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SPECIALTY POULTRY PRODUCTION: IMPACT OF GENOTYPE, FEED STRATEGIES, ALTERNATIVE FEEDSTUFFS, AND DIETARY ENZYMES ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF HERITAGE BREED CHICKENS

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DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

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ABSTRACT OF DISSERTATION

SPECIALTY POULTRY PRODUCTION: IMPACT OF GENOTYPE, FEED STRATEGIES, ALTERNATIVE FEEDSTUFFS, AND DIETARY ENZYMES ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF HERITAGE BREED CHICKENS

There is a growing market for specialty poultry production using alternative genotypes and management systems. However, producers interested in specialty poultry production face several challenges. One challenge is that little published data exists regarding the growth and production parameters for alternative genotypes like slow-growing meat strains and heritage breeds. To address this challenge, research at the University of Kentucky examined the effect of feed strategies, alternative feedstuffs, and dietary enzymes on the growth and performance of heritage breeds of chicken used for either egg- or meat-production. The first trial documented the growth and nutrient intake of pullets from three heritage breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp) and three egg-laying strains (Red Star, Black Star, and ISA Brown) on a self-selection feeding program through nineteen weeks of age. The second trial documented the growth and nutrient intake of males from those same three heritage breeds, a slow-growing meat-type strain (Red Ranger), and males and females from a fast-growing meat-type strain (Cornish Cross). Birds used a self-selection feeding program and were grown to a common weight of 2300 grams. Carcass characteristics of these birds were evaluated in the third trial. The fourth trial evaluated the partial replacement of corn and soybean meal with alternative feedstuffs (field peas, buckwheat, and flax seed) and dietary enzymes on the performance of straight-run commercial broilers and two alternative breeds of chickens: males from a Black Sex-Link cross and straight-run Rhode Island Reds. The fifth trial examined the use of sorghum and field peas to completely replace corn and soybean meal in formulated diets for two heritage breeds (Rhode Island Red and Barred Plymouth Rock). Results of these trials showed that heritage breed pullets had similar growth parameters and nutrient intake as commercial egg-laying strains. Heritage breed cockerels grew significantly slower and exhibited poorer feed efficiency than meat-type birds, but seemed to tolerate low nutrient density diets better. Overall, the findings of these studies could help producers interested in raising slow-growing meat-type chickens and heritage breeds create accurate business plans and determine if they can profitably produce meat and/or eggs for niche markets.

KEYWORDS: heritage breed chickens, self-selection feeding, alternative feedstuffs, growth performance, carcass characteristics

Tatijana Marguerite Fisher

August 17, 2016

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1.1 Introduction

The poultry industry has spent decades figuring out how to quickly and efficiently produce enough chicken meat and eggs to keep up with growing consumer demand. To this end, chicken genetics companies have emphasized commercial traits such as rapid growth rate and efficient feed conversion. Now, a typical meat-type chicken grows to twice the size of a bird from 50 years ago in half the time while consuming less feed per pound of gain. Similarly, egg-type chicken strains produce more eggs. This selection process resulted in birds that can provide a large quantity of meat and eggs to meet consumer demand with relatively low production costs. However, the intensive selection for production traits has not been without its drawbacks.

Alongside improvements in production traits, several undesirable traits have also arisen. In meat-type birds, these undesirable traits include muscle myopathies (Richardson et al., 1980; Siller, 1985; Fanatico et al., 2007b; Castellini et al., 2008; Bailey et al., 2015), skeletal anomalies (Kestin et al., 1992; Lilburn, 1994; Rath et al., 2000; Corr et al., 2003; Paxton et al., 2013), and reduced adaptive immune function (Cheema et al., 2003; Schmidt et al., 2009; Zuidhof et al., 2014). Additionally, the restricted feeding programs that the parent stock of meat-type birds must be raised on to limit their growth presents an animal welfare concern (Weerd et al., 2009; De Jong and Guémené, 2011). In strains selected for high egg production traits, there is a high prevalence of keel bone fractures and deformities (Scholz et al., 2007; Weerd et al., 2009; Casey-Trott et al., 2015) which also represents an animal welfare concern.

With supply demands met, choices abound throughout the agricultural industry and producers are looking to set themselves apart. Additionally, consumers have become more concerned about their health, the lives of the animals they consume, and the impact they have on the planet. These concerns have resulted in a shift in consumer preferences towards food and farm practices that are viewed as more humane and natural and have sparked a debate over how food should be raised (Innes and Cranfield, 2009) and what food animals should be fed (Sapkota et al., 2007). Consumers want to purchase the "right" things, but most don't know what that is so they have a lot of questions about the food they consume: Are genetically modified organisms safe to consume? What about animals fed genetically modified organisms? Does the agricultural industry care about the welfare of their animals, or just profits? Are organic practices safer? Are they healthier? These are all questions that consumers wrestle with when purchasing food for their families. These questions and concerns have helped to fuel a growing niche market for specialty poultry production systems which include organic, free-range, pasture-raised, cage-free, antibiotic-free, etc. Regardless of whether these specialty systems are intrinsically better or not, they represent a growing portion of the agricultural market.

Capitalizing on this demand, large fast food companies like McDonald's and Burger King have announced moves towards using eggs sourced from suppliers that utilize cage-free egg production. Other major retailers like Whole Foods Markets Inc. have announced moves towards purchasing only slow-growing chickens which grow at a rate of approximately 50 grams per day and reach a marketable size about 23% slower than the industry standard (Gee, 2016). However, slow-growing chickens currently make up only a small fraction (1-3%) of the commercially available chicken genetic stock around the world (Gee, 2016) and many slow-growing genotypes are only available in Europe. Therefore, U.S.-based retailers cannot make this transition happen overnight.

1.2 Chicken genotypes

Modern commercial poultry production relies on multi-generational crosses to produce fast-growing meat birds and high-producing egg birds. These commercial strains have been heavily selected for traits suitable for intensive production systems. Meat-type strains have been selected for rapid growth and meat production, while egg-type strains have been selected for persistency of lay and increased egg size. While these intensively-selected strains perform admirably in modern production systems, they may not be well-suited to alternative systems. (Fanatico et al., 2009). Therefore, interest has risen in using slower-growing strains of meat birds and hardier strains of laying hens. In the United States, a few slow-growing meat-type and moderate-producing egg-type strains have been developed, but there are not enough of them to meet the total demand. Therefore, one alternative is to consider using dual-purpose heritage breeds.

1.2.1 Dual-purpose heritage breeds

A heritage breed is one that physically conforms to the standards of the American Poultry Association, mates naturally, has a slow growth rate, and a long, productive lifespan. By definition, a breed is a group of animals with similar characteristics that will produce offspring with the same characteristics when bred together. In other words, each generation will look the same and possess the same production characteristics. Typically, new breeds in agriculture are developed due to geographic isolation or for specific purposes. Most heritage breeds were developed in the 19th century and continue to be marketed with the same claims regarding meat- and egg-production that were made at the time (Ussery, 2008). When compared with modern commercial strains, these breeds are said to have better fertility, better foraging ability, improved longevity, better disease resistance, and better tolerance to heat and cold than modern commercial strains (Heinrichs and Schrider, 2005). If true, these traits would make them better suited to specialty production systems than commercial strains, but most of the evidence to potentially support these claims is anecdotal. With that said, there is little doubt that heritage breeds represent an important reservoir of genetic traits that may be, or have already been, lost through intensive selection which could be vital to food security (Dale, 2003; Smith, 2004; Will, 2014).

Unfortunately, very little research has been done to assist producers interested in raising heritage breeds. When scientific data exists, it is from the 1940s and 1950s and is of little value today due to advances in nutrition and changes in bird genetics. Since the industry moved towards high-production genotypes, most heritage breeds have been selected for show traits (plumage, color, etc) rather than production traits. Therefore, important production characteristics such as growth rate, feed efficiency, and dressing percentage are simply not known for most breeds which leaves producers without accurate data with which to formulate business plans or to determine how to price their products.

1.2.1.1 Rhode Island Red

The Rhode Island Red is a red-feathered heavy egg-laying breed developed in Rhode Island in the 1880’s and 1890’s. The Rhode Island Red is one of the most popular heritage breeds of chicken in America and is what many people picture when they think of heritage breed chickens (Floyd, 2015). Rhode Island Reds lay brown eggs and are expected to produce between 200 and 300 eggs a year. Rhode Island Reds are also known for their hardiness and their ability to produce eggs in marginal conditions (Will, 2014). Females are expected to mature to a live weight of 2.9 kilograms while males are expected to mature to 3.9 kilograms.

1.2.1.2 Plymouth Rock

The Plymouth Rock was developed in New England in the 19^{th} century. The breed's most common color, the barred pattern (black feathers with white bars), is due to a dominant sex-linked gene. The Plymouth Rock is one of the most popular heritage breeds because they are relatively friendly and docile (Floyd, 2015). Additionally, the breed is well known for its hardiness, broodiness, and its meat- and egg-production relative to other heritage breeds (Will, 2014). Plymouth Rocks produce a brown egg. Females are expected to mature to a live weight of 3.4 kilograms while males are expected to mature to 4.3 kilograms.

1.2.1.3 Black Australorp

The Black Australorp was developed in Australia and introduced to the United States in the 1920s. It was initially selected as a meat-producer, but was later developed for its egg-production qualities. While a typical Black Australorp can be expected to lay about 250 eggs per year, one hen set a world record when she laid 364 eggs in 365 days (Will, 2014). Today, the Black Australorp has also become the meat bird preferred by some ethnic populations because of its black feathers and dark shanks. Murray McMurray Hatchery describes the Black Australorp as excellent meat producers and good egg producers with good heat and cold tolerance. Females are expected to mature to 2.9 kilograms while males are expected to mature to 3.9 kilograms.

1.2.2 Meat-type strains

Commercial fast-growing meat-type strains have been developed with a focus on rapid growth and efficient conversion of feed to meat. While interest in slow-growing chickens has increased, slow-growing chickens currently make up a small fraction (1-3%) of commercial chicken genetics globally (Gee, 2016). The European Union, which has a longer history of specialty poultry production, has several slower-growing meat chicken strains commercially available, but these strains aren't available in the United States (Fanatico et al., 2009).

1.2.2.1 Cornish x Rock Cross

The Cornish Cross is a white-feathered, yellow-skinned, fast-growing meaty chicken originally produced by crossing Cornish chickens on Plymouth Rock chickens. Multiple commercial strains are now produced through a variety of multi-generational crosses that have been intensively selected for meat production traits. Murray McMurray Hatchery describes their Cornish Cross as a great meat producer with good cold tolerance, but poor egg production and poor heat tolerance. The Cornish Cross is expected to have a 70% live to dress weight yield with a unique physical conformation of broad breasts and big thighs. Depending on their feeding programs, males will reach a 2.3 kilogram live weight in 6 to 8 weeks. Females are expected to take about a week longer to reach the same body weight. As with other hybrid strains, the Cornish Cross is a hybrid that will not breed true. Additionally, the Cornish Cross birds are at risk of leg problems and other issues due to their rapid growth.

1.2.2.2 Red Ranger

The Red Ranger is one of the few slower-growing meat-type strains of chicken available in the United States. It is a red-feathered and is expected to reach 1.4 to 1.8 kilograms by 8 weeks of age. Anderson et al. (2015) described the Red Ranger as a "heat-tolerant meat bird with moderate egg production". Murray McMurray Hatchery advertises the Red Ranger as an excellent forager with excellent meat production and suggests a 3.0 kilogram live weight at about 80 days of age. The Red Ranger is supposed to have a 70% dressed-weight yield with breast in natural proportion to leg meat. Red Rangers are not recommended for reproduction because they are a hybrid strain and will not breed true.

1.2.3 Egg-type strains

Egg-type strains were developed with a focus on production parameters such as persistence of lay and increased egg sizes (Jones et al., 2001; Leenstra et al., 2016). While these birds are not used for meat production, a few studies have examined the viability of egg-type males as meat birds in response to the backlash against the culling of male chicks within the egg industry (Lichovnikova et al., 2009; Bertechini et al., 2014). Several of the older egg-type strains utilize sex-link crosses. A sex-link cross is one in which the chick can be sexed by the color of its down at the time of hatch. This method of sexing is easier and cheaper than vent sexing or raising birds until secondary sex characteristics begin to develop. Sex-link chickens are produced by crossing two breeds or strains with specific color traits to create a hybrid. This process takes advantage of color inheritance in chickens. Males are homogametic, so they carry two copies of the Z sex chromosome. Females are heterogametes carrying one Z sex chromosome and one W sex chromosome. The genes for some colors are carried on the Z sex chromosome, so males have two copies and females have one copy of these genes.

One common sex-link cross is produced using a barred hen and a solid male. The barred feather color results from a copy of the black gene and the barring gene. When a barred hen is crossed on a solid male, the male chicks get a dose of the barring gene while the female offspring do not. This results in barred sons and solid daughters. At hatch, the female chicks are solid black while the males are black with a white dot on their heads. On the other hand, a barred male mated on a solid female will produce all barred offspring.

Another common sex-link cross is produced by taking advantage of the silver gene which is often found in white chickens. The silver gene is dominant, so it requires only one dose for expression. When a female hen with the silver gene is crossed on a non-white male, the male offspring will be white (silver) and the female offspring will be colored like the sire. When a solid-colored male is used, male chicks have yellow down and females will usually be red or buff. When a barred male is used, the male chicks will have yellow down and the female chicks will be black with white dots and grow to have barred feathers.

1.2.3.1 Black Star

The Black Star is a Black Sex-Link hybrid. At hatch, pullets are solid black and feather out black. Males hatch out black with a white dot on their heads and feather out with black/white barred feathers. The Black Star lays brown eggs. Murray McMurray Hatchery advertises the Black Star as a wonderful layer with good heat tolerance, excellent cold tolerance, and good foraging capabilities. Females should begin laying eggs around 22 to 24 weeks of age and mature to a live weight a little over 2.3 kilograms. Males are expected to reach a standard butcher weight at 16 to 20 weeks of age and mature to about 3.6 kilograms.

1.2.3.2 Red Star

The Red Star is a red sex-link hybrid developed by Hendrix Genetics. At hatch, males are white and feather out to pure white. Females hatch out a reddish orange color and feather out some combination of red and buff. Murray McMurray Hatchery advertises the Red Star as a great egg layer and decent meat bird with good foraging abilities, good heat tolerance, and excellent cold tolerance. Females lay brown eggs and should begin lay around 18 to 20 weeks of age and mature to about 2.7 kilograms. Males should reach a standard butcher weight at 16 to 20 weeks of age and mature to about 3.6 kilograms.

1.2.3.3 ISA Brown

The ISA Brown is a sex-link cross produced by the Institut de Selection Animale by crossing Rhode Island Red type male on a commercial White Leghorn female. ISA Browns are prolific layers and lay a brown egg.

1.3 Research on alternative genotypes

While some research has been done to compare the production characteristics of fast-growing and slow-growing meat-type birds, little data exists regarding the production parameters of heritage breeds.

1.3.1 Research on heritage breeds

One of the few recent publications specific to heritage breed production traits was a study by McCrea et al. (2014) comparing the production of Delaware chickens to a modern broiler. Birds were placed as hatched and were raised in indoor floor pens with natural day lengths. The Delaware chickens took 15 weeks to reach the same live body weight as a 6-week-old broiler, and required twice as much feed (Feed conversion ratio: 1.75 grams of feed per gram gain for broilers; 3.46 grams of feed per gram gain for Delaware chickens). Additionally, the Delaware chickens had lower carcass dressing percent than broilers (65 vs 68%) despite being processed at the same live weight. However, Delaware chickens exhibited lower mortality than broilers (1.6 vs 11.8%), though the authors noted that their sample size was small.

While the McCrea et al. (2014) study was one of the only studies to look at production traits, several researchers have studied heritage breeds to evaluate their susceptibility to *Salmonella* species. Eggs produced by chickens from non-commercial breeds and strains had varying ability to restrict the penetration of *Salmonella* (Jones et al., 2004). Kaur et al. (2013) found differences in the thickness of shell layers as well as in profiles of the matrix proteins that control crystal formation during eggshell production which could influence the size and shape of pores in the shell. Rathgeber et al. (2013) found that the eggs produced by Barred Plymouth Rock were similar in size to those produced by a commercial laying hen (Lohmann LSL-Lite), but their shells were weaker. However, bacterial penetration of Barred Plymouth Rock shells was lower. These results indicated that eggshell resistance to *Salmonella* was influenced by breed, but could not be explained by shell quality differences. Finally, research by Anderson et al. (2015) identified the Dark Cornish, New Hampshire Red, Red Ranger, and Sicilian Buttercup among chicken breeds and strains found to have low susceptibility to *Salmonella* colonization.

1.3.2 Research on egg-type males

Worldwide, 3.34 billion day-old female egg-laying type chicks are hatched each year, and a similar number of male chicks are discarded (Bertechini et al., 2014). Egg producers have been under pressure to change their production practices (Mench et al., 2011) which has led researchers to consider uses for the male egg-laying type chicks.

A study by Bertechini et al. (2014) examined the utility of males from white- or brown-egg-laying strains as meat birds. Their data is included in Table 1.1. At 42 days of age, birds from the brown-egg-laying strain were heavier than birds from the white-egg-laying strain (788 vs. 622 grams) and both were significantly lighter than a typical meat-type bird would have been. The authors noted that the composition of the breast meat muscle of the egg-laying strains were similar to that of broilers, but the breast meat had lower L*, higher a*, and lower b* than typically seen in the literature for broilers (Broiler values: L* = 55.0 a* = 2.2 b* = 9.6; Van Laack 2000). However, drip loss after 48-hour storage was lower than literature values for broilers (0.59 vs 1.42% at 48 hours; (Sirri et al., 2010)). Despite the low body weight, the authors suggested the egg-laying strains could be a viable option for meat production in some situations.

Table 1.1. Production parameters of males from white- and brown-egg-laying strains at 42 days of age (Bertechini et al., 2014)*

	White	Brown	Average	SEM
Growth performance				
Feed intake (days 1-42)	1595 [b]	1652 [a]	1623	13.8
Body weight gain (days 1-42)	606 [b]	741 [a]	673	7.9
Feed conversion (days 1-42)	2.6 [b]	2.2 [a]	2.4	0.02
Final body weight (42 days of age)	622 [b]	788 [a]	705	8.2
Carcass and part yields				
Carcass dressed ready to cook (w/o viscera, feet, head, neck)	61 [b]	62 [a]	61.4	0.45
Breast yield (% of carcass)	19.8 [a]	18.4 [b]	19.1	0.28
Thigh & drumstick yield (% of carcass)	25.9 [b]	27.4 [a]	26.7	0.26
Breast meat characteristics				
Drip loss (24 hours)	0.48	0.51	0.50	0.03
Drip loss (48 hours)	0.55	0.62	0.59	0.04
Lightness (L*)	39.55	40.55	40.05	0.25
Redness (a*)	4.47	5.26	4.87	0.21
Yellowness (b*)	6.63	6.5	6.72	0.27

*Means in the same row without common superscripts are different ($P < 0.05$)

In another study, Lichovnikova et al. (2009) compared the meat quality of males from a laying hybrid (ISA Brown) to a fast- growing broiler (Ross 308) raised under free-range conditions. The study compared the two strains at the same age at two different processing time points (49 and 90 days of age). As expected, the Ross 308 birds had higher live weights, carcass yields, breast meat yields than the ISA Browns. However, ISA Brown breast meat had a lower proportion of fat, significantly higher pH, and had better acceptability scores from a taste panel at 90 days of age. Therefore, the authors concluded that, from a meat quality standpoint, laying males are acceptable for alternative poultry meat production systems.

1.3.3 Research on slow-growing meat-type strains

Over the past several years, slow-growing broiler strains which reach a marketable weight in about 81 days have gained popularity in the European Union (EU) thanks to changes in organic legislation within the EU. While statistics aren't available on the exact numbers of slow-growing broilers in the EU, industry experts estimate they make up between 5 and 10% of total broiler production (Van Horne and Bondt, 2013). Currently, these slow-growing strains make up a very small portion of the poultry market in the United States. Most of their use is within the culinary community where slower-growing breeds are touted as having a richer flavor (Kronsberg, 2014). However, the use of slower-growing breeds may increase if methionine is removed from organic production or consumers continue to put pressure on retailers.

Due to the interest in these slower-growing strains, a growing body of literature exists regarding the growth performance, carcass characteristics, and meat quality of these strains. Rack et al. (2009) conducted a study to evaluate the effect of self-selection feeding and pasture access on slow- and fast-growing broilers fed diets devoid of synthetic methionine. When compared with slow-growing genotypes, fast-growing genotypes demonstrated superior growth performance and carcass characteristics. However, while the performance of the fast-growing birds was reduced when they were housed on pasture, slower-growing birds did not experience a reduction in performance.

Fanatico et al. have conducted numerous experiments to compare the performance of different genotypes (slow-growing, medium-growing, and fast-growing) raised indoors or with outdoor access. As expected, Fanatico et al. (2008) found that fast-growing genotypes had higher breast meat yield, whereas slow-growing genotypes had higher wing and leg yields. Interestingly, the breast meat of the slow-growing birds had more protein and a-tocopherol and half the amount of fat than the meat of fast-growing birds (Fanatico et al., 2007b).

In one study comparing a slow-growing genotype (81-day grow out) to two medium-growing genotypes (67-day grow out) and a commercial fast-growing genotype (53-day grow out) raised either indoors or outdoors, Fanatico et al. (2005a) found that slow-growing birds spent more time outside and were more active than fast-growing birds. Fanatico et al. (2008) found slow-growing birds demonstrate better gait scores and lower incidence of tibial dyschondroplasia. Taken together, this may explain the findings of Rack et al. (2009) which showed that access to pasture decreased performance for the fast-growing broilers while having no effect on the growth of slow-growing broilers.

In another study where birds were provided with either a standard diet or a low-nutrient-density diet, slow-growing birds demonstrated reduced weight gain when fed a low-nutrient-density diet. However, birds from fast-growing genotypes increased their feed intake such that their body weight gain was unaffected, though breast yield was reduced and the birds exhibited poorer feed efficiency (Fanatico et al., 2008).

Additionally, Fanatico et al. (2005a) found differences in the meat quality of the genotypes with slow-growing birds having paler, less red breast meat with poorer water holding capacity when compared with meat from fast-growing birds. In the same experiment, a consumer panel considered meat from all treatments to be tender and weak in flavor with overall hedonics scores in the categories of “like slightly” or “neither like nor dislike” (Fanatico et al., 2006a). In a follow-up study, Fanatico et al. (2007a) compared the sensory attributes of chicken meat from a slow-growing genotype (91-day grow-out) to that of a fast-growing genotype (63-day grow-out) and found no significant differences in overall liking by a consumer panel. However, a trained descriptive panel described the meat from the slow-growing genotype as having more dark meat fat flavor than the fast-growing birds. Taken together, the results of these studies suggest that the claims within the culinary community that slow-growing birds have a richer flavor (Kronsberg, 2014) may be true, but the difference cannot be perceived by the average consumer. However, as suggested by the research by Napolitano et al. (2013), consumer preference for chicken breast may be more affected by information on production than by the sensory properties of the product. Therefore, providing information on product labels that suggests better production practices may increase consumer preference for these products regardless of whether the consumer can perceive an actual difference in flavor or texture.

1.3.4 Research on historical broiler lines

Additional research has been conducted to compare modern broilers with unselected, random-bred populations that have been maintained at various universities. While these birds are no longer used in the commercial industry, they represent an important resource which may help to identify and characterize the genetic changes that have taken place through intensive selection. Most of this research has focused on the effect of intensive selection on meat-type birds, but has also explored some of the changes in high-producing commercial laying hens.

In a series of experiments, Havenstein et al. noted substantial growth improvement when comparing a random-bred bird representative of the 1957 genetics versus an Arbor Acres bird which is representative of the 1991 genetics (Havenstein et al., 1994a; Havenstein et al., 1994b) and a Ross 308 which is representative of the 2001 genetics (Havenstein et al., 2003b, a).

Schmidt et al. (2009) compared the tissue growth of a heritage broiler line maintained at the University of Illinois (UIUC) and a Ross 708 broiler. The UIUC heritage line was a New Hampshire x Plymouth Rock cross developed in the 1950s to represent the typical broiler utilized during that time. The UIUC has been maintained as a random-bred population since its development. The Ross 708 line was introduced in the early 2000s as a high-yielding meat chicken. Therefore, comparing these two lines provides insight into the changes that have occurred as a result of genetic selection for increased growth rate and feed efficiency over the span of 50 years. While Schmidt et al. (2009) found no difference between the lines for body weight at hatch, the Ross 708 line exhibited significantly faster growth rates. The Ross 708 averaged a live weight of 1.8 kilograms within 5 weeks post-hatch whereas the UIUC line averaged only about 1 kilogram over that same time period. Additionally, Looking at specific tissues shows a change in tissue accretion. At 5 weeks post-hatch, the breast muscle of the UIUC heritage line constituted 9% of the total body mass, whereas the breast muscle of the Ross 708 line constituted 18% of the total body mass. Additionally, the relative length of the small intestine was longer in the in the Ross 708 than in the UIUC. However, the relative weight of the heart muscle was smaller for the Ross 708 birds. When birds of equivalent mass were compared, the UIUC birds had larger hearts than the Ross 708 birds. The Ross 708 line had greater feed efficiency than the UIUC line throughout the experiment. Taken together, this demonstrates a clear difference in tissue accretion between the two lines and begs the question as to how the bird’s nutrient needs may have changed over time.

Zuidhof et al. (2014) compared a commercial Ross 308 strain (representative of the genetic stock available in 2005) to two University of Alberta Meat Control strains (one unselected since 1957, the other unselected since 1978). Birds were raised on a modern nutritional program to 56 days of age. Through their analyses, Zuidhof et al. (2014) found that broiler growth increased by over 400% with a concurrent 50% reduction in feed conversion ratio from 1957 to 2005.

Collins et al. (2014) raised a flock of 1955 meat-type chickens (the Athens Canadian Random Bred [ACRB]) alongside a flock of 2012 meat-type chickens (Cobb 500). ACRB were found to be significantly smaller at every age and exhibited a different body conformation. Specifically, the ACRB had significantly heavier feet, wings, internal organs, and feathers, and significantly smaller breast and leg muscles than the Cobb 500 broilers. Similar to previous findings, the Cobb 500 broiler had smaller organs as a percentage of body weight.

1.4 Alternative feeding strategies: self-selection feeding

Wild animals living in natural environments depend on instinct and appetite to select from available feeds in their environment to provide the nutrition needed to grow and reproduce. When animals are domesticated, their freedom of choice is restricted and their dietary needs must be met by their caretakers. Significant research has been conducted to determine the nutrient requirements of poultry species. Leeson and Summers (2001) defined a nutrient requirement as “the minimum amount of the nutrient required to produce the best weight gain, feed efficiency, etc. and the lack of any signs of nutritional deficiency,” which are often referred to as the “minimum nutrients needs.” Nutrient requirements for poultry raised in North America have been based on the recommendations of the National Research Council (NRC). However, the last NRC publication of nutrient requirements of poultry was published in 1994 and is now out of date (Applegate and Angel, 2014).

