Prediction of Carcass Fat, Protein, and Energy Content from Carcass Dry Matter and Specific Gravity of Broilers[1]

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ABSTRACT : Three experiments were conducted to develop and test equations for predicting carcass composition. In the first study using 52 d-old Cobb × Cobb male broilers, twenty four carcasses were selected from 325 processed birds based upon visual appraisal for abdominal fat (low, medium, high) and assayed for specific gravity (SG), dry matter (DM), fat, protein, and ash. In experiment 2, 120 birds were fed rations containing 2 caloric densities (2,880 and 3,200 kcal ME_n/kg diet) and assayed as described above on weeks 2, 3, 4, 5, and 6. Carcass fat was elevated ($p < 0.05$) with increased caloric density. In both studies predictive variables were significantly correlated with chemically determined carcass fat, protein, and ash contents. Pooled across the 2 studies, data were used to form SG, DM, and/or age based equations for predicting carcass composition. Results were tested in experiment 3, where 576 birds reared to 49-d consumed either 2,880, 3,200, or 3,574 kcal ME_n/kg diet while exposed to constant 24℃ or cycling 24 to 35℃ ambient temperatures. Both dietary and environmental effects impacted ($p < 0.05$) carcass composition. The fat content analyzed chemically was enhanced from 12.4 to 15.7%, and predicted fat was also elevated from 13.4 to 14.8% with increasing caloric density. Heat distress reduced ($p < 0.05$) analyzed carcass protein (18.9 vs 18.3%) and predicted protein (18.2 vs 17.5%). Predicted equation values for carcass fat, protein, ash, and energy were correlated with the chemically analyzed values at $r = 0.96$, 0.77, 0.86, and 0.79, respectively. Results suggest that prediction equations based on DM and SG may be used to estimate carcass fat, protein, ash, and energy contents of broilers consuming diets that differ in caloric density (2,800 to 3,574 kcal ME_n/kg) and for broilers exposed to either constant (24℃) or cycling high (24 to 35℃) ambient temperatures during 49-d rearing period tested in the present study.

(Key Words : Broiler, Predictive Equation, Fat, Protein, Dry Matter, Specific Gravity)

INTRODUCTION

Increasing the lean yield of poultry products is one goal of the poultry industry as it strives to meet consumer interests. Efforts have been underway for years to reduce carcass fat through genetic, nutritional, and pharmacological techniques. However, meaningful progress for these areas requires rapid and economical methods for determining carcass composition. Current methods are both laborious and costly.

Specific gravity and dry matter content of carcasses have been used to estimate carcass and body composition of both mammalian species and poultry (Garrett, 1968; Jones et al., 1978; Chambers and Fortin, 1984; Lewis and Perry, 1991). These methods are based upon the premise that fat and nonfat (ash, protein) components have unique densities (Pearson et al., 1968). Specific gravity has been criticized as being impractical for poultry due to the potential for air entrapment in the internal carcass cavity and air sacs in many of the limb bones (Feduccia, 1975). Indeed, air entrapment is an important source of error (Garrett, 1968; Miles, 1976). Fortin and Chambers (1981) attempted to circumvent this problem by measuring specific gravity of individual parts to predict carcass fat, but they found no improvement suggesting that other errors may be involved. One additional source of error could be cellular hydration, since increased cellular hydration accompanies glycogen storage and would increase specific gravity.

The objectives of the studies reported herein were to evaluate the relationship between chemically determined whole carcass fat, protein, energy, and ash composition

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with whole carcass specific gravity and dry matter and age combinations, and further to propose and test resulting predictive equations under a variety of dietary and ambient temperature treatment regimes.

