Growth, Livability, and Feed Conversion of 1957 Versus 2001 Broilers When Fed Representative 1957 and 2001 Broiler Diets[1]

G. B. Havenstein,[2] P. R. Ferket, and M. A. Qureshi

Department of Poultry Science, North Carolina State University, Raleigh, North Carolina 27695

ABSTRACT Body weight, feed consumption, and mortality were measured in the 1957 Athens-Canadian Randombred Control (ACRBC) strain and in the 2001 Ross 308 strain of broilers when fed representative 1957 and 2001 diets. The dietary regimens were chosen to be representative of those used in the industry in 1957 vs. 2001. The 1957 diets were fed as mash, the 2001 starter was as crumbles, and the grower and finisher diets were pellets. Feed consumption and BW were recorded at 21, 42, 56, 70, and 84 d of age to cover the two broiler strains normal span of marketing ages.

Mortality was low, and the mortality of the ACRBC was approximately half that of the modern strain. Average BW for the ACRBC on the 1957 diets were 176, 539, 809, 1,117, and 1,430 g vs. 743, 2,672, 3,946, 4,808, and 5,520 g for the Ross 308 on the 2001 diets at 21, 42, 56, 70, and 84 d of age, respectively. The 42-d feed conversion (FC) on the 2001 and 1957 feeds for the Ross 308 were 1.62 and 1.92 with average BW of 2,672 and 2,126 g and for the ACRBC were 2.14 and 2.34 with average BW of 578 and 539 g, respectively. The Ross 308 broiler on the 2001 feed was estimated to have reached 1,815 g BW at 32 d of age with a FC of 1.47, whereas the ACRBC on the 1957 feed would not have reached that BW until 101 d of age with a FC of 4.42.

(*Key words*: broiler, body weight, livability, genetic change, feed conversion)

2003 Poultry Science 82:1500–1508

INTRODUCTION

A number of breeding companies have been in existence since the late 1940s to early 1950s that have specialized in applying quantitative genetics to the selection of chickens for meat consumption (Havenstein et al., 1994a). The geneticists employed by those companies have greatly increased growth rate and have reduced feed conversion (FC) and age to slaughter for commercial broilers. Those genetic changes, along with management and nutritional changes, combined with the application and efficiencies of vertical integration, ultimately led to the development of the modern broiler industry and its ability to produce poultry meat at about the same price today as it was being produced in the early 1950s. Improvements in genetics, poultry management, and vertical integration have caused broiler meat consumption in the United States to rise from about 4.0 kg in 1950 (Tarver, 1986) to over 31.8 kg (Perez et al., 1991) in 1990 and to nearly 40 kg (USDA, 2002) in 2000.

Some early geneticists had the foresight to develop random breeding populations using crosses of several of the early white-feathered broiler strains as the base population. One such randombred strain was the Athens-Canadian Randombred Control (ACRBC), which was established in 1957 by scientists at Agriculture Canada and which has been maintained for most of its existence at the Southern Regional Poultry Breeding Laboratory or at the University of Georgia Department of Poultry Science, Athens, GA (Merritt and Gowe, 1962; Merritt, 1966, 1968; Marks 1971a,b, 1979; Marks and Siegel, 1971; Gowe and Fairfull, 1990; Havenstein et al, 1994a). Fortunately, the ACRBC strain is still in existence, and it is an extremely valuable tool for measuring genetic change over time. Havenstein et al. (1994a) regressed the 56-d BW of the ACRBC on generations (using data provided by Henry Marks, University of Georgia, Athens, GA) and found that the regression was not significantly different than zero, indicating that the 56-d BW of the ACRBC was the same in 1957 as it was in 1991, when their study was conducted.

The objective of the present study was to compare the performance of the ACRBC and a popular 2001 broiler

Received for publication January 21, 2003.

Accepted for publication May 20, 2003.

[1]Salaries and research support provided by state and federal funds appropriated to the North Carolina State Agricultural Research Service, North Carolina State University. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service or criticism of products not mentioned.

[2]To whom correspondence should be addressed: Gerald_Havenstein@ncsu.edu.

Abbreviation Key: ACRBC = Athens Canadian Randombred Control; FC = Feed conversion.

strain, the Ross 308, when grown on representative 1957 and 2001 dietary regimens to determine changes in growth rate, FC by age, and mortality, as well as how genetics and nutrition have contributed to those changes. Companion papers report data on carcass and parts yield and immune response (Havenstein, et al., 2003; Cheema et al., 2003).

MATERIALS AND METHODS

Strains and Strain Management

Hatching eggs for the ACRBC strain were kindly provided by the University of Georgia, Athens, GA. The ACRBC eggs were set along with hatching eggs kindly provided by Allen's Hatchery, Liberty, NC, from a Ross 308 breeder flock. All chicks were hatched and grown at the North Carolina State University Poultry Educational Unit, Raleigh, NC. The chicks were hatched on November 28, 2001, and were sexed, neck-banded, and subsequently placed 21 birds per pen on top-dressed, used pine-shavings litter (2,120 cm^2 per bird). Due to a poor hatch of the ACRBC strain, only 21 chicks were placed per pen. Thus, the birds in the current study had approximately 635 cm^2/bird more space than was used in the Havenstein et al. (1994a) study. Each pen contained one bell-type hanging waterer and two tube-type feeders. Male exclusion grills were placed in all feeders to prevent the birds from getting into the feeders and scratching out the feed. Continuous light was provided for the first 3 d, and 23L:1D was provided thereafter. Brooder temperature was 32°C and was reduced 2.6°C/wk until an ambient temperature of 21°C was reached. Thereafter, the temperature of the facility was maintained as close as possible to an average of 21°C for the remainder of the study. Water and feed were supplied ad libitum. The 1957 starter diet was supplied from 0 to 42 d of age, and the 1957 grower was supplied from 43 to 84 d of age. For the 2001 dietary regimen, starter was supplied from 0 to 21 d of age, grower 1 from 22 to 35 d of age, grower 2 from 36 to 42 d of age, and the finisher feed was supplied from 57 to 84 d of age.

