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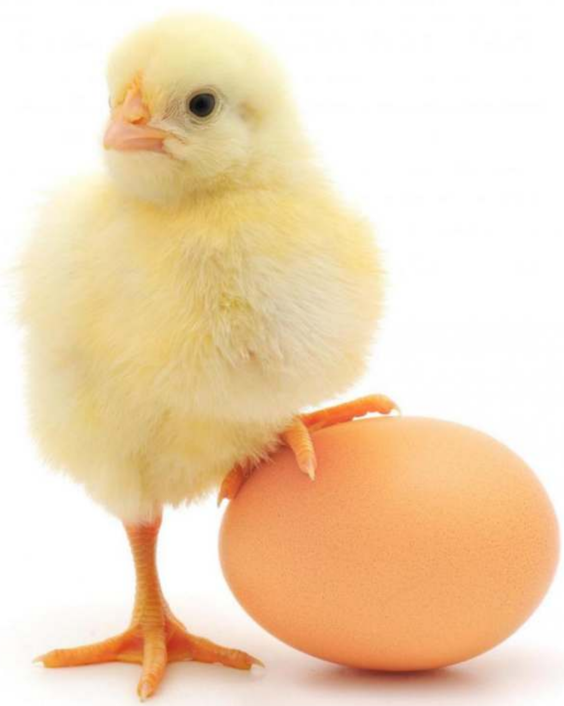

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Maximum Profit Feed Formulation. 4. Interaction Between Energy Content and Feed Form[1]

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Abstract: Empirical nutritional models were developed for comparison of the effects of two feed forms on responses to dietary energy using data from literature to formulate broiler diets by maximum profit feed formulation with real or simulated prices of corn and soybean meal. Broiler diets were formulated based on Corn and Soybean Meal (C-SBM) and or with Wheat and Cottonseed Meal (+W-CM) as alternatives sources. Estimated average body weight gain or feed intake slopes of birds fed mash feed were significantly greater than that of birds fed pelleted feed. The rate of gain per calorie of mash-fed birds was three times higher than that of pellet-fed birds and the rate of feed intake per calorie for pellet-fed birds was six times smaller than for mash-fed birds. The economic energy content in most cases was decreased by pelleted feed compared to mash feed at real or simulated prices. For real prices the energy reductions from mash feed to processed feed were from 3.254 to 3.015 kcal/g for diets based on C-SBM or from 3.2 to 2.961 kcal/g for diets based on +W-CM. These economic energy reductions were around 7% from real prices, up to 10% from simulated corn prices and up to 11% from simulated SBM prices. Broiler diets formulated with +W-CM decreased the economic energy content and increased the profitability compared to those based on C-SBM diets. These data indicate that broiler diets fed as pellets should be formulated with reduced economic energy content due to decreased rate of gain or feed intake per calorie compared to those at mash feed.

Key words: Temperature, feed forms, energy, profit

INTRODUCTION

The nature of response from birds fed pellet and mash diets to increased dietary energy may have different effect on body weight or feed intake per dietary calorie. Accurate quantifications of the predicted body weight and feed intake from energy or dietary nutrient density are essential for the maximum profit feed formulation. Thus interactions between the dietary energy content and feed forms must be considered to produce accurate economic broiler diets.

Conflicting results on the interaction between feed forms and energy have been reported. Whereas some studies have showed significant interactions (Pepper *et al.*, 1960; Reddy *et al.*, 1962; Auckland and Fulton, 1972; Pesti *et al.*, 1983; McNaughton and Reece, 1984; Leclercq and Escartin, 1987; Brickett *et al.*, 2007), others did not (Sell and Thompson, 1965; Yule, 1972; Scott, 2002; Greenwood *et al.*, 2004). It appears that when two energy levels are evaluated, the interaction is statistically not observed as seen in the latter studies. In general terms, there are marked patterns that describe interactions between feed forms and energy on performance. It seems that as the energy is increased, birds fed pelleted or crumbled diets show reduced gain or feed intake rate per calorie compared to those given mash. However, it appears that the rate of growth of birds fed pellet on responses of energy can be increased by adding carbohydrate sources (Leclercq and Escartin, 1987; Plavnik *et al.*, 1997) or decreased by adding fat (Combs, 1959; Pepper *et al.*, 1960; McNaughton and Reece, 1984). Moreover, this rate of growth can be increased by feeding marginal and increasing dietary protein or lysine compared to high or adequate and constant dietary protein as the energy is increased. It has been shown that marginal protein or lysine levels reduces the body weight in birds fed pellets compared to those birds fed mash (Jensen *et al.*, 1965; Bayley *et al.*, 1968). Even these increments of growth rates of birds fed pellets as energy is elevated by adding carbohydrates sources or increasing level of protein may be smaller than growth rates of birds fed mash.