MATERIALS AND METHODS

Experiment 1

Cobb × Cobb male broilers were raised on rice hull litter and allowed to consume a 23% crude protein diet (table 1) composed of corn and soybean meal through 51-d posthatching. To assess the potential of carcass specific gravity and dry matter to predict carcass composition, twenty four carcasses were selected from 325 processed birds (52-d-old) based on visual appraisal of abdominal fat. Carcasses were selected to fall within three categories (low, medium, and high amounts), of abdominal fat to ensure that the range of carcass composition was large. Bird processing was accomplished by hanging the weighed birds on a rail, stunning, exsanquinating by severing the jugular and carotid veins, passing the carcass through a scalding vat, plucking by machine and hand eviscerating. Carcasses were weighed and chilled in ice water for 4 h. Following chilling, carcasses again were weighed and specific gravity was measured by dividing carcass weight in air with {carcass weight in air- (carcass weight in water/10)}. Immediately following specific gravity measurement, all broiler carcasses were placed in polypropylene freezer bags and frozen until analyzed. Carcasses were homogenized by the method of McDonald (1993) and analyzed for nitrogen, dry matter percentage, fat (ether extract), ash, and energy contents (AOAC, 1990).

Experiment 2

The second study was conducted to expand the data base of carcass specific gravity and dry matter and AOAC composition values such that predictive equations might be developed. One hundred twenty birds consumed rations containing two different caloric densities (table 1; 2,880 and 3,200 kcal ME_n/kg diet) and 12 birds fed each diet were processed on weeks 2, 3, 4, 5, and 6 so that dietary and age effects also could be appraised. With the exception of the chicks fed the two different diets and

Table 1. Diets used in experiments 1, 2, and 3 (% of diets)

Ingredients and analysis	Diets			
	23% CP	2,880 kcal ME_n/kg	3,200 kcal ME_n/kg	3,574 kcal ME_n/kg
Ground corn (8.8% CP)	56.05	60.49	52.10	50.53
Soybean meal (48.5% CP)	37.10	34.74	36.40	31.73
Animal fat	2.48	0.90	7.65	13.16
Dicalcium phosphate (22% Ca; 18.5% P)	2.42	1.60	1.58	2.13
Limestone (38% Ca)	0.93	1.25	1.25	1.34
Salt	0.40	0.41	0.41	0.41
Vitamin mix[1]	0.30	0.30	0.30	0.30
DL-methionine (99%)	0.22	0.21	0.21	0.21
Trace mineral mix[2]	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00
Calculated analisis				
ME (kcal ME_n/kg)	3,004	2,880	3,200	3,574
CP (g/kg)	23.00	20.57	20.64	19.85
Ca (%)	1.00	1.00	1.00	1.10
P, Available (%)	0.44	0.44	0.42	0.48
Na (%)	0.16	0.16	0.16	0.17
K (%)	1.00	1.00	1.01	1.02
Cl (%)	0.25	0.25	0.25	0.25

[1] The vitamin mix contained the following per kilogram of diet: vitamin A, 14,109 IU (retinyl acetate); cholicalciferol, 5,291 IU; vitamin E, 47.6 IU (dl-α-tocopheryl acetate); vitamin B_{12}, 0.014 mg; riboflavin, 8.82 mg; niacin, 26.5 mg; d-pantothenic acid, 28.2 mg; choline, 705.5 mg; menadione, 1.16 mg; folic acid, 1.176 mg; pyridoxine, 3.52 mg; thiamin, 3.52 mg; d-biotin, 0.176 mg.

[2] The mineral mix contained the following per kilogram of diet: Ca, 160 mg; Zn, 100 mg; Mn, 120 mg; Fe, 75 mg; Cu, 10 mg; I, 2.5 mg, Se, 0.15 mg.

processed at five different ages, all procedures were the same as described for experiment 1.