Diets Used

The assessment of the nutritional contribution to the improvement in broiler growth and efficiency was accomplished by placing half of the birds from each strain on dietary regimens that were thought to be typical of those being used in 1957 vs. state-of-the-art diets being used in 2001. The 1957 rations were minor modifications of those published by Titus (1961), who indicated they were typical of 1957. The 2001 rations are similar to those being used by North Carolina producers and to those being recommended for Ross broilers during 2001. Of course, no single ration or set of rations is typical of all rations that were being used at either of those points in time, but it is believed that these diets incorporated most of the major nutritional changes that have taken place between those two periods of time. Descriptions of all of the diets involved in the two dietary regimens are provided in Table 1, along with their laboratory analyses for protein, fat, fiber, and ash. Tables 2 and 3 provide the mineral and vitamin premixes and coccidiostats used.

Both dietary regimens were based on corn and soybean meal. The 2001 diets contained higher levels of soybean meal than did the 1957 diets (Table 1). The 1957 diets contained meat and bone meal, alfalfa meal, distiller's grains, dried whey, wheat middlings, and fish meal, which provided some of the vitamins that are supplemented in synthetic form in modern diets. The 2001 diets used poultry meal and poultry fat, which were not present in the 1957 diets.

The 2001 diets contained higher protein and energy levels than the 1957 diets (Table 1). The 2001 diets also contained more lysine, methionine, total sulfur amino acids, and fat but less Ca and P than did the 1957 diets. The 1957 diets were fed as mash, whereas the 2001 diets were fed as crumbles (starter) and pellets (growers and finisher).

The vitamin and trace mineral premixes used for the different diets are provided in Tables 2 and 3. The 2001 diets contained less vitamin A and cholecalciferol but more B_{12}, riboflavin, and niacin than did the 1957 diets. The 2001 diets also contained a number of other added vitamins (Table 3) and Se, which was not in the 1957 diets. The levels of Mn, Fe, Cu, I, and Co also differed between the two dietary regimens (Table 2), and the forms in which these trace minerals were added were also different. Zinc was added to the 2001 diets but not to the 1957 diets.

A change from the 1991 study (Havenstein et al., 1994a) was made, in that the starter for the 1957 diet was fed from 1 to 42 d of age, and the grower was fed thereafter. This is probably more typical of what was actually done in 1957, rather than having the starter diet fed for 3 wk only, as was done in the 1991 study. The 2001 dietary regimen consisted of a starter (d 0 to 21), grower 1 (2 kg/bird), grower 2 (2 kg/bird), and a finisher, which is different than the 0 to 21 d starter and single grower regimen used for the 1991 diet in the 1991 study. The 2001 dietary regimen is similar to many commercial broiler rations that were being fed in the United States during 2001. This change in dietary regimen might have had some effects on the outcome of the current study in comparison to what was observed for the 1991 study but is reflective of nutritional management changes that have taken place in the industry, and those effects will be included in the diet effects from the current study.

Other Experimental Procedures

The birds were placed into a 32-pen curtain-sided house (the same house used by Havenstein et al., 1994a,b) in a randomized block design using a factorial arrangement of two strains, two dietary regimens, and two sexes randomly assigned within each of four replicate blocks (i.e., eight pens per block). Warm-room brooding was accom-

