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Comparative Response of Different Broiler Genotypes to Dietary Nutrient Levels

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COMPARATIVE RESPONSE OF DIFFERENT BROILER GENOTYPES TO DIETARY NUTRIENT LEVELS

COMPARATIVE RESPONSE OF DIFFERENT BROILER GENOTYPES TO DIETARY NUTRIENT LEVELS

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ABSTRACT

Three studies were conducted to evaluate how the broiler has changed over the years due to intense genetic selection. Four different broiler genotypes, one unselected since the 1950's (HER) representing the old meat-type bird and three current strains (Ross 308, Ross 708, and a test product (TY)) were studied. Differences in growth, morphometry, and response in performance and processing yield to different nutrient levels were studied.

Experiment 1 evaluated growth and morphometric analysis. Birds of each strain were killed weekly from day 7 to day 56, necropsied and cut up parts and organs weighed. Measurement of small intestine segments was also done. Results show that current strains have significantly increased body weight (BW) and muscle accretion, especially breast meat. Jejunum and ileum segments are longer in the current genotypes but shorter when related to body weight. Heart and gizzard relative weight has reduced and tibia breaking strength has increased as a side effect of selection.

Experiment 2 evaluated performance and processing yield at four different energy levels. Results show that the HER bird is able to regulate feed intake (FI) in order to regulate energy intake. Increasing energy levels did not affect its performance. The Ross 308 bird is not able to modify FI in order to regulate energy intake. Also, Ross 308 responded to increasing levels of energy by increasing BW while Ross 708 and TY did not. Current genotypes increased caloric conversion ratio with higher levels of energy.

Experiment 3 evaluated performance and processing yield at six different amino acid (AA) levels (80, 85, 90, 95, 100, and 105% of the recommended levels). Results show that HER

bird response to increasing levels of AA was moderate to absent while the response of the three current genotypes was similar increasing BW, FI, and breast meat yield, reducing feed conversion ratio.

In conclusion, results show that a substantial change has occurred in the broiler due to selection, modifying anatomy, and its responses to different nutrient levels. These changes need to be considered when formulating diets for the different broiler genotypes used in the US industry in order to get the best economic return.

This dissertation is approved for recommendation

to the Graduate Council.

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DEDICATION

I want to dedicate this dissertation to my wife, who sparks my desire to be a better professional and human being every day; and to my family, who always encouraged me to reach my goals in life.

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Origins of the domestic chicken

Remains found in different parts of China dating more than 7500 years ago are the oldest proof of chickens being domesticated in South East Asia (West and Zhou, 1988) with the Jungle Fowl the first bird to undergo this process. There is some controversy on which species was the first one to be domesticated. Fumihito et al., (1994) compared mitochondrial DNA of jungle fowl with domestic breeds and concluded that the Red Jungle Fowl (Gallus gallus) was the original species from where all domestic breeds descend. This is in accordance with West and Zhou (1988) but in contradiction with Liu et al., (2006) who through the same mitochondrial analysis concluded that different species of different geographical origin contributed to the modern domestic breeds.

In the past, chickens were used for religious (sacrificial animal) and entertainment (cock fighting) purposes as well as for food or decorative uses (Wood-Gush, 1959). Romans seem to have been the first ones to emphasize the food aspect of chicken breeding. Detailed descriptions of husbandry techniques as well as different breeds and specialist branches within the poultry industry can be found in Columella's work (cited in Wood-Gush, 1959). After that, poultry farming disappeared as an industry and only in nineteenth century England did a new poultry industry forms that set the basis of modern poultry production.

Broiler production in the US began as a commercial industry in the 1930's. The first broilers were Barred Plymouth Rocks. This changed in the early 1940's when almost all the broilers placed in the country were crossbreds of the Barred Plymouth Rock male with either the New

Hampshire or Rhode Island Red female. In the 1950's the use of pure New Hampshire broilers generalized (Warren, 1958).

Modern genetics beginnings

In the early 1900's Thomas Hunt Morgan rediscovered the Mendelian Laws and, based on his fundamental work with *Drosophila* flies, stated that the basis of inheritance lay in the chromosomes, setting the basis of modern genetics. Based on this work, Fisher was the first one to partition genetic variation into dominant, additive, and epistatic components developing the concept of quantitative genetics (Fisher, 1918). The concept of quantitative genetics was first studied practically by J.L. Lush (Lush and Hubbs, 1945) in animal breeding.

Performance influenced by intensive genetic selection in poultry

Body Weight (BW)

Meat-type bird performance in the 1950's was significantly poor compared to performance achieved today. In 1955, a cross of New Hampshire with Barred Columbian weighed 1,082 Kg at 56 days and around 1.3 Kg at 10 weeks (Schoettle et al., 1956). Thomas et al., (1958) studied New Hampshire performance and obtained male weights of 1,488 Kg and female weights of 1,189 at ten weeks.

Genetic selection led to significant improvements in performance. Body weight gain increased significantly together with feed intake while feed efficiency was reduced significantly as well. Different authors have compared old strains with modern ones in order to establish the improvement obtained through genetic selection. Sherwood (1977) compared a random bred strain, the Athens-Canadian Randombred Control (ACRBC) with a modern line from 1976. At the same time, for the purposes of establishing if the progress obtained was due to genetics or to a nutritionally improved diet, two diets were used, a diet from 1953 and a diet from 1976. A 225% increase in growth rate was observed when the two strains were compared. Ninety percent of this increment was calculated to be due to genetics.

Chambers et al., (1981) conducted a similar experiment but with a diet representative of 1978. The authors used as a control the Ottawa Meat Control strain and compared it with two commercial strains. The results showed an increment of 230% in carcass weight. In the same line of experiments, in 1991, Havenstein started a series of experiments (Havenstein et al., 1994a; Havenstein et al., 1994b) that would conclude in 2001 (Havenstein et al., 2003a; Havenstein et al., 2003b) comparing the ACRBC strain previously mentioned to commercial broilers of those years using diets representative of 1957 and 1991 (in the first two experiments) and 2001 (in the last two). In 1991, the results showed that the modern Arbor Acres male was 3.92 times heavier than the ACRBC male at 56 days of age. Over 90% of this difference was due to genetics. Feed conversion for the Arbor Acres male was 2.40 and 2.59 for the ACRBC male at 56 days. Regarding carcass composition and yield, the carcass of the Arbor Acres male was 4.41 times heavier than the ACRBC male carcass at 43 days. Again, over 90% of the difference was due to genetics. For the 2001 experiments, ACRBC was compared with Ross 308. The Ross 308 male was 4.77 times heavier than ACRBC male. Over 95% of this difference was accounted for by genetics this time. Feed conversion for Ross 308 male was 1.94, and 2.23 for the ACRBC male at 56 days with the 2001 diet. Processing results showed that Ross 308 male carcass was 6.11 times heavier than ACRBC male. Over 95% of the progress reported was due to genetics. In 2009, Schmidt et al., (2009) compared a heritage line,cross of New Hampshire with Columbian

Barred, unselected since the 1950's with Ross 708 for 5 weeks. At 35 days, Ross 708 weighed 1.72 times more than the heritage. Today, a male broiler can achieve 2.867 Kgs at 42 days with a FCR of 1.701 and 4.162 Kgs with a FCR of 1.958 (Ross breeders, 2007). Historic data from Aviagen show how the time needed for the broiler to reach 2.3 Kg has decreased due to genetic selection from 1995 to 2005 (Figure 1).

Feed intake (FI)

Intense genetic selection for high BW has come together with significant changes in correlated traits such as the increase in voluntary FI. Birds have been under selection for high BW for over 60 years now, and in order to obtain higher BW it sounds reasonable that the animal needs to consume more feed. Siegel and Wisman (1966) observed that selection for high BW resulted in increased FI. Growth and FI have been estimated to have a correlation of 0.7 (Pym and Nicholls, 1979). In other words, 70% of genetic variation in growth is associated with FI. At the same time, the idea that an animal will eat in order to meet its requirements has always sounded reasonable. Early studies assessing performance with different energy levels utilizing commercial strains from the 1950's showed that broilers efficiently regulate their feed intake to maintain energy intake when energy levels were changed in the diets (Hill and Dansky, 1954; Donaldson et al., 1956; Donaldson et al., 1958). Recent studies with modern lines show divergent results. According to Summers et al., (1964) broilers are still able to regulate feed intake in order to regulate energy intake. On the contrary Saleh et al., (2004a) reported that feed intake was not directly affected by energy levels. Other studies (Cheng et al., 1997; Dozier III et al., 2006; Dozier III et al., 2007) show reduced feed intake as energy increases but it has to be taken into account that pelleted diets were used in these trials and as fats or oil is added to increase energy levels, pellet quality is reduced. A reduction in pellet quality could affect feed intake. Nir et al., (1978) utilized two strains, a heavy breed (White Rock) and a light breed (New Hampshire x White Leghorn) to study the propensity of these birds to be overfed. Results showed that the light breed could be force fed 70% more over their *ad libitum* daily intake whereas the heavy breed could only be force fed 13% more. As a result of overfeeding in the light breed, BW gain increased 35%, and crop, proventriculus, small intestine, pancreas and liver, together with fat pad increased its weight significantly. Overfeeding in the heavy breed increased BW gain 5%, mainly due to increments in organ weights. Results indicate that light breeds do not gain more weight because the bird do not eat more even when the organism could grow more if FI would increase. Based on the concept that the ventromedial hypothalamus inhibits hunger through a feedback mechanism, Burkhart et al., (1983) used two lines of White Plymouth Rocks that had been divergently selected for BW for 22 generations, to study how the chemical lesion of this part of the hypothalamus would affect feeding behavior. The line selected for low weight responded by increasing FI while the high weight did not react to the lesion suggesting that this mechanism is inhibited or reduced in heavy birds. It would seem that at some point, artificial selection has resulted in a reduction or disappearance of satiety mechanisms.

Feed conversion ratio (FCR)

In the 1950's when intense genetic selection was being applied to poultry selection for the first time, a New Hampshire male broiler would need 2.69 kg of feed to generate 1 Kg of BW, while a female would need 2.88 Kg of feed for the same purpose (Thomas et al., 1958). Siegel and Wisman (1962) compared two lines divergently selected for high and low BW and, although there was a significant difference in BW, FCR was the same for both lines. Since then, FCR has been reported to have improved in modern lines in every paper where a modern and an old line were compared (Siegel and Wisman, 1962; Havenstein et al., 1994a; Siegel and Dunnington, 1997; Havenstein et al., 2003b; Siegel and Wolford, 2003; Schmidt et al., 2009) There are two main reasons for this. First, after several generations of selection, difference in time to achieve the same BW gain was great enough to affect FCR positively in high BW selected lines. Second, it was only in the 1970's when direct selection for lower FCR was implemented (Emmerson, 1997). Birds started to be selected not only for BW gain but for more efficient FCR as well, improving this parameter faster than before.

Feed conversion ratio is composed of different traits such as appetite, digestibility, basal metabolism, protein accretion, etc. (Emmerson, 1997). If the bird needs fewer days to reach market weight, the energy spent in maintenance is smaller compared to an unselected bird that takes more days to reach the same weight making it more efficient (Pym and Nicholls, 1979). In other words, as BW gain increases, nutrients utilized for gain increase, and nutrients utilized for maintenance reduce as a percentage, making the bird more efficient. Consequently, caloric conversion ratio decreased as well over time when the amount of calories to reach a specific weight target is studied Figure 2.

At the same time, the gastrointestinal tract of the modern broiler has changed, presumably in order to digest and absorb increased amounts of feed consumed. It has been found in high BW selected birds that small intestine (SI) segments were longer. Jejunum and Ileum, segments of SI, where nutrient absorption takes place, had increased total and relative to BW length, increasing nutrient absorptive surface (Katanbaf et al., 1988a; Katanbaf et al, 1988b). Mott et al., (2008) reported increased number of nutrient transporters Pept1 at 20 days of embryonic age in high BW selected birds compared to low BW birds. Jackson and Diamond, (1996) reported higher intestinal uptakes of glucose and proline in commercial broilers compared to the Jungle Fowl.

Other organ weights such as proventriculus, pancreas and liver have been reported to have increased in high BW birds in order to accommodate increased feed consumption.

Improvement in FCR has been attributed to genetic selection but feed formulation has also helped to get better performance through years of research. Proof of this is the study by Havenstein et al., (2003b) where the same ACRBC line used by Sherwood (1977) was fed a 1957 diet and a 2001 diet. The ACRBC male at 56 days had a FCR of 2.23 with the 2001 diet and 2.37 with the 1957 one. Diets from 2001 had more energy, protein, lysine, methionine and total sulfur amino acids. Other differences between the two diets are the addition to the 2001 diet of Zinc, Selenium, Vit E, Folic acid, and Thiamin among others. At the same time, 2001 diets were crumbled and pelleted while 1957 diets were fed as mash to the birds. Mash feed could have affected FI reducing it compared to pelleted feed.

Breast meat yield (BMY)

Broilers were first selected for growth, and after initial success, selection was oriented to feed efficiency since feed accounted for around 65% of live production costs. When consumer habits changed and poultry started to be deboned and sold in parts, selection focused on BMY since for many years this has been the most preferred cut by consumers in the U.S. and, consequently, the most expensive cut of the bird.

Chambers et al., (1981) assessed growth and carcass composition of a 1958 strain and a 1978 line selected for high body weight and observed no difference in BMY between the lines. Closer in time, with primary breeder companies focusing selection in getting increased BMY, Havenstein et al., (1994b) reported BMY 1.35 times higher for the Arbor Acres male compared to ACRBC. In this case, 28.2 % of the improvement was accounted for by genetics. In 2001, BMY was 1.68 times higher for Ross 308 male (Havenstein et al., 2003a). One hundred per cent of the progress in BMYwas accounted for by genetics in this trial. Reddish and Lilburn (2004) reported a significant increase in total and relative weight of both *Pectoralis major* and *Pectoralis minor* in modern lines compared with an unselected one, observing an increase of 34.4% in BMY. Konarzewski et al., (2000) reported that as early as at 80 grams of body weight, a significant difference in BMY could be observed between a 1997 Ross 308 and a Euribrid Hisex. In agreement with this, Schmidt et al., (2009), observed that the BMY of Ross 708 was already significantly higher at 14 days than the New Hampshire x Columbian Barred line from the University of Illinois. By day 35 breast muscle had increased 3.8 times faster in Ross 308. O'Sullivan et al., (1991) reported differences in BMY as early as 8 days of age between high and low BW lines. Sandercock et al., (2009) also reported similar differences between broilers and layers at ten weeks of age.

Undesirable side effects of intense genetic selection

When selection is focused on specific traits like high BW, FCR and BMY some undesirable effects can be expressed in the animal as a side effect affecting overall performance. The most important traits detected in poultry that can reduce performance and compromise animal welfare are classified as physiological, reproductive and immunological.

Reproductive traits

Selection for high juvenile BW has affected reproductive traits in males and females. According to Marks (1985), high juvenile BW is negatively correlated to spermatozoa motility, and when low and high BW lines were compared, the high BW line had more dead and abnormal spermatozoa with a lower concentration of spermatozoa in semen.

Immune system

The immune system has also been compromised by genetic selection. In 1992, Miller et al., inoculated two lines divergently selected for high and low BW with sheep red blood cells (SRBC) and studied bird immune response through quantitative presence of antibody titers to SRBC. The low BW line showed a prolonged response to SRBC compared to the high BW line. These results are in agreement with Martin et al., (1988) and Liu et al., (1995). Qureshi and Havenstein (1994) compared the immune response of Ross 308 and ACRBC. Results showed higher IgG and IgM antibody production in the ACRBC line. There was no difference in macrophage or natural killer cell activities. Similar results are reported due to genetic selection for growth in turkeys. In 1996 Nestor et al., (1996) inoculated a randombred control (RBC) and three commercial lines of turkeys selected for growth with *Pasteurella multocida*. Mortality for RBC was 26% while it ranged from 54 to 65% in the commercial lines in two trials. Bayyari et al., (1997) assessed the immune response of an unselected line and another selected for high 16-week-BW. The selected line had lower toe web response to phytohemagglutinin-P (PHA) inoculation, lower lymphocyte counts and lower relative spleen weights. Li et al., (2001) challenged a RBC line and a high 16-week-BW line with Newcastle disease and *Pasteurella multocida* vaccines and reported lower phagocytic activity for the selected line but no differences for antibody response for both Newcastle disease and *P. multocida*.

Ascites syndrome

Pulmonary hypertension is the consequence of increased blood flow or resistance in the lung. This results in hypertrophy of the right ventricule, valvular insufficiency, increased venous pressure and ascites (Julian, 1993). Pulmonary hypertension syndrome (PHS) has been related to metabolic oxygen requirement independent of altitude so that any factor that increases oxygen requirement increases ascites incidence caused by PHS (Julian et al., 1987; Julian et al., 1989). Cold or hot environments, increased feed intake of high energy diets, and rapid growth have been signaled as causes for increased ascites during the 1980's and 90's (Scheele et al., 1991; Scheele et al., 1992; Julian, 1993; Currie, 1999). At the same time genetic selection has not only led to higher BW but to smaller lung relative weight (Havenstein et al., 2003b) and volume (Julian, 1989) and heart relative weights (HRW) (Havenstein et al., 1994b; McEnteé et al., 2000; Sandercock et al., 2009).

Scheele et al., (1991) observed that broilers selected for high BW and lower FCR were less flexible in metabolic adaptation to a changing environment and that this could be a cause for ascites. Julian, (1998) proposed that large and heavy breast of modern broiler together with the pressure of abdominal contents on air sacs could also be involved in the development of PHS that leads to ascites. Modern broilers need to be reared paying more attention to environmental conditions in order to minimize ascites expression in the flock (Currie, 1999).

Skeletal problems

Different skeletal problems have been associated with rapid growth of birds selected for high BW (Lilburn, 1994; Julian, 1998) such as Tibial Dyschondroplasia and Spondylolisthesis (Kinky Back).

Deep pectoral myopathy (DPM) and other muscular lesions

Degenerative myopathy of *Musculus supracoracoides* is a disease that affects both turkeys and broilers. It has its origin in the increased internal pressure in the muscle that prevents the blood from reaching the muscle tissue; as a consequence a necrotic lesion is developed (Siller et al., 1979). Assessment of 23 different meat-type chicken strains for DPM showed that the 20 commercial lines selected for high BW had an incidence of DPM ranging from 0 to 43% while the three unselected lines had 0% prevalence of the disease Grunder et al., (1983).

Macrae et al., (2006) assessed *Pectoralis major* lesions in broilers and layers. It was reported that there was an important presence of necrotic fibers in broilers muscle while no presence of abnormal muscle fibers could be detected in the muscle of layers. At the same time, three different plasma markers for muscle damage were measured at different ages in both lines. Creatine kinase, lactate dehydrogenase and aspartate aminotransaminase levels were significantly higher for broilers than from layers with the biggest difference at 9 and 13 weeks of age, meaning that the muscle was damaged at some point during this time in broilers.

Fat deposition

Together with increased BW, fat deposition has increased as well, affecting carcass composition (Havenstein et al., 1994b; Havenstein et al., 2003a) and slightly reducing feed efficiency due to the energetic cost of synthesizing adipose tissue. This fat deposition could be a consequence of increased concentrations of insulin and glucagon in plasma together with insulin resistance (Sinsigalli et al., 1987).

Allometric changes due to intense genetic selection in broilers

Allometry is defined as the study of the growth of organs or parts of an organism in relation to the growth of the whole organism and is another tool to compare how birds have changed over the years.

Heart

Genetic selection has increased muscle accretion, significantly increasing body weight; however although heart weight has increased in modern lines, it has not maintained the same ratio to body weight. Heart weight and its ratio to body weight in broilers have been widely studied. Katanbaf et al. conducted two experiments to compare organ growth in birds selected for high and low juvenile body weight. When both lines were compared at the same BW (180 g), heart weight was no different but when the comparison was done at 56 days of age, birds selected for high juvenile body weight had smaller heart relative weight (HRW) (Katanbaf et al., 1988a). To the contrary, Katanbaf et al (1988b) reported no differences in HRW between two lines also selected for high or low juvenile BW. In agreement with this, O'Sullivan et al., (1991) reports similar HRW at 21 days in lines divergently selected for low and high BW. Havenstein et al., (1994b) reported reduced HRW in the Arbor Acres male when this strain was compared with the ACRBC male (Havenstein et al., 1994b) and ten years later reported an even smaller HRW when the same unselected line was compared to Ross 308 (Havenstein et al., 2003a). McEnteé et al., (2000) studied internal organ morphology comparing a modern strain of broilers with a broiler strain unselected since the 1970's finding similar results. Researchers also reported HRW reduced in the modern line at 42 days of age. Sandercock et al., (2009) conducted a unique experiment comparing 37 different lines of birds. Broilers showed a significantly reduced HRW when compared with layers and traditional chickens at ten weeks of age. Gaya et al., (2007) analyzed information of 42,912 individuals from pedigree broilers of three consecutive years and found that the genetic trend for heart relative weight was -0.004% per hatch-year. In the same line of research, Schmidt et al., (2009) compared a Heritage line (New Hampshire X Columbian Barred) unselected since the 1950's with Ross 708. Researchers killed and necropsied birds on a weekly basis from day 7 to 35 and studied organ morphology reporting a reduced relative growth of heart after 14 days. This is in agreement with Konarzewski et al., (2000) who found no differences at 14 days when compared a broiler strain was compared with a layer one. Moreover, Jackson and Diamond (1996) found no differences between old and modern strains when body mass was the same.

Lungs

Julian (1989) reported smaller relative volume in high BW selected birds. Havenstein et al., (1994b) and Havenstein et al., (2003a) reported lighter relative weight of lungs in commercial lines selected for high growth. O' Sullivan et al., (1991) found that, although smaller, there was no significant difference in lung relative weights between high and low BW lines at 21 days of age.

Liver

Reports on liver relative weight (LRW) are contradictory. Katanbaf et al., (1988a) reported heavier LRW for low BW lines. O'Sullivan et al., (1991) also observed increased LRW in the line selected for low BW compared to the high BW selected line. On the contrary, McEnteé et al., (2000) reported no difference in LRW at 42 days of age between a commercial line and an unselected one from the 1970's. Schmidt et al., (2009) found no difference in LRW from day 7 to 35 between HER and Ross 708. Konarzewski et al., (2000) reported that when birds weighed over 80 grams the line selected for high BW had higher LRW when the ratio was calculated for lean body mass. Nir et al., (1993) also reported increased LRW in a high BW line compared to a low BW line.

Proventriculus

Two lines selected for high and low BW for 27 generations were compared at the same weight (180 grams) and at 56 days of age. Proventriculus weight was higher for high BW birds at the same weight but at 56 days proventriculus relative weight (PRW) was similar for both lines (Katanbaf et al, 1988b). Similar results are reported by McEnteé et al., (2000) who observed similar PRW between two lines 30 years apart in genetic selection for BW at 42 days. Broilers had higher proventriuclus weight than jungle fowl at the same BW (Jackson and Diamond, 1996). O'Sullivan et al., (1991) assessed PRW at hatch, 8 and 21 days on the 28 generation of high and low BW selected birds, finding differences only at 21 days.

Gizzard

A reduction in Gizzard relative weight (GRW) has been reported when lines of different final BW are compared. Katanbaf et al., (1988a) and Katanbaf et al., (1988b) reported reduced GRW for broilers selected for high juvenile BW. The same results are reported by O'Sullivan et al., (1991) when two lines, divergently selected for high and low BW, were compared at 21 days of age though GRW was similar at hatch and 8 days. McEnteé et al., (2000) reported similar results when a commercial line was compared with an unselected one from the 1970's.

Small Intestine (SI)

Together with an incremease in BW, SI has changed significantly with genetic selection for high performance. Data analysis from Katanbaf et al., (1988a) and Katanbaf et al., (1988b) shows higher relative length for lines selected for high BW compared to lines selected for low BW. In 1993, Nir et al., compared a meat type strain bird with an egg strain one. At day 8, small intestine and small intestinal contents were significantly heavier, related to body weight, for the broiler strain. Jackson and Diamond (1996) reported increased SI relative length to body mass when compared to the domestic bird's ancestor, the Jungle Fowl. Konarzewski et al., (2000) also reported an incremease in SI relative weight when Ross 308 was compared to an Euribrid Hisex strain selected for egg laying at 14 days of age. McEnteé et al., (2000) reported higher relative mass for duodenum, jejunum, and ileum at 42 days when broilers from a commercial line were compared with an unselected line from the 1970's. At the same time SI relative length for the three segments was longer for the commercial broiler strain. Schmidt et al., (2009) reports similar results when Ross 708 was compared with a New Hampshire X Columbian Barred Rock from the 1950's were compared. At same age SI relative length was significantly longer for Ross 708. When similar weight birds were compared there was no difference before birds reached 400 grams. After that weight, duodenum length remained unchanged in both strains but jejunum and ileum showed significantly longer lengths in Ross 708 and when all segments were added, total SI length was significantly longer for Ross 708.