Current research has continued to evaluate the requirements of poultry tailored to specific strains and genotypes developed for chicken meat or egg production. The data from this research is used to formulate complete diets designed to meet the bird’s needs and maximize production. However, none of this data has been produced for heritage breeds and there is currently no set of nutritional standards designed specifically for heritage breeds. Therefore, it would be difficult to formulate a complete diet for these breeds with accuracy.

One feeding strategy that can be used to address this concern is to provide multiple feed choices from which the bird can choose. This feeding strategy has been described in the literature as “choice feeding”, “self-selection feeding”, and “cafeteria-style feeding”. In some instances, the term “free-choice feeding” is used; however, this term is confusing because it can also be used to describe feeding a single diet on an *ad libitum* basis. Henceforth, the term “self-selection feeding” will be used. The basic principle of self-selection feeding is that individual birds reared in a flock are able to select various feed ingredients in combination to meet their specific nutrient needs. This provides a theoretical advantage over a formulated diet based on the average requirement for the flock which supplies more than the requirement for some birds and less than the requirement for others. While underfeeding birds has the obvious implication of limiting growth and development, overfeeding birds can negatively impact bird health, feed costs, and the environment. Particularly in regards to nitrogen and phosphorus, when dietary levels are higher than the bird’s requirement, excess supply is excreted in the feces and can remain in the environment as pollution.

Practical application of self-selection feeding typically involves offering a protein source, an energy source, and, In the case of laying hens, a calcium source. Pearl and Fairchild (1921) were some of the first to study self-selection feeding in poultry, citing concerns about feeding birds to meet an average requirement when appetite and performance are highly individualistic biological concerns. Since then, many researchers have demonstrated the ability of chickens to select a balanced diet from a choice of multiple feed ingredients (Graham, 1934; Leeson and Caston, 1993; Rovee-Collier et al., 1996; Olver and Malan, 2000; Sahin, 2003; Fanatico et al., 2013). Most research regarding self-selection feeding provides two choices: one high in protein/low in energy and one low in protein/high in energy. Some research has compared a protein concentrate and a grain such as whole wheat or cracked corn (Clark et al., 2009). A few studies have also compared the bird’s ability to select between diets deficient or adequate in specific nutrients.

1.4.1 Factors affecting feed selection and intake

Feed intake is regulated by complex homeostatic mechanisms which may be influenced by genetic selection, prior experience, and physiological state (Denbow, 1999). Early self-selection feeding studies focusing on rats (Richter et al., 1938) and swine (Evvard, 1915) indicated that these animals were able to self-select a diet to provide adequate nutrition to maintain normal growth and activity. In fact, in the swine study, pigs offered a choice of feeds grew more rapidly than pigs fed a complete diet. This suggests that feed choices were made due to a "special appetite" rather than trial and error. This is consistent with the results of Covasa and Forbes (1996) which showed that, when feed choices are provided from an early age, self-selection-fed chickens offered whole wheat and a standard grower diet do not need special prior training.

Color, taste, and location can all help birds to identify and differentiate between foods with different nutrient compositions. Chickens have smaller olfactory epithelium and fewer olfactory receptor genes than other domesticated animals such as the pig, cow, dog, cat, and horse that have been studied (Roura et al., 2008). However, Balog and Millar (1989) noted that flavor can initially influence feed intake and food preference, but birds seem to learn that there is no nutritional benefit to the different flavors. For example, chickens will readily consume solutions of sucrose (Jacobs and Scott, 1957), glucose (Azahan and Forbes, 1989) and citric acid (Balog and Millar, 1989). However, they will not drink solutions of saccharin, salt or quinine (Jacobs and Scott, 1957). Additionally, Phillips and Strojan (2007) found that chickens were able to detect high levels of iron, copper, and zinc in feed, but could not detect cadmium, lead, or selenium at concentrations just below toxicity levels. Kutlu and Forbes (1993) found that broiler chicks were better able to select between an ascorbic-acid-supplemented food and an unsupplemented food when the foods were colored with red or green dye than when the foods were not colored. Therefore, visual cues are probably more useful to chickens than oral cues when distinguishing between feeds.

Finally, it is important to recognize the limitations of this ability. In order for a bird to successfully select a balanced diet, the choices must be able to meet the requirements when consumed in combination. And birds must be given sufficient time to experiment and adapt to the diet. Yo et al. (1997) found that broiler chickens initially rejected a new form of concentrate (pellets instead of mash) when it was offered. When non-complementary imbalanced foods are presented, the bird must choose a suitable compromise between over-ingesting some nutrients and under-ingesting others. Based on this theory, Raubenheimer and Simpson (1997) developed a framework to describe this phenomenon and the metabolic mechanisms underlying nutritional homeostasis.

1.4.2 Self-selection feeding studies in egg-type pullets and laying hens

Egg-type pullets grow relatively slowly; therefore, their requirement for protein through about 14 weeks of age is primarily related to muscle deposition and feather development. However, as the reproductive system begins to rapidly develop around fifteen weeks of age, pullets' protein requirements increase markedly.

In self-selection-fed pullets, self-selection of crude protein increased at sexual maturity (Scott and Balnave, 1989). Olver and Malan (2000) fed Amberlink pullets a choice of protein concentrate, whole yellow corn, and limestone powder from seven to sixteen weeks of age. They found that self-selection-fed birds, when compared with pullets receiving a pullet grower diet, were heavier at 16 weeks of age and began laying eggs earlier even though they consumed less feed. When these birds were followed through the laying period, there were no differences in hen day production or Haugh unit score, but the self-selection-fed hens had significantly heavier eggs, thicker eggshells, darker yolks, and better feed conversion ratios than hens fed the control diet. Additionally, self-selection feeding appears to improve egg mass output for hens housed in hot temperatures (Scott and Balnave, 1988, 1989).

Early experiments involving self-selection-fed laying hens indicated that providing hens with self-selected diets allowed for satisfactory (Kempster, 1917) or even improved (Rugg, 1925) egg production. Graham (1934) evaluated self-selection feeding among individual hens and found considerable variation in the intake of each feed by each bird. However, Noble et al. (1993) noted genetic differences in self-selection abilities with White Rocks demonstrating an almost immediate preference for a balanced diet while White Leghorns showed minimal preference. This difference in response between the two genetic stocks suggests that some genetic stocks are better able to make rapid adjustments to feed consumption to overcome amino acid deficiencies.

Steinruck and Kirchgessner (1992) used a self-selection feeding trial to examine the extent to which single-caged hens could self-regulate their protein intake during the first laying period. The hens were fed either an 8 or 11% crude protein diet alongside either an 11 or 23% crude protein diet. The total protein intake varied by self-selection feeding treatment, but all hens consumed self-selected diets of between 15 and 19% crude protein. Therefore, it appears that the laying hens were able to select a combination of diets to successfully meet their requirements for production. Steinruck and Kirchgessner (1993a) followed up this study with a trial to determine the effect of sensory cues such as color and flavor on the hen's ability to discriminate between two feed choices. Hens were offered a deficient 8% crude protein diet which was either colored, flavored, marked by both cues, or unaltered. When the hens were subsequently presented with this same deficient diet and a 17% crude protein diet, hens completely rejected the deficient diet, particularly when it was marked with both a color and flavor cue. Finally, Steinruck and Krichgessner (1993) demonstrated hen's innate ability to self-select between a deficient diet (8% crude protein) and a normal diet (17% crude protein).After 10 weeks of consuming either a deficient, appropriate, or excessive supply of protein, the hens showed an immediate response in selecting higher amounts of the normal diet and self-selected diets resulting in a protein level of about 15% regardless of their previous dietary treatment.

Taken together, these results suggest laying hens have an innate ability to meet their protein, energy, and calcium requirements. However, the ability for laying hens to self-select to meet requirements for micronutrients is less clear. Results of a study by Zuberbuehler et al. (2002) indicated young selenium-deficient laying hens can improve their selenium balance when offered a choice of two feeds (one high in selenium and one low) by preferentially selecting the high selenium diet. However, Loetscher et al. (2014) found that laying hens offered a choice of antioxidant-enriched or normal diets showed no intrinsic need to select antioxidant-enriched diets

1.4.3 Self-selection feeding studies in meat-type birds

A variety of self-selection feeding studies have been conducted to evaluate the different aspects of feed and nutrient intake in meat-type birds.

Regardless of the feed choices provided, self-selection-fed birds consumed more energy and less protein than conventionally-fed birds and often had greater fat content in the viscera. (Leeson and Caston, 1993; Sahin, 2003; Cerrate et al., 2007; Syafwan et al., 2012; Fanatico et al., 2013; Catanese et al., 2015). However, Cerrate et al. (2007) showed that protein intake tended to increase as broilers aged. Additionally, broilers seem to have the capacity to regulate their calcium intake when provided with a separate calcium source. Wilkinson et al. (2014) offered birds a formulated diet and a separate calcium source. As the formulated diet decreased in calcium concentration, the birds' consumption of the calcium source increased. At the conclusion of the study, there were no differences in toe ash which indicated that broilers can self-select calcium to meet their requirements.

While self-selection feeding is believed to improve growth performance, the literature does not seem to support that claim. In some experiments, self-selection feeding had no effect on performance. Sahin (2003) offered broilers a concentrate feed and either wheat, sorghum, or corn. Regardless of the cereal, self-selection feeding had no effect on growth, body components, or feed efficiency. In a study comparing self-selection feeding for birds reared in either high or normal temperatures, Syafwan et al. (2012) found that self-selection-fed birds had similar feed intake, body weight gain, and feed efficiency when compared with control-fed birds at high temperatures. Based on the results of Rack et al. (2008) self-selection feeding did not improve performance or carcass characteristics of fast- or slow-growing broilers which indicates this is not limited to one genotype. Clark et al. (2009) replaced various portions of the corn fraction of a complete broiler diet with cracked corn. They found that, alongside a concentrate pellet, up to 25% of the dietary corn can be fed directly as cracked corn from 0 to 41 days of age without a negative impact on the growth performance of broilers.

In other experiments, self-selection feeding reduced carcass yield despite having no effect on growth performance. Fanatico et al. (2013) found that self-selection-fed birds selected diets lower in crude protein (13%) than the formulated diet (20%). While this reduced protein intake did not affect final live weight, self-selection-fed birds had lower ready-to-cook yields and breast yields. Leeson and Caston (1993) had similar results. They found that self-selection feeding with either a starter diet and cracked corn or a starter diet and wheat had no effect on body weight at 49 days of age, but depressed eviscerated carcass weight. This is consistent with other studies which showed that carcass yields were reduced for self-selection-fed birds (Cerrate et al., 2007). However, in another self-selection feeding study (Ozek et al., 2012), carcass yield was not affected.

In other experiments, self-selection-fed birds exhibited poor growth performance when compared with birds fed a complete diet. This was particularly evident when less digestible feedstuffs were utilized. For example, Amerah and Ravindran (2008) found that birds offered a choice of whole wheat and protein concentrate had lower weight gain and feed intake, and poorer feed conversion ratios when compared with birds provided with a complete diet. Cerrate et al. (2007) also found that self-selection fed birds had lower body weights, poorer feed conversion, and poorer carcass characteristics than did birds fed single diets or starter and finisher diets. Catanese et al. (2015) found a negative effect of self-selection feeding on body weight, weight gain and feed conversion efficiency. Ozek et al. (2012) started Ross 308 broiler chicks on a self-selection feeding program with whole triticale at 1 day of age and found lower weight gains, higher feed consumption, and poorer feed efficiency. However, digestive functions were not negatively altered by free choice feeding with triticale and/or dietary enzyme inclusion.

While these experiments utilized a variety of feedstuffs and management practices, these results, when taken together, suggest broilers self-select diets to meet a requirement other than maximal growth or carcass yield. Also, self-selection-fed birds consistently consumed diets that were lower in protein, and therefore less expensive, than their counterparts fed formulated diets (Sahin, 2003; Fanatico et al., 2013). Consequently, utilizing a self-selection feeding strategy could be advantageous depending on the circumstances.

Additionally, self-selection-feeding appears to have a positive impact on birds' stress response and general health. When compared with birds fed complete diets, self-selection-fed birds were better able to handle stressors such as handling and transport (Malheiros et al., 2003), and were less susceptible to coccidiosis (Forbes and Covasa, 1995; Gabriel et al., 2003). Gabriel et al. (2003) suggested that these results were due to the effect of whole wheat on the digestive physiology and intestinal microflora. This has important implications as the use of feed additives such as antimicrobials are removed from the feed. However, self-selection feeding failed to ameliorate oxidative stress caused by high temperatures experienced by meat-type birds(Aydilek et al., 2012).

1.4.4 Practical application of self-selection feeding

Self-selection feeding has several practical implications. Leeson and Caston (1993) found that feed costs could be reduced when broilers were given free-choice selection of cereal grains. Experiments by Sahin (2003) showed similar results – broilers finished on a self-selection feeding program consumed less protein than control birds without a detrimental effect on body components or feed efficiency. Therefore, feed savings achieved through self-selection feeding seem to be the result of a reduction in the consumption of protein, which is an expensive ingredient in most formulated diets.

Self-selection feeding can allow small-scale farmers who do not have access to the computer programs required to properly balance home-mixed rations to better provide for their flocks. Utilizing a pre-mixed protein concentrate, small-scale producers may incorporate alternative energy sources without needing to formulate or mix diets. These sources may include whole grains and home-grown feeds, both of which could represent a significant cost savings. The use of whole grains in particular reduces the costs of grinding, mixing, and many of the handling procedures associated with mash and pellet production.

Self-selection feeding may also have important implications for producers in countries where corn and soybeans are not readily available. Because self-selection feeding doesn’t require precision feed formulation, it offers a method through which unconventional feedstuffs and feedstuffs with unknown nutritive value may be utilized. For example, Madiya et al. (2003) used a self-selection feeding trial to evaluate the use of bakery waste material as an alternative energy source. While the control group was significantly heavier and consumed significantly more feed than the self-selection-fed birds, the authors noted that the self-selection feeding method resulted in approximately 15% higher profit margins. In these cases, reductions in growth may be outweighed by savings in feed costs.

1.5 Alternative feed ingredients

Poultry feed requires sources of protein, energy, vitamins, and minerals. In conventional chicken diets in the United States, corn serves as the main energy source and soybean meal as the main protein source. When the price of corn and soybeans go up, there is increased interest in alternative feedstuffs. In addition, more than 90% of the corn and soybean crops in the United States are genetically modified organisms (GMO). As a way to differentiate their product from conventional chicken meat or egg production, small- and medium-sized farms may consider using vegetarian diets that do not include animal products (such as meat & bone meal or tallow/lard) and that are not corn/soybean meal based. Alternative feedstuffs include, but are not limited to pearl millet, naked oats, sorghum, buckwheat, flax, and field peas. There is some early research looking at the suitability of individual feedstuffs as substitutes for corn or soybean meal in poultry diets, but there is very little research into the use of combinations of these alternative crops as the sole ingredients in a complete poultry feed. Some of the proposed feed ingredients contain anti-nutritive factors (e.g., β-glucans, pentosans) which may limit their use when feed enzymes are not included. Organic feed regulations allow for the use of non-GMO feed enzymes (USDA 2012a; USDA 2012b).

1.5.1 Pearl millet

Pearl millet (*Pennisetum typhoides*) is a highly-drought resistant crop which can be grown in a short, dry summer season, even in infertile sandy soils. Pearl millet has relatively high protein content at 10-16% (Burton et al., 1972) and metabolizable energy of around 3300 kcal/kg (Adeola et al., 1994). Pearl millet is rich in oil with an average fat content of above 5% (Rooney, 1978). Because pearl millet is higher in protein than corn, diets formulated with pearl millet require less soybean meal.

Dozier et al. (2005) found that pearl millet-based diets had acceptable grinding and pelleting performance when compared with typical corn-soybean meal-based diets. While pearl millet is typically ground, laying hens appear to have the capacity to digest unground pearl millet seeds when included in the diet at moderate levels (Garcia and Dale, 2006). Including whole pearl millet in a broiler diet up to 20% did not affect growth performance or carcass yield, but gizzard size increased in birds fed diets containing 10% or more pearl millet (Hidalgo et al., 2004). Broilers fed the pelleted pearl millet-based diets presented lower feed intake, better feed conversion ratio, lower gizzard and heart percentages, and higher carcass weight when compared with corn-based diets (Torres et al., 2013).

Total replacement of corn by pearl millet significantly improved body weight and feed conversion with either no or positive effects on digesta viscosity, gut health, or gut microflora (Baurhoo et al., 2011a; Batonon-Alavo et al., 2015; Afsharmanesh et al., 2016). Supplementation of NSP-hydrolyzing enzymes can enhance feed utilization and increase apparent ileal digestibility of crude protein and amino acids enhance feed utilization (Baurhoo et al., 2011b; Leite et al., 2012), particularly during the starter phase (Rao et al., 2004). However, for broilers and broiler breeder hens, replacing corn with pearl millet resulted in higher abdominal fat deposition (Rao et al., 2000; Torres et al., 2013).

Fully replacing corn with pearl millet in the diets of broiler breeder layers did not affect hen-day egg production (Rao et al., 2000). However, pearl millet appears to improve the fatty acid profile of eggs. According to Collins et al. (1997), pearl millet increased total and long chain n-3 fatty acids and decreased n-6 fatty acids in eggs without affecting production parameters. Furthermore, Amini and Ruiz-Feria (2007) found that pearl millet can be used instead of corn in layer diets to obtain n-3 fatty acid enriched eggs with less flaxseed.

1.5.2 Naked oats

Naked oats are a cultivar of *Avena sativa*, the same species as ‘common oats’. However, naked oats have a dominant gene which gives rise to a phenotype with a non-lignified husk which readily detaches during harvesting (Ougham et al, 1996). Evidence is accumulating on the suitability of naked oats for inclusion in poultry diets up to a high concentration (Hsun and Maurice, 1992; Cave and Burrows, 1993; MacLean et al., 1993) with or without enzyme supplementation (Brenes et al., 1993). The metabolizable energy yield of naked oats is similar to that of corn and higher than that of wheat (MacLeod et al., 2008). Naked oats are higher in essential amino acids than wheat or barley which offers the possibility of replacing soy and animal proteins. Additionally, naked oats have high concentrations of polyunsaturated oils and significant antioxidant activity which may improve egg and meat quality. However, oats are high in β-glucans which may be detrimental.

1.5.3 Sorghum

Sorghum (*Sorghum bicolor*), also referred to as milo, is generally grown in warm climates and is well-suited to low rainfall areas. The digestible energy value for sorghum is similar to corn, but it has more crude protein. Sorghum's use in poultry diets was limited due to lack of pigmenting ability and high tannins in "bird resistant" varieties (Petersen, 1969). Tannins inhibit digestive enzyme activity and form complexes with protein that resist digestion. However, low tannin varieties are readily available now. Additionally, the industry movement towards further-processed products allows for greater variations in chicken skin color. Several studies on sorghum in poultry diets have focused on improving methods used to estimate digestible energy and protein content to allow for more precise feed formulation (Lemme et al., 2004; Ravindran et al., 2005; Ebadi et al., 2011; Sedghi et al., 2011). Some studies have shown that sorghum-based diets had no effect on feed intake, but decreased growth performance when compared with corn-based diets (Batonon-Alavo et al., 2015). However, sorghum-based diets supplemented with enzymes showed no negative effects, suggesting the combination is a viable strategy to improve the nutritional value of the diets and performance results (Leite et al., 2012).

1.5.4 Field peas

Field peas (*Pisum sativum*) contain 20-29% crude protein which makes them suitable as a potential protein-energy source for poultry. However, replacement of a large portion of the soybean meal with field peas can result in slightly reduced performance of growing chickens and laying hens (Farrell et al., 1999; Tuunainen et al., 2016), Nalle et al. (2011) found that broilers fed diets containing as much as 20% field peas had similar growth performance as broilers fed a corn-soy control. Based on their experiments, Farrell et al. (1999) suggested field peas inclusion be limited to 30% of the diet for broilers. The presence of α-galactosides has been proposed as the cause of the poorer growth of the chickens, but the cause of the reduced performance of the laying hens was not known. Peas have high levels of starch, and pea starch is less digestible than the starch of any other cereal grain.

1.5.5 Flax seed

Flax seed contain high levels of protein (26%) and oil (41%) and are an excellent source of omega-3 fatty acids, particularly linolenic acid. Flax is currently used in poultry feeds to alter the fatty acid composition of eggs and produced omega-3 enriched eggs (Amini and Ruiz-Feria, 2007; Nanjappan et al., 2013). However, inclusion of high levels of flaxseed (>10%) resulted in a decrease in overall egg acceptability as assessed by aroma and flavor (Collins et al., 1997). Flax seed has also been shown to be successful in the production of omega-3 enriched chicken meat, although the use of full-fat flax seed resulted in lower live weights and smaller carcasses. For flax seed to be digested, the hard outer shell must be broken open through grinding. Otherwise, the unbroken flax seed passes through the digestive tract, retaining all its nutrients.

1.5.6 Buckwheat

Buckwheat (*Fagopyrum sagittatum*) was a popular poultry feed in the early 1900s and has seen an increase in production in some areas of the Midwest (Jacob, 2007). While little data is available on its use, the literature suggests that buckwheat has reasonable feeding value, roughly comparable to oats or wheat (Leiber et al., 2009). The grain contains 11-13% crude protein and is the best source of lysine among the feed grains, and is the only grain not lysine deficient (Jacob and Carter, 2008). Unfortunately, buckwheat also contains fagopyrin, a compound which causes photosensitization of light-skinned animals. Therefore, high inclusion of buckwheat in diets for broilers raised outdoors may result in increased incidence of carcass downgrading due to skin sun burns.

1.5.7 Enzymes

Digestive enzymes are vital players in the digestive system that catalyze the reactions that break feed down into nutrients which can be absorbed and utilized within the body. While chickens produce endogenous enzymes, their diets are often supplemented with exogenous enzymes, especially those that are not produced by the chicken (Bedford and Partridge, 2001). Supplementation of enzymes has alleviated some industry challenges by reducing feed costs and improving gastrointestinal tract problems through improvement of nutrient utilization (Khattak et al., 2006). Enzymes are particularly valuable when feedstuffs high in non-starch polysaccharides (NSP) or other indigestible factors are utilized. High concentrations of NSP's in the diet can increase gut viscosity and reduce weight gain resulting in poorer feed efficiency.

Tahir et al. (2008) showed that cellulose, hemicellulose, and pectinase supplementation improved carcass weight and feed efficiency in a low-protein corn-soy-based diet. Similarly, Wu et al. (2004) demonstrated an improvement in feed conversion when birds were fed wheat or barley-based diets supplemented with xylanase. Xylanase breaks down the β-1,4 linkages in arabinoxylans into dimers that can be further reduced into fructose molecules (Bedford and Partridge, 2001). Supplementation with β-glucanases can alleviate the negative effects of wheat- and barely-based broiler diets by degrading the aleurone layer and releasing nutrients from the grain endosperm. The result is an improvement in weight gain and feed efficiency (Mathlouthi et al., 2002). While the chicken's pancreas secretes endogenous α-amylase and proteases which degrade starch and polypeptide chains, respectively, further improvements have been noted with exogenous supplementation (Gracia et al., 2003; Angel et al., 2011). Additionally, Angel et al. (2011) noted improvements in bird performance when birds fed low-protein diets (20.5% crude protein) were supplemented at 400 mg/kg. Finally, supplementation with phytase improves feed utilization by releasing phytate-bound minerals, proteins, and starches in the diet (Murai et al., 2002). Additionally, phytase supplementation can reduce the need for additional inorganic phosphorus.

Because each enzyme acts in a different way, supplementation with an enzyme complex with multiple activities is common in poultry diets. Wu et al. (2004) described the effects of xylanase and phytase supplementation individually, and in combination. When birds were fed a wheat-soy basal diet, supplementation with phytase and xylanase seemed to have a synergistic effect which increased villus height in the ileum and crypt depth in the jejunum and ileum.

Allzyme SSF® is a natural enzyme complex produced through solid-state fermentation of a selected strain of *Aspergillus niger*. It contains cellulases, xylanases, glucanases, phytases, proteases, and has been used in diets for poultry, pigs, and fish (Min et al., 2009; Yadava et al., 2009; Deniz et al., 2013; Passos et al., 2015; Zhao et al., 2015). Meta-analyses on the use of Allzyme SSF® in broiler (Hooge et al., 2010a) and layer (Hooge et al., 2010b) diets showed improvements in body weight and egg mass when compared to negative controls. This enzyme complex improves the digestibility of amino acids, energy, calcium, and phosphorus particularly when the diet contains ingredients with low digestibility.

1.6 Gaps in the literature

From this review, it is clear that there are some gaps in the literature, particularly in regards to the growth performance and carcass characteristics of heritage breeds and the utilization of alternative feedstuffs for these breeds. This dissertation presents data from several studies and attempts to address some of these gaps. First, heritage breed pullets were evaluated as replacements for egg-laying strains and heritage breed cockerels were evaluated as meat-type birds. Because the nutrient requirements for heritage breeds are not known, a self-selection feeding program was employed to allow the birds to determine their own nutrient and energy intake. The data from these studies was used to guide the formulation of complete diets using alternative feedstuffs to replace corn and soybean meal which were then evaluated for suitability. The ultimate goal of these experiments was to provide small- and medium-flock producers interested in heritage breed chickens and/or slow-growing meat-type strains with the information they need to create accurate business plans.

CHAPTER 2: Growth performance, nutrient and energy intake of alternative breed replacement pullets provided through the use of a self-selection feeding program

2.1 Abstract

Due to the recent resurgence in the popularity of keeping small flocks of chickens, interest in the production characteristics of heritage chicken breeds has increased. The objective of this study was to determine the growth performance, and the nutrient and energy intake of alternative chicken breeds as replacement pullets using a self-selection feeding program. Seventy-five day-old chicks per genotype (Rhode Island Red, Barred Plymouth Rock, Black Australorp, Black Star, Red Star, and ISA Brown) were divided into three replicate groups which were randomly assigned to floor pens with 892 square centimeters per bird. All chicks received a complete diet for the first two weeks, and then were transitioned to a self-selection feeding program using four feed choices provided on an *ad libitum* basis. The feed choices included a protein concentrate (39% CP with added vitamins and minerals) without added methionine and three grains similar in energy content, but differing in protein and methionine content (cracked corn, naked oats, and pearl millet). The feeds were randomly allocated to four identical feeders within each pen and the location of the feeders was rotated 2-3 times per week. At 133 days of age, individual body weight averaged 1630 g for Red Star, 1623 g for Black Star, 1612 g for Black Australorp, 1565 g for Barred Plymouth Rock, 1523 g for ISA Brown, and 1471 g for Rhode Island Red pullets. The body weights of the Red Star, Black Star, and Black Australorp pullets were significantly different ($P < 0.05$) from that of the ISA Brown and Rhode Island Red pullets. The body weights for the Barred Plymouth Rock pullets were significantly higher from the Rhode Island Red pullets. Average daily feed intake (58.5 grams/bird/day) from placement (1 day of age) through the end of the study was similar ($P > 0.05$) among the genotypes. Additionally, diet selection was similar ($P > 0.05$) among the genotypes. Free-choice feed selection for all genotypes resulted in a diet containing approximately 3098 kcal ME/kg, 15.3% protein, 0.26% methionine, 0.70% lysine, 0.51% calcium, and 0.29% phosphorus. Self-selection resulted in diets that were sufficient in protein, methionine, and phosphorus, but lower in calcium and higher in energy than National Research Council (1994) recommendations.