TABLE 1. Diets used for the 1957 and 2001 broilers and feeds

Ingredient	1957 Broiler diets[1] Starter 1 to 35 d	1957 Broiler diets[1] Grow-finisher 36 to 84 d	2001 Broiler diets[2] Starter 1 to 21 d	2001 Broiler diets[2] Grower 1 22 to 35 d	2001 Broiler diets[2] Grower 2 36 to 42 d	2001 Broiler diets[2] Finisher 43 to 84 d
	(%)					
Corn	61.00	66.50	57.60	67.95	73.25	74.30
Soybean meal (48%)	23.80	13.30	30.00	23.05	17.90	16.80
Poultry meal	0	0	5.00	5.00	5.00	5.00
Poultry fat	0	0	4.00	1.80	1.84	2.20
Meat and bone meal (50% CP)	2.50	3.00	0	0	0	0
Fish meal	2.50	2.50	0	0	0	0
Alfalfa meal (17% CP)	2.50	3.00	0	0	0	0
Wheat middlings	0	10.00	0	0	0	0
Whey	2.50	0	0	0	0	0
Distillers dried grains	2.50	0	0	0	0	0
Dicalcium-P (18.5% P)	1.65	0.55	1.25	0.25	0	0
Limestone	0.70	0.70	1.00	0.65	0.68	0.42
Salt	0.30	0.35	0.40	0.43	0.42	0.44
Mineral premix[3]	0.05	0.05	0.20	0.20	0.20	0.20
Choline Cl (60%)	0	0	0.10	0.10	0.05	0.05
DL-Met	0	0	0.11	0.15	0.17	0.18
L-Lys HCl	0	0	0	0.07	0.14	0.06
2001 vitamins[4]	0	0	0.05	0.05	0.05	0.05
1957 vitamins[4]	0.05	0.05	0	0	0	0
Se premix[5]	0	0	0.10	0.10	0.10	0.10
Hy-D[6]	0	0	0.05	0.05	0.05	0.05
Natuphos[7]	0	0	0.05	0.05	0.05	0.05
Coban 60	0	0	0.05	0.05	0.05	0.05
Baciferm	0	0	0.05	0.05	0.05	0.05
Total	100.05	100.00	100.01	100.00	100.00	100.00
Calculated analysis						
ME (kcal/kg)	2,895	2,930	3,205	3,150	3,200	3,240
Crude protein, %	21.3	17.6	23.0	20.5	18.5	18.00
Lysine %	1.18	0.90	1.25	1.10	1.00	0.90
Met + Cys, %	0.75	0.65	0.91	0.87	0.84	0.80
Threonine, %	0.82	0.66	0.87	0.76	0.68	0.66
Calcium, %	1.35	1.20	0.90	0.55	0.50	0.40
NPP, %	0.61	0.44	0.42	0.23	0.18	0.17
Sodium, %	0.18	0.20	0.22	0.22	0.22	0.22
Laboratory analysis (%)						
Dry matter	89.2	89.8	89.2	89.1	88.7	89.3
Fat	2.8	3.0	7.1	5.1	5.4	5.3
Protein	23.7	19.2	24.8	22.2	20.9	19.8
Ph	0.97	0.55	0.79	0.39	0.42	0.35
Ash	6.5	5.3	6.5	4.9	4.7	4.4

[1]Amounts fed of 1957 diets: starter 2 kg, grower-finisher = remainder of test.

[2]Amounts fed of 2001 diets: starter = 1 kg; grower 1 = 2 kg; grower 2 = 2 kg; finisher = remainder of test.

[3]Trace mineral premixes for the two diets are given in Table 2.

[4]Vitamin premixes and coccidiostats for the two sets of diets are given in Table 3.

[5]Se premix supplied 0.2 mg Se from sodium selenite per kg of complete feed.

[6]Hy-D premix (Roche Vitamins, Inc., Parsippany, NJ) supplied 62.5 μg 25-hydroxy D_3/kg diet.

[7]Natuphos 10000G (BASF, Inc., Parsippany, NJ) supplied 600 phytase units/kg diet.

plished for the present experiment with two propane heaters mounted at the ceiling in each end of the building. The hot air from the heaters was directed into stirring fans aimed at the ceiling that mixed and distributed the warm air evenly into all of the pens. Temperatures at bird level with this system were maintained at ±0.6°C.

Mortality and the BW of all mortalities were recorded daily. All living birds were individually weighed, and the feed remaining for each pen was weighed back at 21, 42, 56, 70, and 84 d of age for the calculation of FC (kg of feed per kg of live weight). The FC was also calculated for total live plus dead weight, but is not reported because mortality was low and the results were similar.

Four birds from each pen were inoculated at 21d of age with SRBC as part of a companion study on immune function (Cheema et al., 2003). The four blocks (eight pens of each strain-sex-diet subgroup) were slaughtered at 43, 57, 71, and 85 d of age for the companion study on processing yield and other carcass measurements (Havenstein, et al. 2003).

Statistical Analysis

All data were analyzed using the general linear models procedure of SAS software (SAS Institute, 1996). When possible, the two- and three-way interactions were in-

TABLE 2. Trace mineral premixes for the two sets of diets[1]

Mineral	1957 Diets	2001 Diets
	(mg/kg of diet)	
Zn	—	120 ($ZnSO_4$)
MN	32 (MnO)	120($MNSO_4$)
Fe	20 (FeCO3)	80 ($FeSO_4$)
Cu	2.5 [$Cu(OH)_2$]	10 ($CuSO_4$)
I	1.2 (KI)	2.5 ($CaIO_3$)
Co	0.2 ($CoCO_3$)	1 ($CoSO_4$)

[1]Sources are given in parentheses.

cluded in the model for analyses of BW, mortality, and FC. At 84 d of age, the first three replicate blocks had already been slaughtered for the companion study (Havenstein et al., 2003) so only one pen per treatment was available, and therefore, only the main effects and one-way interactions of strain, sex, and diet could be included in the 84 d analysis. Percentage mortality data were transformed to arc sine to normalize frequency distribution before analysis. Mortality and FC figures from only one block of eight pens was available at 84 d so no analyses on those two data sets could be performed.

RESULTS AND DISCUSSION

Growth Rate

Body weights at 21, 42, 56, 70, and 84 d of age are summarized in Table 4. As in the Havenstein et al. (1994a) comparison of the 1991 Arbor Acres Broiler with the 1957 ACRBC when fed "typical" 1991 and 1957 diets, highly significant differences were observed in BW due to strain, sex, and diet at all ages. The strain by diet, strain by sex, and sex by diet interactions were significant ($P < 0.05$) at all ages except for the strain by sex interaction at 84 d of age. The three-way interaction was significant at 42, 56, 70, and 84 d of age. Growth rate of Ross 308 broilers was excellent, with the average of both sexes for the flock reaching 2,672 g at 42 d of age and 5,520 g at 84 d of age.