Experiment 3

The third experiment was conducted to evaluate prediction equations developed from experiments 1 and 2 in birds fed three caloric densities (2,880, 3,200, and 3,574 kcal ME_n/kg diet; table 1) and exposed to two ambient temperatures (24℃ or cycling 24 to 35℃). Birds were raised in rice hull-covered floor pens and fed a 23% corn and soybean meal-based diet through 21-d posthatching. On day 22, 576 birds were transferred and allotted randomly to 16 wire-floored battery compartments (82 × 61 × 38 cm) containing 6 birds each housed within a thermostatically (24℃ or cycling 24 to 35℃) controlled environmental chambers. The 6 treatment groups contained 16 replicates of six birds each in the normal and cyling high ambient temperatures and arranged in blocks such that chamber positions could be included in the analysis of variance. All birds were allowed to consume feed and water *ad libitum*. Maximum daily ambient temperature was increased 3.3℃/day during the first 3-d of the study for chicks housed within the 24 to 35℃ temperature. The ambient temperature cycled providing 6 h daily in excess of 32℃, 12 h of constant 24℃, and 6 h increasing or decreasing at a rate of 1.3 ℃/h. On Day 49, birds were weighed, slaughtered, and similar measurements were obtained as in experiment 1.

Statistical analysis

Standard statistical procedures (Steel and Torrie, 1980) were used to obtain the simple and multiple correlation coefficients as well as linear regression equations for predicting carcass fat, protein, ash, and energy. In experiments 2 and 3, an analysis of variance (ANOVA) was performed using the General Linear Model of SAS (1990). When a significant F statistic was detected, means were separated using Duncan's multiple range test.

RESULTS AND DISCUSSION

Experiment 1

Linear regression equations for predicting carcass fat, protein, ash, and energy along with R^2 and root mean square errors are presented in table 2. Correlations between analyzed and predicted carcass composition (table 3) produced R of 0.97, 0.80, 0.65, and 0.85 for carcass fat, protein, ash, and energy, respectively.

Experiment 2

Results of live weight, carcass weight, and laboratory assayed carcass fat, protein, ash, specific gravity, and energy for the five age groups combined are shown in table 4. Mean live weight increased ($p < 0.05$) from 343 to 2,387 g at 2 and 6 weeks of age, respectively. Carcass weight, percent dry matter, and fat had similar trends. Percent dry matter increased ($p < 0.05$) and specific gravity decreased through 4 weeks posthatching, presumably due to an increased ($p < 0.05$) fat content as reported by others (Kubena et al., 1974; Tzeng and

Table 2. Specific gravity, % dry matter, coefficient of determination (R^2), root mean square error (RMSE), and regression equations for the estimation of carcass fat, protein, ash, and energy in experiment 1

Variables	Intercept	Specific gravity[1]	% Dry matter	R^2	RMSE
Carcass fat	429.294	−398.566		0.93	1.558
	−30.887		1.28	0.97	1.077
	126.370	−137.904	0.894	0.98	0.910
Carcass protein	−76.346	90.389		0.79	0.717
	27.406		−0.272	0.77	0.748
	−40.194	59.281	−0.107	0.81	0.718
Carcass ash	5.764	−4.513		0.22	0.194
	0.246		0.023	0.39	0.184
	−14.043	12.530	0.058	0.48	0.180
Carcass energy	30.210	−23.025		0.87	0.134
	3.677		0.072	0.88	0.127
	15.494	−10.362	0.043	0.90	0.121

[1] Specific gravity = carcass wt. in air / {(carcass wt. in air - (carcass wt. in water/10)}.

Table 3. Analyzed and predicted carcass fat, protein, energy, and ash and correlation coefficients of analyzed and predicted variables in experiment 1

Variables	Analyzed	Predicted	Correlation coefficients
Carcass fat (%)	12.53 ± 4.40	12.33 ± 1.07	0.97
Carcass protein (%)	18.26 ± 1.30	18.20 ± 1.01	0.80
Carcass ash (%)	1.00 ± 0.24	1.02 ± 0.10	0.65
Carcass energy (kcal/g)	6.15 ± 0.26	6.12 ± 0.26	0.85

Table 4. Live weight, carcass weight, and carcass composition of the 2 to 6 week old broiler consuming two caloric density rations in experiment 2