The objectives of this study were to develop models for the comparison of two feed forms on responses to energy content using the maximum profit feed formulation when real or simulated price for corn and soybean meal were used.

MATERIALS AND METHODS

Slopes of growth rate and feed intake from feed forms: Data from literature were selected to quantify the growth rate and feed intake on responses of energy content in two feed forms (Table 1). It was intended to select data from literature that did not bias the real effect between feed form and energy. Data were selected from

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Table 1: Effect of feed forms and energy on performance from literature

P	E	ME (Kcal/g)	CP (%)	Lys/ME (%/kcal/g)	Fat/EE (%)	CF (%)	Age Days	Feed Forms	Body gain, g/d Mash	Body gain, g/d P or C	Feed intake (g/d) Mash	Feed intake (g/d) P or C
1*	3	2.457	22.4	0.481	0.0/1.9	5.5			20.3	22.5	66.4	63.4
		2.571	22.3	0.461	3.0/4.8	5.3			21.1	23.1	59.9	62.8
		2.675	21.6	0.425	0.0/2.5	4.5	0-56	M vs P	21.9	22.9	63.1	59.5
		2.776	21.5	0.412	3.0/5.4	4.4			22.8	23.3	58.7	59.8
		2.893	20.8	0.378	0.0/3.2	3.5			22.4	23.7	61.2	60.7
		2.981	20.8	0.370	3.0/6.0	3.4			23.0	23.9	59.5	59.1
2	1	2.849*	21.7	0.391*	0.0/3.1	3.7*			15.1	16.0	36.9	36.6
		2.896	22.5	0.408	2.5/5.4	3.8	0-36	M vs C	15.4	16.0	37.3	35.3
		2.943	23.3	0.424	5.0/7.7	3.9			15.6	16.1	36.2	34.3
3	1	2.896*	20.0	0.375*	0.0/3.2	3.6*		M vs C	17.7	20.5	53.7	56.4
		2.946	20.7	0.377	2.5/5.6	3.6	0-70	M vs P	18.7	19.9	53.8	53.8
		2.995	21.4	0.380	5.0/8.0	3.6			19.1	20.2	52.8	53.2
4	1	2.409	17.4*	0.406*	0.8/3.3	23.0*			6.4	9.5	29.7	29.2
		2.710	19.6	0.406	0.9/3.7	13.0	0-28	M vs P	8.1	9.1	26.3	27.1
		2.861	20.7	0.406	0.95/4.0	8.0			8.5	9.5	27.1	25.4
		3.011	21.8	0.406	1.0/4.2	3.0			9.5	10.0	24.9	25.4
5	1	2.866	17.9	0.363	0.9/3.3	4.2*			10.1	13.7	---	---
		2.979	18.6	0.366	1.5/4.1	3.6	0-14	M v sC	11.2	13.1	---	---
		3.090	19.3	0.366	2.1/4.9	3.1			11.7	13.0	---	---
		3.205	20.0	0.365	2.7/5.8	2.5			11.9	13.0	---	---
6	1	2.900	20.2	0.545*	1.0/4.9	5.2			21.0	23.3	39.5	41.1
		3.100	21.6	0.430	1.2/4.6	2.2	0-21	M vs C	23.0	24.5	42.5	42.7
		3.300	23.0	0.437	6.39.4	2.1			24.7	25.7	42.5	43.0
7	1	3.100	21.6	0.387	2.6/5.9	2.5*			29.8b	30.8ab	46.5	45.4