TABLE 3. Vitamin premixes and coccidiostats for the two sets of diets

Vitamin	1957 Diet	2001 Diet
	(per kg of diet)	
A, IU	8,818	6,600
Cholecalciferol, IU	3,300	2,000
E, IU	—	33
B_{12}, IU	11	19.8
Riboflavin, μg	4.17	6.6
Pantothenic acid, mg	11	—
D-Pantothentate, mg	—	11
Niacin, mg	35	55
Menadione, mg	—	2
Folic acid, mg	—	1.1
Thiamin, mg	—	2
Pyridoxine, mg	—	4
D-Biotin, μg	—	126
Se (Na_2SEO_3), mg	—	0.15
Ethoxyquin, mg	—	50
Nicarbazine, g	45	—

The ACRBC on the 1957 diet weighed only 539 g and 1,430 g at the same ages, which was very similar to the weights achieved at those ages (i.e., 508 g and 1,400 g) in the 1991 study reported in Havenstein et al. (1994a). Using the average of both sexes (Table 4), the BW of the Ross 308 birds on the 2001 diets were 4.22, 4.96, 4.88, 4.30, and 3.86 times heavier than those of the ACRBC birds on the 1957 diet at 21, 42, 56, 70, and 84 d of age, respectively. The Ross 308 birds on the 2001 diet were 3.81, 4.62, 4.45, 3.92, and 3.43 times larger than the ACRBC birds on the 2001 diets at the same ages. The Ross 308 birds on the 1957 diet were 3.47, 3.94, 3.69, 3.4, and 3.13 times heavier than the ACRBC birds on the 1957 diet.

Effects of Diet on Growth

The 2001 diet increased the BW of the ACRBC birds by 7.2 to 12.6% at the five ages measured (Table 4). In the 1991 study reported by Havenstein et al. (1994a), the 1991 diet increased the BW of the ACRBC by 20.1 to 23.5%. This difference between the two studies was a result of the ACRBC in the current study performing slightly better on the 1957 diet in the 2001 than in the 1991 study, and the ACRBC on the 2001 diet grew slightly less well in the current study than it did on the 1991 diet in the 1991 study. Although this result was unexpected, it may be a result of the attempt to eliminate feed wastage by the ACRBC strain in the current study by inserting male exclusion grills in the feeding area of the tube feeders to prevent birds from getting into the feeder and scratching the feed out into the litter. This was not done in the 1991 study. As reported by Havenstein et al. (1994a), a large amount of feed wastage occurred in the 1991 study due to the propensity of the ACRBC strain for getting into the feeders and scratching out the feed. The exclusion grills eliminated most of the feed wastage, and therefore, improved the accuracy of measuring the true FC for the ACRBC but might have also reduced their ability to get at and break down the 2001 pelleted feed. If so, this might have reduced the difference in performance between the control groups on the two diets in this study compared with the difference observed in the 1991 study.

For the Ross 308, the 2001 diet increased BW by 21.4, 25.7, 32.2, 25.1, and 23.2% over that observed with the 1957 diet at 21, 42, 56, 70, and 84 d of age, respectively (Table 4). In the 1991 study, the 1991 diet increased the performance of the Arbor Acres strain by 24.6, 20.2, 14.9, 12.3, and 7.6% respectively at the same ages. This apparent difference in relative BW response in the two studies of the modern bird at the different ages on the modern and old diets may be primarily related to the level of leg problems in the 1991 Arbor Acres in comparison to what was observed for the Ross 308 in the current study. As reported by Havenstein et al. (1994a), a large amount of tibial dischondroplasia was present in the Arbor Acres strain in the 1991 study. It was suggested that leg problems in that study, especially in the males on the 1991 feed, caused the difference between the strains on the two feeds to decline with increasing age. Although tibial

TABLE 4. Body weight by strain, diet, sex, and age

Strain[1]	Diet[2]	Sex	Age (d) 21	42	56	70	84
2001	2001	Male	791	2,903	4,402	5,385	5,958
2001	1957	Male	647	2,271	3,173	4,064	4,661
1957	2001	Male	210	641	1,009	1,412	1,907
1957	1957	Male	184	591	921	1,305	1,715
2001	2001	Female	695	2,441	3,490	4,231	5,083
2001	1957	Female	577	1,981	2,794	3,624	4,298
1957	2001	Female	180	515	762	1,039	1,316
1957	1957	Female	168	487	697	929	1,145
Averages							
2001	2001		743	2,672	3,946	4,808	5,520
2001	1957		612	2,126	2,984	3,844	4,480
1957	2001		195	578	886	1,226	1,611
1957	1957		176	539	809	1,117	1,430
Pooled SEM			7.2	18.0	31.4	43.3	82.5
Source of variation			Probability				
Block			0.70	0.017	0.138	0.004	NA[3]
Strain			0.0001	0.0001	0.0001	0.0001	0.0001
Diet			0.0001	0.0001	0.0001	0.0001	0.0001
Sex			0.0001	0.0001	0.0001	0.0001	0.0001
Strain × diet			0.0001	0.0001	0.0001	0.0001	0.0001
Strain × sex			0.0001	0.0001	0.0001	0.0001	0.74
Sex × diet			0.05	0.0001	0.0001	0.0001	0.024
Strain × sex × diet			0.53	0.003	0.0001	0.0001	0.037

[1]2001 = Ross 308 feather-sexable; 1957 = Athens-Canadian Randombred Control.