Abdominal fat pad

Abdominal fat pad has been the object of study in lines selected for high BW. Katanbaf et al., (1988a) reported an increase in fat pad relative to body weight in broilers selected for high or low body weight. Similar differences were observed when the comparison was done between birds of similar weights of 180 grams (Katanbaf et al 1988b). Havenstein et al., (1994b) and Havenstein et al., (2003a) found similar differences for fat pad and for carcass fat in 1991 and 2001. The same response for genetic selection was reported by Chambers et al., (1981), Sandercock et al., (2009), and Reddish and Lilburn, (2004) but are in disagreement with de Beer (2010), who reported decreased absolute fat when a modern strain was compared to a control, unselected line.

PERFORMANCE INFLUENCED BY DIETARY NUTRIENT LEVELS

The effect of dietary ingredients and nutrients on bird performance and carcass characteristics has been an object of study for many years. Fraps and Carlyle (1941, 1942) were among the first to study how different feed ingredients affected growth and carcass composition while Scott et al., (1947) was able to prove that combinations of high levels of energy and protein improved both growth and feed efficiency. In this trial, the diet that got the best performance was reported to have 40 calories per pound for every 1% of protein. Hill and Dansky (1950) observed that birds would not improve performance with crude protein (CP) levels higher than 20% if energy levels were not raised as well. Even more, when energy was dropped together with CP, birds would grow as well as birds with higher energy and CP levels. In 1954, Biely and March (1954) combined different levels of protein and tallow to discover that combined increasess of CP and energy improved body weight gain in chicks. Peterson et al., (1954), Matterson et al., (1955), and Scott et al., (1955) reached the same conclusion. Until that time, birds were thought to have a limited tolerance to fat (Henderson and Irwin, 1940). The following step was finding the proper ratio between calories and protein in order to obtain the best performance. The concept of energy:protein ratio was first developed in 1955-56 by Combs, Romoser and Donaldson at the university of Maryland (Combs and Rosmoser 1955; Donaldson et al., 1956; Donaldson et al., 1958). This concept was developed as a tool to calculate the amount of protein in the feed in relationship to dietary energy levels necessary for obtaining the best performance. In accordance with previous findings, Scott et al., (1955) reported reduced efficiency when the ratio went over 47:1 while Donaldson et al., (1956) observed an increase in energy intake and carcass fat as the Calorie:Protein widened.

Once it was clear that a specific ratio between energy and protein was needed in order to achieve maximum performance, researchers focused on the relationship between energy and different amino acids. Baldini and Rosenberg (1955) studied the relationship between energy and methionine, concluding that methionine requirements increase with dietary energy increases, suggesting that this could be the same for other nutrients. Experiments studying the ratio of energy to tryptophan and arginine (Griminger et al., 1957), lysine (Schwartz et al., 1958), and arginine (Scott and Forbes, 1958) showed similar results. Leong et al., (1959) found that calorie to protein ratio could be widened if methionine and arginine were increased simultaneously with energy increments.

Since then, energy to amino acid ratio has been widely studied and the aim of these studies changed with time. First, the objective was to obtain the proper balance between energy and crude protein to achieve the best body weight gain (Scott et al., 1955; Donaldson et al., 1956; Donaldson et al., 1958). By providing the best nutrient balance, the bird’s genetic potential could be expressed. After that, with feedstuff prices increasing dramatically, research focused in getting the best FCR and caloric conversion ratio (Emmerson, 1997). In the last few years, with broilers being selected for breast meat yield, the objective changed to obtain maximum breast accretion (Moran and Bilgili, 1990; Kerr et al., 1999; Kidd et al.,2004). At the same time, broilers have been undergoing changes in their anatomy, physiology and behavior for the last sixty years due to an intense genetic selection in order to achieve maximum performance. Due to this change in the broiler, its response to varying levels of energy and protein has changed as well over the years (de Beer, 2010).

Performance influenced by dietary energy level

Energy is the most expensive nutrient in a chicken diet, and the correct level of energy needed to obtain the best performance at the lowest cost has been an object of many studies for the past sixty years.

Early studies

In an elegant study, Hill and Dansky, (1954) formulated three diets, one with 18.1% CP and 994 PE Kcal/lb, another one with 16.1% CP and 1,008 PE Kcal/lb and a basal diet with 20.1% CP and 975 PE Kcal/lb. The basal diet was diluted with different percentages of oat hulls (10 to 50%) reducing the level of energy and protein and, at the same time, oat hulls were included in the basal diet (10 to 40%) at the expense of corn and wheat obtaining diets where protein remained constant while energy decreased in the diet. Results are shown in Table 1. All the diets were fed to Rhode Island Red x Plymouth Rock crossbred chicks. A decrease in performance (body weight and feed conversion) was observed as the inclusion level of oat hulls increased in the diluted diets. Feed consumption increased with increasing levels of oat hulls but performance levels of the basal diet could not be achieved. Performance results of the other two diets (18.1% CP and 16.1% CP) showed that birds did not increase feed intake to compensate for the low protein and BW gain was lower than the one achieved with the basal diet. Performance analysis of constant protein and reduced levels of energy diets showed that feed intake increased while inclusion levels of oat hulls increased as well, but BW gain remained the same as with the basal diet. These results indicated that the bird could adjust its feed intake to compensate for differences in the energy content of the diet but could not do the same for reduced levels of CP when energy remained constant.

Donaldson et al., (1956) combined different levels of CP with two different energy sources and observed that the best weight gains and feed conversions were achieved when the calorie to protein ratios were no wider than 43.9, 48.6 and 53.7 for low, medium and high inclusions of yellow animal grease respectively. In this study, FI decreased with increasing levels of energy independently of the protein level. In agreement with Hill and Dansky, (1954) energy levels modulated FI. In a similar experiment but using poults, the same group of investigators (Donaldson et al., 1958) observed an improvement in BW gain and FCR when energy was increased together with crude protein. This time, calorie to protein ratios differed from the ratios calculated for broilers. Ratios obtained were 27, 45.5 and 47.2 for 1050, 1170 and 1300 PE calories/lb respectively. In this study, FI decreased with increasing levels of energy independently of the protein level. Williams and Grau (1956) replaced cellulose for glucose in lysine deficient diets and observed an improvement in performance due to an increase in feed intake as the level of energy in the diets was reduced due to the increase of cellulose. Griminger et al., (1957) performed a similar study replacing fiber for dextrin and using different levels of tryptophan and arginine. In agreement with the previous studies, BW gain improved with the decrease in the energy content of the diet by the inclusion of fiber, and birds consumed more feed as the energy decreased. In 1959 Leong et al., (1959) combined three levels of energy (950, 1210 and 1450 PE cal/lb) with five levels of crude protein ranging from 17% to 42% at 5% intervals. In accordance with the studies cited previously, it was observed that with increasing levels of energy the best performance was achieved by increasing the levels of CP as well.

In the same line of experiments, Summers et al., (1964) using four levels of energy (2.5, 2.78, 3.05 and 3.33 Kcal ME/g) and five levels of CP (10, 14, 18, 22, and 26%) reported that FI increased with decreasing levels of energy independently of protein levels supporting the idea that the bird from 1960's was capable of adjusting FI to compensate for deficiencies in dietary energy.

Farrell et al., (1973) reported increased BWG and decreased FI with increasing levels of energy in the diet. Similar results were reported by Farrell (1974), and Waldroup et al., (1976). It is important to mention that all these studies were conducted using mash feed since pellet quality can affect performance significantly especially when dietary energy is increased by addition of some type of animal fat.

Pellet quality and it effect in energy studies with broilers

McKinney and Teeter (2004) conducted an experiment where broilers were fed the same energy diets presented with different percentages of pellets from 0 to 100% from 31 to 38 days (Table 2).

Pellets percentage significantly affected BW gain and FCR. As percentage of pellets increased, performance improved increasing BW gain and reducing FCR. Though it was not significant, FI showed a numerical reduction as pellet percentage decreased.

Pellet quality is negatively affected by fat addition prior to pelleting (Jensen and Falen, 1973; Richardson and Day, 1976; Briggs et al., 1999). Dozier III et al., (2006) reported a reduction of pellets from 91.3% (3175 Kcal/Kg and 0.82% poultry oil) to 57.8% (3310 Kcal/Kg and 4.12% poultry oil). At the same time pellet durability index (PDI) decreased from 95.5 to 76.5%. In another trial, the same author (Dozier III et al., 2007) reported a decrease in percentage of pellets of 23.6% and a reduction of 8.4% PDI between two diets with poultry oil inclusion levels of 1.34 and 3.67%.

In recent studies on broiler performance responses to different energy levels, pelleted diets were used to feed experimental birds (Skinner et al., 1992; Cheng et al., 1997; Hidalgo et al., 2004; Saleh et al., 2004a; Saleh et al., 2004b; Dozier III et al., 2006; Dozier III et al., 2007; Dozier III et al., 2008; Dozier III et al., 2011). Common to all these trials, energy was increased in the experimental diets by addition of poultry oil or tallow to the diets with an effect on the pellet quality (Skinner et al., 1992; Cheng et al., 1997; Hidalgo et al., 2004; Saleh et al., 2004a; Saleh et al., 2004b; Dozier III et al., 2006; Dozier III et al., 2007; Dozier III et al., 2008; Dozier III et al., 2011). It is to be expected then that pellet quality affects performance (BWG, FCR, FI, and caloric conversion ratio (CCR)).

Modern strains responses to energy levels

Skinner et al., (1992) studied the effect of dietary nutrient density on performance from 42 to 49 days using diets that ranged from 3080 Kcal/Kg with 16.83% CP to 3465 Kcal/Kg with 18.30 % CP. Increasing levels of energy in the diet decreased BWG and FI but improved FCR. Cheng et al., (1997) reported similar BWG but reduced FI and CCR with increasing levels of energy (3050 and 3250 Kcal/Kg). On the contrary, Dozier et al., (2011) observed increased BWG and similar

FI with increasing levels of energy. Caloric conversion was not affected by energy increments. This is in agreement with Saleh et al., (2004b) for 42 days performance, but at 63 days BWG and FI was similar among treatments with a higher caloric conversion for the higher density diets. A second study by the same researchers (Saleh et al., 2004a) showed significant increment in BWG at 42 and 49 days with dietary energy increments. Energy increments resulted in reduced FI from 42 to 63 days. CCR was higher for the higher energy diets from 42 to 63 days.

Hidalgo et al., (2004) reported improved BWG and FCR but no differences in CCR and FI with increasing levels of energy when studying broiler performance from 1 to 38 days. Dozier et al reported reduced FI, improved CCR with similar BWG when broiler performance was studied from 30 to 59 (Dozier III et al., 2006), 42 to 56 (Dozier III et al., 2007), and 36 to 47 days (Dozier III et al., 2011).

Results are contradictory but it seems that modern broilers continue to perform better with high energy levels improving BWG. CCR results are mixed but it would improve with high energy diets at early stages. At later stages CCR deteriorates as dietary energy increases. It seems that modern birds do not adjust FI to compensate for differences in energy levels anymore or at least this adjustment in FI is not linear to the variation of dietary energy. Though it is not clear to what extent, it appears that higher inclusions of poultry oil would affect pellet quality reducing feed consumption and hiding an unrestricted appetite of the bird that would be eating to maximum fill.

Processing Yield affected by dietary energy levels

Energy effect on processing parameters has been studied. Leeson et al., (1996) reported no effect in BMY but increased fat pad of birds fed increasing levels of energy with constant CP. Similar results were reported by Dozier III et al., (2011) though previous studies by the same researchers showed no effect in BMY nor abdominal fat pad (Dozier III et al., 2006; Dozier III et al., 2007). Results will be affected depending upon whether CP or amino acids are increased proportionally to ME.

Performance influenced by dietary protein levels

Intense genetic selection has changed the meat type bird used sixty years ago. A gradual but unstoppable change took place in the bird changing carcass composition at the same time. Substantial research has been done in order to determine if protein requirements have changed for the changing bird. In 1964, Summers et al studied the effects of different levels of energy and protein on male broilers performance reporting improved BW with increasing levels of CP up to 26%. Jackson et al., (1982) reported improved performance with increasing levels of protein up to 24% CP in male broilers with no effect in FI. Similar results have been reported by Fancher and Jensen, (1989a); Fancher and Jensen, (1989b); Smith and Pesti, (1998) and Smith et al., (1998).

Optimal level of dietary crude protein for maximum BW has been reported to be lower than the level of protein required for improved feed efficiency (Fancher and Jensen 1989a; Moran et al., 1992; Bartov and Plavnik , 1998).

It has been demonstrated that CP levels can be reduced in broiler diets if essential amino acids are supplemented to a certain point (Lipstein and Bornstein, 1975; Moran Jr et al., 1992; Si et al., 2004). Below that point, birds fed low CP diets do not perform as good as birds fed recommended CP even when all essential amino acids are supplemented reducing BWG and increasing FCR (Fancher and Jensen, 1989a; Fancher and Jensen, 1989b; Kerr and Kidd, 1999; Corzo et al., 2005; Waldroup et al., 2005).

Baker and Han, (1994) reported improved BWG and FCR with higher levels of AA when levels 80% and 112% of 1994 NRC recommendations while maintaining the ratio of AA to lysine, for the three to six week period were tested in broilers. Similar results were reported by Kidd et al., (2004) and Corzo et al., (2005). Skinner et al., (1992) observed a reduction in BW during the 42 to 49 days period when birds were fed levels below 90% recommended AA levels with FCR deteriorating below 90% AA levels. Raising levels of arginine, tryptophan, and glycine related to Lysine also improved BW and FCR in birds from 1 to 18 days (Corzo, 2012).

Lysine level influence in performance

Of all the Essential amino acids, lysine (Lys) is the one on which more investigation has been conducted. It has been reported that increasing Lys levels improve different parameters of performance. Body weight is the first parameter to be affected followed by BMY and FCR (Moran Jr and Bilgili, 1990; Han and Baker 1993;Leclercq, 1998; Kerr et al., 1999). In 1955, Williams and Grau, (1956) already showed the importance of Lysine supplementation improving BWG and FCR from 14 to 32 days of age in broilers. Kidd et al., (1997) reported improved BW and FCR with higher levels of Lys when 1.1 and 1.2% Lys levels were fed to chicks from 1 to 18 days of age. Similar results for 1 to 18 days are reported by Kidd et al., (1998) and Kerr et al., (1999). Further research by Kidd and Fancher, (2001) resulted in lysine requirements to be estimated between 1.18 and 1.22% lysine for this period. Han and Baker, (1994) reported increased BWG and reduced FCR with Lysine increments when 0.51, 0.61, 0.71, 0.81, 0.91, 1.01, and 1.11% of digestible Lysine were fed to broilers from three to six weeks of age. Broken line analysis indicated a digestible lysine requirement of 0.85% for males and 0.78% for females in this age period. Renden et al., (1994) compared two levels of lysine (1% and 1.15%) for grower and 0.85% and 1% for finisher reporting improved BWG and FCR for the high Lysine diets. Kidd et al., (1997) observed reduced FCR but no effect in BW when comparing 100% to 105% NRC level of Lysine from 18 to 54 days of age. Kerr et al., (1999) observed improved BWG with Lys levels up to 1.23% Lys, after that BWG deteriorated with higher Lys inclusions for age 21 to 42. On the contrary, Moran and Bilgili (1990) found no differences in performance between 0.95 and 1.05% Lys levels for the 28 to 42 days of age period and Mendes et al., (1997) found no differences between Lys levels (1.0, 1.1, 1.2%) when birds were exposed to heat or cold stress.

Crude protein and AA level influence in different genotypes performance

The effect of varying levels of CP and AA on different bird genotypes has been studied. Leclercq (1983) studied the effect of different levels of CP in two different strains selected for high or low lean or fat carcass composition. Fast growing selected birds performed better with low levels of CP while at higher levels, lean and fat bird performance was similar. Smith and Pesti, (1998) and Smith et al., (1998) compared a high yield strain (Ross 508) with a fast growing strain cross (Peterson x Arbor Acres) at three different CP levels (16, 20 and 24%) keeping energy constant. The high yield bird responded to increasing levels of CP while the fast growing strain did not. Accordingly, FCR reduction was more pronounced in the high yield strain. Feed intake was reduced in both strains with increasing levels of CP. Corzo et al., (2005b) reported no interactions between high and low AA density diets and a high yield and multi-purpose strain. Sterling et al., (2006) found no interactions between lysine levels and genotypes (high yield and multipurpose strain) on live performance from 17 to 42 days of age.

Processing

Dietary CP levels affect processing though results vary. Fancher and Jensen (1989a) reported decreased fat deposition but no effect in BMY with increasing levels of CP. Bartov and Plavnik (1998) observed increased carcass yield, BMY and reduced fat deposition at 57 days of age in similar conditions. This is in partial agreement with Holsheimer and Veerkamp (1992) who observed reduced fat deposition and reduced breast meat with higher levels of CP.

When CP level is reduced below NRC recommendations, carcass yield and BMY are reduced (Moran et al., 1992). This is in agreement with Rezaei et al., (2004) who reported similar results together with an increase in fat pad yield. Sterling et al., (2006) only observed increased fat pad when CP was reduced from 23 to 17%.

Dietary amino acid levels also affect processing yield. A reduction in AA levels 7 days prior to processing (42 to 49 days) increased abdominal fat pad though dressing percentage was not affected (Skinner et al. 1992). Feeding high AA dense diets compared to low AA dense diets was reported to increase BMY and reduce abdominal fat pad yield (Kidd et al., 2004; Corzo et al., 2005b).

Lysine effect in processing yield of birds

Lysine inclusion levels and it effect on yield has been studied thoroughly with different results. According to Tesseraud et al., (1996), the major effect of increasing lysine takes place in the *Pectoralis minor*. Moran and Bilgili, (1990) reported no effect on breast meat when three different dietary levels of Lys (0.85, 0.95, and 1.05%) were compared at 42 days with total carcass fat decreasing with increasing levels of Lys. Holsheimer and Veerkamp, (1992) reported significant increments in BM and wing yield at 56 days with a high Lys level compared to a normal level. In a follow up study (Holsheimer and Ruesink, 1993) the same results were obtained.

Renden et al., (1994) observed an improvement in carcass weight, BMY and a reduction in abdominal fat pad at 56 days with high levels of Lys. Similar results are reported by Kidd et al., (1998) and Kerr et al., (1999). Corzo et al., (2006) reported a similar response in high yield males but a lack of response in females suggesting that lower levels of Lys could be fed without loosing performance.

It has been reported that different bird genotypes respond different to diets varying in CP or AA levels. In 1992, Moran et al., (1992) compared eight different broiler strains using 0.85 and 0.95% Lys in the finisher phase but reported no strain x Lys level interaction. Smith et al., (1998) found no interaction in yield between the high yield and the multi-purpose strain fed different levels of CP. Corzo et al., (2005b) observed significant interaction for fillets yield at 42 days but no effect at 56 days of age. Sterling et al., (2006) reported no interactions between CP and lysine levels at a processing age of 42 days.

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Figure 1. Broiler average days to reach 2.3 Kgs (de Beer, 2010)

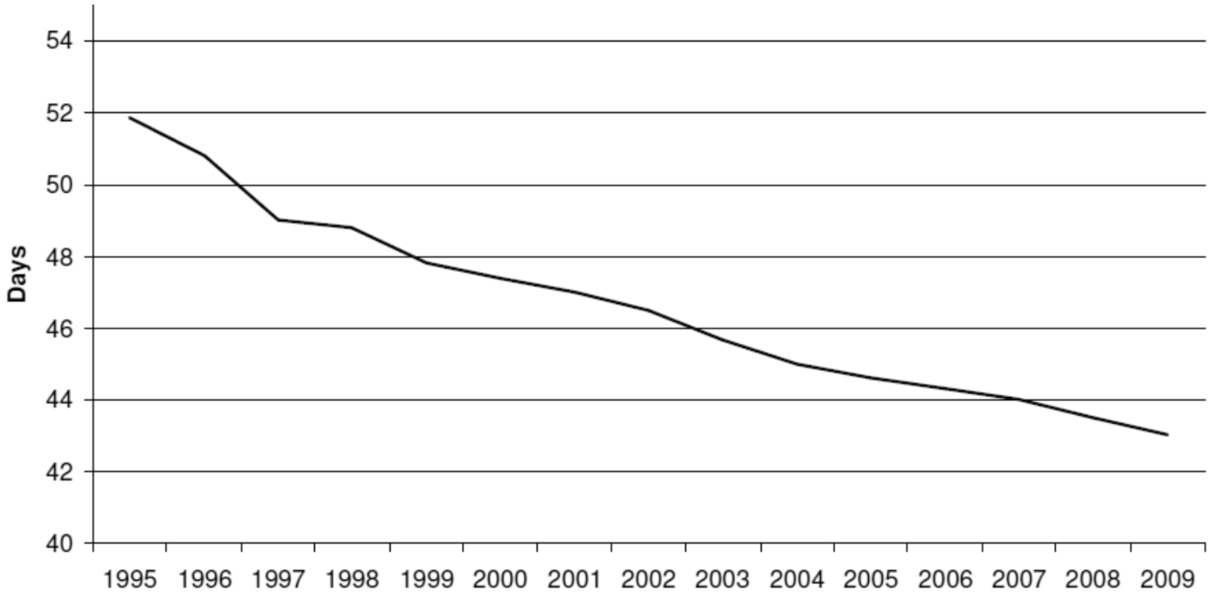

Figure 2. Average calorie conversion ratio to reach 2.3 Kgs (de Beer, 2010)

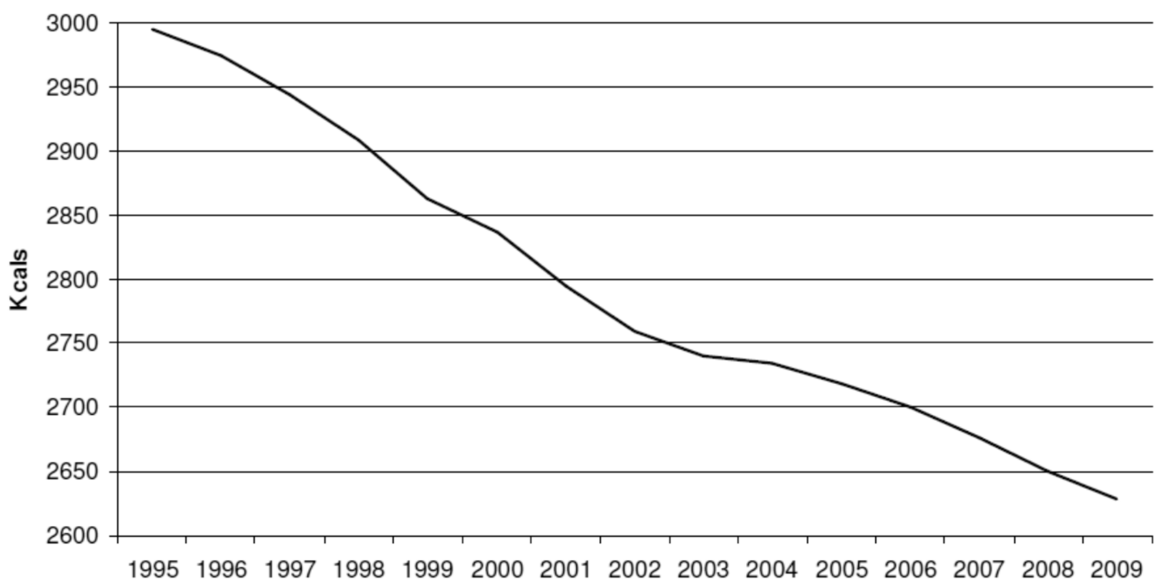

Table 1. Bird performance influenced by energy and protein variations (Hill and Dansky, 1954).