		3.150	21.5	0.381	3.9/7.1	2.5	0-28	M vs C	30.2b	31.7a	46.4	46.3
		3.200	21.4	0.375	5.0/8.1	2.4			31.0ab	30.6ab	46.7	44.8
8	1	2.519	16.6	0.356	2.8/4.6	22.8*			58.8	80.3	175.7	211.4
		2.834	18.6	0.356	3.2/5.2	12.8	14-28	M vs C	73.9	89.0	180.9	206.4
		3.149	20.7	0.356	3.5/5.8	2.8			88.4	94.7	178.5	192.9
9	1	2.328	22.0	0.512*	0.0/1.6	16.9*			19.4c	22.4c	40.3b	51.3a
		2.558	22.0	0.466	3.0/4.6	13.9	0-28	M vs C	22.1b	22.8bc	42.1ab	44.6b
		2.788	22.0	0.428	6.0/7.6	10.9			23.8a	23.5ab	43.0a	44.4b
		3.019	22.0	0.395	9.0/10.5	7.9			24.2a	23.8a	43.5a	43.2b
10	1	2.517	17.8	0.348	1.5/3.2	6.3*			41.9a	51.0d	120.2b	132.8d
		2.721	18.2	0.343	1.5/3.4	4.9	14-42	M vs P	46.0b	52.1d	120.7b	128.7c
		2.952	18.7	0.338	1.5/3.7	3.5			46.6b	53.2e	112.8a	118.5b
		3.139	19.6	0.332	1.5/4.0	2.1			48.7c	54.1e	112.2a	112.2a
11	1	2.800	20.0*	0.384*	0.4/3.1	3.6*			28.1	29.9	53.1a	57.2a
		3.000	20.8	0.384	2.5/5.1	2.9	0-28	M vs P	30.3	31.5	52.8a	56.9a
		3.200	22.3	0.397	6.9/9.1	2.7			32.2	34.1	53.3a	52.9b
12	1	2.800	18.5*	0.343*	0.4/3.2	3.8*			39.6	42.0	96.2	103.5
		3.000	19.4	0.338	1.7/4.5	3.2	0-56	M vs P	41.4	44.0	92.8	97.2
		3.200	20.7	0.332	5.9/7.4	3.1			43.5	44.8	90.3	93.5
13	1	2.650	16.6	0.328	3.7/6.0	5.1			60.3	70.2	134.2	156.3
		2.800	17.5	0.339	4.0/6.0	4.3	28-49	M vs P	63.2	72.3	133.5	152.8
		2.950	18.4	0.349	4.2/6.0	3.5			66.1	74.4	132.9	149.6
		3.100	19.4	0.361	4.5/6.0	2.7			69.0	76.4	132.4	146.7
14	1	2.900	18.0	0.345	1.0/3.5	3.8			50.4	58.1	123.1	138.1
		2.960	18.6	0.351	2.0/4.5	3.6	0-70	M vs P	51.3	58.2	124.7	140.3
		3.130	18.0	0.322	4.3/6.9	3.2			54.4	58.9	124.7	136.5
15	1	2.850	19.7	0.358	1.0/2.7	4.3*		M vs C	45.4	55.2	77.9	91.5
		3.000	19.8	0.375	2.94.8	3.5	0-34	M vs P	49.4	56.0	78.2	89.0
		3.150	20.7	0.396	5.1/7.1	2.8			50.1	55.3	75.9	86.1
16	1	2.858	18.4	---	0.0/2.8	5.5			61.7	80.1	142.0	167.6
		2.573	18.7	---	0.0/2.6	8.8			53.1	78.7	142.3	196.3
		2.967	18.5	---	4.5/6.3	5.0			69.4	78.3	161.6	168.6
		2.566	18.5	---	4.5/7.0	9.8	21-42	M vs P	58.9	82.4	150.7	181.8
		2.808	20.2	---	0.0/2.6	5.8			65.7	83.0	154.6	179.9
		2.574	20.3	---	0.0/2.4	8.9			57.6	78.7	144.6	189.6
		3.112	20.3	---	2.5/4.4	5.7			71.4	82.4	144.2	165.3
		2.773	20.3	---	4.5/7.0	9.9			62.0	65.4	145.1	172.0
14	18	Average	g/d					36.7	42.0	86.7	95.8	
				Proportions (%)					100.0	114.5	100.0	110.5

Table 1 Cont.