2.2 Introduction

Due to the recent resurgence in the popularity of keeping small flocks of chickens, interest in heritage chicken breeds has increased. Heritage breeds are those that physically conform to the standards of the American Poultry Association, mate naturally, have a slow growth rate, and a long, productive lifespan. The heritage breeds selected for this study were the Rhode Island Red, the Barred Plymouth Rock, and the Black Australorp. These breeds were selected because Rhode Island Reds and Barred Plymouth Rocks are two of the most commonly raised heritage breeds. Black Australorps were selected because they are popular with ethnic markets. ISA Brown pullets were used as a commercial control. Black Star and Red Star pullets were used to represent a less heavily selected strain. All six of these breeds/strains typically lay brown eggs which are preferred by consumers in some markets.

Heritage breed chickens are typically fed a complete diet formulated for commercial pullets or broilers. However, because the nutrient requirements for the heritage breeds are not known and may be different from commercial strains, feeding these diets may overfeed or underfeed these breeds Therefore, a self-selection feeding strategy was employed to allow the birds to choose from different feeds in order to meet their individual requirements. In a self-selection feeding program, chickens are typically offered a protein source, an energy source, and, for layers, a calcium source. However, chickens are natural foragers and should be capable of selecting from multiple feed sources. Therefore, these birds were provided with a protein concentrate and three energy sources which differed in protein (particularly with regard to methionine) content. Given proper selection by the chickens, a theoretically adequate diet should have been consumed.

In order to profitably raise chickens, producers need to know how quickly they grow, how much feed they consume, and what their nutrient requirements are. However, there is little to no published data available regarding the production characteristics for heritage breeds. The objective of this study was to determine the growth rate, and feed and nutrient intake of three heritage breed chickens as replacement pullets for egg-laying flocks.

2.3 Materials and methods

Experiments were conducted at the Alltech-University of Kentucky Research Alliance Poultry Farm. All procedures for this study were conducted under protocols approved by the University of Kentucky Institutional Animal Care and Use Committee. This trial was conducted from October 2012 to March 2013.

2.3.1 Birds and housing

One-day-old female chicks from each of three heritage breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp) and two egg-laying strains (Black Star and Red Star) were purchased from Murray McMurray Hatchery (Webster City, IA) and shipped via USPS air mail. Additionally, one-day-old female ISA Brown chicks were purchased from Cal-Maine Foods, Inc. to serve as a commercial control. The ISA Brown chicks were one week younger than the other breeds and strains throughout the experiment; therefore, data for the ISA Browns was matched by age.

Upon arrival, chicks from each genotype (n = 75 per genotype) were weighed and assigned to a pen (n = 3 per genotype). The chicks were housed in 1.22- x 1.83-meter floor pens on clean wood shavings with a space allocation of 892 square centimeters per bird. Birds were brooded at approximately 30.6°C for the first four weeks, then temperatures were reduced to ~21.1°C from 5 to 11 weeks of age, and finally to 15.6°C from 12 to 20 weeks of age. Overall, the temperature averaged 20.4°C. The lighting program provided 22 hours of light from placement through 10 weeks of age. At 10 weeks of age, light was reduced to 16 hours per day and remained at that level through the end of the experiment. Birds were monitored through 133 days of age.

2.3.2 Feeding

All birds were fed a nutritionally complete commercial-type starter diet (22% CP, 3084 kcal ME/kg) from 1 to 14 days of age. At 14 days of age, birds were transitioned to a self-selection feeding program consisting of four feed choices: a protein concentrate (39% CP), cracked corn, pearl millet, and rolled naked oats. These ingredients were chosen and the protein concentrate was formulated in order to provide the birds with choices so that they could theoretically self-select a balanced diet. The nutrient composition of each feed choice is shown in Table 2.1.The protein concentrate consisted of buckwheat, solvent-extracted soybean meal, fishmeal, field peas, dicalcium phosphate, limestone, salt, a vitamin-mineral premix, and an enzyme complex (Allzyme SSF®, Alltech Inc., Nicholasville, KY). Integral® (Alltech Inc., Nicholasville, KY), a glucomannan containing yeast product, was added to the protein concentrate to reduce potential mycotoxin absorption in the birds. The protein concentrate formulation is show in Table 2.2. Each feed ingredient was randomly allocated to one of four identical feeders. Feeder location was rotated two to three times per week. All feed ingredients were offered on an *ad libitum* basis. Water was offered on an *ad libitum* basis using a nipple watering system

2.3.3 Data collection

Chicks were weighed at the time of placement (1 day of age) and then weekly through 133 days of age on a pen basis to calculate average daily gain. To determine uniformity, birds were weighed individually at 56, 70, 84, 98, 112, and 126 days of age. Bird uniformity within breed was determined on a pen basis and was calculated as the percentage of pullets that had a body weight within ± 15% of the flock average at a given age. Consumption of each feed ingredient was measured two to three times per week before feeders were rotated. Ingredient consumption was measured separately and then combined to determine average daily feed intake. Daily mortality was also recorded and accounted for in calculations.

2.3.4 Statistical analysis

This experiment had a completely randomized block design with the experimental unit as the pen blocked by location within the room. Data for this experiment were analyzed as a one-way analysis of variance using the general linear model procedures of SAS® (SAS v. 9.3, Cary, NC) with genotype as the dependent variable. The replicate pen of birds served as the experimental unit. Fisher's least significant difference test was used to determine differences among means with a significance set at $P < 0.05$.

2.4 Results

2.4.1 Body weight

Weekly pullet body weights from 1 through 133 days of age are reported in Table 2.3. At 1 day of age, body weights differed ($P < 0.05$) among genotypes. The ISA Brown pullets were the heaviest at 35 grams. The heritage breeds differed, with the Rhode Island Red pullets (34 grams) being heavier ($P < 0.05$) than both the Barred Plymouth Rock and Black Australorp pullets (32 grams). The Black Star and Red Star pullets were the lightest at 29 grams.

From 14 through 35 days of age, the average individual body weights were similar ($P > 0.05$) among genotypes. However, from 42 to 133 days of age, Rhode Island Red pullets were lighter ($P < 0.05$) than Barred Plymouth Rock, Black Australorp, Red Star, and Black Star pullets.

At 133 days of age, the body weights of Red Star, Black Star, and Black Australorp pullets were heavier ($P < 0.05$) than those of ISA Brown and Rhode Island Red pullets. The average body weights of Barred Plymouth Rock pullets were heavier ($P < 0.05$) than the Rhode Island Red pullets.

2.4.2 Uniformity

Uniformity was calculated for each pen as the percent of the birds within 15% of the average body weight of the pen. Uniformity was calculated every other week from 56 to 126 days of age and reported in Table 2.4. For each week, there were no differences among the breeds; however, uniformity was relatively low overall. From 42 to 98 days of age, average uniformity was below 62% with considerable variation between replicates. At 98 days of age, several small birds were culled from each pen which improved uniformity. By 126 days of age, an average uniformity of 77.6 ± 7.4% had been achieved and there were no differences among breeds ($P > 0.05$).

2.4.3 Feed intake

The cumulative average daily feed intake (58.5 ± 1.8 grams/bird/day; $P > 0.05$) from 21 to 132 days of age was similar among the genotypes (Table 2.5). There was no effect of feeder location on feed intake for any of the breeds or strains ($P > 0.05$). When examined on a weekly basis (Table 2.6), average daily feed intake in grams per bird per day was similar ($P > 0.05$) among the genotypes for most weeks. Additionally, average daily feed intake increased over time with 21-day-old pullets consuming approximately 32 grams of feed per day and 126-day-old pullets consuming approximately 78 grams of feed per day.

2.4.4 Energy and nutrient intake

2.4.4.1 Energy

During the self-selection feeding program from 21 to 132 days of age, pullets consumed an average of 182 ± 5 kcal ME per bird per day with no differences ($P > 0.05$) among genotypes (Table 2.5). When examined on a weekly basis (Table 2.7), average daily energy intake was similar ($P > 0.05$) among the genotypes for most weeks.

2.4.4.2 Protein

During the self-selection feeding program from 21 to 132 days of age, pullets consumed an average of 8.99 ± 0.49 grams of protein per bird per day with no differences ($P > 0.05$) among genotypes (Table 2.5). On a weekly basis, protein consumption expressed in grams per bird per day was similar among genotypes for most weeks (Table 2.8).

2.4.4.3 Methionine

During the self-selection feeding program from 21 to 132 days of age, pullets consumed an average of 0.15 ± 0.01 grams of methionine per bird per day with no differences ($P > 0.05$) among genotypes (Table 2.5). On a weekly basis, methionine consumption expressed in milligrams per bird per day was similar ($P > 0.05$) among genotypes for most weeks (Table 2.9).

2.4.4.4 Lysine

During the self-selection feeding program from 21 to 132 days of age, pullets consumed an average of 0.41 ± 0.03 grams of lysine per bird per day with no differences ($P > 0.05$) among genotypes (Table 2.5). On a weekly basis, lysine consumption expressed in grams per bird per day was similar ($P > 0.05$) among genotypes for most weeks (Table 2.10).

2.4.4.5 Calcium

During the self-selection feeding program from 21 to 132 days of age, pullets consumed an average of 0.30 ± 0.02 grams of calcium per bird per day with no differences ($P > 0.05$) among genotypes (Table 2.5). On a weekly basis, calcium consumption expressed in grams per bird per day was similar ($P > 0.05$) among genotypes for most weeks (Table 2.11).

2.4.4.6 Phosphorus

During the self-selection feeding program from 21 to 132 days of age, pullets consumed an average of 0.17 ± 0.01 grams of phosphorus per bird per day with no differences ($P > 0.05$) among genotypes (Table 2.5). On a weekly basis, phosphorus consumption expressed in grams per bird per day was similar ($P > 0.05$) among genotypes for most weeks (Table 2.12).

2.4.5 Composition of the self-selected diet

There were no differences in overall diet selection among breeds or strains ($P > 0.05$). All pullets selected a diet that consisted of 3,098 ± 17 kcal ME/kg, 15.3 ± 0.4% crude protein, 0.26 ± 0.01% methionine, 0.70 ± 0.03% lysine, 0.51 ± 0.03% calcium, and 0.29 ± 0.01% phosphorus (Table 2.13).

2.5 Discussion

Despite the increased interest in heritage chicken breeds due to the resurgence in the popularity of keeping small flocks of chickens, little to no published data is available regarding the production characteristics of heritage breeds. This study was conducted in order determine the growth rate, and feed and nutrient intake of three heritage chicken breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp) used as replacement pullets for egg-laying flocks. Because the nutrient requirements of these breeds are not known, a self-selection feeding program was employed using four nutritionally distinct feed choices.

While the initial body weights of the chicks varied among genotypes, it is unclear whether this was due to inherent genetic differences or other factors because this study did not control for breeder age, egg weight, or hatching time which may also influence early chick weights (Hulet et al., 2007; Zakaria and Omar, 2013; Mbajiorgu and Ramaphala, 2014; Bergoug et al., 2015; Nangsuay et al., 2015). During the self-selection feeding program consisting of a protein concentrate (39% CP), cracked corn, pearl millet, and rolled naked oats, pullets from all six genotypes demonstrated similar growth rates. However, average body weights at a given age varied among genotypes and flock uniformity within each breed was low.

At 126 days of age, the Black Austrlorp, Barred Plymouth Rock, Black Star, and Red Star pullets achieved weights consistent with the expected body weights published by the National Research Council (1994) for brown-egg-laying pullets. However, the Rhode Island Reds and ISA Browns fell short of the expected body weights published for both brown-egg-laying pullets (National Research Council, 1994) and for ISA Brown pullets (Institut de Sélection Animale). This begs the question as to whether the pullets were selecting diets that met their requirements. However, previous studies by Steinruck and Kirchgessner (1992, 1993a, 1993b) and others suggest that pullets and laying hens are capable of balancing their own diets when given a choice of feeds with either a deficient or excessive supply of protein.

In the present study, the average feed intake each week was similar ($P > 0.05$) among the genotypes for most weeks and fell within a range similar to the expected values for ISA Browns and brown-egg-laying pullets (Institut de Sélection Animale; National Research Council, 1994). On a weekly basis, average daily intake of energy, protein, methionine, lysine, calcium, and phosphorus were similar among genotypes. This suggests pullets were making similar selections from the feeders regardless of genotype.

For most weeks, average daily energy intake fell within or above the ranges published for ISA Browns and brown-egg-laying pullets. This is consistent with the literature on self-selection feeding which shows that self-selection-fed birds tend to consume more energy and less protein than birds fed complete diets (Leeson and Caston, 1993; Sahin, 2003; Cerrate et al., 2007; Syafwan et al., 2012; Fanatico et al., 2013; Catanese et al., 2015).

Average daily protein intake was consistent with expected values for most weeks (Institut de Sélection Animale; National Research Council, 1994). Average daily methionine consumption were typically higher than the National Research Council

(1994) recommendations for brown-egg-laying pullets, but below the recommended values for ISA Browns (Institut de Sélection Animale). However, no deficiency symptoms were identified which suggests methionine requirements were met. Average daily lysine intake for most weeks was higher than National Research Council (1994) recommendations for brown-egg-laying pullets, but similar to or lower than ISA Brown recommendations (Institut de Sélection Animale). Throughout the experiment, calcium consumption each week was consistently lower than recommendations for either ISA Browns or brown-egg-laying strains (Institut de Sélection Animale; National Research Council, 1994). Additionally, there was no evidence of increasing calcium consumption as pullets neared sexual maturity. However, this may have been a result of the ingredients available which were relatively low in calcium. Offering a separate calcium source may have increased calcium intake. On the other hand, phosphorus consumption typically exceeded expected values based on recommendations for brown-egg-laying strains (National Research Council, 1994), but fell short of recommendations for ISA Browns (Institut de Sélection Animale).

The overall nutrient intake during the self-selection feeding program was similar among the genotypes with pullets selecting an average diet consisting of 3,098 ± 17 kcal ME/kg, 15.3 ± 0.4% crude protein, 0.26 ± 0.01% methionine, 0.70 ± 0.03% lysine, 0.51 ± 0.03% calcium, and 0.29 ± 0.01% phosphorus. Consequently, self-selection resulted in diets that were sufficient in protein, methionine, lysine, and phosphorus, but lower in calcium and higher in energy than National Research Council (1994) recommendations. This suggests that heritage breed pullets likely have similar nutrient requirements to pullets from commercial brown-egg-laying strains during rearing phase. Therefore, based on the data from this study, pullets from heritage breeds and sex-link strains can be fed and managed similarly to commercial egg-type pullets through 133 days of age.

A subsequent study, Jacob (2014) followed these pullets into lay and showed that the ISA Brown hens laid their first eggs at approximately 148 days of age, which was significantly earlier than any of the heritage breeds, Black Stars, and Red Stars. Furthermore, the ISA Brown hens had higher average hen day egg production (Appendix C, page 165) and produced larger eggs (Appendix D, page 166) when compared with the heritage breed, Black Star, and Red Star hens. These results suggest that heritage breed hens are not an economically viable alternative to commercial egg-laying strains. However, further research is needed to evaluate the potential viability of heritage breed hens in alternative production systems such as aviaries, free-ranger, and pasture-based systems.

2.6 Tables

Table 2.1. Analyzed nutrient composition of self-selection feed choices

Nutrient	Protein Concentrate	Cracked Corn	Pearl Millet	Rolled Naked Oats
Energy, kcal ME/kg (calculated)	2163	3390	3240	3180
Crude protein, %	39.0	7.9	11.6	14.4
Methionine, %	0.51	0.16	0.28	0.23
Lysine, %	2.47	0.27	0.20	0.58
Calcium, %	2.14	0.01	0.05	0.84
Phosphorus, % available	1.10	0.09	0.10	0.17

Table 2.2. Protein concentrate formulation

Ingredient	Inclusion level
Buckwheat	13.40%
Soybean meal, solvent extracted	64.78%
Fishmeal	4.36%
Field peas	8.93%
Dicalcium phosphate	4.47%
Limestone	2.01%
Salt	1.01%
Vitamin-mineral premix [1]	0.56%
Integral® [2]	0.45%
Enzyme complex [3]	0.04%

[1] Akey Layer Starter Breeder Premix (Akey, Lewisburg, OH)
[2] Integral® (Alltech Inc., Nicholasville, KY)
[3] Allzyme-SSF® (Alltech Inc., Nicholasville, KY)

Table 2.3. Average body weight (grams) by week for pullets by genotype from 1 through 133 days of age[*]

Age (days)	Expected NRC (average)[1]	Expected ISA Brown (Range)[2]	Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
1	37	-	34 ^{b}	31 ^{c}	32 ^{c}	29 ^{d}	29 ^{d}	35 ^{a}	0.3	<0.0001
14	120	110 - 120	123	116	111	123	122	117	3.0	0.0790
21	223	195 - 210	166	171	161	175	180	170	4.2	0..0744
28	325	285 - 305	213	234	224	238	243	230	6.7	0.0786
35	413	380 - 400	270	301	296	307	315	293	9.7	0.0715
42	500	470 - 500	328 ^{b}	378 ^{a}	375 ^{a}	389 ^{a}	395 ^{a}	365 ^{ab}	11.8	0.0204
49	625	560 - 590	407 ^{b}	474 ^{a}	473 ^{a}	481 ^{a}	483 ^{a}	448 ^{ab}	14.6	0.0211
56	750	650 - 680	482 ^{c}	565 ^{ab}	574 ^{ab}	574 ^{ab}	593 ^{a}	530 ^{bc}	20.7	0.0242
63	825	740 - 775	554 ^{b}	657 ^{a}	664 ^{a}	664 ^{a}	693 ^{a}	627 ^{a}	22.2	0.0126
70	900	830 - 865	631 ^{b}	760 ^{a}	757 ^{a}	752 ^{a}	812 ^{a}	660 ^{b}	22.7	0.0005
77	1000	920 - 960	653 ^{b}	814 ^{a}	801 ^{a}	794 ^{a}	842 ^{a}	767 ^{a}	27.2	0.0056
84	1100	1010 - 1050	747 ^{b}	933 ^{a}	919 ^{a}	905 ^{a}	964 ^{a}	910 ^{a}	30.3	0.0048
91	1170	1095 - 1140	860 ^{b}	1075 ^{a}	1050 ^{a}	1037 ^{a}	1106 ^{a}	1038 ^{a}	32.6	0.0038
98	1240	1180 - 1230	991 ^{c}	1209 ^{a}	1183 ^{a}	1167 ^{ab}	1253 ^{a}	1157 ^{bc}	28.9	0.0008
105	1310	1265 - 1320	1136 ^{d}	1320 ^{ab}	1260 ^{bc}	1288 ^{abc}	1347 ^{a}	1231 ^{c}	28.0	0.0012
112	1380	1350 - 1410	1217 ^{c}	1369 ^{ab}	1333 ^{ab}	1367 ^{ab}	1406 ^{a}	1293 ^{bc}	27.3	0.0036
119	1440	1430 - 1505	1279 ^{c}	1452 ^{ab}	1408 ^{ab}	1455 ^{ab}	1476 ^{a}	1384 ^{b}	27.2	0.0023
126	1500	1500 - 1600	1377 ^{c}	1549 ^{a}	1496 ^{ab}	1552 ^{a}	1567 ^{a}	1447 ^{bc}	28.0	0.0027
133	-	-	1471 ^{c}	1612 ^{a}	1565 ^{ab}	1623 ^{a}	1630 ^{a}	1523 ^{bc}	27.0	0.0026

[*] Mean values represent pen averages (n = 3)

[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)

[1] National Research Council 1994 for brown-egg-laying pullets

[2] ISA Brown management guide

Table 2.4. Uniformity for pullets of different genotypes at various ages[*]

Age (days)	Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	Average	SEM	*P*-value
56	44.3	47.7	48.3	57.0	59.3	55.0	51.9	7.5	0.7195
70	43.0	44.3	50.0	50.0	58.0	51.0	49.4	6.7	0.6397
84	47.3	53.0	61.7	49.7	60.0	53.0	54.1	7.0	0.6661
98	44.7	63.4	76.3	55.0	68.7	63.7	62.0	8.9	0.3037
112	62.0	66.7	75.3	67.3	70.7	75.0	69.5	7.9	0.8166
126	81.0	71.3	83.3	71.7	81.0	77.3	77.6	7.4	0.6767

[*] Mean values represent the average percentage of birds within 15% of the mean for each pen (n = 3)

No differences among means were noted ($P > 0.05$)

Table 2.5. Average daily feed intake (ADFI) and nutrient intake of different genotypes from 21 to 132 days of age*

	ADFI (grams/bird/ day)	Energy Intake (kcal ME /bird/day)	Protein Intake (grams/bird/ day)	Methionine Intake (grams/bird/ day)	Lysine Intake (grams/bird/ day)	Calcium Intake (grams/bird/ day)	Phosphorus Intake (grams/bird/ day)
Rhode Island Red	57.8	181	8.45	0.15	0.38	0.26	0.16
Black Australorp	54.9	170	8.46	0.14	0.38	0.28	0.16
Barred Plymouth Rock	57.3	178	8.67	0.15	0.39	0.28	0.16
Black Star	59.6	185	9.17	0.16	0.42	0.31	0.17
Red Star	59.7	183	9.73	0.17	0.45	0.34	0.19
ISA Brown	61.7	192	9.43	0.16	0.43	0.33	0.18
Average	58.5	182	8.99	0.16	0.41	0.30	0.17
SEM	1.8	5.0	0.49	0.01	0.03	0.02	0.01
P-value	0.2121	0.1492	0.3595	0.3699	0.3295	0.3176	0.3668

* Mean values represent pen averages (n = 3)
No differences among means were noted ($P > 0.05$)

Table 2.6. Average daily feed intake (grams/bird/day) by week of pullets from different genotypes at various ages[*]

Age (days)	Expected NRC[1]	Expected ISA[2]	Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
21 to 27	-	25	37.4 ^{bc}	27.3 ^{c}	29.1 ^{c}	36.0 ^{a}	34.2 ^{ab}	30.8 ^{bc}	1.5	0.0028
28 to 34	40.0	32	30.1	27.1	26.2	31.1	34.4	34.3	3.3	0.4167
35 to 41	-	37	30.1 ^{c}	31.1 ^{bc}	33.4 ^{bc}	35.2 ^{ab}	38.5 ^{a}	40.0 ^{a}	1.6	0.0041
42 to 48	50.0	42	37.9	40.7	42.2	40.3	39.2	44.4	2.4	0.4837
49 to 55	-	46	42.0	44.2	53.5	39.7	44.5	46.7	3.8	0.2461
56 to 62	54.3	50	42.6	44.9	45.7	45.6	47.9	47.0	1.2	0.1313
63 to 69	-	54	45.0 ^{cd}	53.3 ^{ab}	52.5 ^{ab}	47.3 ^{bc}	56.7 ^{ab}	38.9 ^{d}	2.4	0.0020
70 to 76	57.1	58	33.2 ^{b}	39.5 ^{b}	40.0 ^{b}	36.1 ^{b}	39.2 ^{b}	59.7 ^{a}	2.4	<0.0001
77 to 83	-	61	50.5	55.1	58.0	54.9	61.5	59.5	3.6	0.3612
84 to 90	60.0	64	58.1 ^{b}	63.7 ^{b}	63.7 ^{b}	62.2 ^{b}	66.8 ^{b}	83.5 ^{a}	3.5	0.0040
91 to 97	-	67	70.3	72.0	70.5	73.3	73.4	77.3	3.1	0.6399
98 to 104	64.3	70	79.5	71.3	75.6	76.9	78.5	80.3	5.3	0.8576
105 to 111	-	73	81.2	73.4	81.2	82.6	80.6	96.9	5.7	0.1835
112 to 118	67.1	76	91.1 ^{ab}	74.1 ^{c}	80.8 ^{bc}	96.6 ^{ab}	87.0 ^{ab}	92.7 ^{ab}	4.1	0.0208
119 to 125	-	80	92.5 ^{ab}	76.7 ^{c}	78.3 ^{c}	94.2 ^{ab}	89.0 ^{abc}	79.9 ^{bc}	4.3	0.0456
126 to 132	71.4	84	84.9 ^{a}	71.1 ^{c}	73.6 ^{c}	83.4 ^{ab}	74.7 ^{bc}	75.8 ^{bc}	3.0	0.0333

[*] Mean values represent pen averages (n = 3)
[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)
[1] National Research Council 1994 for brown-egg-laying pullets
[2] ISA Brown management guide

Table 2.7. Average daily energy intake (kcal/bird/day) by week of pullets from different genotypes at various ages[*]

Age (days)	Expected NRC[1]	Expected ISA[2]	Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
21 to 27	64	74	114.5^{a}	87.4^{cd}	81.1^{d}	110.0^{ab}	104.4^{ab}	97.6^{bc}	4.4	0.0011
28 to 34	112	97	94.1	79.4	83.3	96.9	105.8	107.1	10.1	0.3379
35 to 41	112	111	93.4^{d}	103.5^{cd}	95.4^{cd}	109.4^{abc}	117.8^{ab}	124.2^{a}	5.2	0.0069
42 to 48	140	125	117.3	129.8	125.6	124.2	121.0	138.0	7.5	0.4978
49 to 55	140	137	129.7	168.5	136.6	122.7	136.2	146.5	12.3	0.2059
56 to 62	152	148	134.7	142.3	140.1	143.4	147.1	146.7	3.8	0.2713
63 to 69	152	160	143.2^{bc}	163.4^{ab}	164.9^{ab}	148.9^{b}	175.1^{a}	121.4^{c}	7.6	0.0040
70 to 76	160	171	104.0^{b}	120.9^{b}	119.0^{b}	111.1^{b}	118.3^{b}	181.9^{a}	7.2	<0.0001
77 to 83	160	179	156.4	176.4	166.9	168.5	186.3	186.0	11.1	0.3986
84 to 90	171	187	182.0^{b}	197.8^{b}	196.2^{b}	193.1^{b}	206.1^{b}	255.8^{a}	11.5	0.0094
91 to 97	171	195	219.9	218.2	223.2	226.8	222.6	238.4	8.7	0.6355
98 to 104	183	204	249.5	235.2	220.9	239.0	234.1	250.3	15.2	0.7560
105 to 111	183	212	255.6	247.6	230.3	253.4	244.8	297.0	14.6	0.1021
112 to 118	191	220	281.2^{ab}	251.7^{bc}	229.0^{c}	295.3^{a}	265.2^{abc}	285.9^{ab}	12.3	0.0229
119 to 125	191	228	290.2^{a}	249.2^{b}	240.7^{b}	293.3^{a}	274.6^{ab}	250.6^{b}	12.5	0.0431
126 to 132	203	-	267.3^{a}	234.3^{c}	224.2^{c}	259.2^{ab}	232.6^{c}	239.3^{bc}	7.8	0.0138

[*] Mean values represent pen averages (n = 3)
[1] Based on the feeding program recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163)
[2] Based on feeding program recommended in the ISA Brown Management Guide (Appendix B, page 164)
[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)