[2]2001 = broiler diet typical of those being fed in calendar year 2001; 1957 = broiler diet typical of those being fed in 1957 (adapted from Titus, 1961). The 1957 starter and grower diets were fed as mash, and the 2001 starter was fed as crumbles and the grower and finisher were fed as pellets. The 1957 starter was fed through 42 d of age, and the 2001 starter was fed through 21 d of age.

[3]NA = not applicable; data from only one block of eight pens available for analysis.

dyschondroplasia was not measured in the current study, and some leg problems and late mortality were observed in the Ross 308, the growth advantage provided by the modern diet in comparison to the 1957 diet did not decline much for the birds that survived to the later ages. This response might have been due to the addition of 25-hyrdoxycholecalciferol[3] and phytase[4] to the 2001 diets, which were not added to the 1991 diets. Mitchell et al. (1997) reported that addition of 5 μg 25-hyrdoxycholecalciferol decreased the incidence and severity of tibial dyschondroplasia. Similarly, Punna and Roland (2001) reported 600 phytase units (FTU)/kg Phytase from Natuphos significantly decreased the incidence of severe tibial dyschondroplasia scores.

Historical Growth Data for the ACRBC Strain

Havenstein et al. (1994a) provided a graphic illustration of the historical growth performance of the ACRBC and reported that the regression of BW on year from 1957 through 1991 was not significantly different from zero. Thus, the growth rate of the ACRBC strain was approximately the same in 1991 as in 1957. This finding was in agreement with previously published studies on the ACRBC line (Marks and Siegel, 1971; Marks, 1979). Although no data on the performance of the ACRBC strain have been reported since Havenstein et al. (1994a,b), the performance of the ACRBC strain reported herein is well within the range of historical performance reported in the previous study.

[3]Hy-D, Roche Vitamins, Inc., Parsippany, NJ.

[4]Natuphos, BASF, Inc., Parsippany, NJ.

Comparison with Previous Growth Rate Studies

Chambers et al. (1981) reported that 1978 broilers were approximately 2.3 times as large as the 1958 Ottawa Meat Control at 47 d of age. Marks (1979) reported changes in growth rate that were similar to those reported by Chambers et al. (1981). Sherwood (1977) published one of the first studies that attempted to examine the relative contributions that changes in genetics and nutrition have made on the growth rate of broilers when he compared the performance of the ACRBC strain and the 1976 Hubbard broiler when reared on 1953 and 1976 diets. He reported that the Hubbard broilers he used were 2.2 times heavier than the ACRBC at 56 d of age. In a similar study reported 15 yr later, Havenstein et al. (1994a) reported that 1991 Arbor Acres feather-sexable broilers when fed a representative 1991-type diet were 3.9 times as heavy as the ACRBC strain on a typical 1957 diet and 3.2 times as heavy as the ACRBC on a typical 1991 diet. Thus, it appeared that broiler growth rate had increased by approximately 73 g/yr during the 15 yr (1976 to 1991) between the Sherwood (1977) and Havenstein et al. (1994a) studies.

In the current study, the Ross 308 broiler on the 2001 feed at 56 d weighed 4.87 times as much as the ACRBC strain on the 1957 feed. The Ross 308 broiler was also 838 g heavier on the 2001 feed at 56 d of age in the current study than was the AA on the 1991 feed in the 1991 study (Havenstein et al., 1994a). If the Arbor Acres and the Ross 308 were truly representative of broilers being grown in 1991 and 2001, respectively, this 27% increase in BW indicates that broiler growth rate has increased by nearly 84 g per year from a combination of genetic and nutritional changes during the past 10 yr. As indicated earlier, due to a poor hatch for the ACRBC strain, only 21 broilers were placed per pen in this study versus 30 broilers in the Havenstein et al. (1994a) study, and so the extra space per bird may have contributed somewhat to the difference in BW observed between the modern and control birds in the two studies. The effects of this confounding cannot be evaluated or removed from the two studies. Assuming, however, that the birds in both studies had plenty of room to reach their full genetic potential, especially at 56 d, this increase in growth rate is even more rapid than was reported in the preceding years. That is, the Sherwood (1977) BW data showed an average increase of 58 g/yr from 1957 to 1976, and Havenstein et al. (1994a) estimated that BW had increased 73 g/yr from 1976 to 1991.

As discussed above under diet effects, the difference in performance between the ACRBC groups on the old and modern diets in the current study, and in the 1991 study, make it difficult to interpret how much changes in diet have contributed to the overall performance change. The data of Sherwood (1977) and Havenstein et al. (1994a) indicated that about 85 to 90% of the increase in broiler BW has come about due to the genetic selection that has been applied by commercial breeding companies. Observation of the birds from the current study, even though no direct measurements of leg problems were made, indicated that far fewer leg problems were present in the current than in the Havenstein et al. (1994a,b) study and led to the conclusion that the absence of such problems resulted in better performance at the later ages in the current study, especially for the males. Reductions in leg problems could, of course, be due to genetic changes brought about by either within or between strain selection or due to some of the dietary changes that have been made in the years between the two studies. The change from inorganic to several organic and more digestible sources of minerals, addition of 25-hydroxy D_3, and addition of phytase, as used in the 2001 diet, which improves mineral absorption, might have contributed to this improvement (Simons et al., 1990; Swick and Ivey, 1990; Hoppe and Schwarz, 1993; Mitchell et al., 1997).