1. Arscott *et al.*, 1958. Data included 3 experiments. 2. Pepper *et al.*, 1960. 3. Pepper *et al.*, 1960, 0-70d, M vs C from 0-36d and M vs P from 37-70 d. ME and lysine of dried buttermilk from Guirguis, 1975. 4. Reddy *et al.*, 1962. The basal diet at 99% and tallow fat at 1% was combined with cellulose at 0, 5, 10 and 20%. The ME of basal diet had 3.39 as dry basis and ME of tallow was 6.56 as reported by Young, 1961. The 99% of basal diet and 1% tallow. This basal diet assumed 88% dry matter to be expressed as fed basis. The cellulose was considered as crude fiber. 5. Auckland and Fulton, 1972. 6. Pesti *et al.*, 1983. Average of male and female birds. 7. McNaughton and Reece, 1984. Data average of males and females. 8. Newcombe and Summers, 1985. Data obtained from equation published and feed intake for mash obtained from direct observation by increase the cellulose from 0, 10 and 20%. The cellulose was considered as crude fiber. 9. Shen *et al.*, 1985. The energy content, lysine or crude fat were calculated as the average of three types of diets which contain mainly corn, barley or alfalfa. The cellulose was replaced by fat at 0, 3, 6 or 9%. The cellulose was considered as crude fiber. 10. Leclercq and Escartin, 1987. The energy content, protein and lipids were calculated as the average for mash and pellet. 11. Bertechini *et al.*, 1991. 12. Bertichini *et al.*, 1991. 13. Plavnik *et al.*, 1997. 14. Leeson *et al.*, 1999. 15. Brickett *et al.*, 2007, 0-34d, M vs C for starter and grower and P for finisher diets. The authors did not publish the days for each feeding period. Thus nutrient contents reported were from grower diets. 16. Latshaw, 2008. The nutrient content reported were the average of mash and pellet diets. M = Mash, P = Pellet and C = Crumble. *Nutrients estimated from NRC (1994) data. EE = Ether Extracted values calculated from NRC (1994). P = Publications and E = Experiments; ME = Metabolizable Energy, CP = Crude Protein, Fat = inclusion of dietary fat, CF = Crude Fiber

experiments with 3 or more levels of energy because experiments with two dietary energy levels show variable results and pattern. Linear regression analysis was used to calculate the slopes of growth rate and feed intake as a function of energy content for each set of studies.

Calculation of profitability: Average daily weight gain or feed intake (A) at 49 days of age for male Cobb 500 (Cobb Vantress, 2008) (71.1 and 129.2 g/d), a fixed metabolizable energy (3.1 kcal/g) and average Slopes (S) for body weight or feed intake were used to calculate the Intercepts (I) of body weight gain and feed intake for mash form, according to the following equation:

$$I = A - S \times 3.1$$

Further Proportions (P) of processed feed/mash feed for body weight gain and feed intake (Table 1) were multiplied by average daily weight gain or feed intake in order to calculate the intercepts of body weight and feed intake for processed feed (crumble or pellet) in the following way:

$$I = A \times P - S \times 3.1$$

The predicted Body Weights (BW) or Feed Intakes (FI) were modeled by linear equations in function of Energy Content (E) according to the following form:

$$BW \text{ or } FI = I + S \times E$$

Two models, one for mash and one for processed feed were used to calculate the profitability according to the following equation:

$$\text{Profitability (\$/bird)} = BW \times M - FI \times C$$

Where, M is price of meat, $/kg and C is the cost of diet, $/kg; the BW and FI were multiplied by 49 and divided by 1000 to be expressed in kilograms.

The programming model: The two models were formulated using Solver, which is the default solver of Excel (Frontline Systems, Inc., 1999). It uses the generalized reduced gradient method to solve nonlinear problems. The options, which are specified by the user, were set as follows: iterations = 1000, precision = 0.000000001, convergence = 0.000001, estimates = tangent, derivatives = forward and search = Newton. The composition matrix of ingredients and nutrient needs is shown in Table 2.