Table 2.8. Average daily protein intake (grams/bird/day) by week of pullets from different genotypes at various ages[*]

Age (days)	Expected		Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
	NRC[1]	ISA[2]								
21 to 27	3.9	5.1	6.1	5.1	5.2	6.0	5.7	4.3	0.4	0.0701
28 to 34	6.8	6.8	4.5	4.3	4.5	4.6	5.6	5.2	0.6	0.6991
35 to 41	6.8	7.4	4.7 [c]	5.0 [c]	5.2 [bc]	5.4 [abc]	6.3 [a]	6.1 [ab]	0.3	0.0229
42 to 48	7.5	8.4	5.9	6.4	6.8	6.4	6.1	6.8	0.4	0.5910
49 to 55	7.5	9.1	6.6	6.9	7.6	6.2	7.3	6.8	0.6	0.6623
56 to 62	8.1	9.9	5.9 [c]	6.7 [bc]	6.8 [abc]	6.5 [bc]	7.7 [a]	7.0 [ab]	0.3	0.0346
63 to 69	8.1	10.6	6.0 [c]	8.3 [a]	7.9 [ab]	6.8 [bc]	8.9 [a]	5.8 [c]	0.4	0.0013
70 to 76	8.6	11.4	4.8 [c]	6.9 [b]	6.9 [b]	5.7 [bc]	6.8 [b]	10.0 [a]	0.5	0.0002
77 to 83	8.6	10.4	7.7	9.5	9.8	8.8	10.5	8.8	0.6	0.1184
84 to 90	8.4	10.9	8.4 [c]	10.1 [bc]	9.7 [bc]	9.5 [bc]	10.5 [b]	13.6 [a]	0.6	0.0008
91 to 97	8.4	11.4	10.3	11.1	10.9	11.5	12.5	12.2	0.8	0.4220
98 to 104	9.0	11.8	11.4	11.0	11.4	11.7	14.4	12.0	1.3	0.5349
105 to 111	9.0	12.3	11.5	10.6	13.5	13.3	13.7	15.8	1.7	0.3958
112 to 118	9.4	12.8	14.3	11.6	12.1	15.9	14.5	14.6	1.0	0.0741
119 to 125	9.4	14.1	13.4	11.0	10.4	14.1	14.0	11.6	1.1	0.1085
126 to 132	11.4	-	12.0	9.9	9.7	12.6	11.2	10.5	0.9	0.2612

[*] Mean values represent pen averages (n = 3)

[1] Based on the feeding program recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163)

[2] Based on feeding program recommended in the ISA Brown Management Guide (Appendix B, page 164)

[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)

Table 2.9. Average daily methionine intake (milligrams/bird/day) by week of pullets from different genotypes at various ages[*]

Age (days)	Expected NRC[1]	Expected ISA[2]	Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
21 to 27	64	130	103 [a]	83 [bc]	83 [bc]	97 [ab]	97[ab]	73 [c]	5.3	0.0147
28 to 34	112	172	73	73	73	83	93	90	9.9	0.5433
35 to 41	112	176	80 [d]	87 [cd]	90 [cd]	93 [bc]	107 [a]	103 [ab]	4.3	0.0072
42 to 48	115	198	97	110	113	107	103	103	6.5	0.4672
49 to 55	115	216	110	117	133	103	123	113	9.6	0.3660
56 to 62	125	234	103	110	113	110	127	117	4.9	0.0825
63 to 69	125	252	107 [cd]	140 [a]	137 [ab]	117 [bc]	153 [a]	93 [d]	6.5	0.0002
70 to 76	131	270	80 [c]	113 [b]	113 [b]	93 [bc]	80 [b]	163 [a]	7.2	<0.0001
77 to 83	131	228	130	153	160	147	173	147	10.4	0.1549
84 to 90	114	238	143 [c]	167 [bc]	167 [bc]	160 [bc]	177 [b]	223 [a]	10.5	0.0033
91 to 97	114	249	177	187	183	193	210	207	12.8	0.4271
98 to 104	122	259	197	187	200	200	233	200	19.6	0.6644
105 to 111	122	270	203	183	227	223	230	267	24.2	0.3134
112 to 118	127	280	243	200	210	270	247	247	14.9	0.0518
119 to 125	127	299	237	197	190	250	240	207	16.8	0.1149
126 to 132	150	-	210	180	180	220	200	190	13.5	0.2748

[*] Mean values represent pen averages (n = 3)

[1] Based on the feeding program recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163)

[2] Based on feeding program recommended in the ISA Brown Management Guide (Appendix B, page 164)

[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)

Table 2.10. Average daily lysine intake (grams/bird/day) by week of pullets from different genotypes at various ages[*]

Age (days)	Expected		Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
	NRC[1]	ISA[2]								
21 to 27	0.18	0.29	0.28	0.25	0.25	0.28	0.27	0.18	0.03	0.1520
28 to 34	0.32	0.38	0.20	0.20	0.21	0.21	0.26	0.23	0.03	0.6928
35 to 41	0.32	0.38	0.21	0.23	0.23	0.24	0.30	0.28	0.02	0.0642
42 to 48	0.28	0.43	0.27	0.29	0.31	0.30	0.28	0.32	0.02	0.6685
49 to 55	0.28	0.47	0.30	0.32	0.34	0.28	0.35	0.31	0.03	0.7682
56 to 62	0.30	0.51	0.25^{c}	0.31^{abc}	0.32^{ab}	0.29^{bc}	0.36^{a}	0.32^{ab}	0.02	0.0424
63 to 69	0.30	0.55	0.26^{c}	0.38^{a}	0.36^{ab}	0.30^{bc}	0.41^{a}	0.28^{c}	0.02	0.0033
70 to 76	0.32	0.59	0.23^{c}	0.36^{b}	0.35^{b}	0.28^{bc}	0.33^{b}	0.49^{a}	0.03	0.0003
77 to 83	0.32	0.48	0.36	0.47	0.48	0.43	0.51	0.41	0.03	0.0765
84 to 90	0.25	0.50	0.38^{c}	0.48^{b}	0.44^{bc}	0.44^{bc}	0.48^{b}	0.66^{a}	0.03	0.0006
91 to 97	0.25	0.53	0.47	0.51	0.50	0.53	0.60	0.58	0.05	0.3974
98 to 104	0.27	0.55	0.51	0.51	0.50	0.54	0.71	0.55	0.08	0.3916
105 to 111	0.27	0.57	0.49	0.47	0.63	0.63	0.65	0.74	0.10	0.4722
112 to 118	0.28	0.59	0.65	0.53	0.53	0.73	0.67	0.67	0.06	0.1377
119 to 125	0.28	0.66	0.58	0.46	0.41	0.62	0.63	0.50	0.06	0.1161
126 to 132	0.35	-	0.51	0.40	0.38	0.55	0.48	0.44	0.06	0.3006

[*] Mean values represent pen averages (n = 3)
[1] Based on the feeding program recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163)
[2] Based on feeding program recommended in the ISA Brown Management Guide (Appendix B, page 164)
[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)

Table 2.11. Average daily calcium intake (grams/bird/day) by week of pullets from different genotypes at various ages[*]

Age (days)	Expected		Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
	NRC[1]	ISA[2]								
21 to 27	0.21	0.27	0.23	0.20	0.20	0.22	0.21	0.15	0.02	0.2544
28 to 34	0.36	0.35	0.16	0.14	0.16	0.14	0.20	0.19	0.03	0.5299
35 to 41	0.36	0.43	0.16	0.17	0.17	0.18	0.23	0.22	0.02	0.0892
42 to 48	0.40	0.48	0.20	0.21	0.23	0.22	0.21	0.24	0.02	0.8067
49 to 55	0.40	0.53	0.21	0.23	0.23	0.21	0.26	0.23	0.03	0.8536
56 to 62	0.43	0.57	0.17^{c}	0.22^{bc}	0.22^{abc}	0.21^{bc}	0.17^{a}	0.24^{ab}	0.02	0.0242
63 to 69	0.43	0.62	0.16^{c}	0.29^{a}	0.25^{ab}	0.21^{bc}	0.31^{a}	0.20^{bc}	0.02	0.0049
70 to 76	0.46	0.66	0.15^{d}	0.27^{b}	0.26^{bc}	0.20^{cd}	0.25^{bc}	0.37^{a}	0.02	0.0004
77 to 83	0.46	0.72	0.25	0.35	0.36	0.32	0.37	0.30	0.03	0.1177
84 to 90	0.48	0.75	0.26^{c}	0.36^{b}	0.32^{bc}	0.33^{bc}	0.35^{bc}	0.50^{a}	0.03	0.0029
91 to 97	0.48	0.78	0.32	0.38	0.36	0.41	0.45	0.42	0.04	0.3061
98 to 104	0.51	0.81	0.35	0.38	0.35	0.40	0.54	0.40	0.06	0.3484
105 to 111	0.51	0.85	0.33	0.34	0.47	0.47	0.49	0.58	0.09	0.4131
112 to 118	0.54	0.88	0.50	0.40	0.39	0.57	0.57	0.49	0.05	0.1986
119 to 125	0.54	1.70	0.40	0.33	0.27	0.44	0.46	0.36	0.06	0.1980
126 to 132	1.29	-	0.36	0.28	0.25	0.39	0.34	0.31	0.05	0.3580

[*] Mean values represent pen averages (n = 3)
[1] Based on the feeding program recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163)
[2] Based on feeding program recommended in the ISA Brown Management Guide (Appendix B, page 164)
[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)

Table 2.12. Average daily phosphorus intake (grams/bird/day) by week of pullets from different genotypes at various ages*

Age (days)	Expected		Rhode Island Red	Black Australorp	Barred Plymouth Rock	Black Star	Red Star	ISA Brown	SEM	*P*-value
	NRC[1]	ISA[2]								
21 to 27	0.09	0.12	0.12	0.11	0.10	0.12	0.11	0.07	0.01	0.0720
28 to 34	0.16	0.16	0.08	0.08	0.09	0.09	0.01	0.09.	0.01	0.7161
35 to 41	0.16	0.16	0.09	0.09	0.10	0.10	0.13	0.11	0.01	0.1074
42 to 48	0.18	0.18	0.11	0.12	0.13	0.12	0.12	0.13	0.01	0.6923
49 to 55	0.18	0.20	0.13	0.13	0.14	0.12	0.15	0.12	0.02	0.7818
56 to 62	0.19	0.22	0.11	0.13	0.13	0.12	0.15	0.13	0.01	0.0924
63 to 69	0.19	0.24	0.11 [c]	0.16 [ab]	0.15 [ab]	0.12 [bc]	0.17 [a]	0.11 [c]	0.01	0.0088
70 to 76	0.20	0.25	0.09 [c]	0.15 [b]	0.14 [b]	0.11 [bc]	0.14 [b]	0.20 [a]	0.01	0.0004
77 to 83	0.20	0.26	0.15 [c]	0.20 [ab]	0.20 [ab]	0.18 [abc]	0.22 [a]	0.16 [bc]	0.01	0.0330
84 to 90	0.18	0.27	0.16 [c]	0.20 [b]	0.18 [bc]	0.18 [bc]	0.20 [b]	0.27 [a]	0.01	0.0012
91 to 97	0.18	0.28	0.19	0.21	0.21	0.22	0.25	0.24	0.02	0.4081
98 to 104	0.19	0.30	0.21	0.21	0.21	0.22	0.30	0.23	0.03	0.3792
105 to 111	0.19	0.31	0.20	0.20	0.27	0.26	0.28	0.31	0.05	0.5107
112 to 118	0.20	0.32	0.27	0.22	0.22	0.31	0.28	0.28	0.03	0.1604
119 to 125	0.20	0.37	0.24	0.19	0.17	0.26	0.27	0.21	0.03	0.1257
126 to 132	0.25	-	0.21	0.17	0.16	0.23	0.20	0.18	0.03	0.3115

* Mean values represent pen averages (n = 3)

[1] Based on the feeding program recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163)

[2] Based on feeding program recommended in the ISA Brown Management Guide (Appendix B, page 164)

[a, b, c] Means with the same letter in the same row do not differ ($P > 0.05$)

Table 2.13. Average nutrient composition of self-selected diets by pullets of different genotypes from 21 to 132 days of age*

	Energy (kcal ME/kg)	Protein (% of diet)	Methionine (% of diet)	Lysine (% of diet)	Calcium (% of diet)	Phosphorus (% of diet)
Rhode Island Red	3126	14.6	0.25	0.65	0.46	0.27
Barred Plymouth Rock	3105	15.1	0.26	0.67	0.48	0.28
Black Australorp	3098	15.4	0.26	0.70	0.52	0.29
Red Star	3062	16.3	0.28	0.76	0.56	0.32
Black Star	3097	15.3	0.26	0.70	0.51	0.29
ISA Brown	3102	15.3	0.26	0.70	0.53	0.29
Average	3098	15.3	0.26	0.70	0.51	0.29
SEM	17	0.4	0.01	0.03	0.03	0.01
P-value	0.2459	0.2478	0.2273	0.2194	0.2235	0.2455
Recommended (Brown-egg-layers)[1]	2817	15.3	0.23	0.59	0.83	0.35
Recommended (ISA Brown)[2]	2832	18.2	0.43	0.93	0.43	0.15

* Mean values represent pen averages (n = 3)
[1] Calculated based on National Research Council 1994 guide recommendations
[2] Calculated based on ISA Brown Management guide recommendations

CHAPTER 3: Growth performance, nutrient and energy intake and patterns of alternative breeds used for meat production provided through the use of a self-selection feeding program

3.1 Abstract

This study was conducted to determine the nutrient and energy intake of alternative chicken breeds used for meat production through a self-selection feeding program. Seventy-five day-old chicks per genotype (Cornish Cross males (CCM), Cornish Cross females (CCF), Red Rangers males (RR), and males from three heritage breeds of Rhode Island Red (RIR), Barred Plymouth Rock (BPR), and Black Australorp (BA)) were divided into three replicate groups and randomly assigned to floor pens with space allocated at 892 cm^2/bird. All chicks received a complete diet for the first two weeks, and then were transitioned to a self-selection feeding program using four feed choices provided on an *ad libitum* basis. The feed choices included a protein concentrate (39% CP) without added methionine and three grains that were similar in energy content, but differed in protein and methionine content (cracked corn, rolled naked oats, and pearl millet). The feeds were randomly allocated to four identical feeders within each pen and the location of the feeders was rotated 2-3 times per week. All birds were grown to 2300 grams. CCM, CCF, RR, and the heritage breeds reached this weight at 47, 52, 63, and 138 days respectively. During the self-selection feeding program, all genotypes demonstrated a linear pattern of growth vs time (R^2 = 0.98-0.99), but slopes for the meat-type birds were steeper (P < 0.01). The average daily gain was 58.3, 49.1, 39.6, and 16.4 grams/bird/day for CCM, CCF, RR, and the heritage breeds respectively (P < 0.0001). The heritage breeds had a significantly poorer (P < 0.0001) feed efficiency than the meat-type birds (5.8 vs 2.2 grams feed/gram gain). Models for intake of feed, metabolizable energy, crude protein, and methionine all showed linear relationships to BW for meat-type birds (R^2 = 0.78-0.95) and a quadratic (P < 0.01) relationship to BW for the heritage breeds (R^2 = 0.96). At any given BW, the meat-type birds consumed more energy, CP, and Met than the heritage breeds (P < 0.01). On a dietary concentration basis, the self-selected diets of the meat-type birds were lower in energy (P < 0.0001),

and higher in protein ($P < 0.0001$) than the heritage breeds. Methionine intake varied ($P < 0.0001$) by genotype with CCM having the highest (0.32%), followed by the CCF and RR (0.31%), and was lowest in the heritage breeds (0.27%). Based on self-selection, the nutrient and energy intake varied by genotype and should be considered when rearing these heritage breeds.

3.2 Introduction

In recent years, interest in slower-growing alternatives to the intensively selected commercial meat-type chickens has grown. Slower-growing breeds and strains are believed to be better suited to specialty production systems such as free range and pasture-raised poultry.

In an effort to describe the changes that have occurred in the modern meat-type bird, several studies have been done to compare modern commercial strains to a variety of unselected lines from the 1950s, 1970s, and 1990s that are maintained by universities. (Cheema et al., 2003; Havenstein et al., 2003b, a; Schmidt et al., 2009; Zuidhof et al., 2014) Additionally, some research has been done to compare today's fast-growing strains with slower-growing strains that are commercially available.(Fanatico et al., 2005a; Fanatico et al., 2005b; Fanatico et al., 2006a; Fanatico et al., 2006b; Rack et al., 2009; Carrasco et al., 2014), and some studies have looked at the use of egg-layer-type males for meat production ((Lichovnikova et al., 2009; Bertechini et al., 2014). However, little to no data exists regarding the production parameters of heritage breeds. Heritage breeds are those that physically conform to the standards of the American Poultry Association, mate naturally, have a slow growth rate, and a long, productive lifespan. The heritage breeds selected for this study were the Rhode Island Red, the Barred Plymouth Rock, and the Black Australorp. These breeds were selected because Rhode Island Reds and Barred Plymouth Rocks are two of the most commonly raised heritage breeds. Black Australorps were selected because they are popular with ethnic markets. Red Rangers were used to represent a slow-growing meat-type strain. Cornish Crosses were used to represent a fast-growing meat-type strain.

Heritage breed chickens raised for meat are typically provided a complete diet designed for meat-type birds. However, because the nutrient requirements for the heritage breeds are not known and may be different from commercial strains, feeding these diets may overfeed or underfeed these breeds. Therefore, a self-selection feeding strategy was employed to allow the birds to choose from different feeds in order to meet their individual requirements. In a self-selection feeding program, growing meat-type chickens would typically be offered two feed choices: a protein source and an energy source. However, chickens are natural foragers and should be capable of selecting from more than two feed sources. Therefore, these birds were provided with a protein concentrate and three energy sources which differed in protein (particularly methionine) content. Given proper selection by the chickens, a theoretically adequate diet should have been consumed.

In order to profitably raise chickens, producers need to know how quickly they grow, how much feed they consume, and what their nutrient requirements are. However, there is little to no published data available regarding the production characteristics for heritage breeds. Therefore, the objective of this study was to determine the growth rate and nutrient intake of heritage breed chickens used for meat production and to compare their performance with meat-type chickens.

3.3 Materials and methods

Experiments were conducted at the Alltech-University of Kentucky Research Alliance Poultry Farm. All procedures for this study were conducted under protocols approved by the University of Kentucky Institutional Animal Care and Use Committee. This trial was conducted from October 2012 to February 2013.

3.3.1 Birds and housing

One-day-old chicks were purchased from Murray McMurray Hatchery (Webster City, IA) and shipped via USPS air mail. The meat-type strains used were the Cornish Cross (males, females) and the Red Ranger (males). Heritage breeds used were the Rhode Island Red (males), Barred Plymouth Rock (males), and Black Australorp (males).

Upon arrival, chicks from each genotype (n = 75 per genotype) were weighed and assigned to a pen (n = 3 per genotype). The chicks were housed in 1.22- x 1.83-meter floor pens on clean wood shavings with a space allocation of 892 square centimeters per bird. Birds were grown to a common weight of 2300 grams which is a typical target weight for small flocks. Broiler males, broiler females, and Red Ranger males were raised to 49, 56, and 63 days of age respectively. The heritage breeds (Rhode Island Reds, Barred Plymouth Rocks, and Black Australorps) were raised to 140 days of age.

Birds were brooded at approximately 30.6°C for the first four weeks, then temperatures were reduced to ~21.1°C from 5 to 11 weeks of age, and finally to 15.6°C from 12 to 20 weeks of age. The average temperatures experienced by Cornish Cross males (28.2°C), Cornish Cross females (27.2°C), Red Ranger males (26.3°C), and heritage breeds (20.4°C) from placement through processing differed due to differing grow-out times. The lighting program consisted of 22 hours of light per day from 1 day of age through 10 weeks of age. When the birds reached 10 weeks of age, light was reduced to 16 hours per day and remained at that level through the end of the experiment.

3.3.2 Feeding

All birds were fed a nutritionally complete commercial-type starter diet (22% CP, 3084 kcal ME/kg) from 1 to 14 days of age. At 14 days of age, birds were transitioned to a self-selection feeding program consisting of four feed choices: a protein concentrate (39% CP with added vitamins and minerals), cracked corn, pearl millet, and rolled naked oats. These ingredients were chosen and the protein concentrate was formulated in order to provide the birds with choices so that they could theoretically self-select a balanced diet. The nutrient composition of each feed choice is shown in Table 3.1. The protein concentrate consisted of buckwheat, solvent-extracted soybean meal, fishmeal, field peas, dicalcium phosphate, limestone, salt, a vitamin-mineral premix, and an enzyme complex (Allzyme SSF®, Alltech Inc., Nicholasville, KY. Integral® (Alltech Inc., Nicholasville, KY), a glucomannan containing yeast product, was added to the protein concentrate to reduce potential mycotoxin absorption in the birds. The protein concentrate formulation is shown in Table 3.2. Each feed ingredient was randomly allocated to one of four identical feeders. Feeder location was rotated two to three times per week. All feed ingredients were offered on an *ad libitum* basis. Water was offered on an *ad libitum* basis using a nipple watering system.

At 70 days of age, the heritage breed birds had not yet reached the target weight, so they were split into two groups. Ten birds from each pen were moved as a group to a new pen where they were provided a complete commercial-type starter diet (22% CP, 3084 kcal ME/kg). The other birds remained in their pen on the original self-selection diet. For both feeding strategies, the same feeders were used and feed and water were offered on an *ad libitum* basis.

3.3.3 Data collection

Chicks were weighed at the time of placement (1 day of age) and then once weekly through processing. Because birds were raised to a common weight of 2300 grams, processing occurred at different times for different genotypes. Cornish Cross males, Cornish Cross females, and Red Ranger males were raised to 49, 56, and 63 days of age respectively. The heritage breeds (Rhode Island Reds, Barred Plymouth Rocks, and Black Australorps) were raised to about 140 days of age.

Average daily gain was calculated on a pen basis from 1 day of age to processing. Consumption of each feed ingredient was measured two to three times per week before feeders were rotated. Ingredient consumption was measured separately and then combined to determine average daily feed intake. Feed conversion ratio was calculated as grams of feed required per gram of gain. Daily mortality was also monitored and accounted for in calculations for gain and feed intake.

3.3.4 Statistical analysis

This experiment had a completely randomized block design with the experimental unit as the pen blocked by location within the room. Data for this experiment were analyzed for analysis of variance using the general linear model procedures of SAS® (SAS v. 9.3, Cary, NC) with genotype as the dependent variable. The replicate pen of birds served as the experimental unit. Fisher's least significant difference test was used to determine differences among means with a significance set at $P < 0.05$.

Linear and nonlinear models were constructed to describe the growth and nutrient intake patterns for each type of bird from 21 days of age to processing at a body weight of 2300 grams. Slopes were analyzed as a one-way analysis of variance using the general linear model procedures of SAS® with genotype as the dependent variable and significance set at $P < 0.05$.

3.4 Results and discussion

3.4.1 Body weight

The average body weight for each breed was recorded each week from 1 day of age through processing at a 2300-gram live weight. These values are reported in Table 3.3. At 1 day of age, the body weights differed among breeds and strains. The Red Ranger males were the heaviest ($P < 0.0001$) at 40 grams, followed by the Cornish Cross males at 35 grams, and the Black Australorp males at 32 grams. The Cornish Cross females, Rhode Island Red males and Barred Plymouth Rock males were the lightest ($P < 0.05$) at 30 grams. This is consistent with the results of Paul (2015) which evaluated chicks from the same hatchery. While the differences noted in initial body weight may be influenced by genotype, other factors such as breeder flock age, egg size, and hatch time may also play a role (Hulet et al., 2007; Zakaria and Omar, 2013; Mbajiorgu and Ramaphala, 2014; Bergoug et al., 2015; Nangsuay et al., 2015).

By 14 days of age, the Cornish Cross males were heavier ($P < 0.05$) than the Cornish cross females, and both were heavier ($P < 0.05$) than the Red Ranger males. All three meat-type strains were heavier ($P < 0.05$) than the heritage breeds. This pattern continued each week through processing.

The target weight of 2300 grams was achieved by 49, 56, and 63 days of age respectively for the Cornish Cross males, Cornish Cross females, and Red Ranger males (Table 3.3). In the case of both the Cornish Cross males and females, the target weight was overshot by about 300 grams. Extrapolating from growth rate, it would be expected that the Cornish Cross males and females reached 2300 grams at about 47 and 52 days of age respectively (Table 3.4). This is consistent with the literature and the National Research Council (1994) expected values for broilers.

Throughout the trial, the heritage breeds consistently exhibited low body weights. In fact, during the period from 21 days of age through 56 days of age, the body weights of the heritage breed males utilized in this study fell below the values published for brown-egg-layer pullets (National Research Council, 1994). At 35 days of age, the heritage breeds averaged 348 ± 22 grams which is only 1.16-fold heavier than the weight Jackson and Diamond (1996) reported for Red Jungle Fowl (300 grams) at that age. This suggests that the early growth rate of these heritage breeds has not significantly improved from their wild ancestors.

At 63 days of age, the average body weight of the heritage breed males was 847 ± 28 grams which exceeded the expected body weight for brown-egg-layer pullets with an (National Research Council, 1994). From that point forward, the heritage breed males maintained body weights well above the expected values for brown-egg-layer pullets with an (National Research Council, 1994).

Additionally, some differences were noted among the heritage breeds. From 70 through 91 days of age, Rhode Island Reds had heavier ($P < 0.05$) body weights when compared to Barred Plymouth Rocks and Black Australorps. However, from 98 days of age on, body weights were similar ($P > 0.05$) among the heritage breeds. The heritage breeds reached the target weight of 2300 grams between 133 and 140 days of age. This was nearly three times as long as it took the Cornish Cross males in the study to reach that same weight.

3.4.2 Average daily gain

During the self-selection feeding program, the average daily gain differed ($P < 0.0001$) among genotypes. The overall average daily gain was 58.3, 49.1, 39.6, and 16.4 grams/bird/day for Cornish Cross males, Cornish Cross females, Red Rangers, and the heritage breeds respectively (Table 3.4). The overall average daily gain for the Cornish Cross males in this study was similar to the average daily gain reported by Havenstein et al. (2003b) for the Ross 308 which was developed in 2001 and is still utilized today. Meanwhile, the overall average daily gain for the slow-growing genotype (Red Ranger) utilized in this study was similar to that reported by Havenstein et al. (1994a) for the Arbor Acres broiler which was representative of the genetics available in 1991. Finally, the overall average daily gain for the heritage breeds utilized in this study was similar to the average daily gain reported by Havenstein et al. (1994a); Havenstein et al. (2003b) for the Athens-Canadian random-bred birds which are an unselected line of meat-type birds maintained since 1957.

Average daily gain by week for each genotype is presented in Table 3.5. During each week, Cornish cross males consistently exhibited higher ($P < 0.05$) average daily gain than Cornish cross females, and both exhibited higher ($P < 0.05$) average daily gain than Red Ranger males. All three meat-type strains exhibited higher ($P < 0.05$) average daily gain when compared with the heritage breeds. Among the heritage breeds, average daily gain was similar ($P > 0.05$) with the exception of one week where average daily gain was higher ($P < 0.05$) for Rhode Island Reds than Barred Plymouth Rocks.