Experimental diets	Av weight 6 weeks (kg)	FI 6 weeks	Energy intake (Kcal)	Av weight 11 weeks (kg)	FI 11 weeks	Energy intake (Kcal)
Basal diet (BD)	0.645	1.354	2908	1.491	4.364	9374
BD + 10% hulls	0.646	1.393	2633	1.481	4.397	8310
BD + 20% hulls	0.666	1.593	2585	1.522	4.911	7971
BD + 30% hulls	0.648	1.664	2283	1.461	5.099	6996
BD + 40% hulls	0.642	1.816	2021	1.456	5.448	6064
18% protein	0.616	1.308	2865	1.448	4.303	9424
16% protein	0.589	1.384	3074	1.44	4.45	9883
90% BD + 10% hulls	0.655	1.549	2994	1.51	4.963	9593
80% BD + 20% hulls	0.616	1.546	2656	1.464	5.007	8602
70% BD + 30% hulls	0.607	1.669	2501	1.394	5.048	7592
60% BD + 40% hulls	0.574	1.736	2238	1.371	5.329	6869
50% BD + 50% hulls	0.516	1.731	1859	1.207	5.678	6098

Table 2. Bird performance with different pellet inclusion levels from 31to 38 days (Adapted from Mckinney and Teeter, 2004)

	Pellet inclusion (%)					
	100	80	60	40	20	0 (Mash)
BW gain (g)	725^{a}	701^{ab}	687^{ab}	685^{ab}	675^{bc}	643^{c}
FCR	$1{,}87^{a}$	1.88^{a}	1.92^{a}	1.93^{ab}	1.95^{ab}	2.02^{b}
FI (g)	1348	1306	1312	1316	1313	1280

Comparative growth response of different broiler genotypes and morphometric analysis

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ABSTRACT

Intense genetic selection has significantly improved meat production in the last 50 years but this selection has altered the relative growth of different organs in the selected birds compared to the heritage lines that reflect the old broiler. In this study, a Heritage line (HER) of New Hampshire x Columbia WPR that had been maintained since the 1950's was compared to three modern production lines (Ross 308, Ross 708 and a Test Yield Product (TY) from Aviagen for 8 weeks post hatch. One hundred and sixty two male birds of each line were randomly allocated to battery brooders. Each strain had nine replications. Birds were fed diets that met average nutrient level in the U.S. poultry industry (Agri-Stats, Fort Wayne IN). Feed and water were provided *ad libitum* throughout the experiment. Every week, two birds per pen were killed, one was necropsied and the relative weight of breast, leg, wing and internal organs were compared. The other one was used for full body composition analysis. Ross 308 body weight (BW) was heaviest until 42 days, after that, BW of Ross 708 and TY was similar to Ross 308. Body weight of HER was lighter all through the experiment. Feed conversion ratio (FCR) was affected due to the number of birds necropsied. Breast relative weight was significantly lighter for HER from day 7 to the end of the trial. The TY showed a heavier relative and absolute breast weight at day 56. Leg relative weight was lighter at 56 days for Ross 708 and TY. Heart relative weight was significantly heavier in HER than in the modern lines from 28 days until the end of the experiment. Gizzard relative weight was significantly heavier in HER all along the experiment.

When HER was compared with a modern line of the same weight, gizzard relative weight was still heavier than the modern ones. Tibia breaking force was higher in modern lines than in HER, though tibia diameter was smaller in modern lines than in HER when birds with similar weight were compared. These data indicate that modern breeds have changed in different aspects from the older strains as a secondary effect to genetic selection. At the same time breast meat yield continues to increase with continuing selection.

Key words: Broiler Genotypes, morphometric, broiler, relative weight.

INTRODUCTION

Primary breeders have used intense genetic selection to change the old meat-type bird from the 1950's into the modern broiler widely used in the poultry industry today. Quantitative genetics have been applied to obtain a heavier, more efficient bird with higher yield (Havenstein et al., 1994a; Havenstein et al., 1994b; Havenstein et al., 2003a; Havenstein et al., 2003b; Schmidt et al., 2009). From obtaining a 1.488 Kg male bird with a FCR of 2.69 in ten weeks (Thomas et al., 1958) in 1958, today a male broiler can reach 4.16 Kg with 1.958 FCR in 8 weeks (Ross breeders, 2007).

This outstanding improvement in performance has come with anatomical and physiological changes in the broiler (Jackson and Diamond, 1996; Konarzewski et al., 2000; McEnteé et al., 2000; Havenstein et al., 2003a; Schmidt et al., 2009) the consequences of which are not clear. Some of these changes could be responsible for metabolic or skeletal disorders that have been related to the fast growth of the modern broiler (Lilburn, 1994; Julian, 1998). Even more, it is not clear if, genetic selection for high yield broilers has produced more changes in the bird and if so, how this could affect performance in the future.

The objective of this study was to compare the performance of an old unselected line from the 1950's with three modern strains selected for high growth and for high breast meat yield (BMY) and at the same time, assess differences in allometry, and histological properties of small intestine (SI).

MATERIALS AND METHODS

In this study, a Heritage line of New Hampshire x Columbia White Plymouth Rock from the University of Illinois (HER) that had been maintained unselected since the 1950's, Ross 308, Ross 708, and a Ross Test Yield product (TY) were compared. One hundred and sixty two one-day-old male chicks of each line were randomly allocated to wire floor batteries in a temperature controlled room. At 14 days the birds were transferred to wire floor grow out batteries. Eighteen birds were allocated to each cage with nine replications per line. Light was continuous throughout the trial.

Birds were provided with a starter diet from day 1 to 21, a grower diet from day 22 to 35 and a finisher diet from 36 to 56 days of age. Diets were formulated that met the average nutrient level in the U.S. poultry industry (Agri-stats, Fort Wayne IN) (Table 1). All diets were fed as mash. Feed and water was provided ad libitum all along the experiment. Body weight and FCR were calculated weekly. Every seven days, two birds from each cage were sacrificed by cervical dislocation, one was frozen for full body composition analysis and the other one was dissected to study morphometric differences between the genetic lines. Individual weights for heart, spleen, proventriculus, gizzard, pancreas, liver, breast, wing, and leg were collected. Duodenum, jejunum, and ileum lengths were also measured and samples from each segment collected at 28 days of age to measure villus length and width. Organ relative weights to body weight were calculated weekly. In some cases, when data of birds of similar BW from different strains was available, organ weights were compared. At 56 days the last set of birds was dissected and the experiment terminated.

At 22 days, 18 birds from each line were divided into six replications, allocated randomly to wire floor grow out batteries, and fed with feed previously prepared with Titanium Dioxide (5 gr/Kg) as a tracer. After five days of acclimation to the new diet, birds were sacrificed and ileal content collected. Digestibility was calculated according to the method of Short et al. (1996).

At 21, 35 and 49 days, one tibia was collected from a bird of each cage. Tibias were cleaned of adherent tissues and the biomechanical strength of each bone was measured using an Instron 4502 material testing machine with a 100 kg load cell (Instron Inc.825 University Avenue, Norwood MA 02062-2643). Bones were held in identical positions and the mid-diaphyseal diameter of the bone at the site of impact was measured using a dial caliper. The maximum load at failure was determined using a three-point flexural bend fixture with a total distance of 30 mm between the two lower supporting ends. The load, defined as force in kilograms per square millimeter of cross-sectional area (kilograms per square millimeter), represents bone strength. The rate of loading was kept constant at 20 mm/min collecting 10 data points per second. The data were automatically calculated using Instron Series IX Software.

Statistical analysis of data was performed using JMP Pro (SAS Institute Inc., Cary, NC, USA). Data were analyzed by a one-way analysis of variance (ANOVA) and comparison of means was done using the student t test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Body weight

Results for BW are presented in Table 2. Strains presented different BW from day 7 to the end of the trial. Ross 308 had the highest BW until 49 days of age when Ross 708 and TY achieved similar body weights as Ross 308 through 56 days. Heritage had the lowest body weight throughout the experiment. Ross 308 BW was 2.25 times larger than HER at 42 days and 2.15 times larger at 56 days.

Feed intake and feed conversion ratio

Feed intake was higher for current lines but this parameter was affected by weekly necropsied birds and consequently feed conversion ratio was also affected. For that reason these two parameters are not analyzed in this paper and will be extensively analyzed in accompanying papers.

Breast meat Yield (BMY)

Results for Breast Meat Yield (BMY) are presented in Table 3. Breast meat yield was significantly lower for HER throughout the experiment. The BMY was the same for Ross 308, Ross 708, and TY until 49 days when TY and Ross 708 showed a significantly higher yield than Ross 308. At 56 days, TY had the highest BMY followed by Ross 708, Ross 308, and HER. Wing relative weight was heavier for HER since its body weight was significantly smaller than current lines (data not shown). At 56 days TY BMY was 2.75 times larger than HER and TY total breast was 4.33 times larger than HER.

Carcass composition

Carcass composition results are expressed as percentages in Tabel 4, 5, and 6. Significant results for protein (Table 4) and fat (Table 5) were found at different ages though no explanation or trend could be found for this. Ash content was significantly higher for HER throughout the trial. This indicates that the skeleton is a greater proportion of the total body weight with less musculature than in modern strains.

Allometry

Results for heart relative weights (HRW) are presented in Table 5. The HRW of modern strains were significantly lighter than HER from 28 days on. This is in agreement with Katanbaf et al. (1988), O'Sullivan et al. (1991), Sandercock et al., (2009), Konarzewski et al., (2000), and McEnteé et al.,(2000) who found similar results when old strains were compared to modern ones. Havenstein also reported smaller heart relative weights for Arbor Acres male (Havenstein et al., 1994b) and for Ross 708 (Havenstein et al., 2003a) when compared with the Athens-Canadian Randombred control (ACRBC). Schmidt et al., (2009), who observed heavier relative weights for HER hearts from day 14 until the end the trial at 35 days when the same HER strain used in this trial was compared with Ross 708. Gaya et al., (2007) analyzed information of 42,912 individuals from pedigree broilers of three different years and found that the genetic trend for heart relative weight was -0.004% per hatch-year. Sandercock et al., (2009) assessed the difference between modern broilers and layers and reported heavier HRW for layers. When HER birds were compared with birds from a modern line of the same weight the relative weight of the heart remained the same (Table 6). It would seem that extreme growth of breast disrupts the ratio between heart and BW reducing HRW in modern lines. Smaller HRW have been related to ascites in poultry (Julian, 1993; Closter et al., 2012).

Liver relative weight (LRW) remained constant among the different strains throughout the trial (data not shown). This is in agreement with McEnteé et al., (2000), and Schmidt et al., (2009) and in contradiction with Katanbaf et al., (1988), Nir et al., (1993), and O'Sullivan et al. (1991) who reported higher LRW in lines selected for low BW against lines selected for high BW. On the other hand, , Konarzewski et al., (2000) reported higher LRW for birds selected for high BW when ratio was calculated for lean body mass.

Pancreas and spleen relative weights were similar all along the trial for the four lines studied (data not shown). Proventriculus relative weight was similar for all strains until 28 days when Ross 308 showed a heavier relative weight than the rest of the strains (data not shown). At 35 and 42 days, Ross 308 and HER showed a significantly higher proventriculus relative weight. At 49 and 56 days, HER maintained the difference with the three modern lines that showed similar relative weights. Results are not clear but it is possible that increasingly higher BW in modern lines reduced PRW. These observations are in partial agreement with O'Sullivan et al., (1991) who reported Higher PRW for low BW lines at 21 days but in disagreement with other studies where high BW broilers had higher PRW than 'old lines' (Jackson and Diamond, 1996). Katanbaf (1988) reported higher PRW for high BW birds at 180 grams but similar PRW at 56 days of age. McEnteé et al., (2000) reported similar PRW at 42 days.

Gizzard relative weight (GRW) was significantly heavier in HER all along the experiment (data not shown). When similar BW birds were compared, HER gizzard weight was still heavier than Ross TY (Table 7). This is in agreement with Katanbaf et al., (1988), O'Sulliva et al. (1991) and McEnteé et al., (2000). It is possible that since broiler selection has been done using mash or pelleted feed with small particles, gizzard function was not necessary for grinding particles and gizzard weight reduced with time.

Small intestine (SI) segments measurements showed that duodenum length remained constant for the four strains throughout the trial (49 days data shown in Table 8). On the contrary, Jejunum and ileum segments were significantly longer in the current strains compared to HER from 21 days on (49 days data shown in Table 9 and 10). This is in agreement with Katanbaf et al., (1988), and Schmidt et al., (2009) who compared Ross 708 with the same HER strain used in this study and found the same results. Jackson and Diamond (1996) compared modern broilers with Red Jungle Fowls and observed that small intestine was significantly longer in broilers. McEnteé et al., (2000) also observed not only longer Jejunum and Ileum segments but also longer duodenum segments. At the same time, Nir et al., (1993), and Konarzewski et al.(2000) reported heavier SI segments in broilers when Ross 308 was compared with a layer strain.

These data show that in modern lines each centimeter of SI segment accounts for more grams of BW than in HER (Table 8, 9, and 10). In other words, each cm of SI, in modern lines, supports more mass of body than HER. Analysis of data from similar BW birds comparing Ross 708 and TY with HER strains shows total length of Jejunum and Ileum to be significantly longer in these two lines (Table 11).

Histological analysis of SI sections

Results for histological analysis are shown in Table 12. Small intestine villus length analysis at 28 days of age showed TY and Ross 708 to have significantly longer villus. Jejunum analysis showed that TY and Ross 708 also had longer villus followed by Ross 308 and HER. Longer villus together with longer sections of jejunum and duodenum could explain the capability of current lines to absorb nutrients present in the augmented feed intake compared to HER.

Moreover, Mott et al. (Mott et al., 2008) found more intestinal nutrient transporters in embryos of current strains compared to low BW lines.

Digestibility

Results for protein and energy digestibility (Table 13) showed no differences between the four strains studied. Current lines have increased feed intake but are not more efficient digesting and absorbing nutrients than HER.

Tibia breaking strength

Tibia break force at 21, 35, and 49 days was significantly higher for the modern lines compared to HER (Table 14). When HER tibias were compared to tibias from a modern strain of similar body weight, tibia diameter was significantly larger for HER even when break force was higher for TY (Table 15). These results show that genetic selection for high BW has resulted in changes in bone structure. Different skeletal disorders have been related to fast growth (Julian, 1998) and this could partially explain it.

This study confirms that intense genetic selection has changed the current broiler from the 'old' broiler not only in performance but anatomically and histologically as well. It is still not clear how these changes affect or could affect broiler performance in the future.

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Table 1. Composition (g/kg) and calculated nutrient content of broiler diets formulated to meet minimum industry standards (Agri Stats 2010 yearly average). Values in bold italic are at minimum industry average levels (including meat protein level)

INGREDIENT	Starter	Grower	Finisher
Pro-Plus[1]	46.00	39.40	34.10
Yellow corn	447.00	501.45	555.98
Poultry oil	21.53	26.40	28.52
Soybean meal	314.50	261.08	209.80
DDGS	150.00	150.00	150.00
Ground limestone	4.20	5.11	6.08
Defluorinated phosphate	4.00	3.53	2.98
Sodium chloride	2.98	3.29	3.31
MHA-84[2]	1.96	1.66	1.19
L-Lysine HCl	1.33	1.58	1.54
Vitamin premix[3]	5.00	5.00	5.00
Mintrex P_Se[4]	1.00	1.00	1.00
Coban 90[5]	0.50	0.50	0.50
	1000.00	1000.00	1000.00
Crude protein %	24.33	21.94	19.69
Calcium %	0.90	0.83	0.77
Phosphorus %	0.74	0.67	0.61
Nonphytate P %	0.46	0.41	0.37
Sodium %	0.21	0.22	0.21
Methionine %	0.59	0.53	0.46
Lysine %	1.32	1.19	1.04
TSAA %	1.09	0.91	0.82
Tryptophan %	0.27	0.24	0.21
Threonine %	0.92	0.82	0.74
Arginine %	***1.54***	***1.36***	***1.18***
ME kcal/lb	***1377.00***	***1412.00***	***1440.00***
ME kcal/kg	3034.90	3112.04	3173.75

[1] H. J. Baker & Bro., 595 Summer Street, Stamford, CT 06901.

[2]Methionine hydroxy analogue calcium salt. Novus International, St. Louis MO 63141.

[3] Provides per kg of diet: vitamin A 7715 IU; cholecalciferol 5511 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; choline 1000 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.066 mg; ethoxyquin 125 mg.

[4]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, Inc., St. Louis MO 63141.

[5] Elanco Animal Health division of Eli Lilly & Co., Indianapolis, IN 46825.

Table 2. Body weight by strain and age

Strain	BW 7 d	BW 14 d	BW 21 d	BW 28 d	BW 35 d	BW 42 d	BW 49 d	BW 56 d
Ross 308	0.154^{a}	0.429^{a}	0.864^{a}	1.493^{a}	2.262^{a}	3.044^{a}	3.569^{a}	4.512^{a}
Ross 708	0.131^{b}	0.363^{b}	0.773^{b}	1.390^{b}	2.143^{b}	2.889^{b}	3.506^{a}	4.525^{a}
Ross TY	0.132^{b}	0.369^{b}	0.763^{b}	1.342^{b}	2.089^{b}	2.849^{b}	3.553^{a}	4.373^{a}
Heritage	0.099^{c}	0.237^{c}	0.438^{c}	0.687^{c}	1.014^{c}	1.352^{c}	1.691^{b}	2.096^{b}
Prob > F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
SEM	0.003	0.012	0.028	0.054	0.085	0.116	0.136	0.181

Table 3. Breast meat yield by strain

Strain	Breast (%)								Total Breast (g)
	7 d	14 d	21 d	28 d	35 d	42 d	49 d	56 d	56 d
Ross 308	13.30[a]	18.79[a]	21.09[a]	22.16[a]	24.02[a]	25.99[a]	26.47[b]	26.81[c]	1212.08[b]
Ross 708	13.95[a]	19.78[a]	22.66[a]	24.56[a]	25.61[a]	26.10[a]	29.19[a]	28.83[b]	1305.46[ab]
Ross TY	13.30[a]	19.55[a]	23.41[a]	24.86[a]	26.32[a]	26.01[a]	30.45[a]	30.75[a]	1345.31[a]
Heritage	8.66[b]	12.68[b]	12.96[b]	13.12[b]	13.25[b]	13.69[b]	14.42[c]	14.81[d]	310.65[c]
Prob > F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
SEM	0.428	0.523	0.809	0.832	0.928	1.07	1.096	1.099	75.31

Table 4. Protein carcass content by age and strain

Protein (%)

Strain	7 days	21 days	28 days	35 days	42 days	49 days	56 days
308	71.03	67.19^{a}	63.19	65.72	62.36^{b}	63.80^{b}	65.39
708	74.23	63.67^{b}	64.76	64.99	65.26^{a}	62.44^{b}	63.67
TY	73.54	66.26^{ab}	65.01	64.82	62.73^{ab}	66.61^{a}	63.02
HER	72.96	68.58^{a}	66.04	66.33	65.15^{a}	63.33^{b}	62.08
Prob > F	0.169	0.0128	0.4627	0.565	0.0479	0.0207	0.2838
SEM	0.53	0.566	0.634	0.413	0.489	0.511	0.639

Table 5. Fat carcass content by age and strain

Fat (%)

Strain	7 days	21 days	28 days	35 days	42 days	49 days	56 days
308	20.07	23.51^{bc}	28.38	25.74	29.75^{ab}	27.93	27.21
708	16.34	27.56^{a}	26.48	27.02	26.64^{bc}	29.5	29.02
TY	17.06	24.87^{ab}	26.38	27.09	30.84^{a}	25.54	29.9
HER	16.94	21.44^{c}	24.47	24.02	25.71^{c}	29.5	29.14
Prob > F	0.117	0.0075	0.313	0.078	0.0091	0.1097	0.6021
SEM	0.603	0.669	0.735	0.489	0.65	0.576	0.706

Table 6. Ash carcass content age and strain

Ash (%)

Strain	7 days	21 days	28 days	35 days	42 days	49 days	56 days
308	8.88^b	9.29^b	8.42^b	8.52^b	7.87^b	8.25^b	7.38^b
708	9.42^b	8.76^b	8.75^b	7.97^c	8.09^b	8.05^b	7.30^b
TY	9.39^b	8.86^b	8.6^b	8.08^c	7.51^b	7.83^b	7.06^b
HER	10.09^a	9.97^a	9.47^a	9.64^a	9.13^a	9.01^a	8.76^a
Prob > F	0.014	0.001	0.027	<.0001	<.0001	0.0122	<.0001
SEM	0.137	0.128	0.137	0.133	0.144	0.136	0.172

Table 7. Heart relative weight to BW (%) by strain

Strain	7 days	14 days	21 days	28 days	35 days	42 days	49 days	56 days
Ross 308	0.78	0.77	0.85	0.66^{b}	0.57^{b}	0.52^{b}	0.52^{b}	0.48^{b}
Ross 708	0.76	0.85	0.83	0.66^{b}	0.60^{b}	0.55^{b}	0.47^{b}	0.48^{b}
Ross TY	0.87	0.8	0.91	0.67^{b}	0.57^{b}	0.48^{b}	0.50^{b}	0.45^{b}
Heritage	0.72	0.89	0.88	0.78^{a}	0.78^{a}	0.70^{a}	0.65^{a}	0.58^{a}
Prob > F	0.1121	0.0615	0.4754	0.0016	<.0001	0.0211	<.0001	<.0001
SEM	0.0224	0.0167	0.0205	0.0142	0.0203	0.0276	0.0156	0.0116

Table 8. HER and Ross TY HRW at similar BW

Strain	BW (g)	Heart (%BW)	Age
Heritage	2096.11	0.58	56 days
Ross TY	2185.33	0.574	35days
Prob > F	0.1487	0.8222	
SEM	30.5	0.0125	

Table 9. Gizzard relative weight

Strain	BW (g)	Gizzard rel weight (%)	Age
Heritage	2096.11	1.75975[a]	56 days
Ross TY	2185.33	1.46426[b]	35 days
Prob > F	0.1487	0.014	
SEM	30.5	0.063	

Table 10. Duodenum length at 49 days of age by strain

Strain	Body weight (g)	Duodenum (cm)	Duodenum (g BW/cm)
Ross 308	3768.33a	33.11	114.9b
Ross 708	3642.78a	32.22	113.63b
Test Yield	3732.78a	29.66	127.16a
Heritage	1767.22b	31.22	56.74c
Prob > F	<.0001	0.1508	<.0001

Table 11. Jejunum length at 49 days of age

Strain	Body weight(g)	Jejunum (cm)	Jejunum (g/cm)
Ross 308	3768.33a	90.88a	41.64b
Ross 708	3642.78a	85.77ab	42.70b
Test Yield	3732.78a	81.33b	46.09a
Heritage	1767.22b	67.33c	26.37c
Prob > F	<.0001	<.0001	<.0001

Table 12. Ileum length at 49 days by strain

Strain	Body weight (g)	Ileum (cm)	Ileum (g BW/cm)
Ross 308	3768.33a	95.44a	39.54b
Ross 708	3642.78a	88.88ab	41.30ab
Test Yield	3732.78a	86.44b	43.77a
Heritage	1767.22b	69.00c	25.75c
Prob > F	<.0001	<.0001	<.0001

Table 13. Small intestine data analysis

Strain	Body weight	Duodenum length (cm)	Duode ratio (g/cm)	Jejunum length (cm)	Jejunum ratio (g/cm)	Ileum length (cm)	Ileum ratio (g/cm)	Age
Ross 708	1391.79	30.11	46.4	75.61a	18.44b	78.61a	17.78b	28 days
Ross TY	1385.25	29.27	47.42	75.00a	18.59b	81.38a	17.04b	28 days
Heritage	1427.77	29.05	49.58	64.55b	22.18a	66.44b	21.63a	42 days
Prob > F	0.641	0.652	0.34	0.0005	0.0001	<.0001	<.0001	
SEM	19.194	0.476	0.887	1.45	0.466	1.65	0.509	

Table 14. Small intestine villus morphometry at 28 days of age

Strain	SI villus length (µm)	SI villus width (µm)	Duodenum villus length (µm)	Duodenum villus width (µm)
Ross 308	1574[ab]	231	1286[ab]	145
Ross 708	1637[a]	176	1433[a]	139
Ross TY	1705[a]	203	1385[a]	145
HER	1484[b]	146	1141[b]	136
Prob > F	0.0112	0.471	0.0188	0.5305
SEM	49.05	9.01	84.96	9.71

Table 15. Digestibility by strain

Strain	Protein digestibility	Energy digestibility
Ross 308	88.29	78.86
Ross 708	88.09	78.86
Ross TY	87.73	78.43
HER	87.34	79.05
Prob > F	0.2472	0.9325
SEM	0.178	0.33

Table 16. Tibia break strength at 21, 35, and 49 days

Strain	Break force (Kg/mm2) 21 d	Break force (Kg/mm2) 35 d	Break force (Kg/mm2) 49 d
Heritage	11.91[b]	25.95[c]	23.31[b]
Ross 308	20.5[a]	46.35[a]	39.49[a]
Ross 708	16.67[a]	37.6[b]	37.28[a]
Ross TY	17.09[a]	38.18a[b]	36.04[a]
Prob > F	0.0003	0.0013	0.0001
SEM	1.87	0.835	1.557

Table 17. Tibia diameter and break strengthby body weight

Strain	BW (g)	Diameter (cm)	Break force (Kg/mm$^{2)}$	Age
Heritage	1767.22b	9.555a	23.313b	49 days
Ross TY	2201.25a	8.002b	38.185a	35 days
Prob > F	<.0001	0.0041	0.0008	
SEM	61.9	0.294	2.531	

Comparative response of different broiler genotypes to dietary energy levels

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ABSTRACT: In this study a heritage line (HER) of NH x WPR maintained at the University of Illinois since the 1950's was compared to three modern production lines from Aviagen (Ross 308, Ross 708 and a Test Yield Product (TY)), for 6 weeks post hatch. The genetic lines were compared at four different energy levels. Diets were formulated to contain 0.50, 2, 4, and 6% poultry oil (PO) with other nutrients maintained in ratio to energy. Four hundred and eighty male birds of each line were randomly allocated to 96 pens in a 4 X 4 factorial arrangement. Each treatment had six replications with 20 birds per pen. Ross 308 had the best body weight (BW), feed conversion ratio (FCR) and caloric conversion ratio (CCR) all throughout the experiment. At 21 days, there was no interaction between the strains and the diets. At 35 days, a significant interaction was noted for BW, feed intake (FI), FCR and CCR. For BW, HER did not respond to PO changes in the diet, Ross 308 showed a positive response to increasing levels, and Ross 708 and TY showed a negative response to PO increments. The HER, Ross 708 and TY reduced feed intake as the energy increased in the diets but Ross 308 increased FI with increased dietary energy. While FCR decreased with increasing levels of PO for HER and Ross 308, it remained the same for Ross 708 and TY. The CCR for HER decreased with increasing levels of PO; the opposite effect was observed for Ross 308, Ross 708, and TY with a more pronounced effect for the last two strains. At 42 days the interaction was observed only for FCR and CCR. The effect for FCR was similar to the one observed at 35 but more pronounced. The CCR kept the same pattern for the four strains. At 43 days 3 birds per pen were processed. No interaction was observed at this point. Strain affected Carcass, Wing, Breast, Leg quarters and Rack Yield.

