts by university and industry workers throughout the world have been directed toward improving the utilization of soybean protein by the calf. This paper reviews the literature and summarizes the questionable characteristics and methods of improving utilization of soya protein sources for young calves. Current application of soya protein in calf milk replacers is discussed.

INTRODUCTION

Interest in utilizing vegetable protein in milk substitutes for calves has increased as a result of the potential economy in calf raising and the increasing importance of milk protein for humans. The vast majority of investigations have utilized soybean protein due to its potential nutritional value and its abundance.

Numerous reports have indicated reduced performance of calves when fed milk replacers containing soya flour (1-4). However, chemical modification has resulted in good performance (5-7). Diarrhea has been reportedly increased in calves when soya flour was added to milk replacers (1,3,8), but some workers have not indicated this is a problem (2,4,6,7).