Overall, the average daily gain data from the present study is consistent with the literature which shows that heritage breeds have slower growth rates than broilers (McCrea et al., 2014), and selection for meat production has increased growth rates for modern broiler strains (Havenstein et al., 1994a; Havenstein et al., 1994b; Cheema et al., 2003; Havenstein et al., 2003b, a; Schmidt et al., 2009; Zuidhof et al., 2014). Additionally, the results of this study suggest that the slow-growing meat-type strain (Red Rangers) utilized exhibits a similar growth rate to the meat-type birds used in the late 1970s through the early 1990s (Havenstein et al., 1994a; Zuidhof et al., 2014).

3.4.3 Feed intake

During the self-selection feeding program, the overall average daily feed intake differed ($P < 0.0001$) among genotypes (Table 3.4). The Cornish Cross males consumed more ($P < 0.05$) feed per day than the Cornish Cross females, and both consumed more ($P < 0.05$) feed per day than the Red Rangers. All the meat-type birds consumed more ($P < 0.05$) feed per day than the heritage breeds. Within the heritage breeds, Rhode Island Reds consumed more ($P < 0.05$) feed per day than Barred Plymouth Rocks and Black Australorps.

Average daily feed intake by week is presented in Table 3.6. For each week, the average daily feed intake for Cornish Cross males was higher than the expected values published by the National Research Council (1994) for male broilers. Similarly, Cornish Cross females met or exceeded the expected average daily feed intake for female broilers during most weeks (National Research Council, 1994). For the Red Ranger males, average daily feed intake was initially higher than the expected values for either male or female broilers, but fell below the expected intake at 35 days of age (National Research Council, 1994). Feed consumption for heritage breeds typically exceeded the expected feed intake for brown-egg-laying pullets, but was lower than the expected feed intake for broilers (National Research Council, 1994).

At each time point from placement through processing, the meat-type birds consumed more ($P < 0.0001$) feed per day than the heritage breeds. Each week, Cornish Cross males consumed more ($P < 0.05$) feed than Red Rangers with the feed consumption of the Cornish Cross females typically falling somewhere in between. For most weeks, there were no differences ($P > 0.05$) in feed intake among the heritage breeds. However, when there were differences, Rhode Island Reds typically consumed more ($P < 0.05$) feed than the other breeds. The highest average daily feed intake for heritage breeds was only around 100 grams of feed per bird per day which was about half of the maximum feed intake observed for the Cornish Cross males during the study. This is consistent with the results of McCrea et al. (2014) which showed that the feed intake of the Delaware (a heritage breed chicken) increased throughout the 14-week grow-out period, but never reached the same level of feed intake achieved by broilers at the end of their grow-out.

3.4.4 Feed efficiency

Average feed efficiency from placement at 1 day of age through processing at a 2300-gram live weight was expressed as grams of feed per gram of gain and is listed by genotype in Table 3.4. The Cornish Cross males had better ($P < 0.05$) feed efficiency than the Cornish Cross females, and both had better ($P < 0.05$) feed efficiency than the Red Rangers. All of the meat-type birds had better ($P < 0.0001$) feed efficiency than the heritage breeds.

The heritage breeds in the present study exhibited a feed efficiency of approximately 3.96 grams of feed per gram of gain which is similar to that found by McCrea et al. (2014) for Delaware chickens which are another heritage breed. In that study, the Delaware chickens exhibited a feed conversion ratio of 3.46 grams of feed per gram of gain which was about twice that of the broilers utilized in that study.

In another study, Zuidhof et al. (2014) compared the performance of a commercial Ross 308 strain (representative of the genetic stock available in 2005) to two University of Alberta Meat Control strains (one unselected since 1957, the other unselected since 1978). When Zuidhof et al. (2014) raised these birds on a modern nutritional program to 56 days of age, they found that broiler growth increased by over 400% with a concurrent 50% reduction in feed conversion ratio from 1957 to 2005. This is very similar to what the results of the present study with Cornish Cross males achieving 355% higher growth rates while consuming 51% less feed per gram of gain when compared with the heritage breed males.

3.4.4.1 Energy and nutrient intake

Average energy and nutrient intake for meat-type birds and heritage breeds during the self-selection feeding program from 21 days of age to processing at a 2300-gram live weight was reported in Table 3.7.

3.4.4.1.1 Energy

During the self-selection feeding program, the overall average energy intake (kcal ME/bird/day) followed a similar pattern to feed intake. The Cornish Cross males consumed the most ($P < 0.05$) energy per day (442 kcal ME/bird/day) followed by the Cornish Cross females and Red Rangers (381 kcal ME/bird/day) and then the heritage breeds. Within the heritage breeds, Rhode Island Reds (241 kcal ME/bird/day) consumed more ($P < 0.05$) energy per day than Barred Plymouth Rocks (202 kcal ME/bird/day), with Black Australorps (225 kcal ME/bird/day) intermediate.

Average daily energy intake for each week is presented in Table 3.8. The energy consumption pattern tends to follow the overall consumption pattern. Energy intake for Cornish Cross males and Cornish Cross females were similar to or exceeded expected values for male and female broilers, respectively (National Research Council, 1994). Energy intake for Red Rangers was similar to expected values for female broilers through 35 days of age, but fell below the expected values in the following weeks (National Research Council, 1994). The heritage breed males typically met or exceeded expected energy intake for brown-egg-laying pullets, but were lower than expected for either male or female broilers (National Research Council, 1994).

3.4.4.1.2 Protein

During the self-selection feeding program, the overall average protein intake (grams/bird/day) was higher ($P < 0.0001$) for meat-type birds than heritage breeds (Table 3.7). Within the meat-type birds, protein consumption was higher ($P < 0.05$) for Cornish Cross males than Cornish Cross females, and both were higher than Red Rangers. Within the heritage breeds, protein consumption was highest ($P < 0.05$) for Rhode Island Reds and lowest ($P < 0.05$) for Barred Plymouth Rocks with Black Australorps intermediate.

Average daily protein intake for each week is presented in Table 3.9. Cornish Cross males typically exceeded expected intake for broiler males, while Cornish Cross females typically met expected intake for broiler females (National Research Council, 1994). Protein intake for Red Rangers was similar to expected values for broiler females through 35 days of age, and then fell below those expected values (National Research Council, 1994). Average daily protein intake for heritage breed males was similar to, or exceeded, the expected values for brown-egg-laying pullets during most weeks (National Research Council, 1994).

3.4.4.1.3 Methionine

During the self-selection feeding program, the overall average methionine intake (grams/bird/day) followed a similar pattern as for protein intake except Cornish Cross females and Red Rangers did not differ (Table 3.7). Within the meat-type birds, methionine consumption was higher ($P < 0.05$) for Cornish Cross males (0.47 grams/bird/day) than for the other two strains (0.39 grams/bird/day). Within the heritage breeds, methionine consumption was highest ($P < 0.05$) for Rhode Island Reds (0.22 grams/bird/day) and lowest for Barred Plymouth Rocks (0.18 grams/bird/day) with Black Australorps (0.20 grams/bird/day) intermediate.

Average daily methionine intake for each week is presented in Table 3.10. Average daily methionine intake (grams/bird/day) for Cornish Cross males was lower than the expected values for male broilers for most weeks, but exceeded the expectations for female broilers after 28 days of age (National Research Council, 1994). Cornish Cross females and Red Ranger males consumed less methionine than expected for either male or female broilers, but greatly exceeded the expectations for brown-egg-laying pullets (National Research Council, 1994). Methionine intake for heritage breed males exceeded the expected values for brown-egg-laying pullets for most weeks (National Research Council, 1994).

3.4.4.1.4 Lysine

During the self-selection feeding program, the overall average lysine intake (grams/bird/day) was higher ($P < 0.0001$) for meat-type birds than for heritage breed males (Table 3.7). Within the meat-type birds, lysine consumption was higher ($P < 0.05$) for Cornish Cross males (1.63 grams/bird/day) than Cornish Cross females (1.22 grams/bird/day), and both were higher than Red Rangers (1.05 grams/bird/day). The average consumption of lysine by heritage breed males was 0.53 grams/bird/day with no difference ($P > 0.05$) among the breeds.

Average daily lysine intake for each week is presented in Table 3.11. Lysine intake for Cornish Cross males and Cornish Cross females exceeded the lysine intake expected for broiler males and females, respectively (National Research Council, 1994). Lysine intake for Red Rangers was similar to the expected lysine intake of broiler females through 35 days of age, and then fell below those values (National Research Council, 1994). Heritage breeds initially met the expected lysine values for brown-egg-laying pullets, and then greatly exceed them (National Research Council, 1994).

3.4.4.1.5 Calcium

During the self-selection feeding program, the overall average calcium intake (grams/bird/day) was higher ($P < 0.0001$) for meat-type birds than heritage breeds (Table 3.7). Within the meat-type birds, calcium consumption was higher ($P < 0.05$) for Cornish Cross males (1.35 grams/bird/day) than Cornish Cross females (0.96 grams/bird/day), and both were higher ($P < 0.05$) than Red Rangers (0.79 grams/bird/day). The average consumption of calcium for heritage breed males was 0.39 grams/bird/day and did not differ ($P > 0.05$) among the three heritage breeds.

Average daily calcium intake for each week is presented in Table 3.12. Cornish Cross males met or exceeded the expected calcium intake of broiler males (National Research Council, 1994). Cornish Cross females initially met the expected calcium intake of broiler females, and then fell below expectations after 35 days of age (National Research Council, 1994). Calcium intake for Red Rangers fell below expectations for broiler males and females, but nearly doubled expected values for brown-egg-laying pullets (National Research Council, 1994). Calcium intake for heritage breed chickens fell below expected values for brown-egg-laying pullet through 70 days of age, and then increased to be more in line with expected values after 77 days of age (National Research Council, 1994).

3.4.4.1.6 Phosphorus

During the self-selection feeding program, the overall average phosphorus intake (grams/bird/day) was higher (P < 0.0001) for meat-type birds than heritage breed males (Table 22). Within the meat-type birds, average daily phosphorus consumption was higher ($P < 0.05$) for Cornish Cross males (0.69 grams/bird/day) than for Cornish Cross females (0.52 grams/bird/day), and both had higher ($P < 0.05$) phosphorus consumption than Red Rangers (0.45 grams/bird/day). Average daily consumption of phosphorus for the heritage breeds was 0.22 grams/bird/day and there were no differences ($P > 0.05$) among the three heritage breeds.

Average daily phosphorus intake for each week is presented in Table 3.13. Cornish Cross males and females exceeded the expected phosphorus intake for broiler males and females, respectively (National Research Council, 1994). Phosphorus intake for Red Ranger males was similar to the expected values for broiler females (National Research Council, 1994). Heritage breeds consumed similar amounts of phosphorus to the expected values for brown-egg-laying pullets through 70 days of age, and then exceeded expected levels thereafter (National Research Council, 1994).

3.4.5 Modeling growth and feed intake patterns

3.4.5.1 Growth pattern

Linear and nonlinear models were constructed to describe the growth patterns for each type of bird from 21 days of age to processing at a body weight of 2300 grams (Figure 3.1). All of the linear models for growth vs. time provided a good fit to the data (Table 3.14). Models for the meat-type birds had steeper ($P < 0.01$) slopes than those for the heritage breeds. At any given age, the meat-type birds were heavier ($P < 0.01$) than the heritage breeds.

3.4.5.2 Feed, energy, and nutrient intake patterns

Linear and nonlinear models were constructed to describe the feed, energy, and nutrient intake patterns for each type of bird from 21 days of age through processing at a body weight of 2300 grams. For example, Figure 3.2 shows the patterns of average daily feed intake in grams/bird/day versus body weight in kilograms for each genotype. One equation was used for all three heritage breeds because there was no significant difference among those breeds. The equations for the best-fit lines shown in Figure 3.2 are listed in Table 3.15.

Consumption of feed (grams/bird/day), energy (kcal ME/bird/day), crude protein (grams/bird/day), and methionine (grams/bird/day) all showed linear relationships to body weight for meat-type birds ($R^2 = 0.78 - 0.95$) and a quadratic ($P < 0.01$) relationship to body weight for the heritage breeds ($R^2 = 0.96$). At any given body weight, the meat-type birds consumed more ($P < 0.01$) energy, crude protein, and methionine than the heritage breeds. At any given feed intake, the meat-type birds consumed less energy, more crude protein, and more methionine than the heritage breeds ($P < 0.01$).

The difference in these relationships may be a reflection of the different growth rates of the genotypes. Due to the fast growth rate of the meat-type birds, a large portion of the nutrients consumed go towards growth rather than maintenance. On the other hand, the heritage breeds grow slower and put more nutrients towards maintenance, particularly as they reach maturity. Additionally, broilers would be expected to reach heavier weights at maturity than the heritage breeds.

Finally, linear models were constructed to describe the relationship between energy intake (kcal/bird/day) and feed intake (grams/bird/day) for each genotype. The equations for the best-fit lines are listed in Table 3.16. All showed a strong linear relationship ($R^2 > 0.99$, $P = 0.0001$) with the equation for the Cornish Cross males having a steeper ($P < 0.05$) slope than those for the other genotypes.

3.4.6 Composition of self-selected diets

The overall nutrient composition of the self-selected diets varied by genotype (Table 3.17). The Cornish Cross males, Cornish Cross females and Red Rangers selected diets lower in energy (2887 vs. 2950 vs. 2982 vs. 3068 kcal ME/kg, SEM = 10; $P < 0.0001$), and higher in protein (20.8 vs. 19.2 vs. 18.3 vs. 16.2%, SEM = 0.3; $P < 0.0001$) than the heritage breeds. Methionine intake varied ($P < 0.0001$) by genotype with Cornish Cross males having the highest intake (0.32%), followed by the Cornish Cross females and Red Rangers (0.31%), and the heritage breeds having the lowest methionine intake (0.27%).

3.4.7 Effect of feeding strategy on heritage breeds

At 70 days of age, the Rhode Island Red, Barred Plymouth Rock, and Black Australorp males averaged 945 grams. To evaluate the effect of the self-selection feeding program versus a complete diet, 10 birds per pen were moved into new pens and provided with a complete broiler starter diet (22% CP; 3084 kcal ME/kg). The remaining 10 to 15 birds were left in the pen and continued to receive the self-selection feed choices. This approximately doubled the space allocation per bird. The effect of feeding strategy on average daily gain, average daily feed intake, and average feed:gain from 70 to a 2300-gram live weight was reported in Table 3.18. The effect of feeding strategy on average daily consumption of energy, protein, and methionine was reported in Table 3.19.

For all three heritage breeds, switching to a complete broiler starter diet resulted in increased average daily gain (22.4 vs 18.8 grams/bird/day; SEM = 0.6; $P < 0.0001$) without a change in average daily feed intake (91.9 ± 3.6 grams/bird/day; $P > 0.05$). This suggests that the birds are not balancing their diets to maximize growth. Additionally, it must be acknowledged that the higher nutrient density of the broiler starter diet may have triggered some compensatory growth for birds that were underfed on the self-selection feeding program. Compensatory growth is the accelerated growth of an organism following a period of slowed development due to nutrient deprivation. During compensatory growth, broiler chickens often exhibit higher than normal feed intake relative to their body weight (Zubair and Leeson, 1996). In the present study, there was no difference ($P > 0.05$) in feed intake between birds on the broiler starter and birds using the self-selection feeding program. However, birds on the broiler starter diet exhibited improved feed conversion when compared with birds on the self-selection feeding program (4.21 vs 4.82 grams of feed per gram of gain; SEM = 0.15; $P < 0.05$) which suggests some of the additional nutrients in the broiler starter were put towards growth.

Energy intake (kcal ME/bird/day) was similar ($P < 0.05$) between feeding strategies which is consistent with the literature that suggests birds eat foremost to meet an appetite for energy. Because the complete broiler starter diet contained higher levels of protein and amino acids than the self-selected diets, the birds fed the broiler starter diet consumed more protein and methionine per bird per day than those remaining on self-selection consumed. This is consistent with the literature which shows that self-selection-fed birds often consume less protein than would be provided in a formulated diet (Sahin, 2003; Fanatico et al., 2013). This was not surprising considering the birds on the self-selection feeding program in the present study selected diets that were relatively high in energy and low in crude protein when compared with the broiler starter diet. That pattern of selection is consistent with the literature which shows that birds using self-selection feeding programs consume more energy and less protein than birds fed complete diets (Leeson and Caston, 1993; Sahin, 2003; Cerrate et al., 2007; Syafwan et al., 2012; Fanatico et al., 2013; Catanese et al., 2015).

3.5 Summary and conclusions

When provided with the same feed choices, heritage breeds exhibited significantly slower growth rates than either fast- or slow-growing meat-type strains. In this study, the heritage breeds required 2.8x more time than the Cornish Cross males to reach the targeted live weight of 2300 grams. Additionally, the slow-growing meat-type strain (Red Rangers) studied required about 1.3x longer than the Cornish Cross males to achieve the targeted weight.

While the heritage breeds did consume less feed per day than the meat-type strains, they exhibited poor feed efficiency which resulted in higher overall feed intake to reach the same body weight. When some of the heritage breed males were switched onto a commercial broiler starter diet (22% CP; 3084 kcal ME/kg) at 70 days of age, average daily gain and feed efficiency for heritage breeds was improved when compared with those remaining on the self-selection feeding program. However, these birds still required nearly twice as much feed per gram of gain than fast-growing broiler strains require. Therefore, regardless of the feeding strategy employed, producers interested in raising heritage breeds will need to provide these birds with more feed than would typically be provided to a broiler.

The diets that the heritage breeds self-selected were higher in energy, but lower in protein and methionine than the diets selected by the meat-type birds. This suggests heritage breeds may have lower nutrient requirements which would allow for the use of lower-nutrient-density diets and more marginal feedstuffs. It may also make these breeds potentially useful in alternative production systems such as organic which restrict or ban synthetic amino acid supplementation (USDA 2012a; USDA 2012b).. However, further research would need to be conducted to determine the actual nutrient requirements for these, and other, heritage breeds. Additionally, further research is needed to determine the carcass characteristics and meat quality of heritage breeds.

3.6 Tables

Table 3.1. Analyzed nutrient composition of self-selection feed choices

Nutrient	Protein Concentrate	Cracked Corn	Pearl Millet	Rolled Naked Oats
Energy, kcal ME/kg (calculated)	2163	3390	3240	3180
Crude protein, %	39.0	7.9	11.6	14.4
Methionine, %	0.51	0.16	0.28	0.23
Lysine, %	2.47	0.27	0.20	0.58
Calcium, %	2.14	0.01	0.05	0.84
Phosphorus, % available	1.10	0.09	0.10	0.17

Table 3.2. Protein concentrate formulation

Ingredient	Inclusion level
Buckwheat	13.40%
Soybean meal, solvent extracted	64.78%
Fishmeal	4.36%
Field peas	8.93%
Dicalcium phosphate	4.47%
Limestone	2.01%
Salt	1.01%
Vitamin-mineral premix [1]	0.56%
Integral® [2]	0.45%
Enzyme complex [3]	0.04%

[1] Akey Layer Starter Breeder Premix (Akey, Lewisburg, OH)
[2] Integral® (Alltech Inc., Nicholasville, KY)
[3] Allzyme-SSF® (Alltech Inc., Nicholasville, KY)

Table 3.3. Average body weight (grams) by week for meat-type birds and heritage breed males from 1 to 140 days of age*

Age (days)	Expected (NRC 1994) Broiler Male	Expected (NRC 1994) Broiler Female	Expected (NRC 1994) Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Barred Plymouth Rock (male)	Black Australorp (male)	SEM	*P*-value
1	-	-	37	35^{b}	30^{d}	40^{a}	31^{d}	31^{d}	32^{c}	0.4	<0.0001
14	376	344	120	325^{a}	283^{b}	252^{c}	138^{d}	118^{d}	124^{d}	7.7	<0.0001
21	686	617	223	606^{a}	514^{b}	431^{c}	204^{d}	176^{d}	189^{d}	15.7	<0.0001
28	1085	965	325	935^{a}	817^{b}	674^{c}	279^{d}	240^{d}	264^{d}	19.6	<0.0001
35	1576	1344	413	1487^{a}	1253^{b}	1005^{c}	372^{d}	321^{d}	351^{d}	22.3	<0.0001
42	2088	1741	500	1974^{a}	1691^{b}	1359^{c}	489^{d}	417^{d}	464^{d}	31.0	<0.0001
49	2590	2134	625	2633^{a}	2175^{b}	1693^{c}	629^{d}	533^{d}	591^{d}	43.8	<0.0001
56	-	2506	750	-	2664^{a}	2086^{b}	780^{c}	645^{c}	725^{c}	41.6	<0.0001
63	-	-	825	-	-	2392^{a}	930^{b}	770^{c}	840^{bc}	28.3	<0.0001
70	-	-	900	-	-	-	1060^{a}	893^{b}	909^{b}	11.1	0.0003
77	-	-	1000	-	-	-	1112^{a}	958^{b}	988^{b}	19.0	0.0063
84	-	-	1100	-	-	-	1303^{a}	1107^{b}	1158^{b}	26.5	0.0105
91	-	-	1170	-	-	-	1470^{a}	1278^{b}	1326^{b}	32.9	0.0264
98	-	-	1240	-	-	-	1654	1489	1610	34.5	0.0714
105	-	-	1310	-	-	-	1813	1665	1780	33.8	0.0903
112	-	-	1380	-	-	-	1925	1793	1900	37.4	0.1641
119	-	-	1440	-	-	-	2033	1893	2004	47.9	0.2591
126	-	-	1500	-	-	-	2177	2047	2172	51.3	0.2996
133	-	-	-	-	-	-	2277	2147	2256	59.3	0.4158
140	-	-	-	-	-	-	2412	2275	2381	58.0	0.3800

*Mean values represent pen averages (n = 3)

$^{a, b, c, d}$ Mean values within a row without common superscripts are different ($P < 0.05$)

Table 3.4. Average daily gain, average daily feed intake, and average feed:gain for meat-type birds and heritage breed males from 1 day of age through processing at a 2300-gram live weight[*]

	Time to reach 2300-gram live weight (days)	Average Daily Gain (grams/bird/day)	Average Daily Feed Intake (grams/bird/day)	Average Feed:Gain (grams of feed per gram of gain)
Cornish Cross male	47^{c}	58.3^{a}	111^{a}	1.91^{d}
Cornish Cross female	52^{c}	49.1^{b}	102^{ab}	2.02^{c}
Red Ranger male	63^{b}	39.6^{c}	89^{b}	2.24^{b}
Rhode Island Red male	138^{a}	17.5^{d}	70^{c}	4.02^{a}
Black Australorp male	135^{a}	16.7^{d}	65^{d}	3.89^{a}
Barred Plymouth Rock male	140^{a}	14.9^{d}	63^{d}	3.96^{a}
SEM	2.4	4.4	2.2	0.04
P-Value	<0.0001	<0.0001	<0.0001	<0.0001

[*] Mean values represent pen averages (n = 3)

[a, b, c, d] Mean values within a column without common superscripts are different ($P < 0.05$)

Table 3.5. Average daily gain (grams/bird/day) by week for meat-type birds and heritage breed males from 1 to 140 days of age*

Age (days)	Expected[1] Broilers Male	Expected[1] Broilers Female	Expected[1] Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
1 to 13	24	22	5.9	23^{a}	17^{b}	14^{c}	7^{d}	6^{d}	6^{d}	0.5	<0.0001
14 to 20	44	39	-	40^{a}	33^{b}	26^{c}	10^{d}	9^{d}	8^{d}	1.5	<0.0001
21 to 27	57	50	14.6	47^{a}	42^{b}	34^{c}	11^{d}	11^{d}	9^{d}	1.0	<0.0001
28 to 34	70	54	-	79^{a}	62^{b}	47^{c}	13^{d}	12^{d}	12^{d}	1.3	<0.0001
35 to 41	73	57	12.5	70^{a}	60^{b}	51^{c}	17^{d}	16^{d}	14^{d}	1.3	<0.0001
42 to 48	72	56	-	91^{a}	69^{b}	48^{c}	20^{d}	18^{d}	17^{d}	2.3	<0.0001
49 to 55	-	53	17.9		70^{a}	56^{b}	22^{c}	18^{cd}	16^{d}	1.2	<0.0001
56 to 62	-	-	-			41^{a}	21^{b}	16^{b}	19^{b}	1.5	<0.0001
63 to 69	-	-	10.7				21	16	16	1.4	0.0672
70 to 76	-	-	-				8	11	9	2.3	0.5515
77 to 83	-	-	14.3				27	21	24	1.5	0.1330
84 to 90	-	-	-				24	24	24	1.0	0.9405
91 to 97	-	-	10.0				25	24	22	1.4	0.4805
98 to 104	-	-	-				23	44	25	1.1	0.4250
105 to 111	-	-	10.0				16	17	18	1.2	0.4764
112 to 118	-	-	-				14	15	14	1.6	0.9546
119 to 125	-	-	8.6				21	24	22	1.4	0.3170
126 to 132	-	-	-				14	12	14	1.7	0.6045
133 to 139	-	-	7.1				19	18	18	1.3	0.7388

* Mean values represent pen averages (n = 3)

a, b, c, d Mean values within a row without common superscripts are different ($P < 0.05$)

[1] National Research Council 1994

Table 3.6. Average daily feed intake (grams/bird/day) by week for meat-type birds and heritage breeds from 21 to 140 days of age*

Age (days)	Expected [1] Broilers Male	Expected [1] Broilers Female	Expected [1] Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
1 to 13	19	19	10	36 [a]	34 [ab]	33 [b]	25 [c]	23 [c]	24 [c]	0.7	<0.0001
14 to 20	41	39	10	59 [a]	56 [ab]	51 [b]	32 [c]	27 [c]	29 [c]	2.3	<0.0001
21 to 27	70	63	23	86 [a]	81 [a]	69 [b]	38 [c]	29 [d]	31 [cd]	3.0	<0.0001
28 to 34	101	92	23	137 [a]	116 [b]	100 [c]	41 [d]	36 [de]	28 [e]	2.8	<0.0001
35 to 41	137	105	40	149 [a]	122 [b]	116 [b]	47 [c]	38 [d]	32 [d]	2.3	<0.0001
42 to 48	163	143	40	184 [a]	147 [b]	124 [c]	52 [d]	48 [d]	40 [e]	3.5	<0.0001
49 to 55	183	154	50	204 [a]	165 [b]	141 [c]	64 [d]	58 [d]	46 [d]	6.3	<0.0001
56 to 62	205	166	50	-	167 [a]	138 [a]	66 [b]	56 [b]	49 [b]	11.6	<0.0001
63 to 69	225	178	54	-	-	168 [a]	75 [b]	62 [c]	54 [c]	3.9	<0.0001
70 to 76	-	-	54	-	-	-	59	50	43	5.3	0.1847
77 to 83	-	-	57	-	-	-	83	69	60	5.8	0.0775
84 to 90	-	-	57	-	-	-	89	79	69	4.9	0.0754
91 to 97	-	-	60	-	-	-	94	93	82	6.2	0.3786
98 to 104	-	-	60	-	-	-	95	94	88	4.7	0.5482
105 to 111	-	-	64	-	-	-	103	103	97	3.1	0.3046
112 to 118	-	-	64	-	-	-	104	112	98	6.3	0.3310
119 to 125	-	-	67	-	-	-	111	115	103	4.0	0.1746
126 to 132	-	-	67	-	-	-	108	104	98	4.3	0.2887
133 to 139	-	-	71	-	-	-	107	103	99	2.2	0.0877