Bird age	Diets	Live weight	Carcass weight	Carcass composition					
				DM	Fat	Protein	Ash	Specific gravity[1]	Energy
(wk)	(kcal/ME_n/kg)	(g)	(g)	(%)	········ (% of as is) ········				(kcal/g)
2	2,880	352[e]	193[e]	29.5[d]	8.78[cd]	17.8[b]	0.90[c]	1.056[ab]	5.96[ed]
	3,200	343[e]	170[e]	28.4[d]	7.34[d]	17.9[b]	0.91[e]	1.060[a]	5.80[e]
3	2,880	804[d]	498[d]	30.4[cd]	8.90[cd]	18.1[ab]	1.10[abc]	1.051[bc]	5.97[de]
	3,200	930[d]	591[d]	32.9[bc]	11.30[b]	18.4[ab]	1.40[a]	1.051[bc]	6.10[bcd]
4	2,880	1,474[c]	978[c]	32.0[bc]	9.61[bcd]	18.4[ab]	1.09[abc]	1.053[b]	5.90[de]
	3,200	1,461[c]	975[c]	36.0[a]	15.36[a]	17.8[ab]	1.32[ab]	1.047[c]	6.27[abc]
5	2,880	1,998[b]	1,356[b]	33.6[b]	11.82[b]	18.6[ab]	0.86[c]	1.046[c]	6.03[cde]
	3,200	2,115[b]	1,419[b]	36.2[a]	14.91[a]	17.8[b]	1.40[a]	1.040[d]	6.29[ab]
6	2,880	2,385[a]	1,691[a]	32.2[bc]	9.83[bcd]	18.9[a]	0.98[bc]	1.050[bc]	5.98[de]
	3,200	2,387[a]	1,692[a]	37.3[a]	15.87[a]	18.3[b]	1.42[a]	1.038[d]	6.49[a]

[a-e] Means within a column with no common superscripts differ significantly ($p < 0.05$).
[1] Specific gravity = carcass wt. in air / {carcass wt. in air - (carcass wt. in water/10)}.

Becker, 1981; Summers et al., 1992). Percent ash was low at week 2 compared to the older aged birds, while protein as a percent of wet carcass weight remained unchanged ($p > 0.1$) throughout the 6 week study.

An increased caloric density of the diet increased ($p < 0.05$) dry matter and specific gravity of bird carcasses at 4, 5, and 6 weeks of age, and is reflected by the higher ($p < 0.05$) fat content at each of these ages. Birds fed the higher caloric density had a 5, 4, and 8% increase ($p < 0.05$) in carcass energy at 4, 5, and 6 weeks of age, respectively. Caloric density had no significant effect ($p > 0.1$) on live body weight, carcass weight, or protein (%); in contrast other studies have observed increase in these components with weight (Jones and Wiseman, 1985; Bartov, 1987; Belay and Teeter, 1992).

Correlation coefficients between 2 component predicative equations (specific gravity and dry matter percentage) and analyzed carcass composition produced R of 0.98, 0.87, 0.67, and 0.85 for carcass fat, protein, ash, and energy, respectively, similar to experiment 1 (not shown). Regression equations for predicting carcass composition by specific gravity, percentage dry matter and/or age were pooled between experiments 1 and 2 and displayed in table 5.

Experiment 3

This study was conducted to evaluate accuracy of prediction equations derived from experiments 1 and 2 for broilers fed diets containing 3 caloric densities (2,800, 3,200, and 3,574 kcal ME_n/kg diet; table 1) while exposed to two ambient temperatures (24℃ or cycling 24 to 35℃). No interaction between caloric density and ambient temperature was detected for predicted or AOAC analyzed carcass percent fat, protein, dry matter, ash, and energy content, therefore, only the main effects of each will be discussed. Both diet and ambient temperature significantly altered carcass composition (tables 6 and 7). Carcass fat and energy averaged over ambient temperature

Table 5. Specific gravity, % dry matter, age, coefficient of determination (R^2), root mean square error (RMSE), and *regression equations for the estimation of carcass fat, protein, ash, and energy in experiments 1 and 2*