The current study shows that the 2001 diet increased the growth performance of the Ross 308 by 21 to 32% for the various ages measured over that observed with the 1957 diet. The relative difference in BW between the Ross 308 broiler on the 2001 diet versus the Ross 308 on the 1957 diet indicated that the change in diet increased growth rate by 10.8, 7.4, 9.7, 9.6, and 12% at the five ages measured. This is in good agreement with the reports by Sherwood (1977) and Havenstein et al. (1994a) that 10 to 15% of the growth rate increases for broilers has been contributed by improvements in nutrition.

Mortality and Comparison with Previous Study

Cumulative mortality figures for each strain, sex, diet, and age group are provided in Table 5. Mortality in general was quite low during the early part of the experiment, with cumulative mortalities of only 1.78% for the ACRBC on the 1957 diet and 3.57% for the Ross 308 through 42 d of age. Mortality rates were approximately half those reported by Havenstein et al. (1994a) in the similar 1991 study. None of the strain, diet, sex, or interaction effects were significant at any age from 21 through 70 d. Mortality did increase considerably in the Ross 308 males at 56 through 84 d and in the Ross females at 84 d of age, but due to the limited numbers of birds used, the only significant effect was for strain ($P = 0.029$) at 84 d of age. Because livability as a trait has very low heritability (e.g., see Kinney, 1969), it is assumed that the large decrease in mortality rate between the current and the 1991 study was primarily due to improvements made in brooding management within the test facility during the past 10 yr. Some of the difference may be due to the use of different "modern" strains in the current and Havenstein et al. (1994a) study, but the fact that the mortality in the ACRBC strain in the current study decreased by approximately half at the same time that the mortality of the modern strain decreased by approximately half leads us to conclude that most of the change in mortality for the modern strains in the two studies was probably due to an improved growing environment. Most of the late mortality that did occur in the Ross 308 line in the current study was due to leg-associated problems. However, specific measurements of tibial dyschondroplasia were not made in the present study, as they were in the Havenstein et al. (1994a) study, due to budgetary restrictions.

Feed Conversion

Cumulative FC data are summarized by strain, sex, diet, and age in Table 6. Strain, diet, and sex effects were present ($P < 0.01$) except at 84 d of age when, due to the limited data available, they only approached significance. None of the interaction effects were significant except for the strain × diet interactions at 21and 42 d of age. In both of those cases, the difference in FC between diets was much larger in the modern strain than in the control strain. At d 21, the ACRBC males on the 1957 diet unexpectedly had better FC than the ACRBC males on the 2001 diets. This finding also contributed to the significant

TABLE 5. Cumulative mortality and mortality by period for each strain, diet, sex, and age group

			Age (d)				
Strain[1]	Diet[2]	Sex	21	42	56	70	84
			(birds on which mortality/period is based)[3]				
2001	2001	Male	84	83	60	39	19
2001	1957	Male	84	84	62	40	19
1957	2001	Male	84	82	61	40	21
1957	1957	Male	84	83	62	41	20
2001	2001	Female	84	83	61	40	19
2001	1957	Female	84	81	60	40	20
1957	2001	Female	84	83	61	42	21
1957	1957	Female	84	83	61	40	21
			(% cumulative mortality)				
2001	2001	Male	2.38	4.76	11.11	7.14	14.29
2001	1957	Male	1.19	3.57	6.35	4.76	14.29
1957	2001	Male	2.38	2.38	3.17	4.76	0
1957	1957	Male	1.19	1.19	1.58	2.38	4.76
2001	2001	Female	1.19	2.38	3.17	4.76	14.29
2001	1957	Female	3.57	3.57	3.17	2.38	4.76
1957	2001	Female	1.19	2.38	1.59	0	0
1957	1957	Female	1.19	2.38	3.17	4.76	0
Averages							
2001	2001		1.78	3.57	8.92	5.95	14.29
2001	1957		2.38	3.57	4.76	3.57	9.52
1957	2001		1.78	2.38	3.17	2.38	0
1957	1957		1.19	1.78	4.75	3.57	2.38
Pooled SEM							
Source of variation[4]			Probability				
Strain			0.534	0.231	0.107	0.472	0.029
Diet			0.534	0.907	0.765	0.898	0.500
Sex			0.721	0.907	0.276	0.472	0.086
Strain × diet			0.378	0.666	0.765	0.472	0.086
Strain × sex			0.534	0.507	0.276	0.898	0.502
Sex × diet			0.534	0.507	0.391	0.472	0.086
Strain × sex × diet			0.721	0.457	0.702	0.701	NA[5]

[1]2001 = Ross 308 feather-sexable; 1957 = Athens-Canadian Randombred Control.

[2]2001 = broiler diet typical of those being fed in calendar year 2001; 1957 = broiler diet typical of those being fed in 1957 (adapted from Titus, 1961). The 1957 starter and grower diets were fed as mash, and the 2001 starter was fed as crumbles and the grower and finisher were fed as pellets.