*Mean values represent pen averages (n = 3)
[a, b, c, d] Mean values within a row without common superscripts are different ($P < 0.05$)
[1] National Research Council 1994

Table 3.7. Average daily energy and nutrient consumption of meat-type birds and heritage breeds from 21 days of age through a 2300-gram live weight*

	Energy Intake (kcal ME /bird/day)	Protein Intake (grams/bird/day)	Methionine Intake (grams/bird/day)	Lysine Intake (grams/bird/day)	Calcium Intake (grams/bird/day)	Phosphorus Intake (grams/bird/day)
Cornish Cross males	442 [a]	30.9 [a]	0.473 [a]	1.63 [a]	1.35 [a]	0.69 [a]
Cornish Cross females	396 [b]	24.6 [b]	0.400 [b]	1.22 [b]	0.96 [b]	0.52 [b]
Red Ranger	366 [b]	22.1 [c]	0.370 [b]	1.05 [c]	0.79 [c]	0.45 [c]
Rhode Island Red	241 [c]	12.6 [d]	0.223 [c]	0.55 [d]	0.39 [d]	0.24 [d]
Black Australorp	225 [cd]	11.8 [de]	0.197 [cd]	0.55 [d]	0.41 [d]	0.23 [d]
Barred Plymouth Rock	202 [d]	10.4 [e]	0.177 [d]	0.48 [d]	0.36 [d]	0.23 [d]
SEM	10.6	0.7	0.0119	0.039	0.033	0.016
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[*] Mean values represent pen averages (n = 3)

[a,b,c,d,e] Mean values within a column without common superscripts are different ($P < 0.05$)

Table 3.8. Average daily energy intake (kcal ME/bird/day) by week for meat-type birds and heritage breeds from 21 to 140 days of age*

Age (days)	Expected[1] Broilers			Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
	Male	Female	Brown-egg-layer (female)								
21 to 27	223	203	64	247 [a]	235 [a]	200 [b]	114 [c]	84 [d]	91 [cd]	8.9	<0.0001
28 to 34	322	293	112	389 [a]	338 [b]	292 [c]	125 [d]	108 [de]	85 [e]	9.4	<0.0001
35 to 41	439	337	112	435 [a]	363 [b]	347 [b]	144 [c]	117 [d]	100 [d]	7.1	<0.0001
42 to 48	522	458	140	535 [a]	433 [b]	370 [c]	160 [d]	147 [de]	123 [e]	10.1	<0.0001
49 to 55	586	494	140	602 [a]	497 [b]	427 [c]	194 [d]	178 [d]	142 [d]	19.3	<0.0001
56 to 62	655	533	152	-	513 [a]	419 [a]	204 [b]	173 [b]	153 [b]	33.0	<0.0001
63 to 69	721	570	152	-	-	509 [a]	230 [b]	192 [bc]	168 [c]	12.9	<0.0001
70 to 76	-	-	160	-	-	-	181	148	132	16.3	0.1757
77 to 83	-	-	160	-	-	-	250	210	180	19.1	0.1041
84 to 90	-	-	171	-	-	-	272	242	210	15.0	0.0688
91 to 97	-	-	171	-	-	-	287	286	249	17.7	0.3026
98 to 104	-	-	183	-	-	-	290	289	270	14.4	0.5776
105 to 111	-	-	183	-	-	-	318	318	301	8.6	0.3422
112 to 118	-	-	191	-	-	-	316	336	302	14.3	0.3036
119 to 125	-	-	191	-	-	-	343	356	322	12.3	0.2156
126 to 132	-	-	203	-	-	-	337	324	305	13.1	0.2839
133 to 139	-	-	203	-	-	-	335	321	309	7.1	0.1112

* Mean values represent pen averages (n = 3)

[1] Based on the feeding programs recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163) and broilers (Appendix E, 167)

[a, b, c, d] Mean values within a row without common superscripts are different ($P < 0.05$)

Table 3.9. Average daily protein intake (grams/bird/day) by week for meat-type birds and heritage breeds from 21 to 140 days of age[*]

Age (days)	Expected[1] Broilers Male	Expected[1] Broilers Female	Expected[1] Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
21 to 27	16.0	14.6	3.9	18.5 [a]	16.3 [b]	14.1 [c]	7.0 [d]	5.7 [d]	5.7 [d]	0.6	<0.0001
28 to 34	20.1	18.3	6.8	30.1 [a]	23.7 [b]	20.2 [c]	6.8 [d]	6.0 [de]	5.0 [e]	0.4	<0.0001
35 to 41	27.4	21.1	6.8	29.4 [a]	22.6 [b]	21.0 [b]	7.5 [c]	6.0 [cd]	5.2 [d]	0.5	<0.0001
42 to 48	32.6	28.6	7.5	37.0 [a]	28.5 [b]	22.3 [c]	8.7 [d]	8.2 [d]	6.9 [d]	0.9	<0.0001
49 to 55	32.9	27.8	7.5	39.7 [a]	29.2 [b]	24.7 [c]	10.3 [d]	9.2 [d]	7.1 [d]	1.4	<0.0001
56 to 62	36.8	30.0	8.1	-	27.4 [a]	23.2 [a]	10.3 [b]	8.9 [b]	7.4 [b]	2.6	0.0006
63 to 69	40.6	32.0	8.1	-	-	29.1 [a]	12.0 [b]	9.3 [c]	8.0 [c]	0.5	<0.0001
70 to 76	-	-	8.6	-	-	-	9.8	9.1	7.4	1.0	0.2994
77 to 83	-	-	8.6	-	-	-	14.5 [a]	11.8 [ab]	10.4 [b]	0.9	0.0402
84 to 90	-	-	8.4	-	-	-	14.1	12.6	11.4	0.9	0.1898
91 to 97	-	-	8.4	-	-	-	15.6	14.8	13.9	1.4	0.7206
98 to 104	-	-	9.0	-	-	-	15.5	14.9	14.0	0.9	0.5611
105 to 111	-	-	9.0	-	-	-	16.0	16.1	14.4	0.8	0.3085
112 to 118	-	-	9.4	-	-	-	17.1	20.3	15.3	2.4	0.3958
119 to 125	-	-	9.4	-	-	-	17.6	17.4	15.0	0.7	0.0684
126 to 132	-	-	11.4	-	-	-	16.1	15.5	14.5	0.7	0.3838
133 to 139	-	-	11.4	-	-	-	15.8	15.1	14.4	0.5	0.1766

[*] Mean values represent pen averages (n = 3)
[1] Based on the feeding programs recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 167) and broilers (Appendix E, 170)
[a, b, c, d, e] Mean values within a row without common superscripts are different ($P < 0.05$)

Table 3.10 Average daily methionine intake (milligrams/bird/day) by week for meat-type birds and heritage breeds from 21 to 140 days of age*

Age (days)	Expected[1] Broilers Male	Expected[1] Broilers Female	Expected[1] Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
21 to 27	348	317	64	287 [a]	257 [b]	227 [c]	117 [d]	93 [d]	93 [d]	8.8	<0.0001
28 to 34	382	349	112	453 [a]	370 [b]	327 [c]	117 [d]	103 [de]	83 [e]	7.3	<0.0001
35 to 41	521	401	112	453 [a]	357 [b]	353 [b]	130 [c]	103 [cd]	90 [d]	9.5	<0.0001
42 to 48	619	543	115	563 [a]	450 [b]	373 [c]	147 [d]	140 [d]	117 [d]	15.0	<0.0001
49 to 55	586	494	115	623 [a]	487 [b]	420 [c]	180 [d]	157 [d]	123 [d]	20.2	<0.0001
56 to 62	655	533	125	-	467 [a]	400 [a]	183 [b]	150 [b]	127 [b]	40.9	0.0003
63 to 69	721	570	125	-	-	497 [a]	207 [b]	160 [c]	140 [c]	10.3	<0.0001
70 to 76	-	-	131	-	-	-	170	147	117	16.2	0.1444
77 to 83	-	-	131	-	-	-	247 [a]	197 [b]	170 [b]	14.0	0.0219
84 to 90	-	-	114	-	-	-	250 [a]	213 [ab]	187 [b]	13.2	0.0395
91 to 97	-	-	114	-	-	-	273	247	227	20.5	0.3400
98 to 104	-	-	122	-	-	-	277	250	233	13.2	0.1424
105 to 111	-	-	122	-	-	-	290	267	243	12.3	0.0945
112 to 118	-	-	127	-	-	-	303	320	257	32.6	0.4175
119 to 125	-	-	127	-	-	-	317 [a]	297 [ab]	257 [b]	12.0	0.0319
126 to 132	-	-	150	-	-	-	293	270	250	15.0	0.2057
133 to 139	-	-	150	-	-	-	293	263	253	6.6	0.0130

* Mean values represent pen averages (n = 3)

[1] Based on the feeding programs recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163) and broilers (Appendix E, 167)

[a, b, c, d, e] Mean values within a row without common superscripts are different ($P < 0.05$)

Table 3.11 Average daily lysine intake (grams/bird/day) by week for meat-type birds and heritage breeds from 21 to 140 days of age[*]

Age (days)	Expected [1] Broilers Male	Expected [1] Broilers Female	Expected [1] Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
21 to 27	0.77	0.70	0.18	0.97 [a]	0.84 [b]	0.71 [c]	0.34 [d]	0.28 [d]	0.28 [d]	0.034	<0.0001
28 to 34	1.01	0.92	0.32	1.63 [a]	1.25 [b]	1.01 [c]	0.31 [d]	0.28 [d]	0.25 [d]	0.029	<0.0001
35 to 41	1.37	1.05	0.32	1.53 [a]	1.14 [b]	1.01 [c]	0.33 [d]	0.26 [de]	0.23 [e]	0.025	<0.0001
42 to 48	1.63	1.43	0.28	1.97 [a]	1.46 [b]	1.06 [c]	0.40 [d]	0.38 [d]	0.32 [d]	0.053	<0.0001
49 to 55	1.56	1.31	0.28	2.01 [a]	1.39 [b]	1.15 [b]	0.47 [c]	0.42 [c]	0.32 [c]	0.085	<0.0001
56 to 62	1.74	1.41	0.30	-	1.25 [a]	1.04 [a]	0.46 [b]	0.41 [b]	0.34 [b]	0.136	0.0021
63 to 69	1.91	1.51	0.30	-	-	1.33 [a]	0.54 [b]	0.42 [c]	0.36 [c]	0.028	<0.0001
70 to 76	-	-	0.32	-	-	-	0.46	0.46	0.37	0.056	0.4307
77 to 83	-	-	0.32	-	-	-	0.67	0.57	0.52	0.048	0.1547
84 to 90	-	-	0.25	-	-	-	0.62	0.59	0.54	0.050	0.5033
91 to 97	-	-	0.25	-	-	-	0.69	0.70	0.67	0.079	0.9695
98 to 104	-	-	0.27	-	-	-	0.66	0.71	0.66	0.055	0.7787
105 to 111	-	-	0.27	-	-	-	0.66	0.77	0.66	0.046	0.2468
112 to 118	-	-	0.28	-	-	-	0.74	1.03	0.71	0.148	0.3164
119 to 125	-	-	0.28	-	-	-	0.75	0.78	0.66	0.037	0.1492
126 to 132	-	-	0.35	-	-	-	0.66	0.69	0.64	0.031	0.5871
133 to 139	-	-	0.35	-	-	-	0.63	0.66	0.62	0.029	0.6297

[*] Mean values represent pen averages (n = 3)
[1] Based on the feeding programs recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163) and broilers (Appendix E, 167)
[a, b, c, d, e] Mean values within a row without common superscripts are different ($P < 0.05$)

Table 3.12. Average daily calcium intake (grams/bird/day) by week for meat-type birds and heritage breeds from 21 to 140 days of age[*]

Age (days)	Expected [1] Broilers Male	Expected [1] Broilers Female	Expected [1] Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
21 to 27	0.70	0.63	0.21	0.81 [a]	0.67 [b]	0.55 [c]	0.26 [d]	0.22 [d]	0.22 [d]	0.026	<0.0001
28 to 34	0.91	0.83	0.36	1.36 [a]	0.99 [b]	0.79 [c]	0.23 [d]	0.20 [d]	0.20 [d]	0.029	<0.0001
35 to 41	1.23	0.95	0.36	1.25 [a]	0.90 [b]	0.76 [c]	0.24 [d]	0.19 [d]	0.18 [d]	0.023	<0.0001
42 to 48	1.47	1.29	0.40	1.63 [a]	1.16 [b]	0.81 [c]	0.28 [d]	0.28 [d]	0.25 [d]	0.048	<0.0001
49 to 55	1.46	1.24	0.40	1.70 [a]	1.08 [b]	0.86 [b]	0.33 [c]	0.31 [c]	0.23 [c]	0.078	<0.0001
56 to 62	1.64	1.33	0.43	-	0.96 [a]	0.78 [a]	0.32 [b]	0.30 [b]	0.24 [b]	0.111	0.0026
63 to 69	1.80	1.42	0.43	-	-	1.01 [a]	0.38 [b]	0.29 [bc]	0.25 [c]	0.028	<0.0001
70 to 76	-	-	0.46	-	-	-	0.32	0.35	0.29	0.050	0.7084
77 to 83	-	-	0.46	-	-	-	0.49	0.43	0.41	0.038	0.3614
84 to 90	-	-	0.48	-	-	-	0.45	0.44	0.44	0.047	0.9882
91 to 97	-	-	0.48	-	-	-	0.49	0.55	0.54	0.071	0.8334
98 to 104	-	-	0.51	-	-	-	0.46	0.53	0.51	0.048	0.6580
105 to 111	-	-	0.51	-	-	-	0.46	0.58	0.47	0.044	0.1922
112 to 118	-	-	0.54	-	-	-	0.54	0.81	0.55	0.128	0.2944
119 to 125	-	-	0.54	-	-	-	0.52	0.59	0.48	0.032	0.1470
126 to 132	-	-	1.29	-	-	-	0.44	0.51	0.48	0.027	0.2819
133 to 139	-	-	1.29	-	-	-	0.42	0.48	0.45	0.026	0.3385

[*] Mean values represent pen averages (n = 3)
[1] Based on the feeding programs recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163) and broilers (Appendix E, 167)
[a, b, c, d] Mean values within a row without common superscripts are different ($P < 0.05$)

Table 3.13. Average daily phosphorus intake (grams/bird/day) by week for meat-type birds and heritage breeds from 21 to 140 days of age*

Age (days)	Expected[1] Broilers Male	Expected[1] Broilers Female	Expected[1] Brown-egg-layer (female)	Cornish Cross (male)	Cornish Cross (female)	Red Ranger (male)	Rhode Island Red (male)	Black Australorp (male)	Barred Plymouth Rock (male)	SEM	*P*-value
21 to 27	0.31	0.29	0.09	0.42 [a]	0.36 [b]	0.31 [c]	0.15 [d]	0.12 [d]	0.12 [d]	0.02	<0.0001
28 to 34	0.35	0.32	0.16	0.70 [a]	0.54 [b]	0.45 [c]	0.14 [d]	0.12 [d]	0.11 [d]	0.01	<0.0001
35 to 41	0.48	0.37	0.16	0.65 [a]	0.49 [b]	0.44 [c]	0.14 [d]	0.11 [de]	0.10 [e]	0.01	<0.0001
42 to 48	0.57	0.50	0.18	0.83 [a]	0.62 [b]	0.46 [c]	0.17 [d]	0.16 [d]	0.14 [d]	0.02	<0.0001
49 to 55	0.55	0.46	0.18	0.84 [a]	0.59 [b]	0.50 [b]	0.20 [c]	0.18 [c]	0.14 [c]	0.04	<0.0001
56 to 62	0.61	0.50	0.19	-	0.52 [a]	0.45 [a]	0.20 [b]	0.17 [b]	0.14 [b]	0.06	0.0025
63 to 69	0.68	0.53	0.19	-	-	0.57 [a]	0.23 [b]	0.17 [c]	0.15 [c]	0.01	<0.0001
70 to 76	-	-	0.20	-	-	-	0.20	0.20	0.15	0.02	0.3695
77 to 83	-	-	0.20	-	-	-	0.29	0.24	0.22	0.02	0.1265
84 to 90	-	-	0.18	-	-	-	0.27	0.24	0.22	0.02	0.3024
91 to 97	-	-	0.18	-	-	-	0.30	0.28	0.29	0.03	0.9125
98 to 104	-	-	0.19	-	-	-	0.29	0.29	0.27	0.02	0.8147
105 to 111	-	-	0.19	-	-	-	0.29	0.31	0.27	0.02	0.4070
112 to 118	-	-	0.20	-	-	-	0.32	0.43	0.29	0.07	0.3516
119 to 125	-	-	0.20	-	-	-	0.32	0.32	0.27	0.02	0.0808
126 to 132	-	-	0.25	-	-	-	0.29	0.28	0.26	0.01	0.4144
133 to 139	-	-	0.25	-	-	-	0.27	0.27	0.25	0.01	0.5241

* Mean values represent pen averages (n = 3)

[1] Based on the feeding programs recommended in the National Research Council 1994 for brown-egg-laying pullets (Appendix A, page 163) and broilers (Appendix E, 167)

[a, b, c, d] Mean values within a row without common superscripts are different ($P < 0.05$)

Table 3.14. Slope and intercept of linear equation describing the relationship of body weight (grams) to age (days) for meat-type birds and heritage breeds from 21 days of age through a 2300-gram live weight

	Slope	Intercept	R^2	*P*-Value
Cornish cross males	72.8 [a]	1019.3	0.9856	0.0001
Cornish cross females	62.3 [b]	879.9	0.9847	0.0001
Red Ranger males	47.0 [c]	635.9	0.9915	0.0001
Heritage breed males[1]	19.2 [d]	325.1	0.9915	0.0001

Equation: Body weight, grams = Slope*(Age, days) – Intercept

[1] Heritage breed males are grouped because there was no difference ($P < 0.05$) among the three breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp)

[a, b, c, d] Mean values with different superscripts in the same column differ ($P < 0.01$)

Table 3.15. Best-fit equations describing the relationship of average daily feed intake (ADFI, grams/bird/day) to body weight (BW, kilograms) for meat-type birds and heritage breeds from 21 days of age through a 2300-gram live weight

	Best-fit equation	R^2	*P*-value
Cornish cross males	ADFI, gram/bird/day = 60.12*(BW, kilograms) + 63.08	0.9476	0.0001
Cornish cross females	ADFI, gram/bird/day = 47.41*(BW, kilograms) + 65.15	0.9313	0.0001
Red Ranger males	ADFI, gram/bird/day = 41.66*(BW, kilograms) + 65.11	0.8837	0.0001
Heritage breed males[1]	ADFI, gram/bird/day = -13.11*(BW, kilograms)^2 + 69.5*(BW, kilograms) + 18.56	0.9613	0.0001

[1] Heritage breed males are grouped because there was no difference ($P < 0.05$) among the three breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp)

Table 3.16. Slope and intercept of average daily energy intake vs average daily feed intake for meat-type birds and heritage breeds[*]

	Slope	Intercept	R^2	*P*-Value
Cornish cross males	0.33 [a]	4.48	0.9988	0.0001
Cornish cross females	0.32 [b]	7.39	0.9969	0.0001
Red Ranger males	0.32 [b]	6.05	0.9985	0.0001
Heritage breed males[1]	0.32 [b]	1.38	0.9987	0.0001

Average daily energy intake, kcal ME/bird/day = Slope*(Average Daily Feed Intake, grams/bird/day) + Intercept

[*] Mean values represent pen averages (n = 3)

[1] Heritage breed males are grouped because there was no difference ($P < 0.05$) among the three breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp)

[a,b] Mean values with different superscripts in the same column differ ($P < 0.05$)

Table 3.17. Average energy and nutrient composition of self-selected diets for meat-type birds and heritage breeds from 21 days of age through a 2300-gram live weight[*]

	Energy (kcal ME/kg)	Protein (% of diet)	Methionine (% of diet)	Calcium (% of diet)	Phosphorus (% of diet)
Cornish Cross males	2887 [d]	20.8 [a]	0.32 [a]	0.92 [a]	0.47 [a]
Cornish Cross females	2950 [c]	19.2 [b]	0.31 [b]	0.77 [b]	0.42 [b]
Red Ranger males	2982 [b]	18.3 [c]	0.31 [b]	0.66 [c]	0.38 [c]
Rhode Island Red males	3064 [a]	16.2 [d]	0.28 [c]	0.51 [d]	0.31 [d]
Black Australorp males	3068 [a]	16.2 [d]	0.27 [d]	0.56 [d]	0.32 [d]
Barred Plymouth Rock males	3072 [a]	16.1 [d]	0.27 [d]	0.57 [d]	0.31 [d]
SEM	10.1	0.3	0.003	0.02	0.01
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[*] Mean values represent pen averages (n = 3)

[a,b,c,d] Mean values with different superscripts in the same column differ ($P < 0.05$)

Table 3.18. Effect of feeding strategy (complete broiler starter or self-selection feeding) on average daily gain, and average daily consumption of feed and average feed to gain for three heritage breeds from 70 to a 2300-gram live weight [*]

		Average daily gain (gram/bird/day)	Average feed intake (gram/bird/day)	Average feed to gain (grams of feed per gram gam)
Breed main effects				
Rhode Island Red (RIR)		21.5	94.7	4.49
Black Australorp (BA)		20.8	93.1	4.51
Barred Plymouth Rock (BPR)		19.5	87.9	4.53
SEM		0.72	2.5	0.19
P-value		0.1619	0.1837	0.9885
Feeding strategy main effects				
Self-selection feeding		18.8 [b]	90.3	4.82 [a]
Broiler starter		22.4 [a]	93.5	4.21 [b]
SEM		0.58	2.1	0.15
P-value		0.0009	0.2903	0.0145
Interactive Effects				
Breed	Feeding strategy			
RIR	Broiler starter	23.7	94.1	4.02
BA	Broiler starter	22.5	94.1	4.20
BPR	Broiler starter	21.1	92.4	4.40
RIR	Self-selection feeding	19.4	95.3	4.96
BA	Self-selection feeding	19.1	92.1	4.83
BPR	Self-selection feeding	17.9	83.5	4.67
SEM		1.0	3.6	0.26
P-value		0.8633	0.3737	0.4705

The Rhode Island Reds and Black Australorps on broiler starter reached 2300 grams by 127 days of age while the Barred Plymouth Rocks on broiler starter and all birds on the self-selection feeding program reached the target by 141 days of age.

[*] Mean values represent pen averages (breed main effects, n = 6; feeding strategy main effects, n = 9; interactive effects, n = 3)

[a,b,c,d] Mean values with different superscripts in the same column differ ($P < 0.05$)

Table 3.19. Effect of feeding strategy (complete broiler starter diet or self-selection feeding) on average daily consumption of energy, protein, and methionine for three heritage breeds from 70 to a 2300-gram live weight *

		Average energy intake (kcal ME/bird/day)	Average protein intake (gram/bird/day)	Average methionine intake (gram/bird/day)
Breed main effects				
Rhode Island Red (RIR)		291	18.0	0.39
Black Australorp (BA)		287	17.7	0.38
Barred Plymouth Rock (BPR)		271	16.7	0.36
SEM		8	0.6	0.01
P-value		0.1867	0.2747	0.1531
Feeding strategy main effects				
Self-selection feeding		278	14.3 [b]	0.25 [b]
Broiler starter		288	20.6 [a]	0.51 [a]
SEM		6	0.5	0.01
P-value		0.2651	<0.0001	<0.0001
Interactive Effects				
Breed	Strategy			
RIR	Broiler starter	290	20.7	0.51
BA	Broiler starter	290	20.7	0.51
BPR	Broiler starter	285	20.3	0.50
RIR	Self-selection feeding	293	15.2	0.27
BA	Self-selection feeding	283	14.7	0.25
BPR	Self-selection feeding	258	13.1	0.22
SEM		11	0.8	0.02
P-value		0.3881	0.5186	0.3857

The Rhode Island Reds and Black Australorps on broiler starter reached 2300 grams by 127 days of age while the Barred Plymouth Rocks on broiler starter and all birds on the self-selection feeding program reached the target by 141 days of age.

* Mean values represent pen averages (breed main effects, n = 6; feeding strategy main effects, n = 9; interactive effects, n = 3)

[a,b,c,d] Mean values with different superscripts in the same column differ ($P < 0.05$)

3.7 Figures

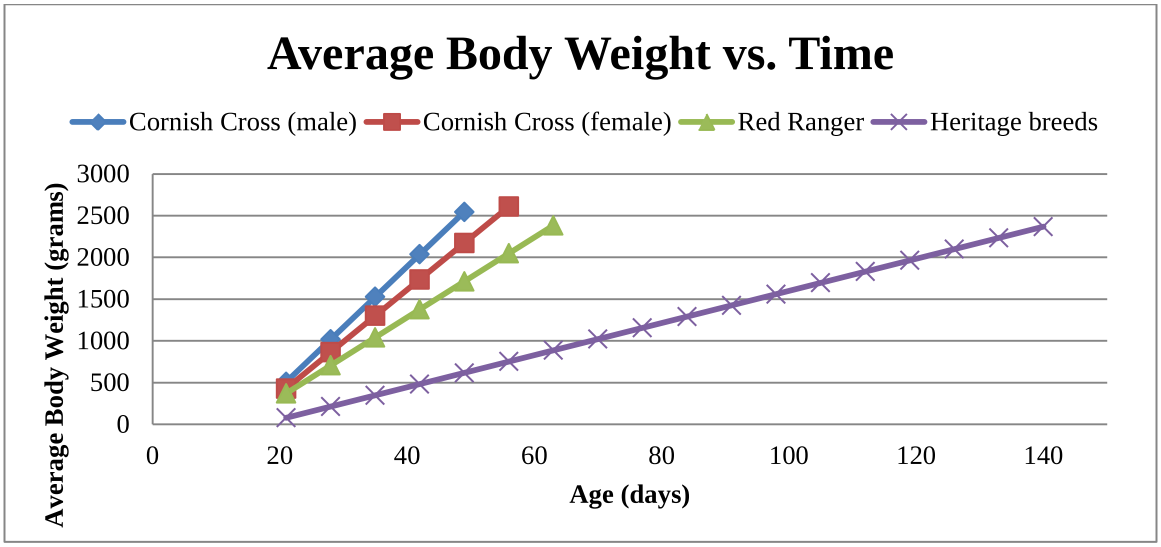

Figure 3.1. Pattern of average body weight (grams) versus time (days) for meat-type birds and heritage breeds from 21 days of age to a 2300-gram live weight

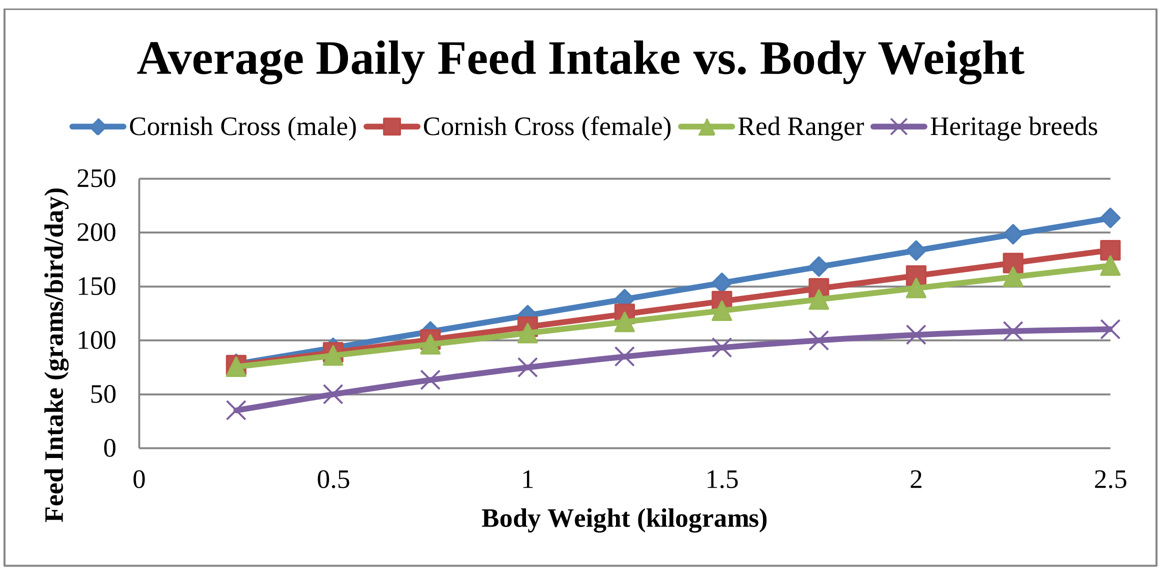

Figure 3.2. Pattern of average daily feed intake (grams/bird/day) versus body weight (kilograms) for meat-type chickens and heritage breeds from 0.25 to 2.5 kilograms

CHAPTER 4: Carcass traits of alternative breed meat birds provided either a self-selected feeding program or a complete broiler starter diet.