Variables	Intercept	Specific gravity[1]	% Dry matter	Age	R^2	RMSE
Carcass fat (%)	407.636	−377.735			0.87	1.989
	−23.610		1.060		0.96	1.096
	7.471			0.086	0.41	3.693
	74.192	−87.328	0.877		0.97	1.010
	83.977	−97.166	0.931	−0.028	0.97	0.905
Carcass protein (%)	−39.862	55.291			0.50	0.903
	22.377		−0.129		0.45	0.927
	17.784			0.008	0.14	1.028
	−26.996	44.086	−0.034		0.50	0.904
	−37.733	54.881	−0.093	0.030	0.69	0.757
Carcass ash (%)	10.951	−9.386			0.22	0.381
	−0.233		0.041		0.37	0.362
	1.009			0.002	0.10	0.389
	−16.325	14.369	0.072		0.42	0.356
	−15.568	13.608	0.076	−0.002	0.44	0.356
Carcass energy (kcal/g)	30.907	−23.666			0.74	0.200
	4.050		0.062		0.76	0.194
	5.842			0.005	0.35	0.280
	16.514	−11.131	0.038		0.78	0.186
	17.029	−11.648	0.041	−0.001	0.79	0.186

[1] Specific gravity = carcass wt. in air / {carcass wt. in air - (carcass wt. in water/10)}

Table 6. Caloric density effects on analyzed and predicted carcass fat, protein, and ash percentage in experiment 3

Variables	Diets (kcal ME_n/kg)		
	2,800	3,200	3,574
Analyzed fat (%)	12.41 ± 3.34[c]	14.41 ± 2.83[b]	15.74 ± 3.24[a]
Predicted fat (%)	13.41 ± 4.07[c]	14.62 ± 3.09[b]	16.79 ± 3.57[a]
Analyzed protein (%)	18.59 ± 1.82	18.45 ± 1.91	18.73 ± 2.06
Predicted protein (%)	17.89 ± 1.35	17.76 ± 1.31	17.62 ± 2.29
Analyzed ash (%)	1.02 ± 0.16	1.06 ± 0.17	1.06 ± 0.18
Predicted ash (%)	1.18 ± 0.31	1.28 ± 0.33	1.36 ± 0.34
Analyzed energy (kcal/g)	6.35 ± 0.22[b]	6.53 ± 0.19[b]	6.62 ± 0.20[a]
Predicted energy (kcal/g)	6.20 ± 0.23[b]	6.28 ± 0.20[b]	6.38 ± 0.20[a]

[a,b,c] Means within a row with no common superscripts differ significantly ($p < 0.05$).

increased ($p < 0.05$) from 12.4 to 15.7% and 6.35 to 6.62 kcal/g, respectively with increasing caloric density, while carcass protein and ash remained constant ($p > 0.1$). Heat distress reduced ($p < 0.05$) carcass protein but had no effect ($p > 0.1$) on carcass fat, energy, and ash.

Correlation coefficients between predicted based on SG and DM (%) and analyzed carcass compositions were 0.96, 077, 0.86, and 0.79 for carcass fat, protein, ash, and energy, respectively (figures 1-4). The correlations observed for carcass fat were high reflecting a strong capability to predict carcass fat and energy differences among the caloric densities. No differences ($p > 0.1$) were observed between analyzed or predictive carcass protein and ash along with increasing caloric density.

Table 7. Ambient temperature effects on analyzed and predicted carcass fat, protein, and ash percentage in experiment 3

Variables	Ambient temperature (℃)	
	24	24-35
Analyzed fat (%)	14.20±1.42	14.33±1.38
Predicted fat (%)	15.15±2.19	15.07±2.02
Analyzed protein (%)	18.90±1.90[a]	18.29±1.94[b]
Predicted protein (%)	18.18±2.01[a]	17.49±2.05[b]
Analyzed ash (%)	1.06±0.17	1.02±0.16
Predicted ash (%)	1.30±0.32	1.25±0.34
Analyzed energy (kcal/g)	6.48±0.21	6.52±0.21
Predicted energy (kcal/g)	6.28±0.22	6.30±0.22

[a,b] Means within a row with no common superscripts differ significantly ($p < 0.05$).