Poultry oil affected carcass yield, decreasing it as the energy level increased. Strains seem to be affected in different ways by different levels of PO. The HER reduced FI and did not respond to energy increments; Ross 708 and TY responded the same way. Ross 308 responded positively to incremental levels of PO by increasing FI and BW. These data indicate that different broiler strains may respond differently to changes in dietary nutrient density

Key words: broilers, genotype, strain differences, dietary energy

INTRODUCTION

Intense genetic selection during the last sixty years has improved broiler performance dramatically. At the beginning, selection addressed rapid growth to market age, then, it was feed efficiency and, finally breast meat yield (Emmerson, 1997). Along with the changes in selection programs, the broiler has changed as well resulting in a different final product (Havenstein et al., 1994a; Havenstein et al., 1994b; Havenstein et al., 2003a; Havenstein et al., 2003b; Schmidt et al., 2009)

In the past, broilers were fed diets with low levels of energy (Robertson et al., 1948; Panda and Combs, 1950). Later it was discovered that broilers would perform better by raising energy levels up to a certain point and that broilers would consume feed to meet its energy requirements (Hill and Dansky, 1954). It was observed that broiler performance improved when energy increased together with protein levels. The concept of energy:protein ratio was first developed in the 1950's (Donaldson et al., 1956; Donaldson et al., 1957; Donaldson et al., 1958) and it has been the object of study over the years to learn how to obtain the best performance.

Little is known of how different strains have changed its response to different energy levels along the years due to genetic selection. The objective of this study was to evaluate response of different strains to increasing dietary energy levels and its effect at processing. Since energy is the most expensive nutrient in the broiler diet, a better understanding on how energy affects modern strains could help increase economic returns in the poultry industry.

MATERIALS AND METHODS

In this study, a Heritage line (HER) of New Hampshire x Columbia White Plymouth Rock from the University of Illinois that had been maintained unselected since the 1950's, Ross 308, Ross 708, and a Ross test yield product (TY) were studied. Four hundred and eighty, one-day-old male birds of each strain were allocated to floor pens in a temperature controlled room. A series of diets (starter, grower and finisher) were formulated to meet the nutrient requirements for average performance of broiler males suggested by Rostagno et al., (2005). The first diet was formulated to contain 0.50% PO to provide sufficient Essential Fatty Acid content while the remaining diets were formulated to contain 2, 4, and 6% supplemental poultry oil (Table 1, 2, and 3). Mash diets were fed to the different strains resulting in a 4 X 4 factorial arrangement. Each treatment had six replications of 20 birds each. Mean pen weights were taken at one day of age and at 21, 35, and 42 days of age. Feed consumption was determined during the same time periods. Calculations were made of feed conversion ratio (FCR) (kg of feed per kg of gain) and caloric conversion (CCR) (Kcal per Kg of gain). Water and feed were provided ad libitum all throughout the experiment. At 43 days, three birds from each pen were tagged, fasted for eight hours, individually weighed, and processed at a pilot processing plant to determine dressing percentage and parts yield.

Statistical analysis of data was performed using JMP Pro software (Statistical Analysis System, SAS Institute Inc., Cary, NC, USA). Data were analyzed by a one-way analysis of variance (ANOVA) and comparison of means was done using the student's t test. All statements of significance are based on $P<0.05$. Pen means served as the experimental unit for performance data while individual birds were the experimental units for processing data as birds were processed randomly and not in pen order.

RESULTS

Performance

Performance data for 21 days is shown in Table 4. At 21 days, Ross 308 broilers showed the highest BW and lowest FCR and CCR followed by Ross 708, TY and HER. Poultry oil levels did not affect BW or FI. Chicks fed the two percent level of PO showed the lowest FCR and CCR. Ross 308 had the highest FI followed by Ross 708 TY and HER. There was no interaction between the strains and the diets at this age.

Performance data for 35 days is shown in Table 5 and Figures 1 to 4. At 35 days, Ross 308 had significantly higher BW and lower FCR and CCR followed by Ross 708, TY and HER. Poultry oil level did not affect BW. Chicks fed poultry oil level of 0.5% showed a significantly higher FCR than other levels. Chicks fed the six percent PO level had the highest CCR. A significant interaction was noted for BW, FI, FCR and CCR at this age. For BW, HER did not respond to

PO changes in the diet, Ross 308 showed a positive response to increasing levels of PO, and Ross 708 and TY showed a negative response to the energy increments in the diet. Heritage reduced feed intake as the energy increased in the diets with the same behavior observed for Ross 708 and TY. On the contrary, Ross 308 increased FI with increased energy. While FCR decreased with increasing levels of PO for HER and Ross 308, it remained the same for Ross 708 and TY. The CCR of HER remained the same with increasing levels of PO while CCR increased for Ross 308, Ross 708, and TY with a more pronounced effect for the last two strains.

Performance data for 42 days is shown in Table 5 and Figures 5 and 6. At 42 days, Ross 308 kept the highest BW. Heritage had the highest FCR and CCR. Ross 308, Ross 708 and TY showed similar FCR and CCR. Body weight was not affected by PO levels. Chicks fed the poultry oil level of 0.5 % had the highest FCR, and together with those fed the 2% PO level, the lowest CCR. Interactions were observed only for FCR and CCR. The effect of PO on FCR was similar to the one observed at 35 but more pronounced. Caloric conversion ratio kept the same significant pattern for the four strains. Ross 308 had the highest FI followed by TY, Ross 708 and HER. Feed intake was not affected by PO at this age.

Processing

Results for processing are presented in Table 7. No interaction between strain and PO was observed at this time. Strain affected Carcass, Wing, Breast, Leg quarters and Rack Yield. Ross 708 and TY had the highest carcass yield followed by Ross 308 and HER. Heritage had the highest Wing Yield. Test Yield presented significantly higher breast meat yield (BMY) than the other strains followed by Ross 708, Ross 308 and HER. Ross 308, Ross 708 and TY had higher leg yield than HER. Rack Yield was higher for HER followed by Ross 308, Ross 708 and TY.

When total breast was analyzed, TY had the heaviest breast followed by Ross 708, Ross 308 and HER. Poultry oil only affected carcass yield decreasing it as the energy level increased. Because the birds were mechanically eviscerated, abdominal fat content was not determined. Increased abdominal fat may have been associated with the higher energy levels.

DISCUSSION

Ross 308, a bird selected for fast growth and high efficiency, had the best growth, followed by Ross 708 and TY which are birds selected for high yield and present a slower growth at this age (Ross Breeders, 2012a; Ross Breeders 2012b). Heritage performance was in accordance with Baker and Han (1994) and Schmidt et al., (2009) who used the same strain over the years.

Strain x PO interactions were significant only at 35 days, probably because the growth curve is steeper at this age for the four strains and any dietary effect in performance is going to be more pronounced in this period. Poultry oil effect in HER is in agreement with Hill and Dansky, (1954), Donaldson et al., (1956), Donaldson et al., (1957), and Summers et al., (1964) who reported reduced FI and FCR with increasing levels of dietary energy using broilers from the 1950's and 1960's. The HER bird, unselected since the 1950's, used in this trial reduced FI in order to regulate energy intake. On the contrary, Ross 308 responded positively to increments in dietary energy increasing FI and BW. Results for BW are in agreement with Saleh et al., (2004a), Saleh et al.,(2004b), and Hidalgo et al., (2004) who reported increased BWG with increasing levels of energy by poultry oil inclusion, at 42 days of age, though in this cases, FI was similar or decreased with higher energy levels. These cited trials were conducted using Ross 308 or Cobb 500 birds, fast growing, highly efficient strains, and fed pelleted diets. It is known that high inclusion levels of fat can reduce pellet quality (Jensen and Falen, 1973; Briggs et al., 1999;

Richardson and Day, 1976). Dozier III et al., (2006) and Dozier III et al., (2007) reported pellet reductions of over 20% together with significant reductions in pellet durability index when diets were added increasing levels of PO. It is also known that a low pellet quality can affect performance reducing FI and BWG ((McKinney and Teeter, 2004; Skinner-Noble et al., 2005) so pellet quality could have affected performance by affecting FI and BWG. Ross 708 and TY, birds selected for high breast meat yield, behaved different than Ross 308 reducing FI and BW with increasing energy levels in the diet. In agreement with these results, Dozier III et al., (2011) studied Ross 708 response to energy from 36 to 47 days of age and reported similar BW and reduced FI with increasing levels of energy. It appears that during the process of intense genetic selection for fast growth represented by the Ross 308 line the capability of the bird to reduce FI to regulate energy intake has been lost. It is possible that, due to the fact that high yield birds were not selected for growth as fast as Ross 308, FI could not have been affected. Siegel and Wisman (1966) observed that selection for high BW resulted in increased FI. Body weight and FI have a very high correlation (0.7) (Pym and Nicholls, 1979). Burkhart et al., (1983) proposed that artificial selection for growth has resulted in a reduction or disappearance of satiety mechanisms.

Increased CCR with increasing levels of energy has been reported (Dozier III et al., 2007; Skinner et al., 1992; Saleh et al., 2004a;Saleh et al., 2004b) but some researchers report reduced CCR with higher energy levels (Dozier III et al., 2006; Dozier III et al., 2011). Lack of effect in FCR in modern strains is in contradiction with Lei and Van Beek, 1997,Saleh et al., 2004b; Saleh et al., 2004a; Dozier III et al., 2006; Dozier III et al., 2007; Skinner et al., 1992; Leeson et al., 1996a) that report reduced FCR with increments in dietary energy. Again, these results could have been affected by variations among treatments in pellet quality. In the present experiment, Ross 308 gained more weight with increased dietary energy and increased FI maintaining similar FCR. At the same time high yield strains reduced FI reducing BWG while maintaining similar FCR. Heritage reduced FI translated into a reduced FCR and constant CCR while Ross 308 increased FI increased CCR with a constant FCR. Increased energy affected Ross 708 and TY in a more pronounced CCR with energy increments probably due to the lower requirements at that point for the high yield strains.

Regression analysis of current genotypes data show significant differences between the multipurpose line (308) and high yield lines (708 and TY) for body weight at 35 days (Figure 7) and caloric conversion at 35 days (Figure 8) as well as body weight at 42 days (Figure 9).

Processing

Processing results are shown in Table 7. Differences between HER and current strains are in accordance with Chambers et al., (1981), Havenstein et al., (1994b), Havenstein et al., (2003a), Sandercock et al., (2009), and Schmidt et al., (2009). All these authors reported increased BMY in modern strains compared to ‘old’ strains. Heritage highest wing yield was due presumably to relative lower weight of the rest of the parts compared to modern strains. Unfortunately there is not a lot of published work on the differences between modern genotypes. Scheuermann et al., (2004) compared BMY between a modern strain selected for high yield and another one selected for fast growth. In agreement with results of this trial, at 35 days the high yield strain had significantly higher BMY than the other one. Reddish and Lilburn (2004) also reported higher BMY for strains selected for this purpose compared to a strain unselected for conformation.

Poultry oil effect on carcass yield is probably due to increased fat pad in birds fed high energy diets as reported by Leeson et al., (1996a), Saleh et al., (2004a), and Dozier III et al., (2007) when high and moderate energy diets were compared but in contradiction with Skinner et al., (1992), Hidalgo et al., (2004), Saleh et al., (2004b), Dozier III et al., (2007)) when a low and moderate energy diets were compared. Poultry oil lack of effect on any other carcass part is in agreement with Saleh et al., (2004a), Saleh et al., (2004b), Dozier III et al., (2006), Dozier III et al., (2007), Hidalgo et al., (2004), Leeson et al., (1996b), and Lei and Van Beek, (1997).

Genetic selection for different objectives has affected strain response to dietary energy in different ways. Different nutritional recommendations should be considered for strains selected for different purposes in order to maximize performance and increase economic returns.

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Table 1. Composition (g/kg) and calculated nutrient content of broiler starter diets with different levels of poultry oil. Values in bold italic are at minimum specified level

	A	B	C	D
Yellow corn	606.52	577.31	538.54	499.72
Poultry oil	5.00	20.00	40.00	60.00
Soybean meal	351.24	364.95	383.04	401.21
Ground limestone	7.64	7.63	7.62	7.60
Dicalcium phosphate	16.87	17.34	17.96	18.58
Feed grade salt	4.37	4.37	4.37	4.37
MHA-84[1]	3.03	3.14	3.29	3.44
L-Lysine HCl	2.02	1.95	1.86	1.76
L-Threonine	0.56	0.56	0.57	0.57
2 X Broiler premix[2]	0.25	0.25	0.25	0.25
Coban 90[3]	0.50	0.50	0.50	0.50
Mintrex P_Se[4]	1.00	1.00	1.00	1.00
Choline Cl 60%	1.00	1.00	1.00	1.00
	1000.00	1000.00	1000.00	1000.00
Crude protein	20.84	21.25	21.79	22.34
Calcium	***0.88***	***0.90***	***0.92***	***0.95***
Total P	0.72	0.73	0.74	0.76
Nonphytate P	***0.44***	***0.45***	***0.46***	***0.47***
ME kcal/lb	1356.00	1383.50	1419.80	1456.25
ME kcal/kg	2988.61	3049.23	3129.23	3209.56
Methionine	0.62	0.63	0.65	0.67
Lysine	1.29	1.31	1.35	1.38
Threonine	0.86	0.88	0.90	0.92
TSAA	0.96	0.98	1.00	1.02
Dig Met	0.53	0.54	0.56	0.58
Dig Lys	***1.14***	***1.16***	***1.20***	***1.23***
Dig Thr	***0.74***	***0.76***	***0.78***	***0.80***
Dig Val	***0.86***	***0.87***	***0.90***	***0.92***
Dig TSAA	***0.81***	***0.83***	***0.85***	***0.87***

[1]Methionine hydroxy analogue calcium salt. Novus International, St. Louis MO.

[2] Provides per kg of diet: vitamin A (from vitamin A acetate) 7715 IU; cholecalciferol 5511 IU; vitamin E (from dl-alpha-tocopheryl acetate) 16.53 IU; vitamin B_{12} 0.013 mg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione (from menadione dimethylpyrimidinol) 1.5 mg; folic acid 0.9 mg; choline 1000 mg; thiamin (from thiamin mononitrate) 1.54 mg; pyridoxine (from pyridoxine HCl) 2.76 mg; d-biotin 0.066 mg; ethoxyquin 125 mg.

[3] Elanco Animal Health division of Eli Lilly & Co., Indianapolis, IN 46825.

[4]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, Inc., St. Louis MO 63141.

Table 2. Composition (g/kg) and calculated nutrient content of broiler grower diets with different levels of poultry oil. Values in bold italic are at minimum specified level

	A	B	C	D
Yellow corn	641.70	613.27	575.38	537.53
Poultry oil	5.00	20.00	40.00	60.00
Soybean meal	319.14	332.12	349.42	366.69
Ground limestone	7.32	7.30	7.28	7.25
Dicalcium phosphate	14.91	15.34	15.91	16.48
Feed grade salt	4.39	4.39	4.39	4.39
MHA-84[1]	2.67	2.78	2.92	3.06
L-Lysine HCl	1.75	1.68	1.58	1.48
L-Threonine	0.37	0.37	0.37	0.37
2 X Broiler premix[1]	0.25	0.25	0.25	0.25
Coban 90[1]	0.50	0.50	0.50	0.50
Mintrex P_Se[1]	1.00	1.00	1.00	1.00
Choline Cl 60%	1.00	1.00	1.00	1.00
	1000.00	1000.00	1000.00	1000.00
Crude protein	19.59	19.97	20.48	20.98
Calcium	***0.80***	***0.82***	***0.84***	***0.86***
Total P	0.67	0.68	0.69	0.70
Nonphytate P	***0.40***	***0.41***	***0.42***	***0.43***
ME kcal/lb	1373.30	1401.00	1437.90	1474.72
ME kcal/kg	3026.76	3087.79	3169.12	3250.26
Methionine	0.57	0.58	0.60	0.62
Lysine	1.18	1.21	1.24	1.27
Threonine	0.79	0.81	0.83	0.85
TSAA	0.90	0.92	0.94	0.96
Dig Met	0.49	0.50	0.52	0.53
Dig Lys	***1.05***	***1.07***	***1.10***	***1.13***
Dig Thr	***0.68***	***0.69***	***0.71***	***0.73***
Dig Val	***0.81***	***0.82***	***0.84***	***0.86***
Dig TSAA	***0.76***	***0.77***	***0.79***	***0.81***

[1]As given in Table 1.

Table 3. Composition (g/kg) and calculated nutrient content of broiler finisher diets with different levels of poultry oil. Values in bold italic are at minimum specified level

	A	B	C	D
Yellow corn	672.57	644.78	607.74	570.68
Poultry oil	5.00	20.00	40.00	60.00
Soybean meal	290.83	303.23	319.74	336.27
Ground limestone	7.04	7.01	6.98	6.95
Dicalcium phosphate	13.31	13.70	14.23	14.76
Feed grade salt	4.41	4.41	4.41	4.41
MHA-84[1]	2.42	2.52	2.65	2.78
L-Lysine HCl	1.83	1.76	1.66	1.56
L-Threonine	0.34	0.34	0.34	0.34
2 X broiler premix[1]	0.25	0.25	0.25	0.25
Mintrex P_Se[1]	1.00	1.00	1.00	1.00
Choline Cl 60%	1.00	1.00	1.00	1.00
	1000.00	1000.00	1000.00	1000.00
Crude protein	18.52	18.88	19.35	19.83
Calcium	***0.74***	***0.76***	***0.78***	***0.80***
Total P	0.62	0.63	0.65	0.66
Nonphytate P	***0.37***	***0.38***	***0.39***	***0.40***
ME kcal/lb	1389.13	1417.09	1454.36	1491.65
ME kcal/kg	3061.64	3123.25	3205.41	3287.60
Methionine	0.54	0.54	0.56	0.58
Lysine	1.12	1.14	1.17	1.20
Threonine	0.75	0.76	0.78	0.80
TSAA	0.85	0.87	0.89	0.91
Dig Met	0.46	0.47	0.48	0.50
Dig Lys	***0.99***	***1.01***	***1.04***	***1.06***
Dig Thr	***0.64***	***0.65***	***0.67***	***0.69***
Dig Val	***0.76***	***0.78***	***0.80***	***0.82***
Dig TSAA	***0.71***	***0.73***	***0.74***	***0.76***

[1]As given in Table 1.

Table 4. Broiler performance at 21 days.

Strain (ST)	BW kg	FCR kg/kg	CCR Mcal/kg	FI Kg	Mort %
Heritage	0.366[d]	1.64[a]	5074.16[a]	0.606[c]	1.11E-16
Ross 308	0.755[a]	1.557[c]	4820.82[c]	1.229[a]	0.958
Ross 708	0.703[b]	1.597[bc]	4941.73[bc]	1.147[b]	0.208
TY	0.678[c]	1.612[ab]	4988.96[ab]	1.140[b]	0.625
% PO					
0.5	0.622	1.646[a]	4923.96[b]	1.05	0.208
2	0.639	1.553[c]	4735.95[c]	1.015	1.166
4	0.614	1.623[ab]	5081.87[a]	1.032	1.11E-16
6	0.628	1.583[bc]	5083.89[a]	1.024	0.416
Prob > F					
Strain	<.0001	0.0021	0.0027	<.0001	0.1366
PO	0.1178	0.0002	<.0001	0.2357	0.0568
Strain x PO	0.5821	0.507	0.5452	0.2326	0.3895
SEM	0.016	0.008	28.269	0.026	0.159

Table 5. Broiler performance at 35 days.

Strain (ST)	BW kg	FCR kg/kg	CCR Mcal/kg	FI (Kg)	Mort (%)
Heritage	0.861[c]	1.889[a]	5888.48[a]	1.641[c]	0.625
Ross 308	1.989[a]	1.669[c]	5210.66[c]	3.385[a]	0.958
Ross 708	1.845[b]	1.704[b]	5317.03[b]	3.178[b]	0.833
TY	1.813[b]	1.719[b]	5363.48[b]	3.167[b]	0.833
% PO					
0.5	1.619	1.784[a]	5380.50B[c]	2.867	0.833
2	1.645	1.735[b]	5334.85[c]	2.856	1.166
4	1.616	1.734[b]	5470.79[b]	2.82	0.416
6	1.631	1.728[b]	5593.52[a]	2.827	0.833
Prob > F					
Strain	<0.001	<.0001	<.0001	<.0001	0.952
PO	0.2894	0.0013	<.0001	0.3321	0.6489
Strain x PO	0.0269	0.012	0.0252	0.0358	0.3982
SEM	0.046	0.01	33.969	0.047	0.200