4.1 Abstract

Due to the recent resurgence in the popularity of keeping small flocks of chickens, interest in the production characteristics of heritage chicken breeds has increased. This study was conducted to evaluate the carcass yield of alternative chicken genotypes raised for meat production. Birds were raised on a self-selection feeding program that included a protein concentrate (39% CP with added vitamins and minerals) without added methionine and three grains that were similar in energy content, but differed in protein and methionine content (cracked corn, naked oats, and pearl millet). The chickens utilized were Cornish Cross males (CCM), Cornish Cross females (CCF), Red Rangers males (RR), and males from three heritage breeds (Rhode Island Red (RIR), Barred Plymouth Rock (BPR), and Black Australorp (BA). Birds were processed after the average body weight for the genotype reached 2300 grams. CCM, CCF, and RR reached this weight by 49, 56, and 63 days of age respectively. At 70 days of age, the heritage breeds had not yet reached target weight and were split into two groups – one remaining on self-selection and one placed on a complete broiler starter diet (3084 kcal ME/kg, 22% CP). The heritage breeds reached target weight by 140 days of age. The parameters measured at processing included live weight, carcass weight without giblets (WOG), part weights (boneless breasts with skin, whole legs, and wings), fat pad weight, and organ weights. CCM and CCF had higher WOG yields when compared with the other genotypes (74.8 vs. 67.4%, SEM = 1.2%; $P < 0.0001$). CCF had higher boneless breast yields than CCM, and both had higher boneless breast yields than the other genotypes (33.5 vs. 31.2 vs. 19.2%, SEM = 0.7%; $P < 0.0001$). Conversely, whole leg and wing yields were lower ($P < 0.0001$) for the CCM and CCF than for the other genotypes. As a percentage of live weight, liver weights were higher ($P < 0.0001$) for the CCM, CCF, and RR than for the heritage breeds. CCM, CCF, and RR had smaller ($P = 0.0001$) gizzards than the heritage breeds on self-selection diets. Heritage breeds switched to broiler starter had smaller ($P < 0.05$) gizzards and smaller ($P < 0.05$) fat pads than those remaining on self-selection. However, there was no difference ($P > 0.05$) in carcass, liver, heart, or lung yields between heritage breeds using the two feeding strategies.

4.2 Introduction

While heritage breeds and slow-growing genotypes currently make up a small portion of the global commercial chicken meat industry, there is growing interest in utilizing these breeds. Proponents of these breeds suggest they have better fertility, better foraging ability, improved longevity, better disease resistance, and better tolerance to heat and cold than modern commercial strains (Heinrichs and Schrider, 2005). If true, these may make these birds particularly well-suited to specialty production systems such as organic and free-range. However, there is little to no data available to producers interested in raising these breeds. One of the few published studies regarding a heritage breed found that, at the same body weight, Delaware chickens (a heritage breed) had lower WOG yields than commercial meat-type birds (McCrea et al., 2014). This agrees with the general findings of other researchers that slow-growing meat-type strains have lower WOG and breast yields than fast-growing strains (Havenstein et al., 2003a; Fanatico et al., 2005c; Golian et al., 2007; Chen et al., 2013; Del Castilho et al., 2013; Collins et al., 2014). This is not surprising considering the visual difference in conformation between the broad breasted modern broilers and other types of chickens. However, the production characteristics including carcass and part yields are vital information for producers needing to formulate business plans or determine how to price their products. Therefore, the objective of this study was to evaluate the carcass and part yields of males from three heritage breeds and compare these with a slow-growing meat-type strain (Red Ranger) and a fast-growing meat-type strain (Cornish Cross).

4.3 Materials and methods

This experiment was conducted at the Alltech-University of Kentucky Research Alliance Poultry Farm. All procedures for this study were conducted under protocols approved by the University of Kentucky Institutional Animal Care and Use Committee (IACUC). This study utilized the birds from the experiment in Chapter 3.

4.3.1 Animals and husbandry

Birds were raised on a self-selection feeding program that included a protein concentrate (39% CP) without added methionine and three grains that were similar in energy content, but differed in protein and methionine content (cracked corn, naked oats, and pearl millet). The breeds utilized were Cornish Cross males, Cornish Cross females, Red Rangers males, and males from three heritage breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp). Birds were processed when the average body weight for the genotype reached 2300 grams. Cornish Cross males, Cornish Cross females, and Red Ranger males reached this weight by 49, 56, and 63 days of age respectively. At 70 days of age, the heritage breeds had not yet reached target weight and were split into two groups – one remaining on self-selection and one placed on a complete broiler starter diet (3084 ME kcal/kg, 22% CP). The heritage breeds reached target weight by 140 days of age.

4.3.2 Data collection

Due to expected differences in growth rates, birds were processed when the average body weight for a genotype reached 2300 grams. Therefore, Cornish Cross males, Cornish Cross females, and Red Ranger males were processed at 52, 60, and 69 days of age respectively, and Rhode Island Red, Barred Plymouth Rock, and Black Australorp males were processed at 148 days of age. Feed was removed 10 hours before processing. At processing, four birds per pen were weighed, and then euthanized by electrical stunning followed by exsanguination in accordance with University of Kentucky IACUC approved procedures. After euthanasia, birds were immersed in a hot water bath and then de-feathered using a semi-automated chicken plucker. The head, neck, feet, and internal organs were removed to determine a hot carcass weight. The heart, liver, lungs, gizzard, and abdominal fat (fat pad) weights were recorded. Following a 3-hour chill, the cold carcass weight without giblets (WOG) was recorded and then breast filets (*pectoralis major* – deboned with and without skin), tenders (*pectoralis minor*), wings, and whole legs were removed from each carcass and weighed to determine part yields.

4.3.3 Statistical analyses

Data for this experiment were subjected to statistical analysis of variance using the general linear model function of SAS® (SAS v. 9.3, Cary, NC) with genotype as the dependent variable. The replicate pen of birds served as the experimental unit. Fisher's least significant difference test was used to determine significance among means with a significance set at $P < 0.05$.

To compare the effect of a complete broiler starter vs. self-selection feeding, analysis of variance was conducted for the data using the general linear model function of SAS® (SAS v. 9.3, Cary, NC) with feeding strategy as the dependent variable. The replicate pen of birds served as the experimental unit. Fisher's least significant difference test was used to determine differences among means with a significance set at $P < 0.05$.

4.4 Results

4.4.1 Live weight

The intent was to process birds at a common weight of 2300 grams. However, due to issues with scheduling, the live weight of all but the Barred Plymouth Rock birds exceeded the target of 2300 grams at processing. The Cornish Cross males, Cornish Cross females, Red Ranger males, and heritage breeds were processed at 52, 60, 69, and 148 days of age respectively. The average live weight for the processed birds from each genotype is shown in Table 4.1. The Cornish Cross males and females (2766 grams) were heavier than the heritage breeds (2366 grams), and the Red Rangers were intermediate at 2628 grams (SEM = 79; $P < 0.0001$).

4.4.2 Chilled carcass weight without giblets (WOG) yield

The average weight of the chilled carcass without giblets (WOG), expressed in grams and listed in Table 4.1, followed a similar pattern to live weight with the exception of the Red Ranger. Chilled WOG weights were higher ($P < 0.01$) for Cornish Cross males and females than for Red Rangers or the heritage breeds. Expressed as a percentage of the live weight (Table 4.2), the chilled WOG yield was higher for Cornish Cross males and females (74.8%) than for the other breeds (67.4%; SEM = 1.2%; $P = 0.0001$).

4.4.3 Abdominal fat yield

The average weight of the abdominal fat (fat pad) for each genotype was reported in Table 4.1. Fat pad weight was similar among genotypes (45.4 ± 7.2 grams; $P > 0.05$), but there were differences (*P* < 0.05) among genotypes in fat pad yield as a percentage of the live weight as shown in Table 4.2.

4.4.4 Visceral organ yields

4.4.4.1 Liver

The average weight of the liver for each genotype was reported in Table 4.1. On a weight-basis, the meat-type birds (Cornish Cross males, Cornish Cross females, and Red Ranger males) had heavier livers than the heritage breeds (45.5 vs 26.4 grams; SEM = 1.8; *P* = 0.0001). This pattern remains when liver yield is expressed as a percentage of the live weight as shown in Table 4.2. The meat-type birds had higher liver yields than the heritage breeds (1.7 vs 1.1%; SEM = 0.06%; *P* = 0.0001).

4.4.4.2 Heart

The average weight of the heart for each genotype was reported in Table 4.1. Heart weights varied by genotype with Red Rangers having heavier (*P* < 0.05) hearts than Cornish Cross males, and both having heavier (*P* < 0.05) hearts than the heritage breeds. Within the heritage breeds, Rhode Island Reds had heavier (*P* < 0.05) hearts than Black Australorps and both had heavier (*P* < 0.05) hearts than Barred Plymouth Rocks. The heart weight for Cornish Cross females was intermediate between Rhode Island Reds and Black Australorps. When expressed as a percentage of the live weight (Table 4.2), heart yield was highest for Red Rangers (0.55%) and lowest for Cornish Cross females (0.41%) with the other genotypes intermediate (SEM = 0.02%; *P* < 0.01).

4.4.4.3 Gizzard

Gizzard weights varied by genotype with heritage breeds having heavier (*P* < 0.05) gizzards than meat-type birds as shown in Table 4.1. When expressed as a percentage of live weight (Table 4.2), the gizzard yield was highest for the Barred Plymouth Rock birds (2.64%), followed by the other two heritage breeds (2.09%), with the meat-type birds having the lowest gizzard yield (1.46%; SEM = 0.09%; *P* = 0.0001)

4.4.4.4 Lung

Lung weights varied (*P* < 0.05) by genotype with no consistent pattern as shown in Table 4.1. When expressed as a percentage of live weight (Table 4.2), the lung yield was higher for the Red Ranger males (0.72%) than for any of the other genotypes (0.55%; SEM = 0.04%; $P < 0.05$).

4.4.5 Boneless breast yield (with and without skin)

The average weight of the boneless breasts (*pectoralis major)* with and without skin for each genotype is listed in Table 4.3. Boneless breasts with skin were weighed for all genotypes. Cornish Cross females had heavier ($P < 0.05$) boneless breast with skin weights than Cornish Cross males (699 vs 638 grams), and both Cornish Cross birds had heavier ($P < 0.05$) boneless breast with skin weights than the Red Ranger males (362 grams). The heritage breeds had the lowest ($P < 0.05$) boneless breast with skin weights (299 grams) with no difference among the three breeds. When expressed as a percentage of the chilled WOG weight (Table 4.4), boneless breast with skin yield was higher for the Cornish Cross females (33.5%) than for the Cornish Cross males (31.2%), and both had higher yields than the other genotypes (19.2%; SEM = 0.7%; $P = 0.0001$).

Boneless, skinless breast weights were obtained for all genotypes except for the Cornish Cross males and followed a similar pattern. Cornish Cross females had higher ($P = 0.0001$) boneless, skinless breast weights than the Red Rangers and heritage breeds. Boneless, skinless breast yield as a percentage of the chilled WOG weight was also higher ($P = 0.0001$) for Cornish Cross females than for the Red Rangers and heritage breeds.

4.4.6 Whole leg yield

The average whole leg weight, which included both the thigh and the drumstick, for each genotype was reported in Table 4.3. There were no differences among the genotypes for the weight of the whole leg (590 ± 21 grams; $P > 0.05$). However, when expressed as a percentage of the chilled WOG weight (Table 4.4), whole leg yield was higher ($P < 0.05$) for the heritage breeds (36.2%) than for the Red Ranger males (34.1%), and both were higher than the Cornish Cross males (30.3%). The Cornish Cross females had the lowest whole leg yield (27.9%; SEM = 0.2%; $P < 0.0001$).

4.4.7 Wing with tip yield

Both wings (with tip) were weighed and the average weight for each genotype was reported in Table 4.3. On a weight basis, the Red Ranger males had heavier ($P <$

0.05) wings than the Black Australorp and the Barred Plymouth Rock, and the other genotypes were intermediary with no clear pattern. However, a clear pattern emerges when wing yield is expressed as a percentage of the chilled WOG weight as reported in Table 4.4. The heritage breeds had the largest wing yield (12.5%), followed by the Red Ranger males (13%), with the Cornish Cross males and females having the lowest wing yield (10.2%; SEM = 0.2%; P = 0.0001).

4.4.8 Effect of feeding strategy

At 70 days of age, about half of the heritage breed birds in each pen were switched on to a broiler starter. The effect of breed and feeding strategy on chilled WOG, fat pad, and organ yields at 148 days of age were reported in Table 4.5. There was no effect (P > 0.05) of breed or feeding strategy on chilled WOG yield or lung yield as a percentage of live weight. However, heritage breeds on self-selection diets had greater gizzard yields (2.27 vs 1.92%, SEM = 0.08%; P < 0.01) and greater fat pad yields (1.79 vs 0.94%, SEM = 0.12%; P < 0.001) than those switched to broiler starter.

While there was no main effect of breed or diet on liver yield, an interactive effect of breed x diet was noted. For Rhode Island Reds, birds fed broiler starter had greater liver yields than birds on self-selection feeding. Meanwhile, the opposite was true for Barred Plymouth Rocks with birds on the broiler starter diet having lower liver yields than birds on self-selection feeding. Finally, there was no difference in liver yields between the two feeding strategies for Black Australorps.

The effect of breed and feeding strategy on breast (boneless, with and without skin), whole leg, and wing yields as a percentage of the chilled WOG weight were reported in Table 4.6. There was no difference (P > 0.05) in part yields between the feeding strategies. With the exception of wing yield, part yields were similar (P > 0.05) among breeds. Black Australorps had lower (P < 0.05) wing yields than either Rhode Island Reds or Barred Plymouth Rocks.

4.5 Discussion

Previous research (Chapter 3) showed that males from three heritage breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp) and a slow-growing meat-type strain (Red Ranger) had slower growth rates and poorer feed efficiency than fast-growing meat-type strains (Cornish Cross). Additionally, the heritage breeds were shown to self-select diets that were higher in energy and lower in protein than the diets selected by fast-growing meat-type chickens. However, the implications of this growth depression and difference in diet selection on carcass yield were unclear. Therefore, this study was conducted to evaluate the carcass and part yields of the heritage breeds and the slow-growing meat-type strain.

4.5.1 Use of alternative genotypes

At a common live weight of approximately 2300 grams, Cornish Cross males and females had higher chilled WOG yields than Red Rangers or heritage breeds (74.8 vs 67.4%, SEM = 1.2%; $P < 0.05$). These results are consistent with the findings of McCrea et al. (2014) which showed that Delaware chickens (a heritage breed) had lower WOG yields than a commercial broiler strain. Additionally, Collins et al. (2014) showed that the Athens Canadian Random Bred meat-type chickens (representative of 1950's genetics) had lower carcass yields than Cobb 500 high-yielding broilers at 6, 8, and 10 weeks of age.

Additionally, there was a conformational difference in the carcasses of Red Rangers and heritage breeds when compared with Cornish Crosses. When compared with the Cornish Cross, the Red Ranger and heritage breeds had lower boneless breast and higher whole leg and wing yields as a percentage of their respective chilled WOG weights. These results are consistent with the findings of a study by Fanatico et al. (2008) which showed that slow-growing genotypes had lower breast meat yields, but higher wing and leg yields than fast-growing genotypes. Furthermore, the results make sense in the context of selection pressure placed on broilers which has increased the overall muscle mass of the chicken, with particular emphasis on breast muscle production (Havenstein et al., 2003b; Schmidt et al., 2009; Zuidhof et al., 2014). The average breast yield of the heritage breeds utilized in this study was actually similar to the breast yield (~19.1 ± 0.3%) reported by Bertechini et al. (2014) for males from white- and brown-egg-laying strains.

Zuidhof et al. (2014) reported that commercial selection pressures have reduced fat deposition in broilers. This is partially supported by the data from the present study which showed that heritage breeds had higher abdominal fat yields than Cornish Cross males. However, Cornish Cross females had similar abdominal fat yields as heritage breeds. This may be a reflection of the dietary choices these breeds made on the self-selection feeding program which were described in Chapter 3.

While the effect of genotype on the yield of visceral organs has not been extensively studied, a few differences between fast- and slow-growing meat-type birds have been noted in the literature. In one such study, Collins et al. (2014) found that Athens Canadian Random-bred birds (representative of 1950s meat-type chickens) had significantly higher internal organ weights relative to their body weight than Cobb 500 broilers at 6, 8, and 10 weeks of age. In the present study, differences among the genotypes for relative visceral organ weights were also noted. In particular, on the self-selection diet, heritage breeds had larger gizzards than the Cornish Cross birds which could allow the birds to better process larger feedstuffs. Additionally, the relative lung capacity for Red Rangers was higher than that of either fast-growing meat-type strains or heritage breeds. However, there was no difference in relative lung capacity for heritage breeds when compared with Cornish Cross males. This contradicts the findings of Havenstein et al. (1994b, 2003a) which reported significantly smaller relative lung weights in modern broilers when compared with historical stains like the Athens Canadian Random Bred.

In the present study, the relative heart weights for the three heritage breeds were similar to that of the Cornish Cross males. This disagrees with the findings of Schmidt et al. (2009) which compared the tissue growth of a heritage broiler line maintained at the University of Illinois (UIUC) and a Ross 708 broiler. The UIUC heritage line was a New Hampshire x Plymouth Rock cross developed in the 1950s to represent the typical broiler utilized during that time. The UIUC has been maintained as a random-bred population since its development. The Ross 708 line was introduced in the early 2000s as a high-yielding meat chicken. Schmidt et al. (2009) noted that the relative weight of the heart muscle was smaller for the Ross 708 birds. When birds of equivalent mass were compared, the UIUC birds had larger hearts than the Ross 708 birds. On the other hand, Schmidt et al. (2009) found that comparably sized UIUC and Ross 708 birds had comparably sized livers, while the heritage breeds in the present study had smaller livers than both the fast-and slow-growing meat-type birds. One factor that may explain the difference in findings is that Schmidt et al. (2009) evaluated organ yields at 35 days of age and the average live weights were smaller for both the UIUC and the Ross 708 than the live weight of the birds in the present study.

4.5.2 Use of alternative feeding strategies for heritage breeds

The results of Chapter 3 indicated that heritage breeds on a broiler starter diet had higher average daily gain and improved feed efficiency when compared to those on the self-selection feeding program. When the carcasses of these birds were examined, heritage breeds using a self-selection feeding program had larger gizzards.

Additionally, birds on the self-selection feeding program had larger fat pads than those fed a complete broiler starter diet. This is consistent with the literature which shows that regardless of the feed choices provided, self-selection-fed birds consumed more energy and less protein than conventionally-fed birds and often had greater fat content in the viscera. (Leeson and Caston, 1993; Sahin, 2003; Cerrate et al., 2007; Syafwan et al., 2012; Fanatico et al., 2013; Catanese et al., 2015).

Feeding strategy had no effect on chilled WOG yield as a percentage of the live weight or part yields as a percentage of the chilled WOG weight. This is consistent with some of the literature which suggests self-selection feeding does not affect carcass yield (Rack et al., 2008; Ozek et al., 2012). However, additional literature suggests self-selection feeding reduced carcass yield when compared with feeding formulated diets (Leeson and Caston, 1993; Fanatico et al., 2013). These differences may simply be a reflection of the differences in the nutrient composition of the diets used in the studies, but they also suggest that the effects of self-selection feeding vary and may be affected by a number of factors.

4.6 Conclusions

Based on the results of this study, it is clear that genetic selection of meat-type birds has effectively improved both growth performance and carcass yields of these birds when compared with heritage breeds. Therefore, more heritage breed chickens are needed to produce the same amount of meat as a single fast-growing meat-type bird. The inefficiency of the heritage breed chickens makes them a poor, unsustainable choice for us in meat production, particularly on a large scale. While slow-growing meat-type strains such as the Red Ranger are a more viable option than heritage breed chickens, these strains will also require more feed and produce less meat per bird than fast-growing meat-type strains. Consequently, producers interested in utilizing slow-growing meat-type birds and/or heritage breeds need to command a premium price to make their products economically viable. In the current marketplace, this likely means utilizing an alternative production system such as free-range or pasture poultry. However, further research would need to be done to determine whether this type of management affects the carcass and part yields for these birds. Additionally, the effect of genotype and management system on meat quality traits such as texture, flavor, color, and oxidative stability would need to be evaluated.

4.7 Tables

Table 4.1. Effect of genotype on average live weight, chilled carcass without giblets (WOG), abdominal fat (fat pad), and organ weights for meat-type birds and heritage breeds on self-selection diets*

Genotype	Age at processing (days)	Average weight (grams)						
		Live weight	Chilled WOG	Fat pad	Liver	Heart	Gizzard	Lung
Cornish cross males	52	2775^{a}	2048^{a}	29.3	46.8^{a}	13.4^{b}	41.5^{c}	16.6^{ab}
Cornish cross females	60	2757^{a}	2087^{a}	52.6	46.7^{a}	11.4^{cd}	36.3^{d}	13.5^{bc}
Red Ranger males	69	2628^{ab}	1781^{b}	63.9	43.1^{a}	14.5^{a}	41.3^{cd}	18.9^{a}
Rhode Island Red males	148	2453^{bc}	1663^{bc}	34.5	25.9^{b}	12.2^{c}	48.5^{b}	13.5^{bc}
Black Australorp males	148	2415^{bc}	1620^{bc}	48.1	25.7^{b}	11.1^{d}	53.1^{b}	12.7^{c}
Barred Plymouth Rock males	148	2230^{c}	1490^{c}	43.8	27.5^{b}	9.7^{e}	58.9^{a}	13.0 c
SEM		79	71	7.2	1.8	0.3	1.7	1.1
P-value		0.0022	0.0003	0.0539	0.0001	0.0001	0.0001	0.0068

*Mean values are averages of four birds per pen (n = 3)

[a, b, c, d] Mean values within a column without common superscripts are different ($P < 0.05$)

Table 4.2. Effect of genotype on chilled carcass without giblets (WOG), abdominal fat (fat pad), and organ yields as a percentage of live weight for meat-type birds and heritage breeds on self-selection diets[*]

Genotype	Chilled WOG	Fat pad	Liver	Heart	Gizzard	Lung
Cornish cross males	73.8^{a}	1.06^{c}	1.69^{a}	0.48^{b}	1.50^{c}	0.60^{b}
Cornish cross females	75.7^{a}	1.91^{ab}	1.69^{a}	0.41^{c}	1.32^{c}	0.49^{b}
Red Ranger males	67.8^{b}	2.43^{a}	1.64^{a}	0.55^{a}	1.57^{c}	0.72^{a}
Rhode Island Red males	67.8^{b}	1.41^{bc}	1.06^{b}	0.50^{ab}	1.98^{b}	0.55^{b}
Black Australorp males	67.1^{b}	1.99^{ab}	1.06^{b}	0.46^{bc}	2.20^{b}	0.53^{b}
Barred Plymouth Rock males	66.8^{b}	1.96^{ab}	1.23^{b}	0.43^{bc}	2.64^{a}	0.58^{b}
SEM	1.2	0.2	0.06	0.02	0.09	0.04
P-value	0.0001	0.0002	0.0001	0.0048	0.0001	0.0005

[*] Mean values are averages of four birds per pen (n = 3)
[a, b, c] Mean values within a column without common superscripts are different ($P < 0.05$)

Table 4.3. Effect of genotype on average weight of carcass parts for meat-type birds and heritage breeds on self-selection diets*

	Average weight (grams)			
	Breast *(pectoralis major)*			
Genotype	Boneless with skin	Boneless, skinless	Whole leg	Wing (with tip)
Cornish cross males	638^{b}	--	620	212^{ab}
Cornish cross females	699^{a}	620^{a}	583	211^{abc}
Red Ranger males	362^{c}	299^{b}	607	231^{a}
Rhode Island Red males	317^{d}	276^{bc}	602	212^{ab}
Black Australorp males	301^{d}	271^{bc}	591	196^{bc}
Barred Plymouth Rock males	279^{d}	247^{c}	536	190^{c}
SEM	13.7	11.6	20.7	7.0
P-value	0.0001	0.0001	0.1477	0.0191

* Mean values are averages of four birds per pen (n = 3)

a, b, c, d Mean values within a column without common letters are different ($P < 0.05$)

Table 4.4. Effect of genotype on part yields as a percentage of the chilled carcass weight without giblets for meat-type birds and heritage breeds on self-selection diets[*]

	Breast *(pectoralis major)*			Wing
Genotype	Boneless with skin	Boneless, skinless	Whole leg	(with tip)
Cornish cross males	31.2 [b]	--	30.3 [c]	10.3 [c]
Cornish cross females	33.5 [a]	29.7 [a]	27.9 [d]	10.1 [c]
Red Ranger males	20.3 [c]	16.8 [b]	34.1 [b]	13.0 [a]
Rhode Island Red males	19.0 [c]	16.6 [b]	36.2 [a]	12.8 [a]
Black Australorp males	18.6 [c]	16.7 [b]	36.5 [a]	12.1 [b]
Barred Plymouth Rock males	18.7 [c]	16.6 [b]	36.0 [a]	12.8 [a]
SEM	0.7	0.7	0.2	0.2
P-value	0.0001	0.0001	0.0001	0.0001

[*] Mean values are averages of four birds per pen (n = 3)
[a, b, c, d] Mean values within a column without common superscripts are different ($P < 0.05$)

Table 4.5. Effect of breed and feeding strategy on chilled carcass weight without giblets (WOG), abdominal fat (fat pad), and organ yields as a percentage of live weight for three heritage breeds at 2300-gram live weight[*]

		Chilled WOG	Fat pad	Liver	Heart	Gizzard	Lung
Breed main effects							
Rhode Island Red (RIR)		67.7	0.98 ^{b}	1.18	0.50 ^{a}	1.89	0.60
Black Australorp (BA)		67.6	1.70 ^{a}	1.08	0.45 ^{b}	2.14	0.54
Barred Plymouth Rock (BPR)		67.3	1.42 ^{ab}	1.42	0.47 ^{b}	2.26	0.57
SEM		0.5	0.15	0.04	0.01	0.10	0.03
P-value		0.4186	0.0176	0.1778	0.0089	0.0622	0.3112
Feeding strategy main effects							
Broiler starter		67.6	0.94 ^{b}	1.16	0.48	1.92 ^{b}	0.59
Self-selection feeding		67.2	1.79 ^{a}	1.12	0.46	2.27 ^{a}	0.55
SEM		0.4	0.12	0.03	0.01	0.08	0.02
P-value		0.3707	0.0004	0.3957	0.3181	0.0088	0.2702
Interactive Effects							
Breed	Feeding strategy						
RIR	Broiler starter	67.5	0.55	1.30 ^{a}	0.51	1.81	0.64
BA	Broiler starter	68.0	1.40	1.10 ^{bc}	0.43	2.08	0.55
BPR	Broiler starter	67.3	0.88	1.08 ^{c}	0.50	1.87	0.56
RIR	Self-selection feeding	67.8	1.41	1.06 ^{c}	0.50	1.98	0.55
BA	Self-selection feeding	67.1	1.99	1.06 ^{c}	0.46	2.20	0.53
BPR	Self-selection feeding	66.8	1.96	1.23 ^{ab}	0.43	2.64	0.58
SEM		0.7	0.21	0.05	0.02	0.14	0.04
P-value		0.4971	0.5059	0.0063	0.0570	0.0631	0.3580

The Rhode Island Reds and Black Australorps on broiler starter were processed at 134 days of age while the Barred Plymouth Rocks on broiler starter and all birds on the self-selection feeding program were processed at 148 days of age.