[3]One pen from each group was exsanguinated at 43, 57, 71, and 85 d of age to gather processing information. Therefore, mortality during the subsequent periods was based on the number alive in the remaining pens at the start of each period.

[4]Block effects were not significant, so they were not included in the analysis. Probabilities are reported on the analysis of the arc sin percentage data.

[5]NA = not applicable; data from only one block of eight pens available for analysis.

strain × sex interaction. All subsequent ages performed as expected for the ACRBC strain.

The FC (average of both sexes) for the Ross 308 was 1.63 at 42 d of age with a BW of 2,672 g (Tables 4 and 6). By using the 21 and 42 d BW and FC, one can estimate that the Ross 308 strain reached 1,815 g at approximately 32 d of age on a FC of approximately 1.46. In contrast, 10 yr earlier, the Arbor Acres used in the 1991 study (Havenstein et al., 1994a) reached 1,815 g at approximately 37 d of age on a feed conversion of approximately 1.92. The FC of the ACRBC strain on the 1957 diet was 2.34 at 42 d of age, which was considerably better than the FC of 3.00 reported for the same group by Havenstein et al. (1994a). As was noted in that study, excessive feed wastage occurred in the ACRBC pens and was believed to be the primary cause of the inflated FC figures. Assuming that the efforts to curb feed wastage in the current study were successful and, therefore, that the FC figures and BW for the ACRBC strain on the 1957 diet herein are reasonable for the strain, it then appears that one could predict that it would have taken the ACRBC strain about 17 additional d (i.e., to 101 d) to reach 1,815 g BW and that FC at that weight would have been approximately 4.42. Sherwood (1977) predicted that it would have taken 103 d for the ACRBC strain to reach 1,815 g BW. The current estimate assumes that the BW and FC changes during the 70-to-84-d period would have continued at the same rate for the next 2 to 3 wk. Thus, genetics, nutrition, and other management changes over the last 44 yr have resulted in 2001 broilers that require approximately one-third the time (32 vs. 101 d) and a threefold decrease in the amount of feed consumed to produce a 1,815 g broiler.

In conclusion, genetics, nutrition and other management changes over the last 44 yr have resulted in a 2001 broiler that required approximately one-third the time

TABLE 6. Cumulative feed conversion and by period for each strain, diet, sex, and age group

Strain[1]	Diet[2]	Sex	Age (d) 0 to 21	0 to 42	0 to 56	0 to 70	0 to 84
			(g:g)				
2001	2001	Male	1.31	1.58	1.94	2.08	2.68
2001	1957	Male	1.48	1.88	2.28	2.46	3.26
1957	2001	Male	1.78	2.05	2.23	2.88	2.95
1957	1957	Male	1.72	2.28	2.37	3.13	3.57
2001	2001	Female	1.32	1.67	1.98	2.41	2.76
2001	1957	Female	1.58	1.96	2.43	2.78	3.32
1957	2001	Female	1.86	2.23	2.48	3.24	3.69
1957	1957	Female	1.90	2.40	2.70	3.58	4.11
Averages							
2001	2001	$\bar{x}$	1.32	1.63	1.96	2.26	2.72
2001	1957	$\bar{x}$	1.53	1.92	2.35	2.62	3.29
1957	2001	$\bar{x}$	1.82	2.14	2.35	3.06	3.32
1957	1957	$\bar{x}$	1.81	2.34	2.54	3.36	3.84
Pooled SEM			0.056	0.032	0.058	0.052	0.045
Source of variation			Probability				
Block			0.8649	0.0264	0.2693	0.2898	NA[3]
Strain			0.0001	0.0001	0.0001	0.0001	0.0502
Diet			0.0154	0.0001	0.0001	0.0001	0.0524
Sex			0.0323	0.0001	0.0001	0.0001	0.0792
Strain × diet			0.0094	0.0455	0.0944	0.3169	0.6772
Strain × sex			0.3263	0.1764	0.0453	0.3460	0.1014
Sex × diet			0.2709	0.4107	0.7668	0.5222	0.4365
Strain × sex × diet			0.9258	0.5448	0.7074	0.5222	NA

[1]2001 = Ross 308 feather-sexable; 1957 = Athens-Canadian Randombred Control.

[2]2001 = broiler diet similar to those being fed in calendar year 2001; 1957 = broiler diet typical of those being fed in 1957 (adapted from Titus, 1961). The 1957 starter and grower diets were fed as mash, and the 2001 starter was fed as crumbles and the grower and finisher were fed as pellets. The 1957 starter was fed through 42 d of age, and the 2001 starter was fed through 21 d of age.

[3]NA = not applicable, data from only one block of eight pens available for analysis.

(32 vs. 101 d) and over a threefold decrease in the amount of feed consumed (estimated FC of 1.47 vs. 4.42) to produce an 1,815-g broiler. Assuming the use of the Arbor Acres strain in the Havenstein et al. (1994a) study and the use of the Ross 308 in the current study were representative of the commercial broilers being grown at those two periods, the difference in growth between the modern strains in the two studies in relation to the growth of the ACRBC strain led to the conclusion that broiler growth rate has continued to increase at least at the same rate, and possibly faster during the past 10 yr than reported earlier, and that within and between strain selection is the primary contributor to this change in performance. Mortality was approximately twice as much in the modern strain in the current study as it was in the ACRBC strain, but is still at a modest level at normal market ages (ACRBC = 1.78%; Ross 308 = 3.57% at 42 d of age).