Design of analysis: Two types of diets were formulated; one based on corn and soybean meal and one based on wheat and cottonseed meal as alternatives sources. The fixed maximum level for wheat was 40% and for cottonseed meal was 20% according to studies by Partridge and Wyatt (1995) and Watkins and Waldroup (1995) respectively. Prices of main feed ingredients from November, 2008 were used to formulate broiler diets and predict performance for each model. Further increments of corn or soybean meal prices at -25%, +25%, +50%, +75% or +100% from real prices were simulated to calculate the economic energy contents for each model.

Statistical analysis: The slopes of the linear regressions for body weight gain or feed intake for the two feed forms were compared by paired t-test. Linear regressions and comparisons by paired t-test were obtained using JMP Software (JMP, version 7).

RESULTS

Estimated slopes of body weight gain and feed intake for feed forms are shown in Table 3. There were significant differences among the slopes. The average body weight or feed intake slopes of birds fed mash were significantly higher compared to those of birds fed processed feed. The predicted body weight gain and feed intake in function of energy content from 2.8 to 3.3 kcal/g for feed forms are shown in Fig. 1.

Table 2: Composition matrix of ingredients and nutrient needs in the nonlinear programming models[1]

Ingredients	ME (Kcal/g)	CP (%)	Ca (%)	NPP (%)	Na (%)	Lys (%)	Met (%)	TSSA (%)	Thr (%)	Cost[2] $/kg	Min (%)	Max (%)
Corn	3.35	8.5	0.02	0.08	0.02	0.26	0.18	0.36	0.28	0.135	0	100
Soybean meal	2.44	48.5	0.27	0.22	0.02	2.96	0.67	1.39	1.81	0.267	0	100
Wheat	3.120	11.50	0.05	0.00	0.06	0.35	0.17	0.42	0.36	0.124	0	40
Cottonseed meal	2.135	44.7	0.15	0.37	0.00	1.79	0.72	1.49	1.44	0.250	0	20
Poultry oil	8.25	....	....	....	....	....	....	....	....	0.350	0	6
Limestone	....	....	38	....	....	....	....	....	....	0.034	0	100
Phosphorus	....	....	21	16	....	....	....	....	....	0.281	0	100
Common salt	....	....	....	....	39	....	....	....	....	0.061	0	100
Vitamin premix	....	....	....	....	....	....	....	....	....	3.700	0.1	0.1
Mineral premix	....	....	....	....	....	....	....	....	....	1.746	0.1	0.1
DL-Methionine	3.68	57.52	....	....	....	....	98	0.98	....	2.533	0	100
L-Lysine HCl	4.60	94.4	....	....	....	74.42	....	....	....	1.762	0	100
L-Threonine	3.150	73.5	....	....	....	....	....	....	99.00	3.500	0	100
ME[3]											2.6	3.4
Nutrient needs[4]	3.115	18.71	0.928	0.463	0.195	1.086	0.436	0.833	1.103			
Maximum		23.00	1.100		0.400							

[1]The nutritional composition for the ingredients was obtained from the NRC (1994).

[2]Reference prices for corn and soybean meal were obtained from the month of November of 2008 and wheat and cottonseed meal from Feedstuffs, Nov, 2008.

[3]The metabolizable energy (ME) represents the dietary nutrient density. The energy/nutrient ratio was kept constant during its variation. [4]Nutrient needs from average of 0-49d of Cobb 500, 2008 was used kept the energy/nutrient ratio. Live Weight Equivalent Price (LWP) was 1.092 $/kg calculated from the following equation: LWP = (Wholecarcass price - processing cost) x dressing percentage = (1.73-0.319) x 0.774. Wholecarcass price from November, 2008 USDA. ME = Metabolizable Energy, CP = Crude Protein, Ca = Calcium, NPP = Nonphytate Phosphorus, Na = Sodium, Lys = Total Lysine, Met = Total Methionine, TSSA = Total Sulfur Amino Acids, Thr = Threonine