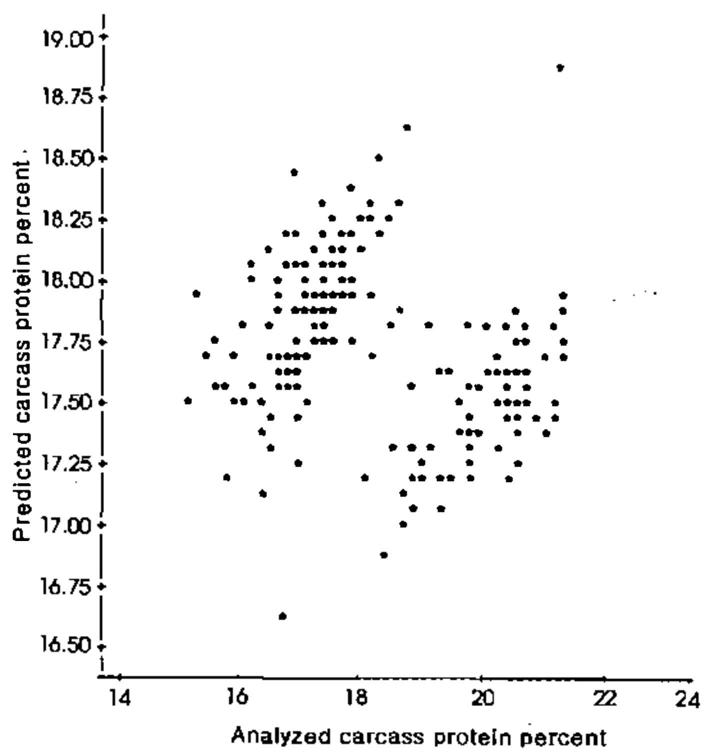

Figure 2. Analyzed and predicted carcass protein percentage in experiment 3 ($R = 0.77$).

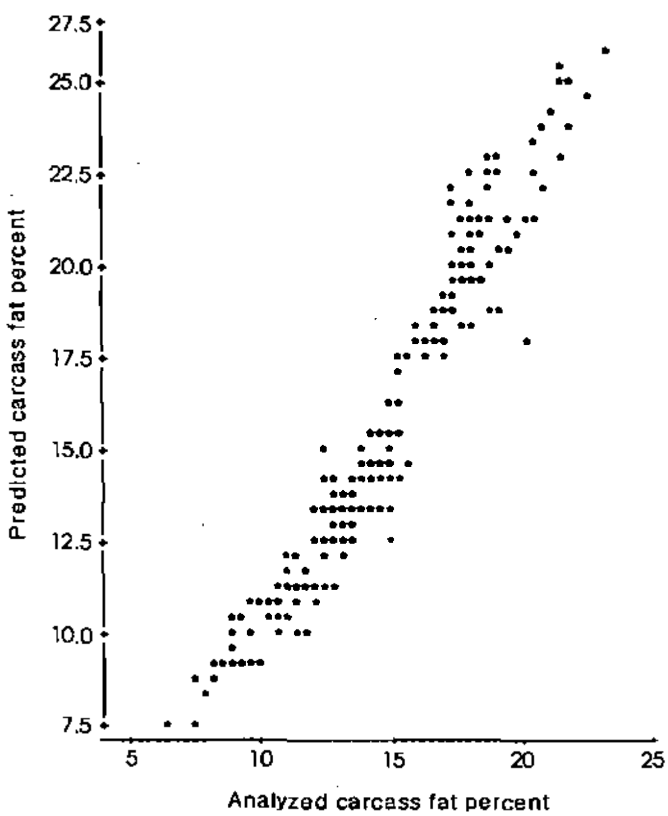

Figure 1. Analyzed and predicted carcass fat percentage in experiment 3 ($R = 0.96$).