Figure 1. Poultry oil x strain interaction for Body weight at 35 days

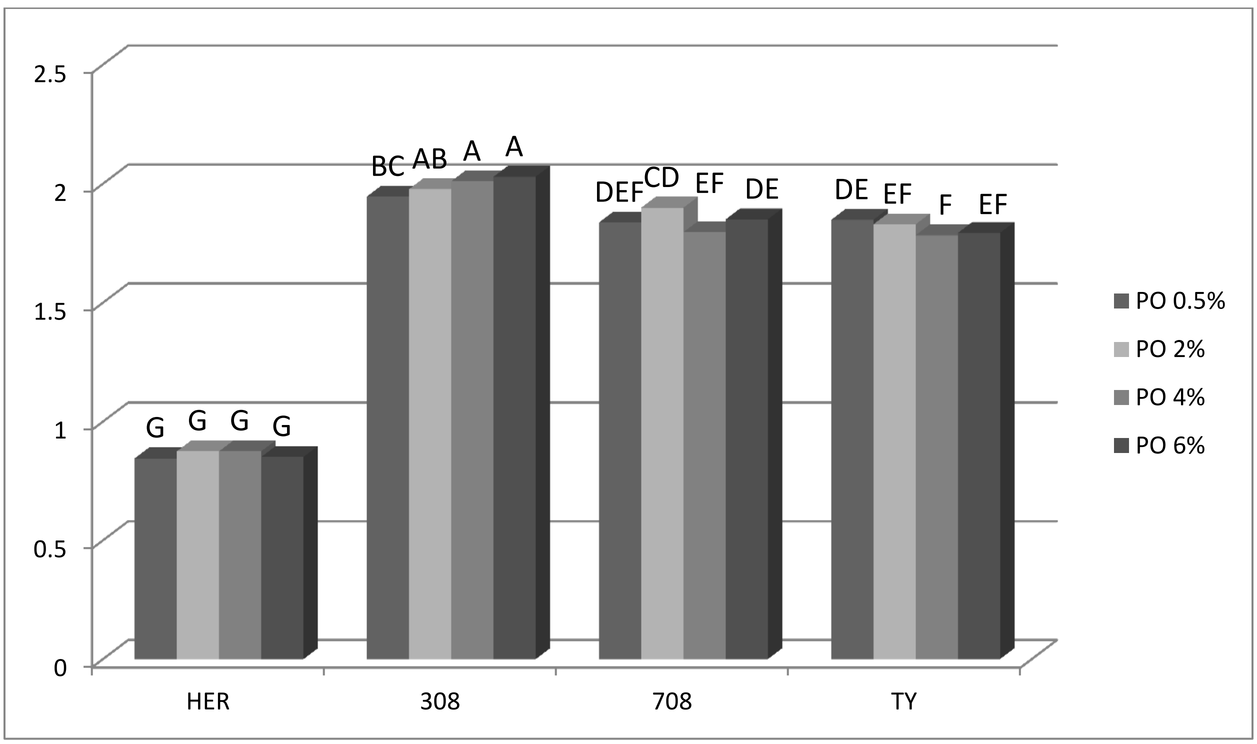


Figure 2. Poultry oil x strain interaction for feed intake at 35 days

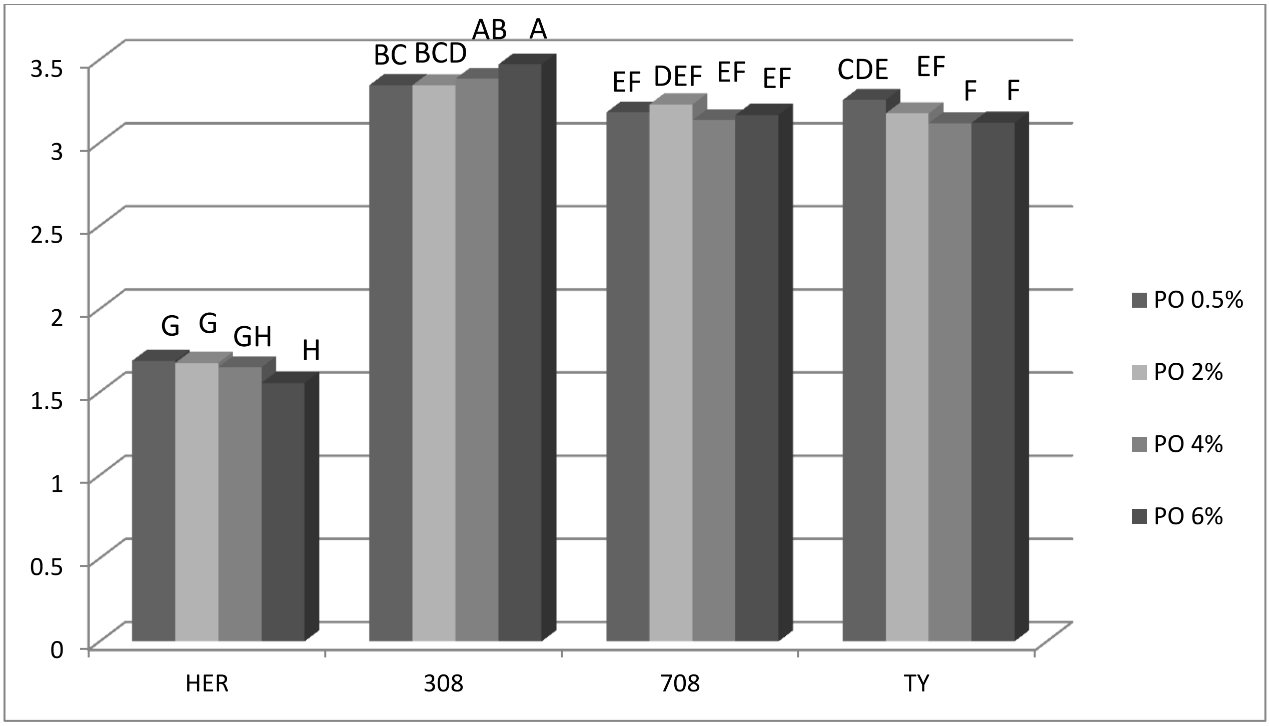


Figure 3. Poultry oil x strain interaction for feed conversion ratio at 35 days

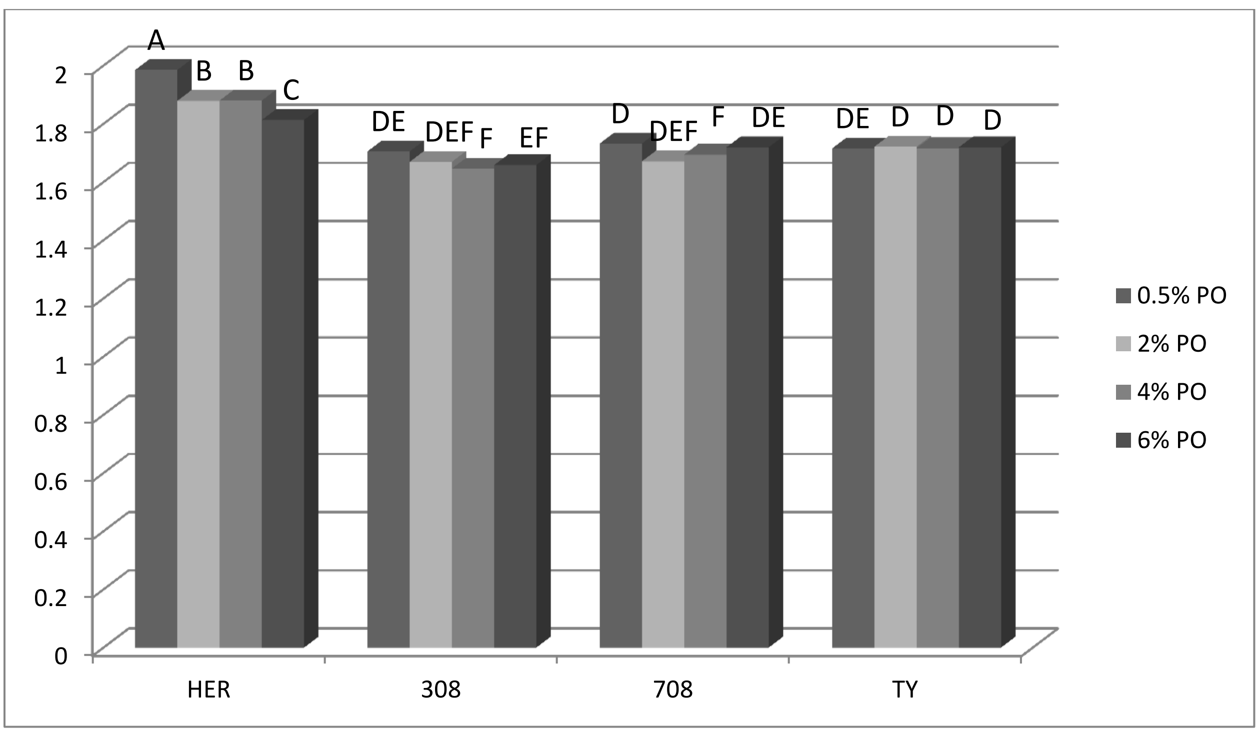


Figure 4. Poultry oil x strain interaction for caloric conversion ratio at 35 days

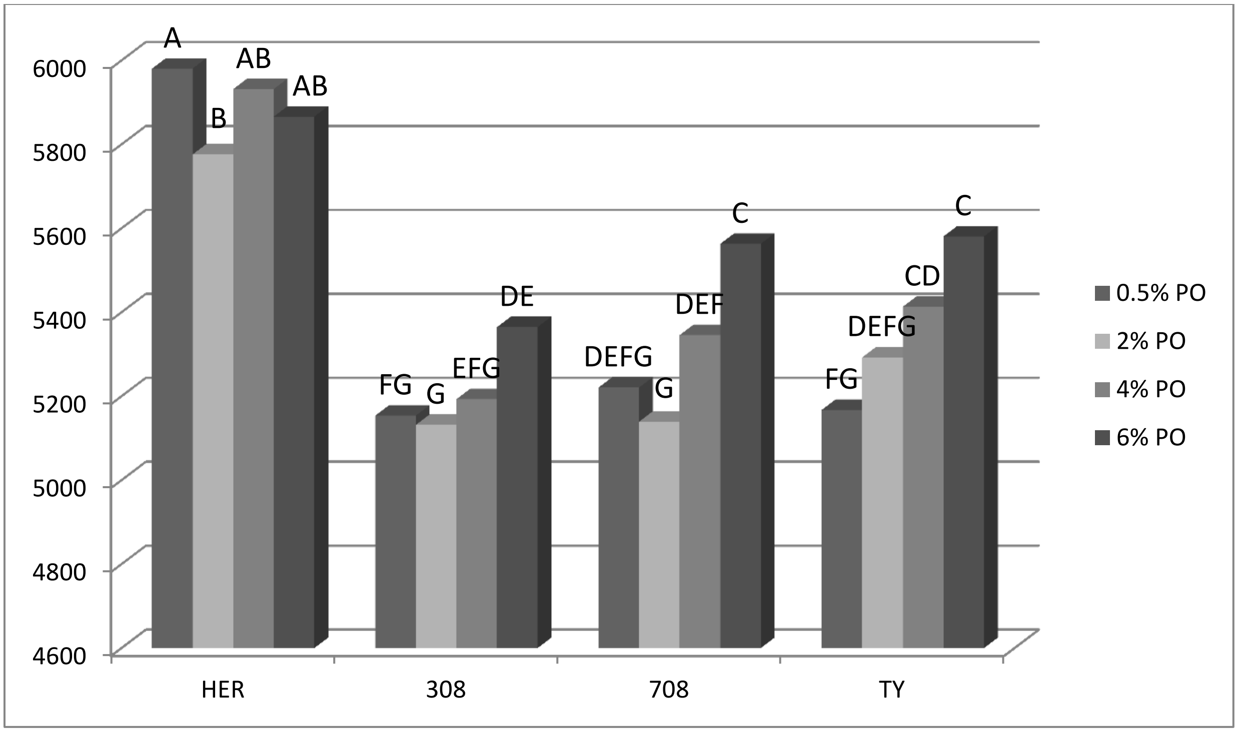


Table 6. Broiler performance at 42 days

Strain (ST)	BW kg	FCR kg/kg	CCR Mcal/kg	FI (Kg)	Mort (%)
Heritage	1.163[c]	1.977[a]	6191.50[a]	2.311[c]	0.833
Ross 308	2.639[a]	1.771[b]	5578.28[b]	4.732[a]	1.208
Ross 708	2.489[b]	1.772[b]	5553.30[b]	4.460[b]	0.833
TY	2.488[b]	1.780[b]	5578.28[b]	4.480[b]	0.833
% PO					
0.5	2.179	1.862[a]	5641.40[c]	4.023	0.833
2	2.218	1.823[b]	5629.85[c]	4.021	1.416
4	2.185	1.814[b]	5749.09[b]	3.973	0.416
6	2.197	1.801[b]	5855.91[a]	3.965	1.041
Prob > F					
Strain	<.0001	<.0001	<.0001	<.0001	0.892
PO	0.5427	0.0003	<.0001	0.4241	0.393
Strain x PO	0.7132	0.0166	0.0456	0.2978	0.087
SEM	0.062	0.01	33.786	0.029	0.209

Figure 5. Poultry oil x strain interaction for feed conversion ratio at 42 days

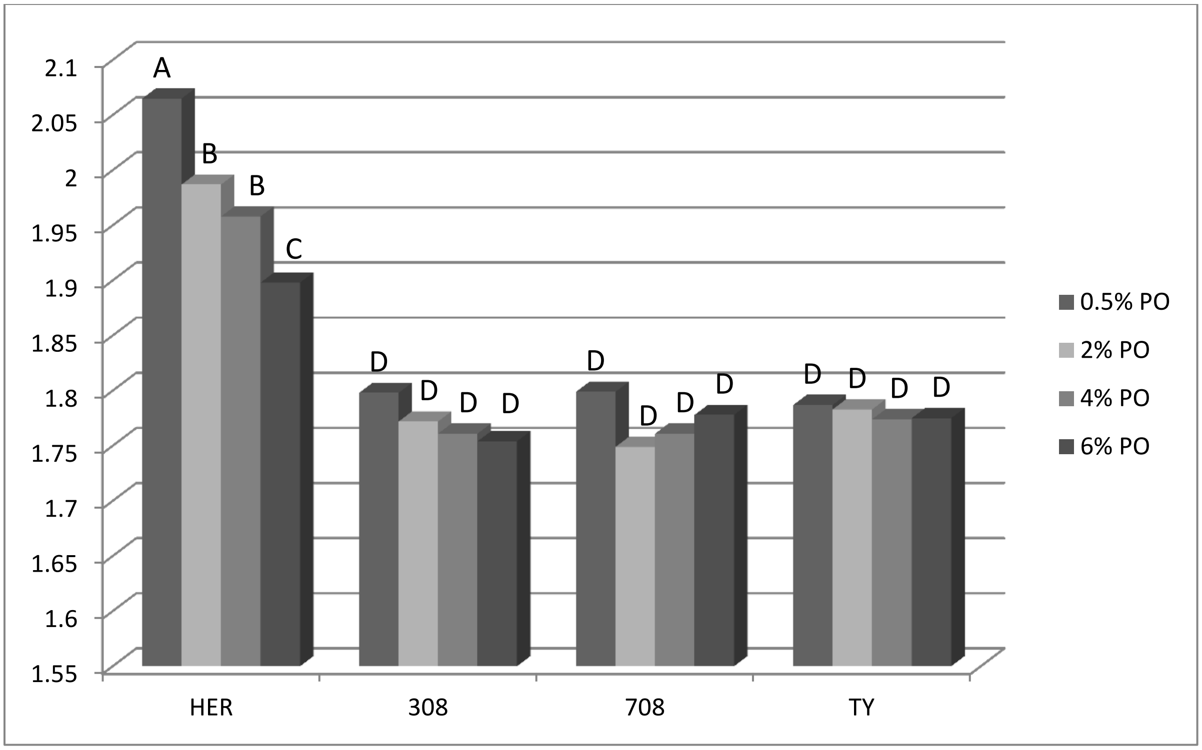


Figure 6. Poultry oil x strain interaction for caloric conversion ratio at 42 days

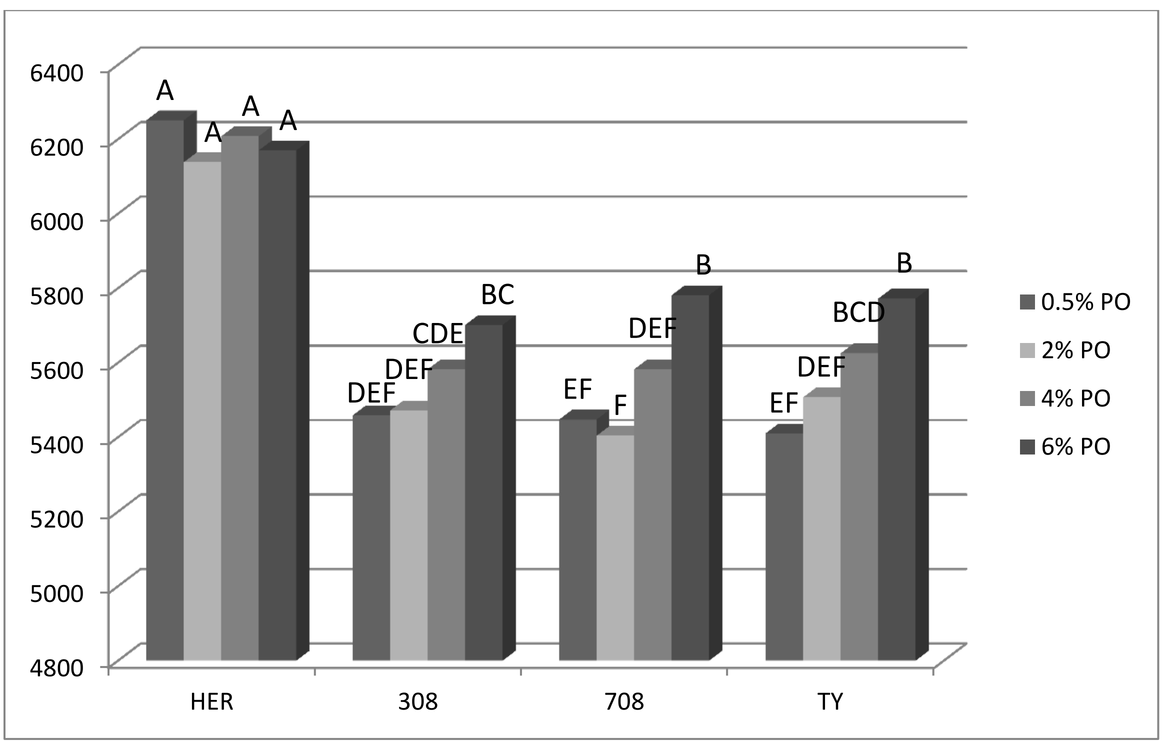
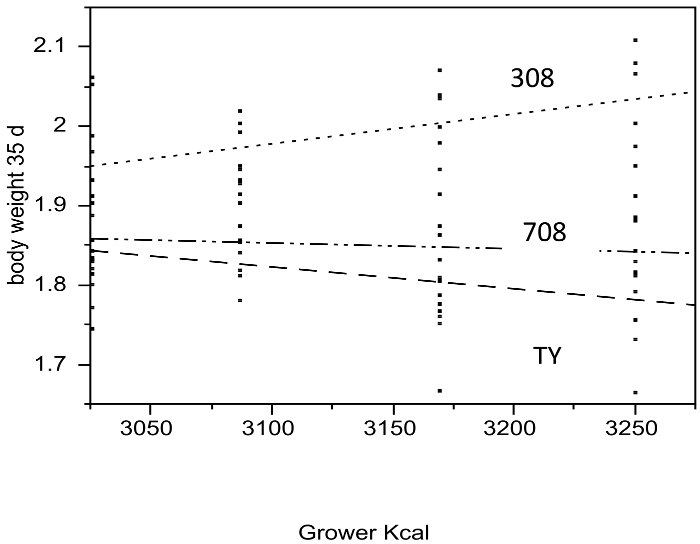


Figure 7. Regression analysis for body weight at 35 days

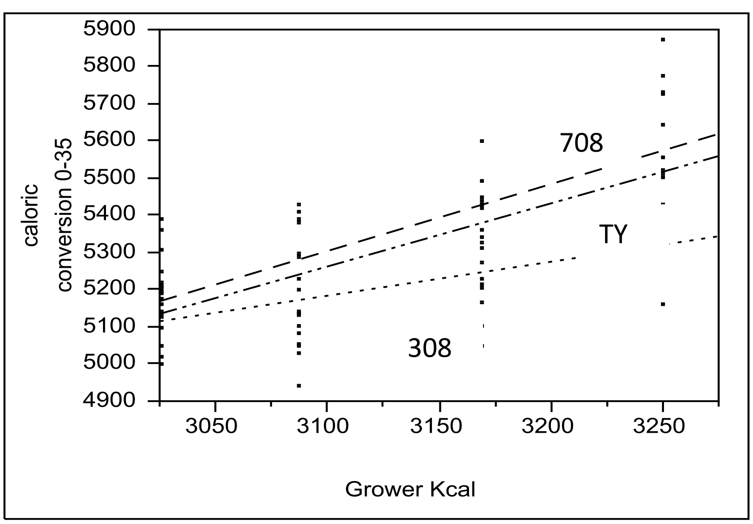


Ross 308 body weight 35 d = 0.8152936 + 0.0003751*Grower Kcal level

Ross 708 body weight 35 d = 2.0803235 - 7.3316e-5*Grower Kcal level

TY body weight 35 d = 2.675705 - 0.0002751*Grower Kcal level

Figure 8. Regression analysis for caloric conversion ratio at 35 days

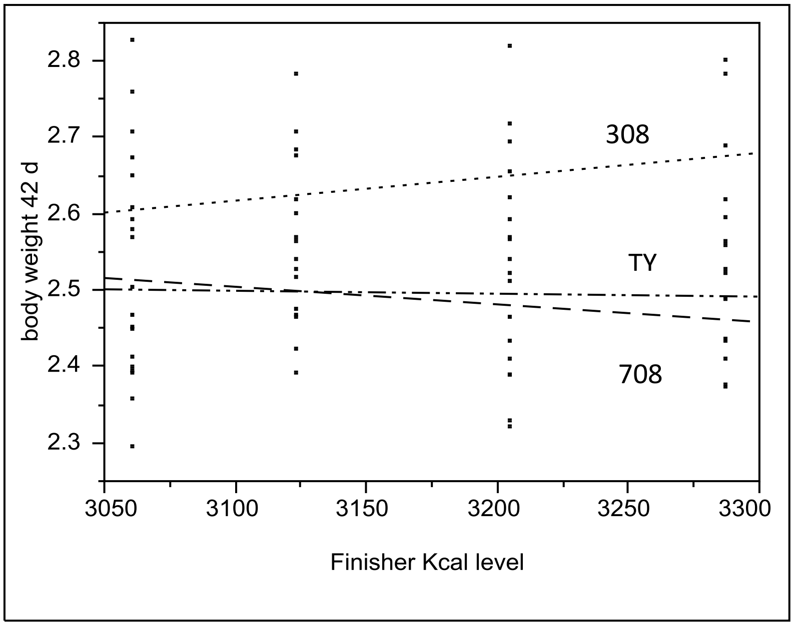


Ross 308 caloric conversion 0-35 = 2348.7844 + 0.9144968*Grower Kcal level

Ross 708 caloric conversion 0-35 = -4.389303 + 1.6989607*Grower Kcal level

TY caloric conversion 0-35 = -282.7195 + 1.8021707*Grower Kcal level

Figure 9. Regression analysis for body weight at 42 days



Ross 308 body weight 42 d = 1.6487778 + 0.0003124*Finisher Kcal level

Ross 708 body weight 42 d = 2.6180181 - 0.0000383*Finisher Kcal level

TY body weight 42 d = 3.2180669 - 0.0002302*Finisher Kcal level

Table 7. Processing results at 43 days

Strain (ST)		Carcass Yield %	Wing %	Breast %	LQ %	Rack %	Breast (grs.)
`Heritage		64.75[c]	8.91[a]	10.38[d]	22.64[b]	21.02[a]	124.27[c]
Ross 308		72.39[b]	7.68[b]	21.13[c]	23.44[a]	19.63[b]	568.15[ab]
Ross 708		73.12[a]	7.64[b]	22.20[b]	23.35[a]	18.96[c]	562.83[b]
Ross TY		73.49[a]	7.59[b]	22.92[a]	23.11[a]	18.96[c]	586.13[a]
% PO							
0.5		71.56[a]	7.95	19.23	23.04	19.84	454.01
2		71.13[ab]	7.91	19.49	22.96	19.76	473.75
4		70.45[c]	7.97	19.11	23.3	19.47	461.08
6		70.61B[c]	7.99	18.79	23.24	19.6	452.55
ST	PO						
HER	0.5	66.54	8.81	10.56	22.82	21.24	126.47
HER	2	64.54	8.88	10.36	22.12	21.43	122.71
HER	4	64.04	9.00	10.58	23.17	20.62	128.82
HER	6	63.88	8.99	10.03	22.47	20.81	119.11
308	0.5	72.89	7.78	20.87	22.89	20.19	540.20
308	2	72.75	7.63	21.99	24.00	19.38	583.36
308	4	71.93	7.66	21.20	23.28	19.53	585.89
308	6	72.01	7.66	20.50	23.60	19.43	563.17
708	0.5	73.09	7.68	22.22	23.31	19.22	553.00
708	2	73.67	7.56	23.05	23.16	18.67	607.88
708	4	72.66	7.63	21.74	23.49	18.82	549.28
708	6	73.09	7.70	21.82	23.46	19.16	541.17
EXP	0.5	73.75	7.54	23.29	23.16	18.74	596.39
EXP	2	73.57	7.58	22.59	22.59	19.58	581.06
EXP	4	73.18	7.62	22.96	23.26	18.94	580.33
EXP	6	73.49	7.63	22.84	23.44	19.03	586.76
Prob > F							
Strain		<.0001	<.0001	<.0001	0.012	<.0001	<.0001
PO		0.0032	0.6751	0.0743	0.3631	0.2964	0.1589
Str x PO		0.191	0.8478	0.211	0.0992	0.1877	0.0689
SEM		0.244	0.04	0.316	0.077	0.089	12.03

Comparative response of different broiler genotypes to dietary amino acid levels

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ABSTRACT: In this study a heritage line (HER) of NH x WPR maintained at the University of Illinois since the 1950's was compared to three modern production lines (Ross 308, Ross 708 and a Test Yield Product (TY) from Aviagen) for 6 weeks post hatch. At 42 days, 3 birds per pen were processed at a pilot processing plant and results studied for interactions. The genetic lines were compared at six different amino acid levels. Diets were formulated to contain 80, 85, 90, 95, 100, and 105% of suggested amino acid needs at a constant energy level. Four hundred and eighty one-day-old male birds of each line were randomly allocated to 96 pens in a 4 X 6 factorial arrangement. Each treatment had four replications with 20 birds per pen. Ross 308 had the highest BW and feed intake all through the experiment, followed by Ross 708, TY and HER. Mortality was not affected by genotype or AA level throughout the trial. At 20 days an interaction was noted for body weight. Current genotypes responded to increasing AA levels by gaining more weight while HER response was moderate. At 35 days a similar interaction was observed. At 41 days the same interaction was observed. Processing results showed genotype x AA interactions for carcass yield, wing yield and total breast. Heritage parameters were not affected by AA levels while current strains increased carcass yield and total breast with increasing levels of AA, reducing wing yield at the same time. These data indicate that current broiler genotypes respond different to amino acid levels than broilers used in the past.

Key words: Genotype, amino acid density, breast meat yield, performance.

INTRODUCTION

Primary breeders have modified the bird used for meat production sixty years ago into new genotypes through intense genetic selection. Current genotypes grow faster, are more feed efficient, and have increased protein deposition; especially in the breast muscle (Havenstein et al., 1994a; Havenstein et al., 1994b; Havenstein et al., 2003a; Havenstein et al., 2003b; Schmidt et al., 2009). Different selection criteria have changed the broiler; and will continue to change it, into different genotypes to fit specific market needs. Genotypes have been developed for high yield at processing or for fast growth and feed efficiency (multi-purpose) with different processing ages.