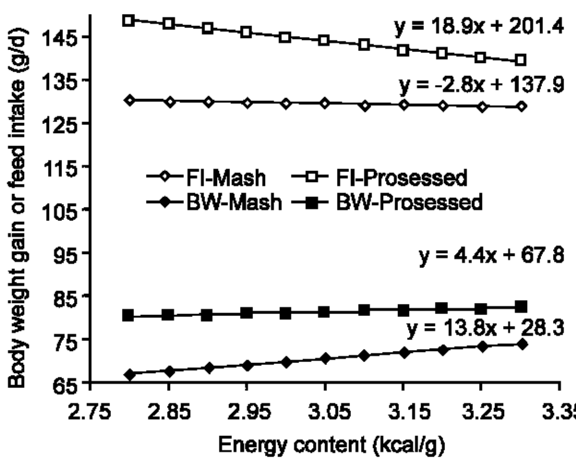

Fig. 1: Linear equations of Body Weight Gain (BW) and Feed Intake (FI) for feed forms

The economic energy contents or dietary nutrient density obtained in the maximum profit feed formulation at processed feed were approximately 7% lower than mash feed for both corn-soybean meal or wheat and cottonseed meal diets (Table 4). For instance, using processed feed the broiler diets had 239 kcal/kg or 1.4% less protein than did mash feed. Using the wheat and cottonseed meal diet reduced the dietary nutrient density and increased the profitability compared to corn and soybean meal diets. This reduction of nutrients was equivalent around 2% less. These broiler diets had 40% of wheat, the fixed maximum level, whereas the cottonseed meal was not taken due to the lower soybean meal price. As expected the profitability of processed feed was higher than did mash feed.

Extra broiler diets were formulated at fixed energy levels assuming no interaction between energy and feed forms on diets based with corn and soybean meal. For example if in the processed feed the energy content is increased from 3.015 to 3.254 kcal/g, the same economic energy at mash feed, the profitability is reduced from 2.9425 to 2.9005 $/bird, the diet cost is increased from 0.1972 to 0.2179 $/kg, the body weight is increased from 3.972 to 4.024 kg and the feed intake is reduced from 7.026 to 6.855 kg. Thus for processed feed the reduction of feed intake or increment of body weigh did not compensate for the high cost of 3.254 kcal/g diet.

Economic energy content variations related to changing the price of corn or soybean meal in corn-soybean meal or corn-soybean meal with alternative ingredients are shown in Table 5. The economic energy content was different as the corn or soybean meal prices changed. In general for processed feed the economic energy content was lower than for mash feed. This economic energy reduction was up to 10% for corn variation and up to 11% for SBM variation. In general as the corn price was increased, the economic energy content tended to decrease. The wheat was used at 40% replacing mainly corn as the corn price increased except at -25%. When the program allowed the inclusion of poultry oil, the economic energy content was elevated and then the

Table 3: Regression slopes (g gain or feed intake/kcal/g) of the effects of feed forms on responses to energy content or dietary nutrient density

	Gain		Feed intake	
P	Mash	Processed	Mash	Processed
1	4.9	2.6	-9.5	-7.4
2	5.1	1.5	-7.6	-24.1
3	13.7	-2.9	-9.1	-34.0
4	5.1	0.7	-7.3	-6.9
5	5.2	-2.0	---	---
6	9.3	6.2	7.7	4.8
7	12.1	-2.5	1.6	-6.8
8	47.0	22.8	4.5	-29.5
9	7.1	2.2	4.5	-10.6
10	10.0	5.0	-15.3	-34.4
11	10.3	10.4	0.4	-10.8
12	10.0	6.8	-14.9	-25.0
13	19.3	13.8	-3.8	-21.3
14	17.5	3.7	5.2	-10.5
15	15.6	0.3	-6.7	-18.1
16	28.3	2.5	8.2	-48.4
Average	13.8	4.4	-2.8	-18.9
Mean difference	-9.338		-16.06	
Standard error	1.988		3.760	
T-ratio	-4.763		-4.271	
Prob<t	0.0002		0.0004	