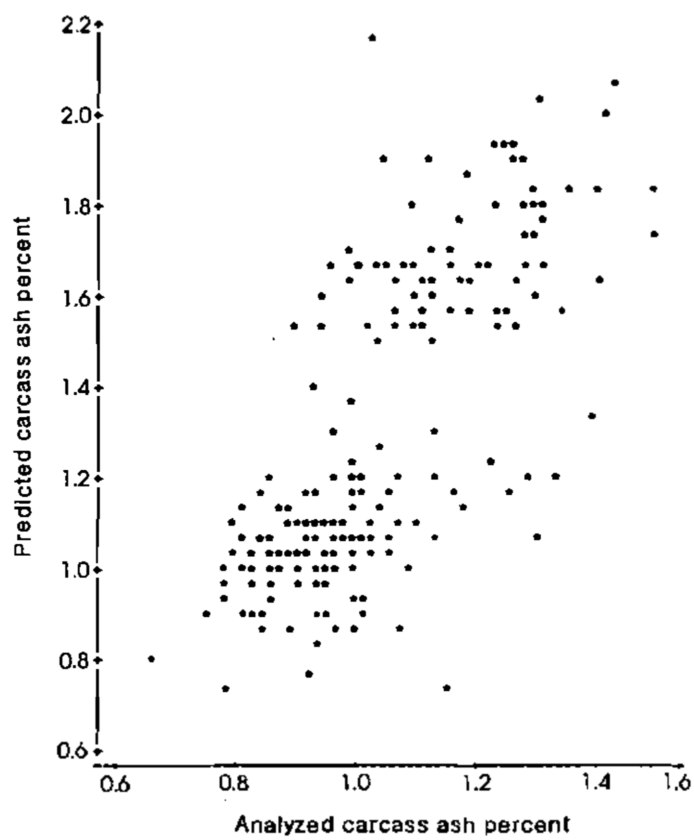

Figure 3. Analyzed and predicted carcass ash percentage in experiment 3 ($R = 0.86$).

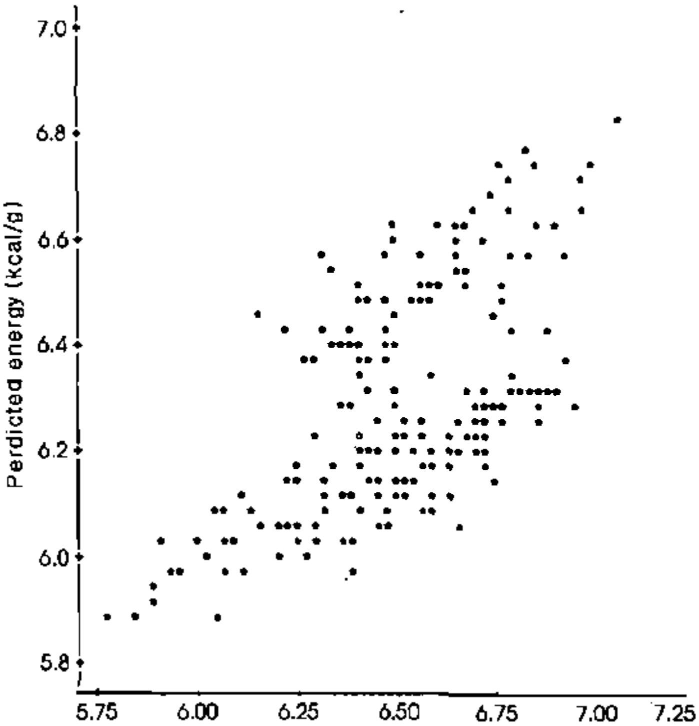

Figure 4. Analyzed and predicted carcass energy values in experiment 3 (R = 0.79).

However, heat distress reduced ($p < 0.05$) analyzed carcass protein (18.9 vs 18.3%) and predicted carcass protein (18.2 vs 17.5%) compared to birds housed within 24°C. In conclusion, the regression equations, obtained in experiments 1 and 2, for predicting carcass fat, energy, protein, and ash indicated strong correlations with AOAC determinations. The ability of prediction equations to separate treatment means, among birds housed in different thermal environments (constant to cycling high ambient temperatures) and fed diets ranging from 2,880 to 3,574 kcal ME/kg diet is encouraging.

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