At the same time, the effect of varying levels of dietary crude protein (CP) on live performance and processing yield in broilers has been the object of study for many years. Increasing levels of CP or amino acid (AA) density have been shown to increase performance (Baker and Han, 1994; Kidd et al., 1998; Kerr et al., 1999; Kidd et al., 2004; Rezaei et al., 2004; Waldroup et al., 2005) and breast meat yield up to a certain point while reducing fat deposition at the same time (Fancher and Jensen, 1989; Moran et al., 1992; Bartov and Plavnik, 1998; Holsheimer and Veerkamp, 1992), but how different genotypes performance and yield are affected by amino acid density is not yet clear. Since high-yield and multipurpose birds grow differently, body weight, feed intake, feed efficiency, and carcass characteristics are different (Smith and Pesti, 1998; Smith et al., 1998; Corzo et al., 2005). Accordingly, nutrient recommendations for the different phases could be different as well (Gous, 1998; Gous, 2010). When feed cost and retail price for valuable cut up parts like breast meat are taken into account for calculating the economic return for US poultry integrators, a proper understanding of each genotypes amino acid requirement could provide an extra tool to make decisions in order to obtain the maximum profit.

The objective of this trial was to determine how an old line and three current genotypes selected for different purposes respond to varying levels of dietary amino acid density on live performance and processing yield.

MATERIALS AND METHODS

In this study a Heritage line (HER) of New Hampshire x Columbia WPR from the University of Illinois (that had been maintained unselected since the 1950's) was compared to Ross 308, Ross 708, and a Ross test yield product (TY). Four hundred and eighty, one-day-old male birds of each strain were allocated to floor pens in a temperature controlled room. A series of diets were formulated to meet the nutrient requirements for high performing broiler males suggested by Rostagno et al. (2011). Starter, grower, and finisher diets were formulated to contain 80, 85, 90, 95, 100, and 105% of the amino acid needs at a constant energy level (Tables 1, 2 and 3). Corn and soybean meal of known protein and moisture content were used as intact sources of protein with supplemental methionine, lysine, threonine and valine available. All mixed diets were assayed for crude protein, calcium, total P, and sodium by commercial laboratories specializing in these assays. Diets with 80, 90, and 100% levels were assayed for total amino acid content and results were in good agreement with calculated levels. Mash diets were fed to the different strains resulting in a 6 X 4 factorial arrangement. Each treatment had four replications of 20 birds each. Mean pen weights were taken at one day of age and at 20, 35, and 41 d of age. Feed consumption was determined during the same time periods and calculations were made of feed conversion (kg of feed per kg of gain). Water and feed was provided for ad libitum consumption all along the experiment. At 42 days three birds from each pen were tagged, fasted for eight hours, individually weighed and processed at a pilot processing plant to determine dressing percentage and parts yield.

Statistical analysis of data was performed using the software JMP Pro (Statistical Analysis System, SAS Institute Inc., Cary, NC, USA). Data were analyzed by a one-way analysis of variance (ANOVA) and comparison of means was done using the student's t test. All statements of significance are based on $P<0.05$. Pen means served as the experimental unit for performance data while individual birds were the experimental units for processing data as birds were processed randomly and not in pen order.

RESULTS

Performance

Performance data is shown in Table 4. At 20 days, Ross 308 broilers showed the highest body weight (BW) followed by Ross 708, TY and HER. The same pattern was observed for feed intake (FI). Ross 308 had significantly better feed efficiency together with Ross 708 and TY than HER. Birds fed amino acid levels of 105, 100, and 95% had the highest BW followed by those fed 90, 85, and 80% (Figure 1). For FI, birds fed diets with higher levels of AA showed higher feed consumption (Figure 3). Birds fed amino acid levels of 105 and 100% were the most efficient followed by those fed 95, 90, 85 and 80%. Feed efficiency improved together with increasing levels of AA (Figure 2). Strain x AA level interaction was significant only for BW (Figure 1). While the three modern strains increased BW with increasing levels of AA, HER

BW response was minimal to AA density increments. Mortality was not affected by strain or AA level throughout the trial.

At 35 days, Ross 308 continued to show the highest BW followed by Ross 708, TY and HER (Figure 4). Test Yield and Ross 708 showed the lowest FCR followed by Ross 308 and HER (Table 4, Figure 5). Ross 308 continued to have the highest FI followed by Ross 708, TY, and HER (Figure 6). Body weight was positively affected by increasing levels of AA with birds fed 105, 100, and 95% showing the highest BW. Birds fed higher levels of AA (105, 100, and 95%) continued to have the best feed efficiency while FI increased with increasing levels of AA. Body weight showed a significant strain x AA level interaction (Figure 4). While modern strains reacted positively to increasing levels of AA improving BW, HER had a moderate response slightly increasing BW with increasing AA levels. Other interactions at this point were not significant.

At 41 days, Ross 308 still had the highest BW followed by Ross 708, TY, and HER (Figure 7). Feed intake had the same pattern while FCR was lower for Ross 308, Ross 708, and TY followed by HER (Figures 8 and 9). Strain x AA level interaction was significant at this point for BW (Figure 7).

Processing

Processing results are shown in Table 5. Strain x AA interactions were significant for carcass yield, wing yield, and total breast (Figures 10, 11 and 15). Strain affected carcass, wing, leg, breast, rack yield, and total breast. Heritage strain had the lowest carcass, breast meat yield and total breast (Figures 10, 12, and 15). At the same time, HER showed the highest wing and rack yield (Figures 11, 14). Ross TY had the highest BMY, and together with Ross 708 it had the highest carcass yield (Figures 10 and 12). Total breast was similar for all three current lines (Figure 15). Ross 308 showed higher leg yield than the rest of the genotypes (Figure 13). Amino acid density also affected processing results. Increasing levels of AA increased carcass and BMY together with total breast weight. Strain x AA level interactions were detected for carcass (Figure 10) and wing yield (Figure 11), and total breast weight (Figure 15). While HER carcass yield was not affected by increasing levels of AA, all three current lines increased it together with increments in AA levels. A similar effect was observed for total breast weight, HER was not affected by AA levels while the other three genotypes studied increased its breast weight with higher levels of AA. On the contrary, increasing levels of AA reduced wing yield in current lines while HER was not affected.

DISCUSSION

Performance

Performance responses to AA levels are in agreement with Skinner et al., (1992), Baker and Han (1994), Kidd et al., (2004), and Corzo et al., (2005), and. The increased feed intake increment with AA levels increments is in agreement with Sterling et al., (2006) who studied three different Lys levels but in disagreement with Smith and Pesti (1998) and Smith et al., (1998). The differences in FI could be explained by the low levels of AA in this trial and the low levels of Lys used by Sterling et al while AA levels used in Smith et al., (1998) trials were not mentioned though CP levels used were not marginal.

Strain performances are in agreement with previous trials utilizing high yield and multi-purpose genotypes (Corzo et al., 2005; Sterling et al., 2006) and other studies comparing old and current genotypes, (Havenstein et al., 1994a; Havenstein et al., 2003b; Schmidt et al., 2009). Through genetic selection, broilers achieve significantly higher body weights compared to body weights achieved in the past. Ross 308 is a fast growing strain that outgrows high yield strains at processing ages of 42 days (Ross Breeders, 2012)

Strain x AA interactions are in partial agreement with literature. Baker and Han (1994), showed moderate response of HER to AA levels above NRC recommendations at 21 days, though the lack of response of this genotype at 41 days has not been reported before to our knowledge. Response of current strains to increasing levels of AA are in agreement with Corzo et al., (2005), and Sterling et al., (2006) but in disagreement with Smith and Pesti, (1998), and Smith et al., (1998). The differences between the old and the new genotypes could be explained by the AA effect on muscle accretion. Since muscle content of modern strain bird is significantly higher than in old strains, an AA effect in muscle increases BW significantly. Different current genotypes seem to have the same response to AA increments at this age.

Processing

Amino acid effects on processing parameters are in agreement with literature. Increasing levels of CP or AA density reduces abdominal fat pad deposition (Fancher and Jensen, 1989; Holsheimer and Veerkamp, 1992; Sterling et al., 2006) and increases carcass weight and BMY (Moran et al., 1992; Bartov and Plavnik, 1998; Kidd et al., 2004; and Corzo et al., 2005). In this study, since the birds were mechanically eviscerated, abdominal fat content was not determined. Increased carcass yield with increasing levels of AA could be associated with a reduction in abdominal fat pad.

Differences in processing parameters between current genotypes and old genotypes has been reported in the past (Havenstein et al., 1994b; Havenstein et al., 2003a; Schmidt et al., 2009) and are in agreement with results from this study. Higher carcass yield from Ross 708 and TY and higher BMY than Ross 308 is explained by the fact that these are high yield birds and the latter is a multipurpose bird. Similar results have been reported by Corzo et al., (2005), Smith and Pesti, (1998), and Smith et al., (1998). For the same reason, Ross 708 had the highest total breast meat. Ross Test Yield has a different growth curve and at this point has not reached its maximum BW and breast weight (Mussini et al, in press). Strain x AA interactions could be explained by the AA effect on BW. Since AA has no effect at 41 days in HER BW there is no effect in carcass yield while the current strains respond positively to higher AA levels increasing carcass yield. A similar effect is appreciated in total breast meat. Wing yield strain x AA interaction could be linked to variations in BMY as increasing BMY reduces wing yield.

Intense genetic selection has modified broiler genotypes anatomically and in its responses to dietary nutrient levels. These changes have improved live performance and processing yield and will probably continue to do it in the future. Considering that both Ross 708 and TY genotypes have been developed for processing weights of around 4 Kgs and that increases its body weight gain at later stages, AA effects during these stages should be studied in the future.

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Table 1. Composition (g/kg) and calculated nutrient content of broiler starter diets with different levels of amino acids. Values in bold italic are at minimum specified level

	80%	85%	90%	95%	100%	105%
Yellow corn	729.87	696.62	667.03	635.25	603.66	572.23
Poultry oil	6.75	11.73	16.23	21.03	25.80	30.55
Soybean meal	221.53	250.13	275.46	302.75	329.85	356.82
Ground limestone	10.26	10.00	9.74	9.47	9.21	8.95
Dicalcium phosphate	18.84	18.67	18.52	18.36	18.20	18.04
Feed grade salt	5.69	5.68	5.67	5.66	5.65	5.64
DL-Methionine	1.84	2.00	2.26	2.46	2.67	2.88
L-Lysine HCl	2.25	2.16	2.08	1.99	1.90	1.81
L-Threonine	0.72	0.76	0.76	0.78	0.81	0.83
2 X Broiler premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Coban 90[2]	0.50	0.50	0.50	0.50	0.50	0.50
Mintrex P_Se[3]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Crude protein	17.10	18.19	19.16	20.20	21.24	22.27
Calcium	0.93	0.93	0.93	0.93	0.93	0.93
Total P	0.70	0.71	0.71	0.72	0.73	0.74
Nonphytate P	0.46	0.46	0.46	0.46	0.46	0.46
ME kcal/lb	1425.00	1425.00	1425.00	1425.00	1425.00	1425.00
ME kcal/kg	3140.71	3140.71	3140.71	3140.71	3140.71	3140.71
Methionine	0.48	0.51	0.54	0.58	0.61	0.64
Lysine	1.03	1.09	1.16	1.22	1.29	1.35
Threonine	0.71	0.76	0.80	0.84	0.89	0.93
TSAA	0.77	0.81	0.86	0.90	0.95	1.00
Gly+Ser	***1.54***	***1.64***	***1.73***	***1.83***	***1.93***	2.03
Dig Met	0.43	0.46	0.50	0.53	0.56	0.59
Dig Lys	***0.96***	***1.02***	***1.08***	***1.14***	***1.20***	***1.26***
Dig Thr	***0.62***	***0.67***	***0.70***	***0.74***	***0.78***	***0.82***
Dig Val	0.72	0.77	0.81	0.86	0.90	0.95
Dig TSAA	***0.68***	***0.72***	***0.77***	***0.81***	***0.85***	***0.90***

[1] Provides per kg of diet: vitamin A (from vitamin A acetate) 7715 IU; cholecalciferol 5511 IU; vitamin E (from dl-alpha-tocopheryl acetate) 16.53 IU; vitamin B_{12} 0.013 mg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione (from menadione dimethylpyrimidinol) 1.5 mg; folic acid 0.9 mg; choline 1000 mg; thiamin (from thiamin mononitrate) 1.54 mg; pyridoxine (from pyridoxine HCl) 2.76 mg; d-biotin 0.066 mg; ethoxyquin 125 mg.
[2] Elanco Animal Health division of Eli Lilly & Co., Indianapolis, IN 46825.
[3] Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 20 mg; Zn (as zinc methionine hydroxy analogue complex) 20 mg; Cu (as copper methionine hydroxy analogue complex) 10 mg; Se (as selenium yeast) 0.15 mg.Novus International, Inc., St. Louis MO 63141.

Table 2. Composition (g/kg) and calculated nutrient content of broiler grower diets with different levels of amino acids. Values in bold italic are at minimum specified level

	80%	85%	90%	95%	100%	105%
Yellow corn	747.93	722.05	692.72	663.43	634.10	604.77
Poultry oil	10.05	13.90	18.30	22.69	27.09	31.50
Soybean meal	203.26	225.29	250.46	275.63	300.80	325.98
Ground limestone	9.55	9.33	9.08	8.84	8.60	8.35
Dicalcium phosphate	16.68	16.55	16.40	16.26	16.11	15.96
Feed grade salt	5.71	5.70	5.70	5.68	5.67	5.66
DL-Methionine	1.72	1.93	2.13	2.32	2.52	2.72
L-Lysine HCl	2.10	2.12	2.05	1.97	1.89	1.81
L-Threonine	0.63	0.70	0.72	0.74	0.76	0.78
L-Valine	0.12	0.18	0.19	0.19	0.21	0.22
2 X Broiler premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Coban 90[1]	0.50	0.50	0.50	0.50	0.50	0.50
Mintrex P_Se[1]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Crude protein	16.07	16.94	17.91	18.88	19.86	20.83
Calcium	0.84	0.84	0.84	0.84	0.84	0.84
Total P	0.65	0.65	0.66	0.67	0.68	0.69
Nonphytate P	0.42	0.42	0.42	0.42	0.42	0.42
ME kcal/lb	1435.12	1435.12	1435.12	1435.12	1435.12	1435.12
ME kcal/kg	3163.00	3163.00	3163.00	3163.00	3163.00	3163.00
Methionine	0.45	0.48	0.51	0.54	0.57	0.60
Lysine	0.95	1.01	1.07	1.13	1.19	1.25
Threonine	0.66	0.70	0.74	0.78	0.82	0.86
TSAA	0.72	0.76	0.81	0.85	0.89	0.94
Gly+Ser	1.43	***1.51***	***1.60***	***1.70***	***1.79***	***1.88***
Dig Met	0.40	0.44	0.47	0.49	0.52	0.55
Dig Lys	***0.88***	***0.94***	***0.99***	***1.05***	***1.10***	***1.16***
Dig Thr	***0.57***	***0.61***	***0.65***	***0.68***	***0.72***	***0.75***
Dig Val	***0.68***	***0.72***	***0.76***	***0.80***	***0.85***	***0.89***
Dig Ile	***0.59***	0.63	0.67	0.71	0.76	0.80
Dig TSAA	***0.64***	***0.67***	***0.71***	***0.75***	***0.79***	***0.83***

[1]As given in Table 1.

Table 3. Composition (g/kg) and calculated nutrient content of broiler finisher diets with different levels of amino acids. Values in bold italic are at minimum specified level

	80	85	90	95	100	105
Yellow corn	760.28	738.68	713.60	688.54	663.45	638.36
Poultry oil	11.53	14.70	18.44	22.16	25.89	29.63
Soybean meal	197.18	215.31	236.65	257.98	279.32	300.66
Ground limestone	8.41	8.24	8.02	7.82	7.61	7.40
Dicalcium phosphate	10.70	10.60	10.48	10.35	10.23	10.11
Feed grade salt	5.73	5.72	5.71	5.70	5.69	5.69
DL-Methionine	1.58	1.83	2.05	2.26	2.48	2.70
L-Lysine HCl	1.84	1.95	1.96	1.98	1.99	2.00
L-Threonine	0.47	0.58	0.64	0.70	0.76	0.81
L-Valine	0.03	0.14	0.20	0.26	0.33	0.39
2 X broiler premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Coban 90	0.50	0.50	0.50	0.50	0.50	0.50
Mintrex P_Se[1]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Crude protein	15.83	16.56	17.40	18.25	19.09	19.93
Calcium	0.66	0.66	0.66	0.66	0.66	0.66
Total P	0.53	0.54	0.55	0.55	0.56	0.57
Nonphytate P	0.31	0.31	0.31	0.31	0.31	0.31
ME kcal/lb	1451.91	1451.91	1451.90	1451.90	1491.90	1451.90
ME kcal/kg	3200.00	3200.00	3200.00	3200.00	3200.00	3200.00
Methionine	0.43	0.47	0.50	0.53	0.56	0.59
Lysine	0.91	0.97	1.03	1.09	1.14	1.20
Threonine	0.63	0.67	0.71	0.75	0.79	0.83
TSAA	0.70	0.74	0.79	0.83	0.87	0.91
Gly+Ser	1.42	1.48	1.56	1.64	1.71	1.79
Dig Met	0.39	0.42	0.45	0.48	0.51	0.54
Dig Lys	***0.85***	***0.90***	***0.95***	***1.01***	***1.06***	***1.11***
Dig Trp	***0.15***	0.16	0.17	0.19	0.20	0.21
Dig Thr	***0.55***	***0.59***	***0.62***	***0.66***	***0.69***	***0.72***
Dig Val	***0.66***	***0.70***	***0.74***	***0.79***	***0.83***	***0.87***
Dig Ile	0.58	***0.61***	***0.65***	***0.69***	***0.72***	***0.76***
Dig TSAA	***0.62***	***0.66***	***0.70***	***0.74***	***0.77***	***0.81***

[1]As given in Table 1.

Table 4. Performance by age and strain

	20 d				35 d				41 d			
Strain (ST)	BW kg	FCR kg/kg	FI	Mort %	BW kg	FCR kg/kg	FI	Mort %	BW kg	FCR kg/kg	FI	Mort %
Heritage	0.390^{d}	1.551^{a}	0.605^{d}	0.625	0.924^{d}	1.799^{a}	1.677^{d}	0.833	1.189^{d}	1.922^{a}	2.301^{d}	0.833
Ross 308	0.759^{a}	1.413^{b}	1.079^{a}	0.625	2.064^{a}	1.621^{b}	3.376^{a}	0.833	2.747^{a}	1.693^{b}	4.680^{a}	0.833
Ross 708	0.722^{b}	1.416^{b}	1.023^{b}	0.416	1.992^{b}	1.598^{bc}	3.211^{b}	1.041	2.650^{b}	1.670^{b}	4.458^{b}	1.458
Ross TY	0.658^{c}	1.423^{b}	0.945^{c}	0.416	1.890^{c}	1.591^{c}	3.024^{c}	0.416	2.540^{c}	1.66^{b}	4.271^{c}	0.833
% AA												
0.8	0.570^{d}	1.543^{a}	0.880^{c}	0.937	1.591^{d}	1.730^{a}	2.789^{bc}	0.312	2.130^{d}	1.802^{a}	3.866^{c}	0.937
0.85	0.603^{c}	1.488^{b}	0.895^{c}	0.312	1.648^{c}	1.698^{a}	2.770^{c}	0.937	2.200^{c}	1.786^{a}	3.859^{c}	0.937
0.9	0.628^{b}	1.449^{c}	0.907^{bc}	0.625	1.711^{b}	1.658^{b}	2.810^{bc}	0.937	2.275^{b}	1.747^{b}	3.908^{bc}	0.937
0.95	0.654^{a}	1.422^{d}	0.928^{ab}	0.937	1.774^{a}	1.600^{c}	2.820^{bc}	0.937	2.329^{a}	1.698^{c}	3.922^{bc}	0.937
1	0.667^{a}	1.406^{de}	0.934^{a}	0	1.787^{a}	1.617^{c}	2.909^{a}	0.937	2.371^{a}	1.698^{c}	4.020^{a}	1.25
1.05	0.668^{a}	1.401^{e}	0.935^{a}	0.312	1.792^{a}	1.608^{c}	2.86^{ab}	0.625	2.384^{a}	1.692^{c}	3.980^{ab}	0.937
Prob > F												
Strain	<.0001	<.0001	<.0001	0.9269	<.0001	<.0001	<.0001	0.6743	<.0001	<.0001	<.0001	0.6336
AA	<.0001	<.0001	<.0001	0.4151	<.0001	<.0001	0.0016	0.8867	<.0001	<.0001	0.0012	0.9971
Str x AA	0.0064	0.3633	0.168	0.1499	0.0456	0.8371	0.5685	0.1102	0.0511	0.6723	0.5142	0.2315
SEM	0.015	0.008	0.019	0.1567	0.048	0.011	0.069	0.1862	0.067	0.013	0.097	0.2043