The data in the current study, in agreement with the studies of Sherwood (1977) and Havenstein et al. (1994a), indicate that genetic selection brought about by commercial breeding companies has brought about 85 to 90% of the change that has occurred in broiler growth rate over the past 45 yr. Nutrition has provided 10 to 15% of the change.

REFERENCES

Chambers, J. R., J. S. Gavora, and A. Fortin. 1981. Genetic changes in meat-type chickens in the past twenty years. Can. J. Anim. Sci. 61:555–563.

Cheema, M., M. A. Qureshi, and G. B. Havenstein. 2003. A comparison of the immune response of a 2001 commercial broiler with a 1957 randombred broiler strain when fed representative 1957 and 2001 broiler diets. Poult. Sci. 82:1519–1529.

Gowe, R. S., and R. W. Fairfull. 1990. Genetic controls in selection. Pages 935–954, in Poultry Breeding and Genetics. R. D. Crawford, ed. Animal and Veterinary Sciences 22. Elsevier Science Publishing, New York.

Havenstein, G. B., P. R. Ferket, and M. A. Qureshi. 2003. Carcass composition and yield of 1957 versus 2001 broilers when fed "typical" 1957 and 2001 broiler diets. Poult. Sci. 82:1509–1518.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson. 1994a. Growth, livability and feed conversion of 1991 vs 1957 broilers when fed "typical" 1957 and 1991 broiler diets. Poult. Sci. 73:1785–1794.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson. 1994b. Carcass composition and yield of 1991 vs 1957 broilers when fed "typical" 1957 and 1991 diets. Poult. Sci. 73:1795–1804.

Hoppe, P. P., and G. Schwarz. 1993. Experimental approaches to establish the phosphorus equivalency of *Aspergillus niger*-phytase in pigs. Pages 187–192 in Proceedings of the 1st Symposium, Enzymes in Animal Nutrition. C. Wenk and M. Boessinger, ed. ETH, Zurich, Switzerland.

Kinney, T. B., Jr. 1969. A summary of reported estimates of heritabilities and of genetic and phenotypic correlations for traits of chickens. Agric. Handbook No. 363, ARS/USDA.

Marks, H. L. 1971a. Evaluation of the Athens-Canadian randombred population. Poult. Sci. 50:1505–1507.

Marks, H. L. 1971b. Evaluation of the Athens-Canadian randombred population. 2. Comparison with parental population. Poult. Sci. 50:1507–1509.

Marks, H. L. 1979. Growth rate and feed intake of selected and non-selected broilers. Growth 43:80–90.

Marks, H. L., and P. B. Siegel. 1971. Evaluation of the Athens-Canadian randombred population. 1. Time trends at two locations. Poult. Sci. 50:1405–1411.

Merritt, E. S. 1966. Estimates by sex of genetic parameters for body weight and skeletal dimensions in a randombred strain of meat type fowl. Poult. Sci. 45:118–125.

Merritt, E. S. 1968. Genetic parameter estimates for growth and reproductive traits in a randombred control strain of meat type fowl. Poult. Sci. 47:190–199.

Merritt, E. S., and R. S. Gowe. 1962. Development and genetic properties of a control strain of meat-type fowl. Pages 66–70 in Proc. 12th World's Poultry Congress, Sydney.

Mitchell, R. D., H. M. Edwards, Jr., and G. R. McDaniel. 1997. The effects of ultraviolet light and cholecalciferol and its metabolites on the development of leg abnormalities in chickens genetically selected for a high and low incidence of tibial dyschondroplasia. Poult. Sci. 76:346–354.

Perez, A. M., M. R. Weimer, and S. Cromer. 1991. Page 110 in U. S. Egg and Poultry Statistical Series, 1960–90. United States Department of Agriculture, Economic Research Service, Station Bulletin 833, Washington, DC.

Punna, S., and D. A. Roland, Sr. 2001. Influence of dietary phytase supplementation on incidence and severity in broilers divergently selected for tibial dyschondroplasia. Poult. Sci., 80:735–740.

SAS Institute. 1996. SAS/STAT8 User's Guide: Statistics. SAS Institute Inc., Cary, NC.

Sherwood, D. H. 1977. Modern broiler feeds and strains: What two decades of improvement have done. Feedstuffs 49:70.

Simons, P. C. M., H. A. J. Versteegh, A. W. Jongbloed, P. A. Keeme, P. Slump, K. D. Bos, M. G. E. Wolters, R. F. Beudeker, and G. J. Verschoor. 1990. Improvement of phosphorus availability by microbial phytase in broilers and pigs. Br. J. Nutr. 64:525–540.

Swick, R. A., and F. J. Ivey. 1990. Effect of dietary phytase addition on broiler performance in phosphorus deficient diets. Poult. Sci. 69(Suppl. 1):133. (Abstr.)

Tarver, F. R., Jr. 1986. Pages 20–22 in Poultry and egg marketing. National Food Review. United States Department of Agriculture, Economic Research Service, Washington, DC.

Titus, H. W. 1961. Pages 20–22 in The Scientific Feeding of Chickens. 4th ed. The Interstate Printers and Pub, Danville, IL.

USDA. 2002. United States Department of Agriculture, Economic Research Service, Washington, DC. http://www.ers.usda.gov/. Accessed Aug. 2002.