P = Publications. 1. Arscott *et al.*, 1958; 2. Pepper *et al.*, 1960, 0-36d; 3. Pepper *et al.*, 1960, 0-70d; 4. Reddy *et al.*, 1962; 5. Auckland and Fulton, 1972; 6. Pesti *et al.*, 1983; 7. McNaughton and Reece, 1984; 8. Newcombe and Summers, 1985; 9. Shen *et al.*, 1985; 10. Leclercq and Escartin, 1987; 11. Bertechini *et al.*, 1991, 0-28d; 12. Bertichini *et al.*, 1991, 0-56d; 13. Plavnik *et al.*, 1997; 14. Leeson *et al.*, 1999; 15. Brickett *et al.*, 2007; 16. Latshaw, 2008

Table 4: Performance of feed forms based on Corn and Soybean Meal (C-SBM) diets and Wheat (W)

	Feed forms			
	Mash		Processed feed	
Characteristics	C-SBM	+W	C-SBM	+W
Profitability ($/bird)	2.5422	2.5495	2.9425	2.9751
Diet cost ($/kg)	0.2179	0.2101	0.1972	0.1894
Body weight (kg)	3.587	3.550	3.972	3.961
Feed intake (kg)	6.311	6.318	7.026	7.126
ME (kcal/g)	3.254	3.200	3.015	2.961
Crude protein (%)	19.55	19.22	18.11	17.79
Lysine (%)	1.134	1.116	1.051	1.032
Met+Cys (%)	0.870	0.856	0.806	0.792
Threonine (%)	1.152	1.133	1.068	1.048
Nonphytate P (%)	0.484	0.476	0.448	0.440
Calcium (%)	0.969	0.953	0.898	0.882
Corn (%)	60.79	24.71	72.04	35.96
Wheat (%)	---	40.00	---	40.00
Soybean meal (%)	28.24	24.25	23.31	19.32
Poultry oil (%)	6.0	6.0	0.0	0.0
Ground limestone (%)	1.03	0.88	0.99	0.84
Calcium phosphate (%)	2.33	2.52	2.12	2.31
Sodium chloride (%)	0.48	0.43	0.44	0.39
L-Threonine (%)	0.48	0.49	0.44	0.46
L-Lysine HCl (%)	0.19	0.26	0.23	0.30
DL-Methionine (%)	0.26	0.27	0.23	0.23

Standard price, $/kg: corn (C) = 0.135, SBM = 0.267, Wheat (W) = 0.124. Live weight equivalent price = 1.092 $/kg

energy also tended to reduce as corn price increased. This reduction in some case was allowed at the expense of increments of protein, calcium or sodium sources due to the lack of bulkiness. Likewise, as the Soybean Meal (SBM) price was increased the economic energy content tended to decline. This reduction was more marked in mash feed than in processed feed. After +25% SBM price, the cottonseed meal was included at 19.7% for processed feed and 20% for mash feed.

DISCUSSION

The three times higher rate of gain per calorie in mash feed compared to processed feed may be a response of the compensation due to reduced body weight of birds fed mash and on the other hand, a response of the achievement of the maximum genetic potential of birds fed processed feed. These variations in genetic potential are subjected to nutritional effects. Thus it seems that this difference can be reduced from three to two times when constant dietary fat and increased carbohydrates are added as dietary energy is elevated (Leclercq and Escartin, 1987; Plavnik *et al.*, 1997) because growth per calorie rate is increased probably due to a good pellet quality. On the other hand, when the dietary energy is increased by adding fat, this difference of growth per calorie rate between mash and processed feed can be increased probably because the fat decreases the pellet quality and consequently reduces the growth per calorie. It has been shown that the body weight is reduced due to reduced pellet quality by adding fat (Richardson and Day, 1976; Plavnik *et al.*, 1997; Briggs *et al.*, 1999). Moreover, this difference can also be reduced when marginal protein or lysine levels are fed to birds fed pellets compared to those consuming mash (Jensen *et al.*, 1965; Bayley *et al.*, 1968). The increased rate of gain or feed intake per calorie at mash compared to processed feed could be accounted for by increased dietary density due to addition of fat observed in mash rather than pellets. Therefore, it appears that the high rate of feed intake per calorie may be a major part of the high rate of gain per calorie of birds fed mash compared to birds fed processed feed. However, this difference is not completely explained because the rate of feed intake per calorie is not three times the rate of gain per calorie. Thus it seems that birds fed processed feed regulate the feed intake in order to increase slightly the energy intake or body weight gain as dietary energy is increased.