Figure 1. Body weight at 20 days

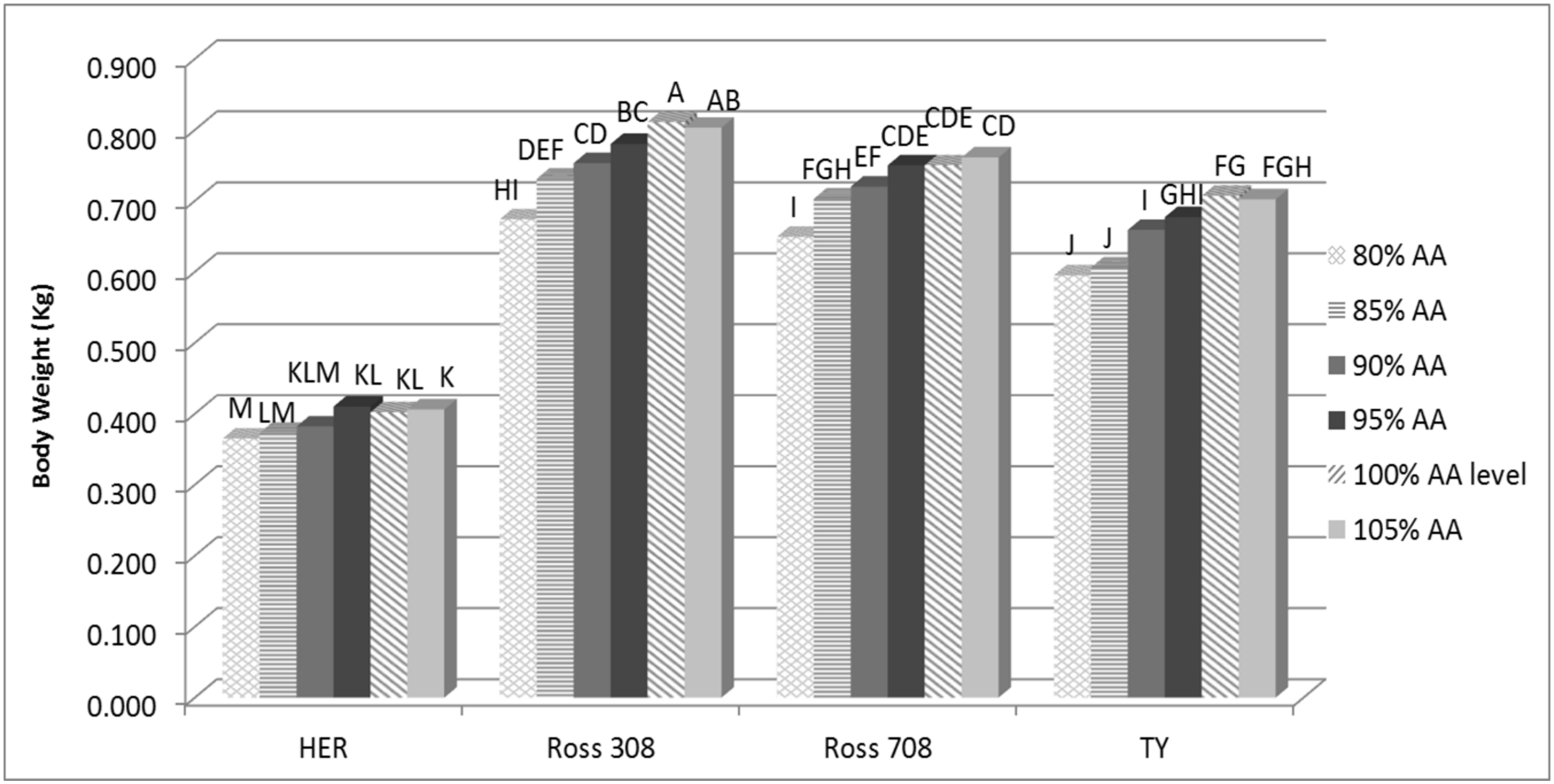


Figure 2. Feed Conversion Ratio at 20 days

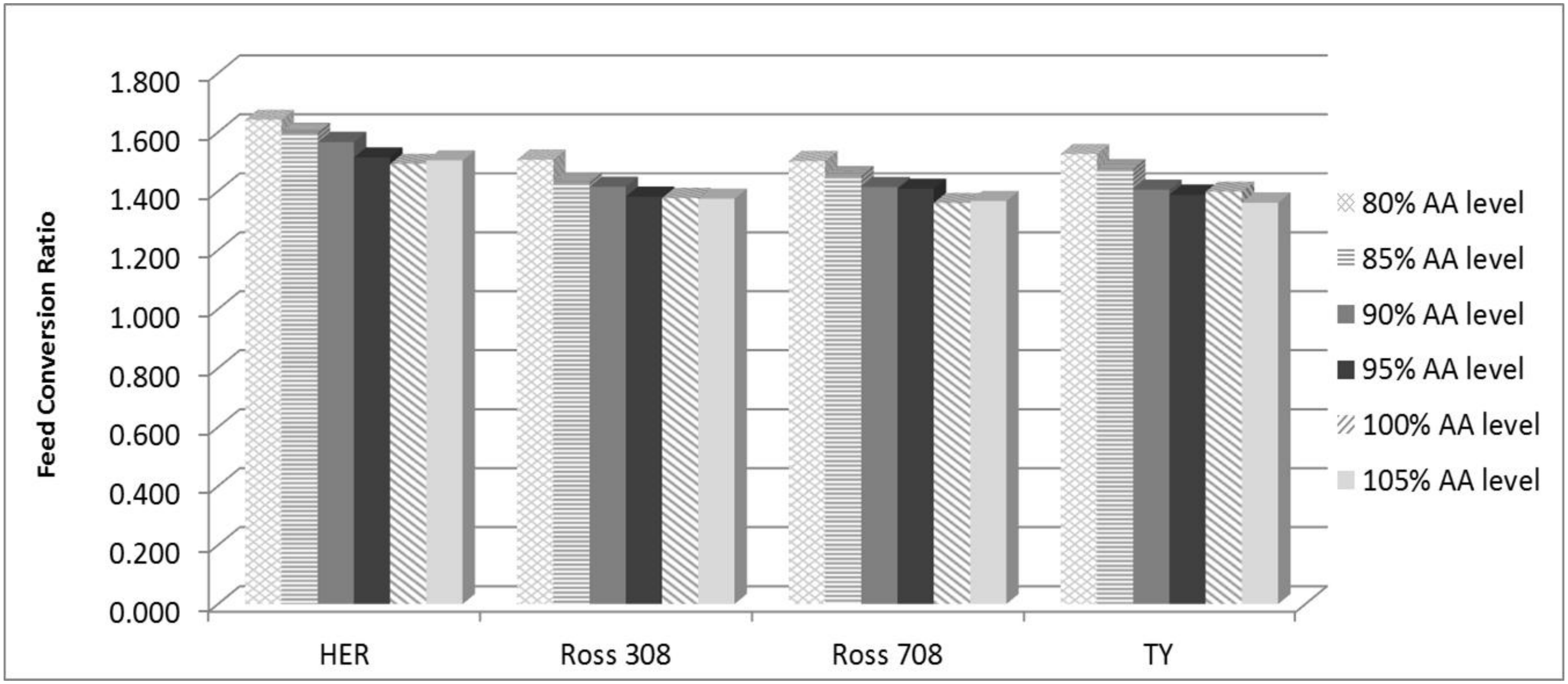


Figure 3. Feed intake at 20 days

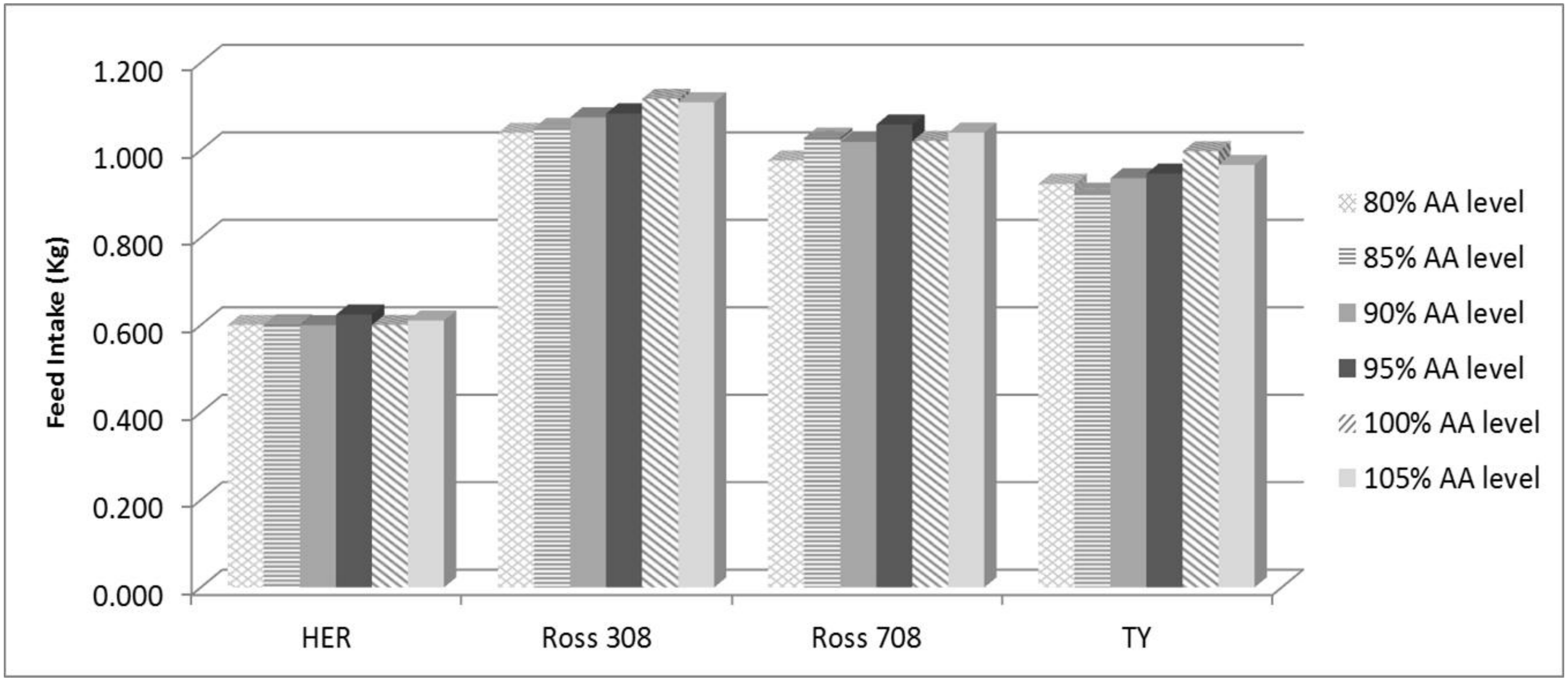


Figure 4.Body weight at 35 days

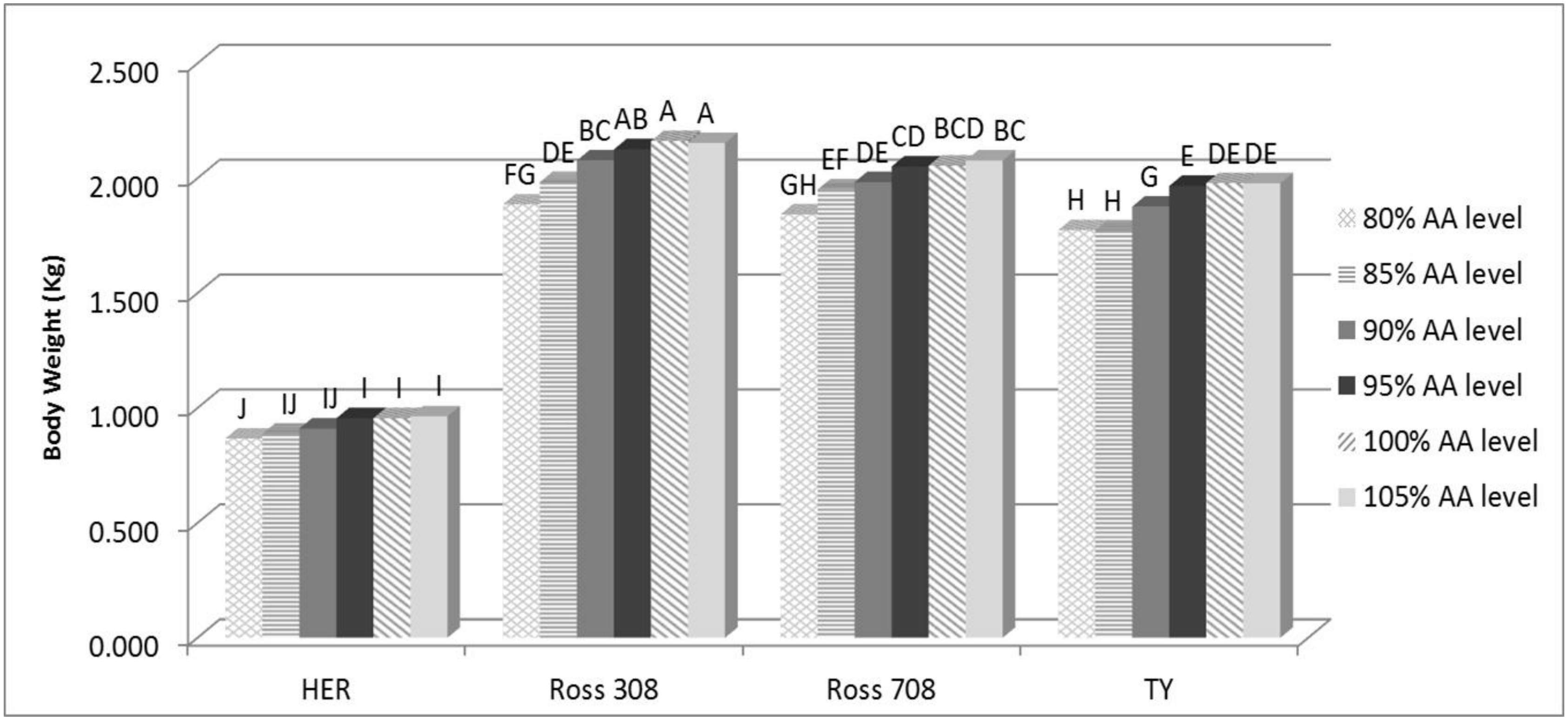


Figure 5. Feed conversion ratio at 35 days

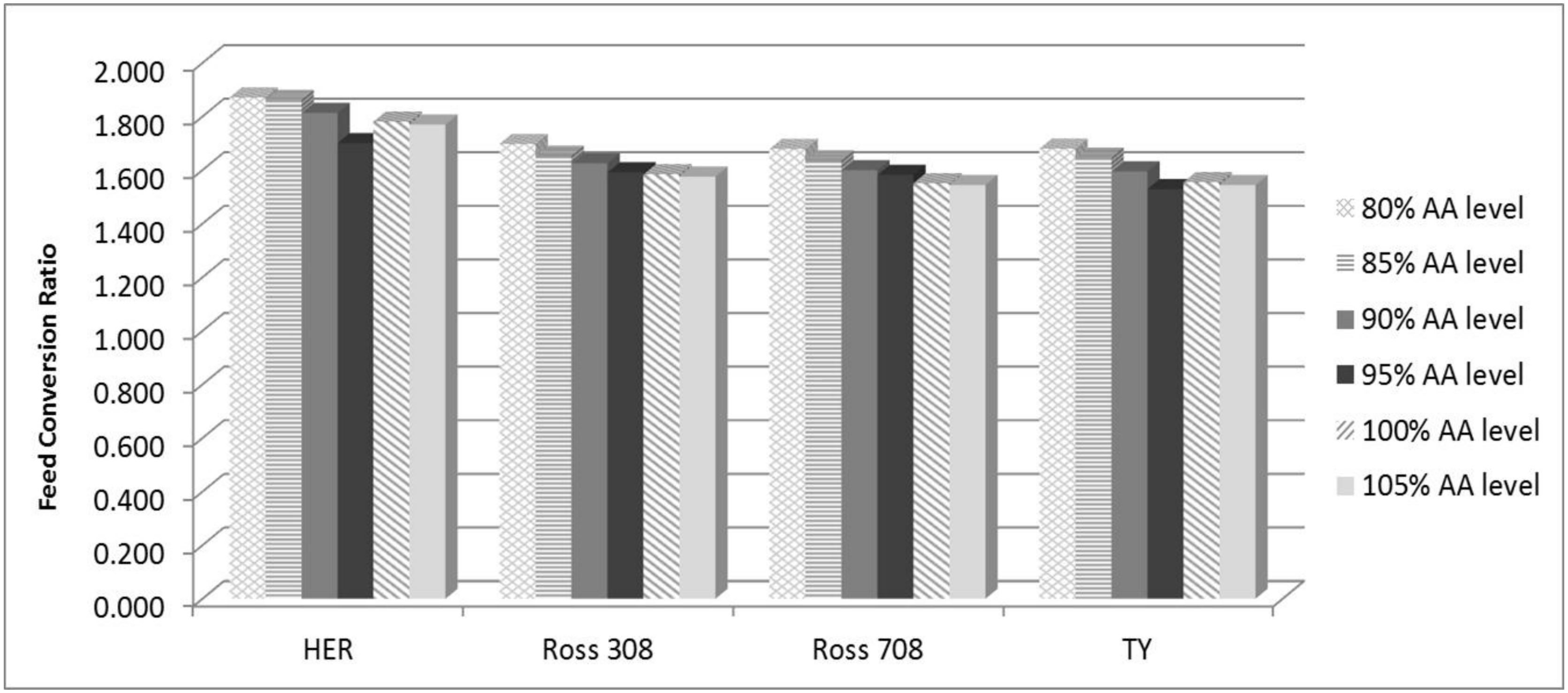


Figure 6. Feed intake at 35 days

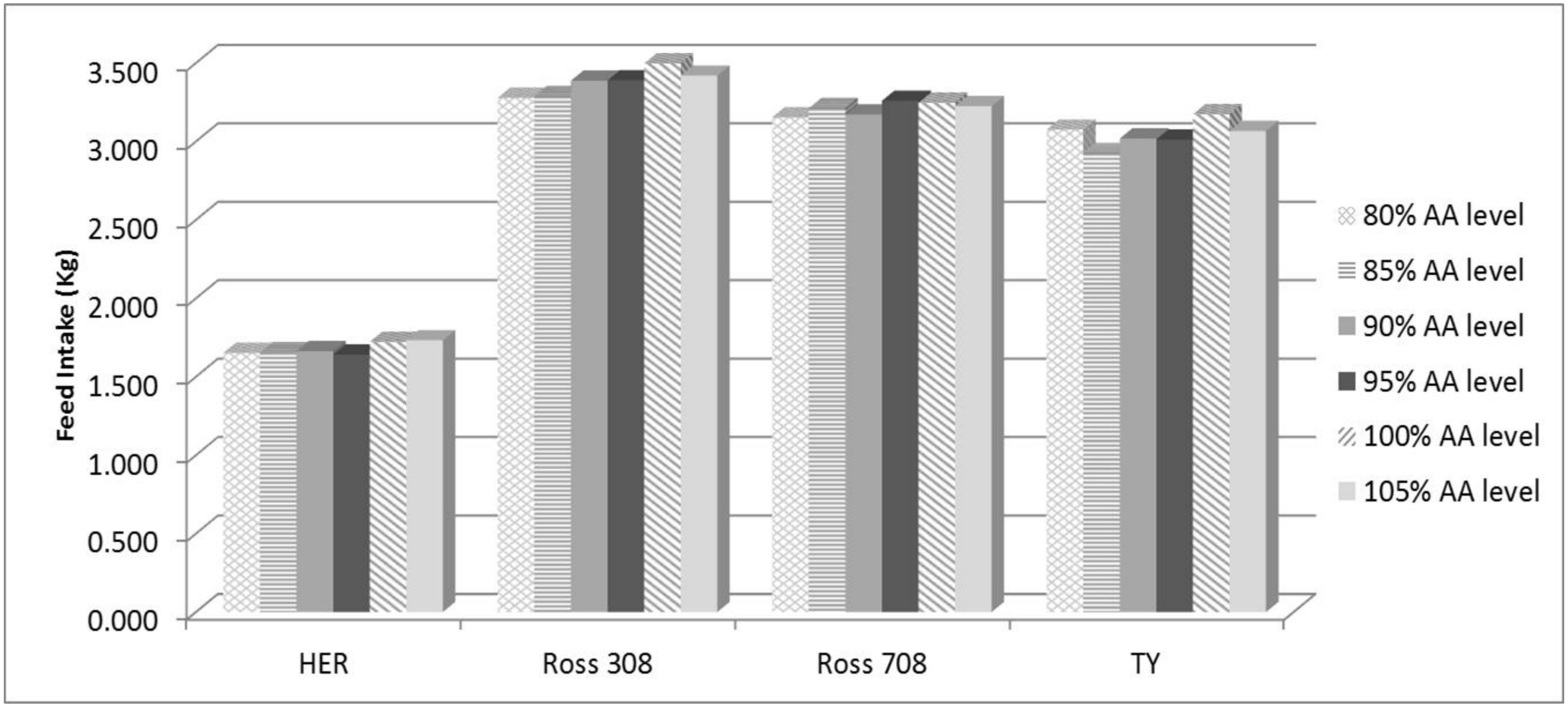


Figure 7. Body weight at 41 days

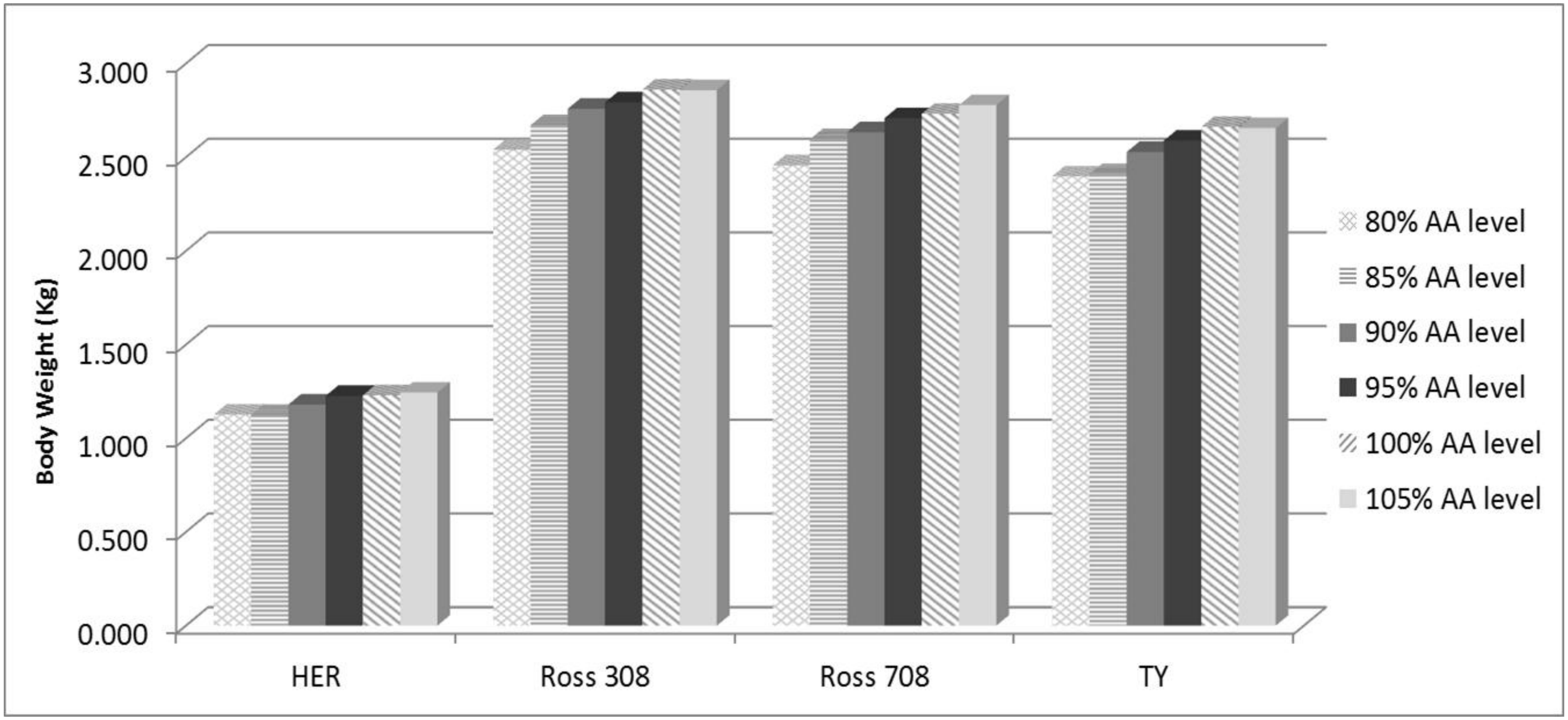


Figure 8. Feed conversion ratio at 41 days

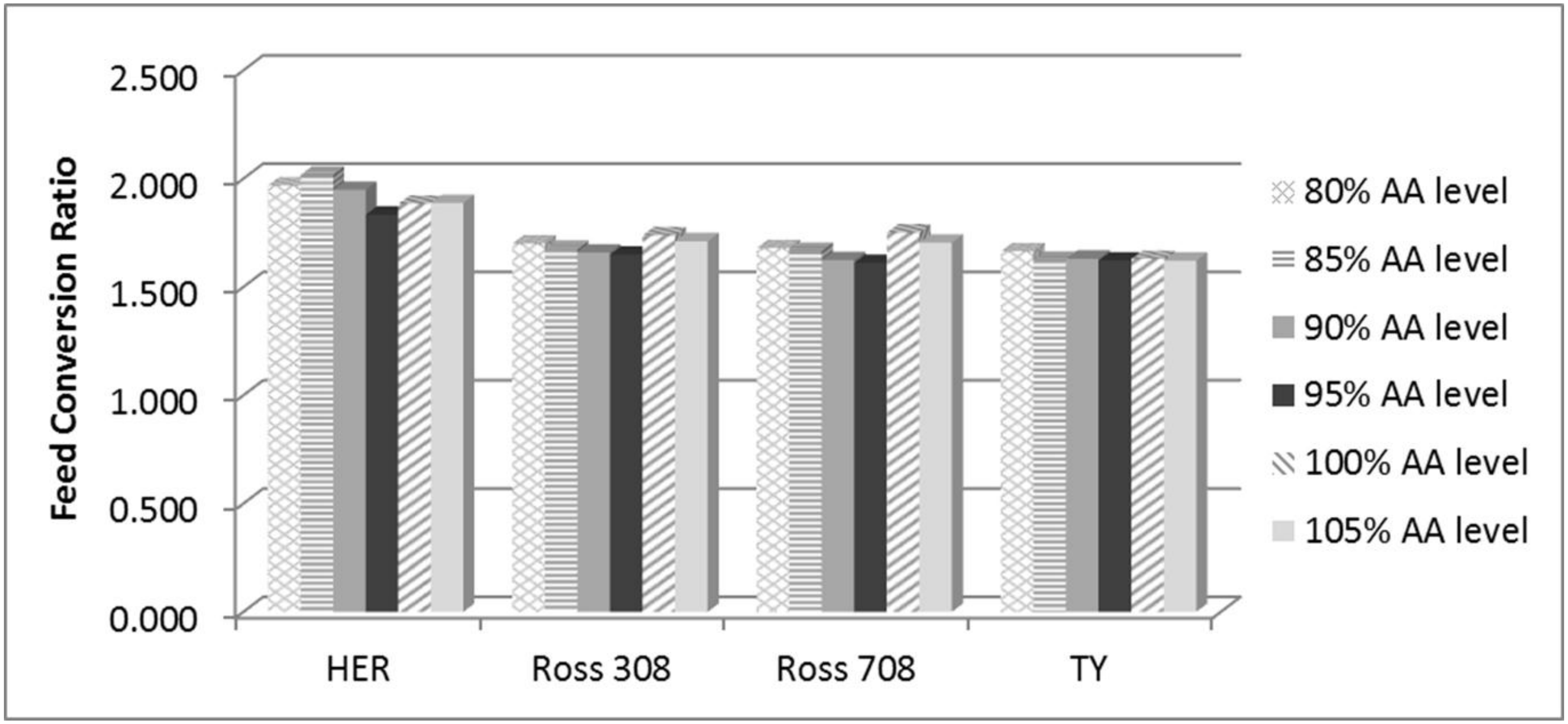


Figure 9. Feed intake at 41 days

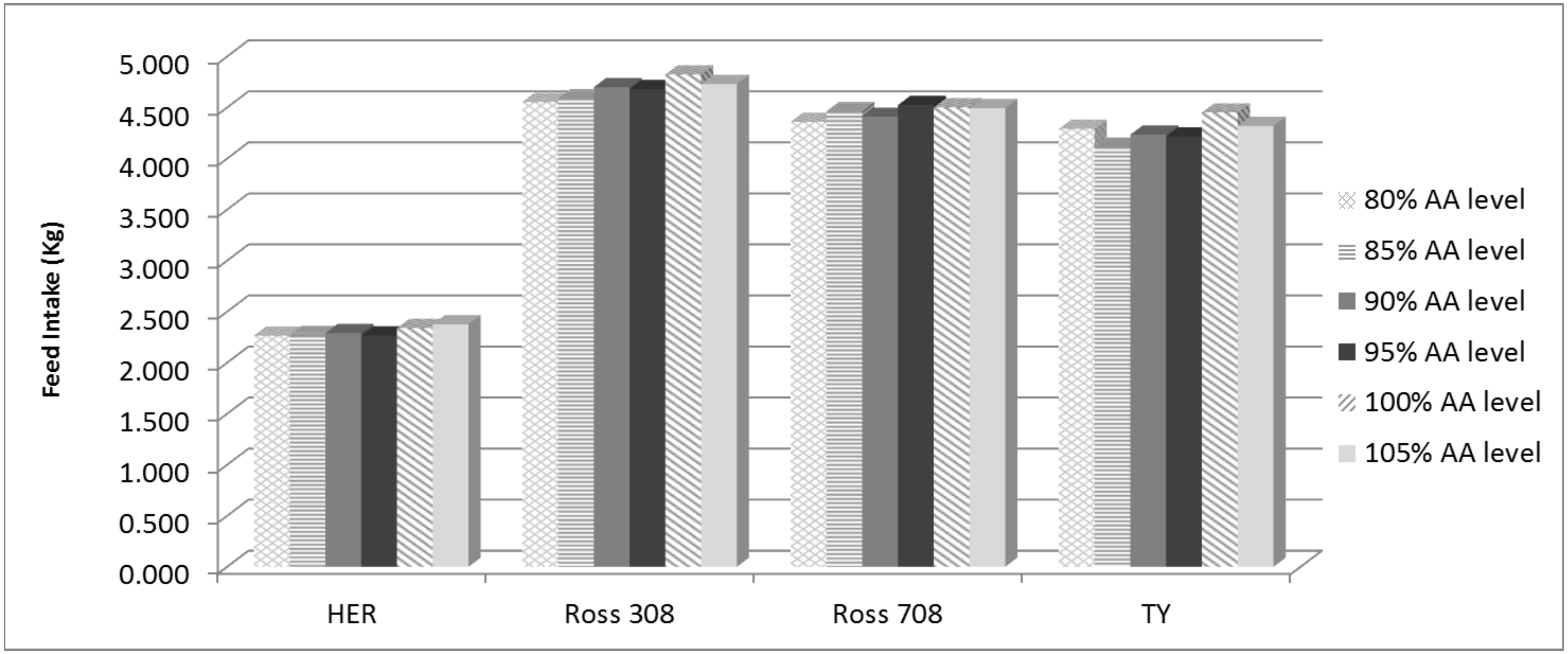


Table 5. Processing results at 42 days

Strain (ST)	Carcass Yield %	Wing %	Breast %	LQ %	Rack %	Breast (grs.)
Heritage	64.25[c]	8.96[a]	10.62[d]	22.53[b]	21.14[a]	126.26[b]
Ross 308	72.09[b]	7.48[c]	21.28[c]	23.17[a]	19.33[b]	602.22[a]
Ross 708	73.25[a]	7.46[c]	22.88[b]	22.67[b]	19.29[b]	615.41[a]
TY	73.32[a]	7.66[b]	23.40[a]	22.39[b]	19.05[b]	600.44[a]
% AA						
0.8	69.67[d]	7.91	18.28[d]	22.73	19.81	424.57[c]
0.85	70.43[c]	7.98	19.2[c]	22.54	19.83	450.27[c]
0.9	70.75[bc]	7.84	19.84[c]	22.48	19.69	496.01[b]
0.95	70.92[abc]	7.95	19.17[b]	22.90	19.88	480.90[b]
1	71.20[ab]	7.83	20.3a[b]	22.64	19.57	529.13[a]
1.05	71.40[a]	7.81	20.47[a]	22.85	19.42	535.63[a]
Prob > F						
Strain	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
AA	<.0001	0.1473	<.0001	0.2958	0.4879	<.0001
Str x AA	0.0114	0.0303	0.3672	0.6214	0.5461	0.0104
SEM	0.251	0.045	0.336	0.065	0.091	13.79