It is interesting to note that by other methodology McKinney and Teeter (2004) suggested that pellets of 100% pellet quality have 187 kcal/kg more energy than mash. This indicates that for equal energy needs pellet diets should be formulated with 187 kcal/kg less energy than mash diets. A value that falls within the range of energy of mash minus pellet is proposed herein. Both models are based on predicted body weight as a

Table 5: Variations of corn and soybean meal prices in feed forms on economic energy contents of broiler diets

	Feed forms			
	Mash		Processed	
Price variation $/kg	C-SBM	+W,CM	C-SBM	+W,CM
Standard prices	3.254	3.200	3.015	2.961
Corn, -25%, 0.101	3.254	3.254[y]	3.015	3.015[y]
Corn, +25%, 0.169	3.254	3.200	2.964	2.876[2]
Corn, +50%, 0.203	3.254	3.200	3.213[z]	3.130[2,z]
Corn, +75%, 0.236	3.213	3.143	3.159[1,2]	3.075[1,2,3]
Corn, +100%, 0.270	3.213	3.143	3.140[1,2,3]	3.075[1,2,3]
SBM, -25%, 0.200	3.254	3.254[y]	2.964	2.895
SBM, +25%, 0.334	3.254	3.142[x]	3.015	2.904[x,o]
SBM, +50%, 0.401	3.254	3.142	3.015	----
SBM, +75%, 0.467	3.015[s]	2.917[o,s]	2.999[2]	----
SBM, +100%, 0.534	3.015	----	2.999[2]	----

Standard prices, $/kg: corn (C) = 0.135, soybean meal (SBM) = 0.267, wheat = 0.124, cottonseed meal = 0.250, poultry oil = 0.350. [1]Fixed maximum level: 23% of crude protein.
[2]Fixed maximum level: 1.1% of calcium.
[3]Fixed maximum fixed level: 0.4% of sodium.
[y]Only at this level the wheat (W) is not taken.
[x]After this SBM price, the Cottonseed Meal (CM) is taken 20% for mash and 19.7% for processed feed.
[o]After this SBM price, SBM is not taken.
[z]After this corn price, the poultry oil is taken until its maximum level, 6%.
[s]After this SBM price, the poultry oil is not taken

function of dietary energy. For example, the reductions of economic energy content of processed feed compared to mash were 239 kcal/kg from real prices, from 41 to 324 kcal/kg from simulated corn price and from 16 to 355 kcal/kg from simulated SBM price.

It appears that the linear equations presented in this study are suitable to demonstrate differences between two feed forms as energy is increased; however, accurate estimations of body weight or feed intake are needed by non linear equations (Pesti and Miller, 1997; Guevara, 2004; Eits *et al.*, 2005a,b; Cerrate and Waldroup, 2009). As the corn price was increased, the alternative energy sources were included and the economic energy contents were increased or decreased depending on the energy content of substitute sources such as poultry oil or wheat. Similarly, as the Soybean Meal (SBM) price was increased, the Cottonseed Meal (CM) was included and the economic energy content was slightly reduced due to the smaller metabolizable energy of CM compared to that of SBM.

The energy needs should be reconsidered in order to be used for least cost feed formulation due to marked difference of growth or feed intake slopes found in the two feed forms. Furthermore, the maximum profit feed formulation produces broiler diets with a wide range of economic energy content or dietary nutrient density according to feed ingredient prices or alternatives feed ingredients. In this study in most cases reduced economic energy contents at feed processed have been observed. The results of this study showed that the energy needs should be reconsidered for feed forms in order to be used in maximum profit feed formulation or even in least cost feed formulation. In general the use of processed feed reduced the economic energy content due to the decreased rate of gain or feed intake per calorie compared to those fed mash feed.

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