Figure 10. Carcass Yield (%)

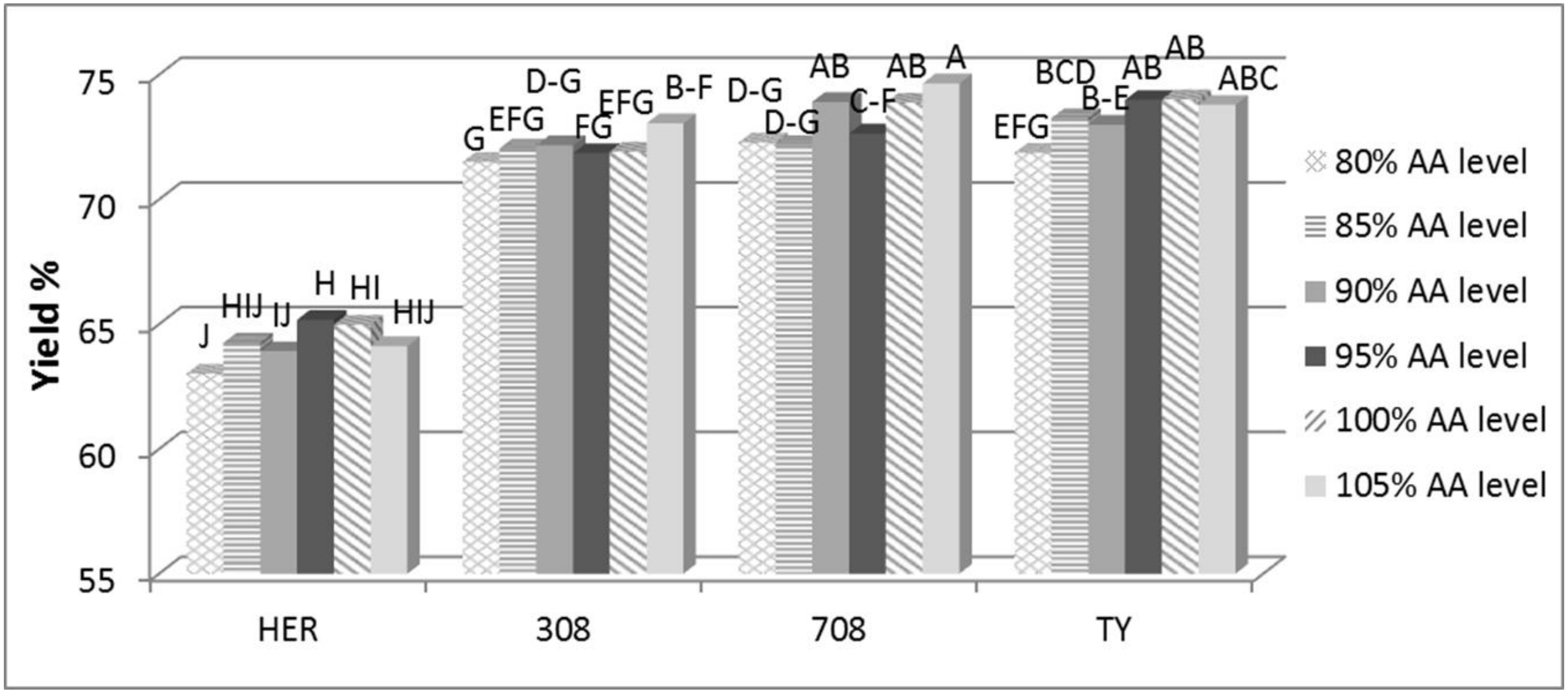


Figure 11. Wing Yield (%)

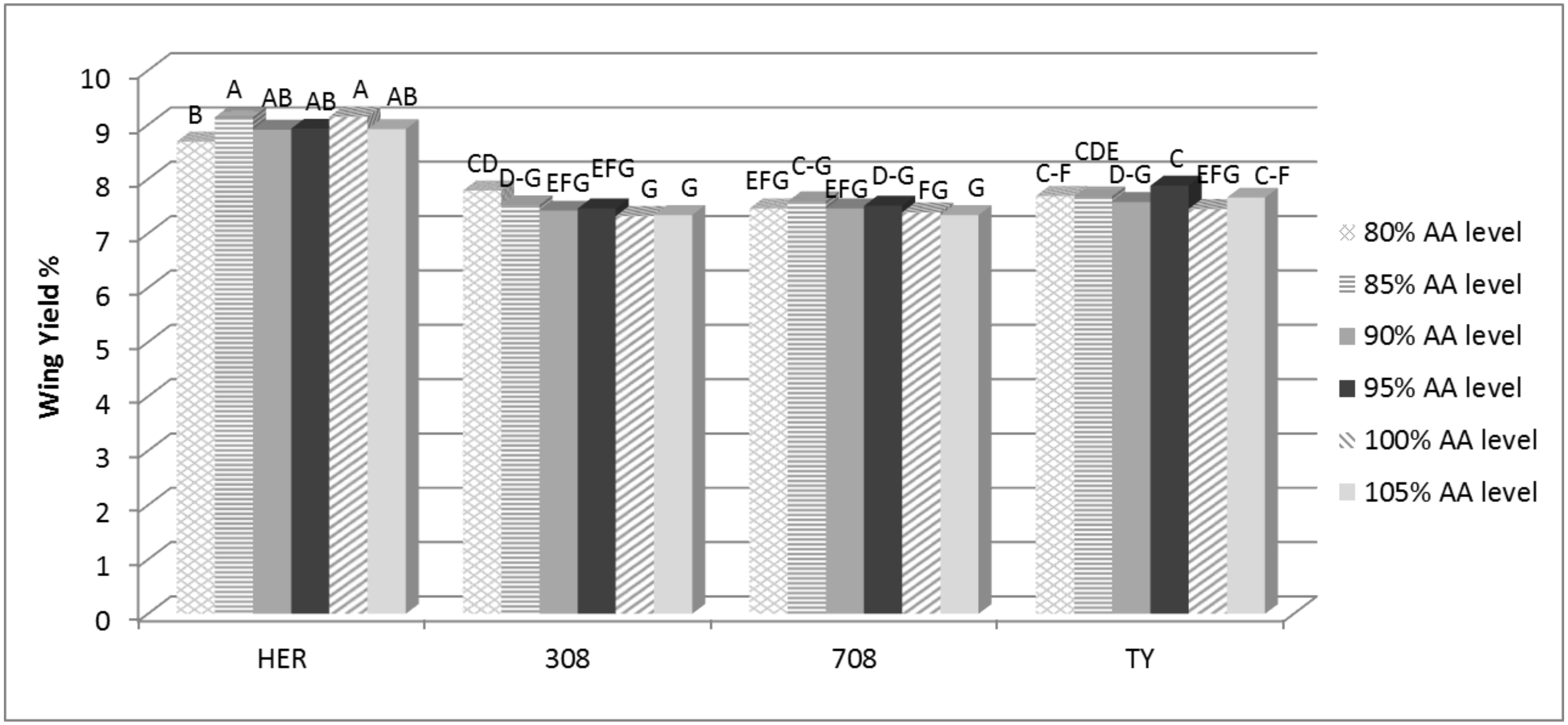


Figure 12. Breast Meat Yield (%)

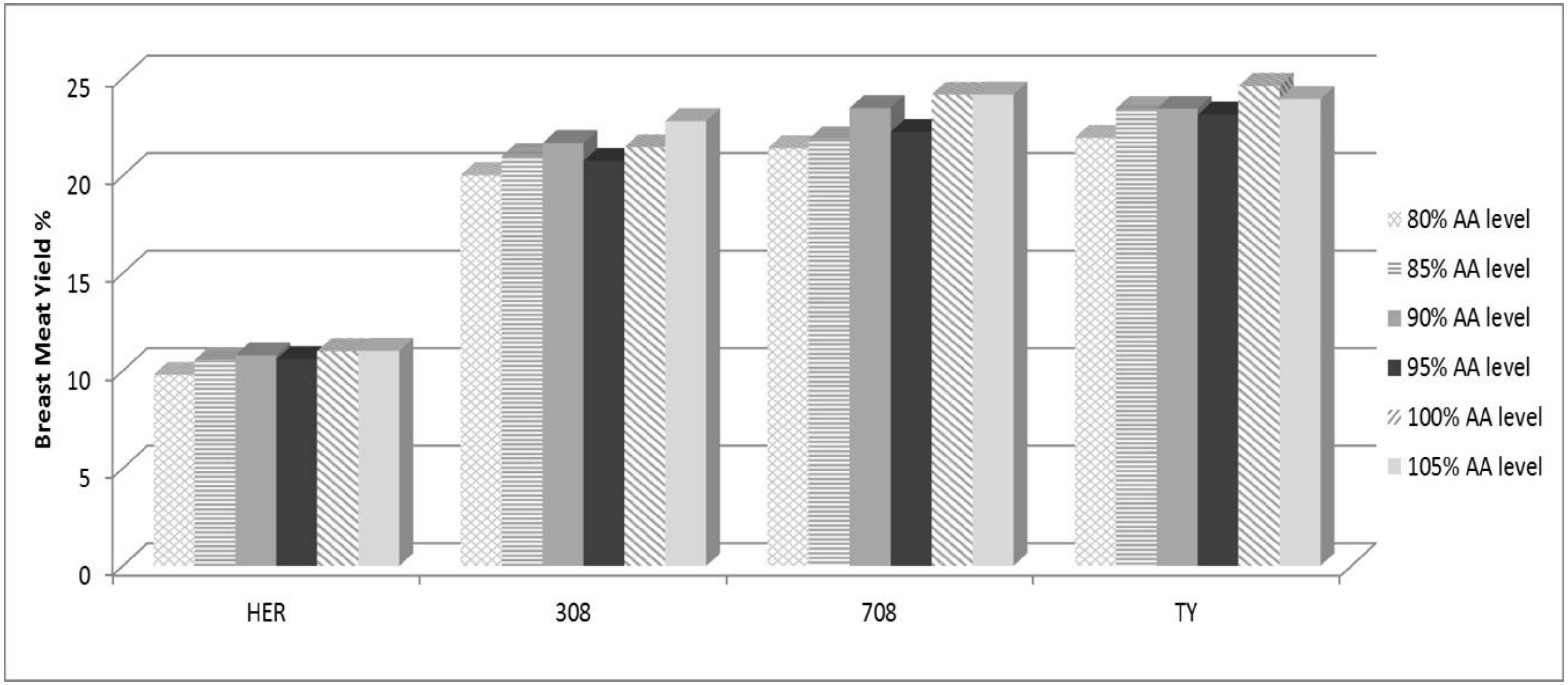


Figure 13. Leg Yield (%)

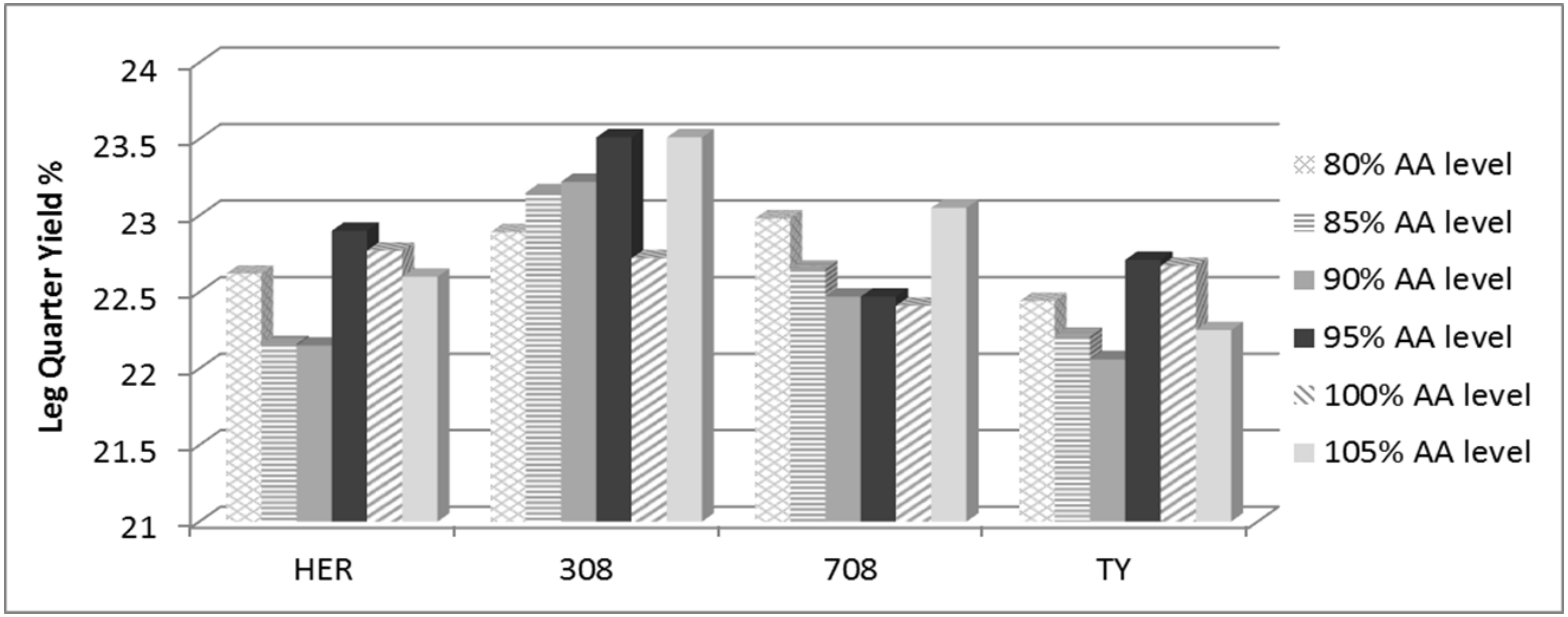


Figure 14. Rack Yield (%)

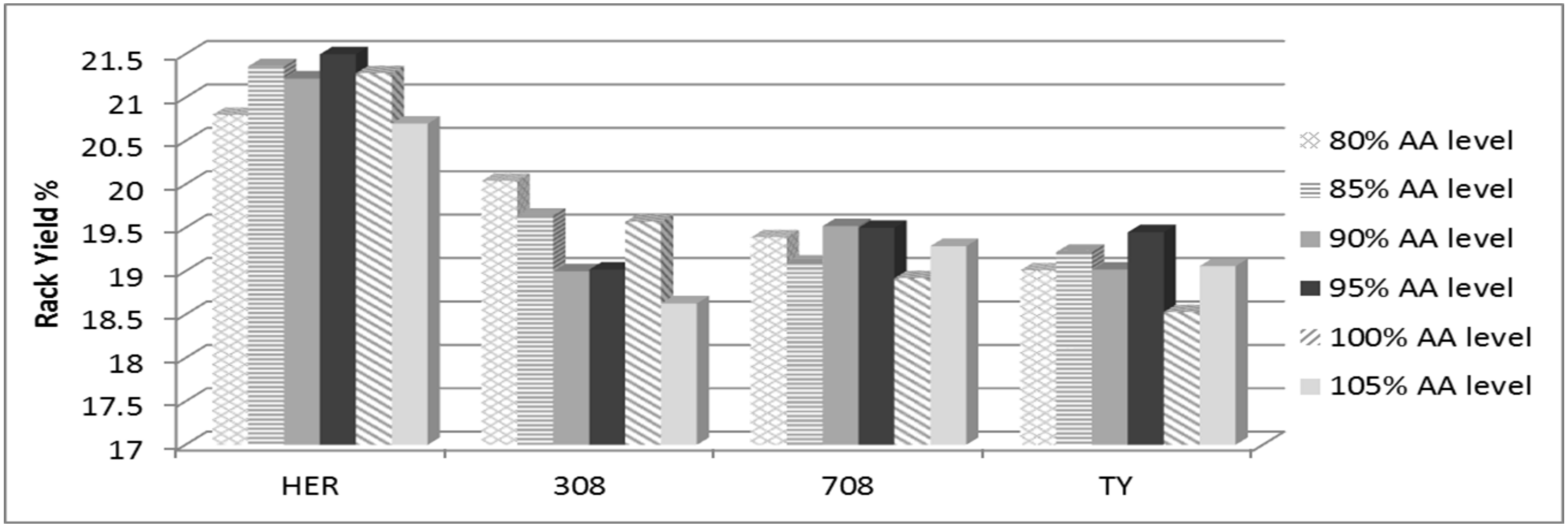
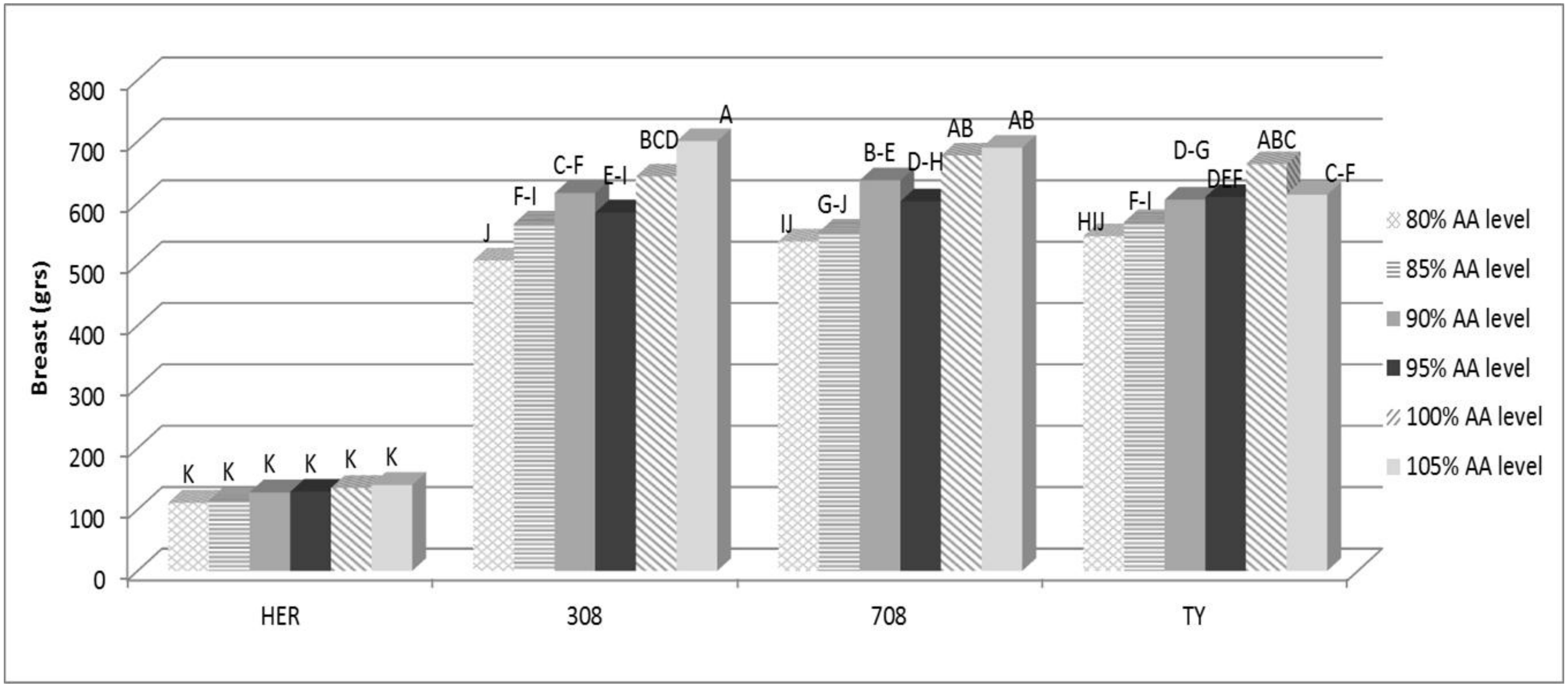


Figure 15. Total breast weight



CONCLUSION

The changes in different broiler genotypes due to intense genetic selection, together with the response of these genotypes to different dietary nutrient levels, were evaluated in three different studies. Current genotypes (high yield and multipurpose strains) used

widely in the poultry industry and an old strain (Heritage) unselected since the 1950's were compared. A strong difference in performance was observed in the three studies, with the current genotypes growing faster and utilizing feed more efficiently than the old one. At the same time numerous morphometric differences were observed in the first study. Current genotypes had much higher breast meat yield compared to the old one. In modern strains, jejunum and ileum segments of the small intestine had higher relative length as well as total villi length, increasing digestive and absorptive surface area. Gizzard and heart relative weights were reduced in current strains. Tibia break force increased in modern strains, though tibia diameter decreased.

Genotypes responded differently to different dietary energy levels. Heritage birds reduced feed intake to regulate energy intake and its performance was not affected by the energy levels. High yield modern strains reduced feed intake reducing body weight gain and increasing caloric conversion ratio. The multipurpose strain increased feed intake with increasing levels of energy increasing caloric conversion ratio and slightly increasing body weight. No effect was observed in processing parameters due to the different energy levels.

Response to different levels of dietary amino acids was different between the heritage and the modern strains. The old strain did not respond to increases in amino acids levels while the modern strains increased body weight gain, decreased feed conversion and increased breast meat yield.

In summary, significant differences between the heritage line and the current lines have been detected as a consequence of intense genetic selection. Morphometric differences should be considered when continuing genetic selection since these could have negative effects in the broiler performance. At the same time, differences between modern genotypes could be used to formulate specific feed programs for each strain maximizing performance and economic return of broilers.