[*] Means are averages of four birds per pen (breed main effects, n = 6; feeding strategy main effects, n = 9; interactive effects, n = 3)

$^{a, b, c}$ Mean values within a column without common superscripts are different ($P < 0.05$)

Table 4.6. Effect of breed and feeding strategy on breast (boneless, with and without skin), whole leg, and wing yields as a percentage of the chilled carcass weight without giblets for three heritage breeds at a 2300-gram live weight*

		Breast *(pectoralis major)*		Whole leg	Wing
		Boneless with skin	Boneless, skinless		(with tip)
Breed main effects					
Rhode Island Red (RIR)		19.0	16.7	36.1	13.1 [a]
Black Australorp (BA)		19.2	17.1	36.0	12.0 [b]
Barred Plymouth Rock (BPR)		19.0	17.0	36.4	12.8 [a]
SEM		0.46	0.41	0.24	0.17
P-value		0.9082	0.6787	0.5509	0.0019
Feeding strategy main effects					
Broiler starter		19.4	17.2	36.1	12.8
Self-selection feeding		18.8	16.6	36.2	12.5
SEM		0.38	0.34	0.20	0.13
P-value		0.3294	0.2693	0.6230	0.3087
Interactive Effects					
Breed	Feeding strategy				
RIR	Broiler starter	18.9	16.7	36.0	13.4
BA	Broiler starter	19.9	17.5	35.6	12.0
BPR	Broiler starter	19.3	17.4	36.7	12.9
RIR	Self-selection feeding	19.0	16.6	36.2	12.8
BA	Self-selection feeding	18.6	16.7	36.5	12.1
BPR	Self-selection feeding	18.7	16.6	36.0	12.8
SEM		0.65	0.58	0.34	0.22
P-value		0.5492	0.7917	0.0762	0.3272

The Rhode Island Reds and Black Australorps on broiler starter were processed at 134 days of age while the Barred Plymouth Rocks on broiler starter and all birds on the self-selection feeding program were processed at 148 days of age.

* Means are averages of four birds per pen (breed main effects, n = 6; feeding strategy main effects, n = 9; interactive effects, n = 3)

[a, b] Mean values within a column without common superscripts are different ($P < 0.05$)

CHAPTER 5: Effects of alternative feedstuffs and dietary enzymes on the growth performance, carcass yield, and meat quality of alternative breed chickens

5.1 Abstract

This study was conducted to assess the effect of replacing corn and soybean meal with alternative feedstuffs and dietary enzymes on the performance and carcass characteristics of straight-run commercial broilers (BR) and two alternative breeds of chickens: males from a Black Sex-Link cross (BSL) and straight-run Rhode Island Reds (RIR). A 3 x 5 factorial arrangement of breeds and dietary treatments was used with the following isocaloric (3000 kcal ME/kg) and isonitrogenous (20% CP) diets: 1. Corn-soybean meal (CSM) based diet; 2. ~30% of CSM in Diet 1 replaced with field peas (Peas); 3. Diet 2 with a dietary enzyme complex (Allzyme SSF®, Alltech Inc., Nicholasville, KY) added at 0.02% of diet (Peas+); 4. ~50% of CS in Diet 1 replaced with a 3:1:1 ratio of field peas, buckwheat, and flax seed (Mix); 5. Diet 4 with 0.02% Allzyme SSF® added (Mix+). Twelve chicks per pen were placed for three replicates of BR and RIR, and two replicates of BSL males. Birds were housed in floor pens (0.19 m^2/bird) with diets and water provided on an *ad libitum* basis. Average daily feed intake and average daily gain were higher ($P < 0.05$) for BRs than for BSL males, which in turn were higher than RIRs. BRs had lower ($P < 0.05$) feed:gain ratios when compared with the BSL males and the RIR birds. Replacing 30% of the CSM with field peas did not alter growth performance of chicks. However, replacing 50% of the CSM with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced ($P < 0.05$) average daily gain and increased ($P < 0.05$) average daily feed intake resulting in poorer ($P < 0.05$) feed:gain ratios. These negative effects were alleviated by adding enzymes to the diet.

Two males and two females from each pen of BR (42 days of age) and RIR (96 days of age), and four males from each pen of BSL (96 days of age) were weighed and processed. Average live weight was 2073 grams for BR males, 2067 grams for BR females, 1796 grams for RIR males, and 1328 grams for RIR females, and 1916 grams for BSL males. Main effects of breed, sex, and diet, as well as interactive effects were evaluated. BR breast meat was redder ($P < 0.05$) than RIR and BSL breast meat. Breast

meat of birds fed CSM was yellower (P < 0.05) than that of those fed other diets. Drip loss was not affected (P > 0.05) by breed or dietary treatment for boneless skinless breast or leg quarters. For breast and thigh meat samples, Thirobarbituric Acid Reactive Substances (TBARS) increased during storage. At each time point, BR had lower (P < 0.05) TBARS values than RIR and BSL. Birds fed CSM, Peas, and Peas+ had lower (P < 0.05) TBARS values than birds fed Mix and Mix+. Birds fed Mix+ had lower (P < 0.05) TBARS values than birds fed Mix.

In summary, broilers had better growth performance than BSL males and RIRs. For all three breeds, field peas replaced 30% of the CSM diet without reducing growth performance or carcass yields. However, a 50% replacement of CSM with a 3:1:1 ratio of field peas, buckwheat, and flax seed reduced growth performance and carcass yield. Additionally, the latter diet negatively affected lipid peroxidation, but this effect was mitigated through the inclusion of dietary enzymes.

5.2 Introduction

As interest in alternatives to the conventionally-produced meat-type birds grows, the demand for slower-growing meat-type birds has grown. Unfortunately, these strains make up only a small portion of the global broiler industry and many breeds are only available in Europe (Gee, 2016). One alternative that would be readily available are layer-type males. Worldwide, 3.34 billion day-old female egg-laying type chicks are hatched each year, and a similar number of male chicks are discarded (Bertechini et al., 2014). Egg producers have been under pressure to change their production practices (Mench et al., 2011) which provides further benefits to the use of egg-laying-type males as meat birds. Rather than cull billions of male chicks a year, these chicks could serve to fill this niche market. Unlike the slow-growing meat-type strains, demand for egg-laying-type males is unlikely to outpace supply. There have been a few studies looking at egg-laying-type males as meat birds; however, these studies have fed birds typical broiler diets. While these studies found low body weights after a typical broiler-length grow-out (Bertechini et al., 2014), the meat quality for these birds was deemed to be acceptable (Lichovnikova et al., 2009; Bertechini et al., 2014)

In the present study, three genotypes were compared: commercial broilers (Cobb 700), Rhode Island Reds, and males from a Black Sex-Link cross. Rhode Island Reds are one of the most popular heritage breeds of chicken in America. The Black Sex-Link cross utilized in this study was created by crossing Rhode Island Red roosters on Barred Plymouth Rock hens. The inheritance of the barring gene (which is carried on the Z sex chromosome) produces chicks which can be sexed by the color of their down at hatch. This enables males and females to easily be identified even without an experienced chick sexer. In turn, males and females can be raised separately with their intended purpose (meat or egg production) in mind from day one.

Rhode Island Reds and Black Sex-Link crosses are more likely to be used in alternative production systems such as organic, free-range, or pasture poultry than in conventional production systems. Therefore, diet is another aspect that must be considered consider. This study utilized alternative ingredients such as field peas, buckwheat, and flax seed to partially replace corn and soybean meal in the diets. These types of feeds are more prevalent in organic systems where producers cannot use genetically modified crops (USDA 2012a; USDA 2012b)., so the ability of these chickens to adapt to alternative ingredients in their diets, whether naturally or through the use of exogenous enzymes added to the diet, is important. Therefore, the objective of this study was to evaluate the replacement of corn and soybean meal with alternative feedstuffs and dietary enzymes on the performance and carcass characteristics of straight-run commercial broilers, straight-run Rhode Island Reds, and males from a Black Sex-Link cross.

5.3 Materials and methods

Experiments were conducted at the Alltech-University of Kentucky Research Alliance Poultry Farm. All procedures for this study were conducted under protocols approved by the University of Kentucky Institutional Animal Care and Use Committee (IACUC). This trial was conducted from April 2014 through July 2014.

5.3.1 Animals, dietary treatments, and husbandry

The fifteen experimental treatments utilized a 3 x 5 factorial arrangement which consisted of 3 genotypes and 5 diets. The genotypes utilized were a commercial broiler (as hatched), Rhode Island Red (as hatched), and a Black Sex-Link cross (males only). The chicks were produced from the University of Kentucky's breeder flocks. The commercial broiler utilized was the Cobb 700 which is a high-yielding meat-type strain commonly used for meat production. The Black Sex-Link cross utilized in this study was created by crossing Rhode Island Red roosters on Barred Plymouth Rock hens. The parent stock was initially purchased as chicks from Murray McMurray Hatchery (Webster City, IA).

The following isocaloric (3000 kcal AMEn/kg) and isonitrogenous (20% CP) diets were used: Diet 1) corn-soybean meal (CSM); Diet 2) ~30% of the CSM-based diet replaced with field peas; Diet 3) Diet 2 with and enzyme complex (Allzyme SSF®, Alltech Inc., Nicholasville, KY) added; Diet 4) ~50% of the CSM replaced with a 3:1:1 mixture of field peas, buckwheat, and flax; and Diet 5) Diet 4 with the enzyme complex added. Integral® (Alltech Inc., Nicholasville, KY), a glucomannan containing yeast product, was added to each diet at a 0.1% inclusion level to reduce potential mycotoxin absorption in the birds. The diet composition and nutrient content of each diet is described in Table 5.1. Three replicate groups of 12 chicks were placed for each genotype x diet combination for Rhode Island Red and broilers. However, due to insufficient numbers of males hatched from the Black Sex-Link cross, there were only two replicate groups of 12 chicks placed for each treatment of Black Sex-Link birds.

Chicks were housed in floor pens bedded with dried pine shavings. The floor pen dimensions were 1.22 x 1.83 meters which provided 0.19 square meters of space to each bird. Birds were brooded at 29.4°C for three weeks with temperature reduced each week until reaching ambient outdoor temperatures. The average temperature experienced by broilers was 26.7°C, while the average temperature experienced by Rhode Island Red and Black Sex-Link birds was 25°C. The lighting program provided 22 hours of light per day throughout the experiment. Feed was provided on an *ad libitum* basis in a hanging tube feeder. Water was provided on an *ad libitum* basis via a nipple drinking system with three nipples per pen.

5.3.2 Growth performance

Chicks were weighed at the time of placement (1 day of age) and then weekly through processing at 42 days of age (broilers) or 96 days of age (Rhode Island Red and Black Sex-Link birds). Average daily gain and was calculated on a pen basis. Weekly feed consumption was recorded for each pen and used to calculate average daily feed intake. Feed conversion ratio was calculated as grams of feed consumed per gram of body weight gain. Daily mortality was monitored and accounted for in average daily gain and average daily feed intake calculations.

5.3.3 Carcass yield and sample collection

Due to expected differences in growth rates, broilers were processed at 42 days of age, while the Rhode Island Red and Black Sex-Link birds were processed at 96 days of age. At processing, two males and two females from each broiler and Rhode Island Red treatment, and four males from each Black Sex-Link treatment per pen were euthanized via electrical stunning followed by exsanguination in accordance with University of Kentucky IACUC approved procedures. After euthanasia, birds were immersed in hot water bath and then de-feathered using a semi-automated chicken plucker. The digestive tract, giblets (heart, liver, gizzard, and neck), lungs, feet, and shanks were removed. Abdominal fat (fat pad) weights were recorded (expressed as a percentage of live weight). Following a 3-hour chill, the chilled carcass weight without giblets (WOG) was recorded (expressed as a percentage of the live weight) and then breast filets (*pectoralis major* – deboned, skinless), tenders (*pectoralis minor*), wings, and leg quarters were removed from each carcass and weighed to determine part yields. Breast filets and leg quarters were retained and stored on ice for meat quality analysis.

5.3.4 Drip loss and color score analysis

Drip loss was measured using the suspension method. Deboned, skinless breast filets (1 filet/pen) and leg quarters (1 quarter/pen) were weighed and individually suspended in sealed, gallon-sized plastic storage bags. Bagged breast filets and leg quarters were stored at 4°C. After 3 and 7 days of storage, each sample was weighed and percent drip loss was calculated (expressed as a percentage of the initial weight). Additionally, color changes in the breast fillets were measured objectively for the Commission Internationale de l'Eclairage (CIE) values of lightness (L*), redness (a*), and yellowness (b*) using CR-310 Chroma Meter (Minolta Co, Ltd., Osaka, Japan) calibrated against a white tile. Color measurements were measured in duplicate on the ventral surface of each breast filet on day 0, 3, and 7 of storage.

5.3.5 Oxidative stability

The effect of genotype and dietary treatment on lipid oxidation of raw breast filets and chicken thighs was assessed by measuring thiobarbituric acid reactive species (TBARS) according to procedures similar to Paul (2015). One breast filet (deboned, skinless) and one thigh (deboned, skinless) were used per pen. Each breast filet and thigh sample was cut into three equal sections. Each section was separately placed onto a Styrofoam tray with a moisture pad and then covered with polyvinyl chloride (PVC) overwrap and stored in a retail cooler set to 2°C under 1300 lux fluorescent lighting. TBARS assay was performed at 1, 3, and 7 days of storage. For the TBARS assay, 5 grams of meat were homogenized in 22.5 ml of 11 trichloroacetic acid (TCA) solution using an Ultra-Turrax® T25 rotor-stator homogenizer and saw tooth dispersing element (IKA® Works, Inc., Wilmington, NC). The homogenate was filtered through Whatman #1 filter paper (in duplicate). Then 1 ml of the filtrate was mixed with 1 ml of 20 mM thiobarbituric acid (TBA) and incubated at 25°C. A blank was prepared by mixing 2ml of 11 TCA solution with 2ml of 20 mM TBA solution. After 20 hours of incubation, the absorbance of the malondialdehyde (MDA) in the solution was read at 532 nm on a Thermo Scientific GENESYS™ 10S UV-Vis Spectrophotometer. Given the MDA extinction coefficient factor of 1.56 x $105M^{-1}cm^{-1}$, the concentration of MDA (expressed as mg MDA/kg meat) was calculated based upon Beer's Law (1852) and the following equation:

$$MDA\ Concentration = \frac{ABS}{Length\ (1) x K}\, x\, \frac{1L}{Tissue\ Concentration}$$

Where, ABS refers to absorbance of MDA at 532 nm, Length refers to path length of the sample, K (a constant) refers to the product of the extinction coefficient factor and molecular weight of MDA, and Tissue Concentration accounts for the concentration of the meat sample after homogenization and dilution in TCA and TBA solutions.

5.3.6 Bone quality

At 42 days of age (broilers) and 96 days of age (Black Sex-Link males and Rhode Island Red birds), two birds per pen were randomly selected and euthanized by argon gas asphyxiation followed by cervical dislocation. Left tibae and humeri were collected and pooled by pen for breaking strength analysis via Instron Testing Instrument (Model 4301). Excess soft tissue was removed from the bone shaft prior to analysis of breaking strength. Bones were placed flat on a raised platform where a stainless steel wedge probe aligned perpendicular to the center of the bone shafts applied 100 kilograms of force at a speed of 40 millimeters per second until the bones fractured. Right tibae and humeri were collected and pooled by pen for percent ash analysis. Bones were boiled in deionized water for 15 minutes to remove flesh and dried at 105°C for a minimum of 12 hours. Bones were then de-fatted in changes of petroleum ether until petroleum ether solution appeared to be free of fat residues. De-fatted bones were dried overnight at 105°C in a forced air oven and then ashed at 600°C for 6 hours in a muffler furnace. Ash percent was calculated on a dry matter basis.

5.3.7 Statistical analyses

For growth performance, color score, and bone quality, an analysis of variance for a 3 x 5 factorial arrangement of treatments was conducted using the general linear model procedures of SAS® (SAS v. 9.3, Cary, NC). This analysis allowed for the determination of the main effect of genotype, the main effect of diet, and the interactive effects of genotype and diet. To determine the effect of sex on carcass and part yields, an analysis of variance for a 2 x 2 x 5 factorial arrangement of genotype, sex, and diet was conducted. For TBARS, an analysis of variance 2 x 2 x 5 factorial arrangement of genotype, tissue, and diet was used. Fisher's least significant difference test was used to determine differences among means with significance set at $P < 0.05$.

5.4 Results

5.4.1 Growth performance

Growth performance was monitored from 1 day of age until processing (42 days of age for broilers and 96 days of age for Black Sex-Link males and Rhode Island Red birds). Parameters measured included average daily gain, average daily feed intake, and feed conversion ratio (Table 5.2). No breeds x diet interactions ($P > 0.05$) were observed for growth performance parameters, so only main effects were reported.

5.4.1.1 Effect of breed

Initial body weight for broiler chicks (45.4 ± 0.5 grams) was higher ($P < 0.05$) than the initial body weights of Black Sex-Link and Rhode Island Red chicks (42.3 ± 0.3 grams). Broilers had higher ($P < 0.01$) average daily gain than Black Sex-Link males, and both had higher ($P < 0.05$) average daily gain than Rhode Island Red birds. At processing, average body weight was 1994 grams for broilers, 1860 grams for Black Sex-Link males, and 1577 grams for Rhode Island Red birds. Average daily feed intake for broilers was higher ($P < 0.05$) than that of Black Sex-Link males was higher, and both consumed more ($P < 0.05$) feed per day than the Rhode Island Red birds. Broilers had better ($P < 0.0001$) feed conversion than either Black Sex-Link males or Rhode Island Red birds.

5.4.1.2 Effect of diet

The initial body weight of chicks at placement was similar ($P > 0.05$) among dietary treatments, but there was a main effect of dietary treatment on growth performance. Replacing 30% of the CSM-based diet with field peas had no effect ($P > 0.05$) on average daily gain, average daily feed intake, or feed:gain ratios. However, replacing 50% of the CSM-based diet with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced ($P < 0.05$) average daily gain and increased ($P < 0.05$) average daily feed intake resulting in poorer ($P < 0.01$) feed:gain ratios. The addition of the dietary enzyme complex alleviated some of these negative effects.

5.4.2 Carcass yield: Broilers vs. Rhode Island Reds (males and females)

Broilers were processed at 42 days of age and Rhode Island Reds were processed at 96 days of age. Two males and two females from each pen were weighed and processed in order to evaluate the effects of breed, diet, and sex on carcass yield. The main effects of breed, sex, and diet on carcass and part weights are reported in Table 5.3 and interactive effects are reported in Table 5.4. The main effects of breed, sex, and diet on carcass and part yields are reported in Table 5.5 and the interactive effects are reported in Table 5.6.

5.4.2.1 Live weight

Broilers had heavier ($P < 0.0001$) live weights than Rhode Island Reds, and males had heavier ($P < 0.0001$) live weights than females. However, there was an interactive effect of breed x sex for live weights ($P < 0.0001$). While the average live weights of male and female broilers were similar ($P > 0.05$) at 2070 grams, Rhode Island Red males were heavier than Rhode Island Red females (1796 vs. 1328 grams, SEM = 44; $P < 0.05$).

A main effect of diet was also noted. Replacing 30% of the CSM-based diet with field peas had no effect ($P > 0.05$) on live weight when compared with the CSM-based diet. However, replacing 50% of the CSM-based diet with a 3:1:1 mixture of field peas, buckwheat, and flax seed reduced ($P < 0.05$) live weight regardless of whether exogenous enzymes were added to the diet. Additionally, a breed x diet interaction ($P < 0.05$) was noted with the 50% replacement diet resulting in greater live weight depression for broilers than for Rhode Island Reds.

5.4.2.2 Chilled carcass without giblets (WOG)

The weights of the chilled carcass without giblets (WOG) followed the same patterns as live weight. As a percentage of live weight, the chilled WOG yield was higher ($P < 0.0001$) for broilers than Rhode Island Reds with no effect ($P > 0.05$) of sex or interactive effect of sex x genotype.

A main effect of diet was also noted ($P < 0.0001$). Replacing 30% of the CSM-based diet with field peas did not affect chilled WOG yield ($P > 0.05$). However, replacing 50% of the CSM-based diet with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced ($P < 0.05$) the chilled WOG yield regardless of whether dietary enzyme was added to the diet. Additionally, a breed x diet interaction ($P < 0.0001$) was noted – chilled WOG yields were depressed by the 50% replacement diets for broilers, but not for Rhode Island Reds.

5.4.2.3 Abdominal fat (fat pad)

Abdominal fat (fat pad) weight was not affected ($P > 0.05$) by genotype, sex, or interactive effects. However, as a percentage of the live weight, fat pad yields were higher ($P < 0.0001$) for Rhode Island Reds than for broilers, and were higher ($P < 0.05$) for males than for females. Additionally, a genotype x sex interaction was noted with broiler males having higher ($P < 0.05$) fat pad yields than broilers females, while Rhode Island Red females had higher ($P < 0.05$) fat pad yields than Rhode Island Red males.

A main effect of diet ($P < 0.0001$) was noted for both abdominal fat pad weight and yield as a percentage of live weight. Replacing 30% of the CSM-based diet with field peas did not affect ($P > 0.05$) fat pad weight or fat pad yield. However, replacing 50% of the CSM-based diet with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced ($P < 0.05$) fat pad weight and yield regardless of whether dietary enzyme was added to the diet. Additionally, a genotype x diet interaction was noted for fat pad yield with a greater ($P < 0.05$) reduction in fat pad yield for Rhode Island Reds fed the 50% replacement diet than for the broilers fed the same diet.

5.4.2.4 Breast filets (pectoralis major)

Boneless, skinless breast filet (*pectoralis major)* weights were heavier for broilers than Rhode Island Reds (442 vs 166 grams; SEM = 2; $P < 0.05$). When expressed as a percentage of live weight, breast filet yield was higher for broilers than Rhode Island Reds (27.9 vs 15.9%; SEM = 0.3; $P < 0.0001$).While the breast filet weights from males were heavier ($P < 0.0001$) than those from females, there was no main effect ($P > 0.05$) of sex on breast filet yield as a percentage of the chilled WOG weight. Interestingly, there was a genotype x sex effect ($P < 0.001$) for both breast filet weight and breast filet yield. Breast filet weights were similar ($P > 0.05$) between male and female broilers, but Rhode Island Red males had heavier ($P < 0.05$) breast filets than Rhode Island Red females. As a percentage of live weight, breast filet yields were higher ($P < 0.05$) for female broilers than for male broilers. Conversely, Rhode Island Red females had higher ($P < 0.05$) breast filet yields than Rhode Island Red males.

A main effect of diet ($P < 0.0001$) was noted for both breast weight and breast yield as a percentage of chilled WOG weight. Replacing 30% of the CSM-based diet with field peas did not affect ($P > 0.05$) breast filet weight or yield. However, replacing 50% of the CSM-based diet with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced ($P < 0.05$) breast filet weight and yield regardless of whether dietary enzyme was added to the diet. A genotype x diet interactive effect ($P < 0.001$) was noted for both breast weight and breast yield as a percentage of live weight. There was a genotype x diet interactive effect ($P < 0.001$) with Rhode Island Reds having similar ($P > 0.05$) breast filet weights and yields regardless of diet, while broilers had reduced breast filet weights and yields when 50% of the CSM-based diet was replaced with a 3:1:1 mixture of field peas, buckwheat, and flax seed.

5.4.2.5 Tenders (pectoralis minor)

Tender (*pectoralis minor)* weights were heavier for broilers than for Rhode Island Reds (84.4 vs 44.8 grams; SEM = 1.7; $P < 0.0001$). As a percentage of the live weight, tender yields were higher for broilers than for Rhode Island Reds (5.4 vs 4.3%; SEM = 0.1%; $P < 0.0001$). No main effect of sex on tender weights was noted, but tender yields were higher ($P < 0.05$) for females than for males. A breed x sex interaction was noted – tender weights and yields were similar ($P > 0.05$) between male and female Broilers, but tender weights were heavier ($P < 0.05$) for Rhode Island Red males than for Rhode Island Red females. Conversely, when expressed as a percentage of WOG weight, tender yields were lower ($P < 0.05$) for Rhode Island Red males than for Rhode Island Red females.

A main effect of diet ($P < 0.0001$) was noted for both tender weight and tender yield as a percentage of chilled WOG weight. Replacing 30% of the CSM-based diet with field peas did not affect ($P > 0.05$) tender weight or yield. However, replacing 50% of the CSM-based diet with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced ($P < 0.05$) tender weight and yield regardless of whether dietary enzymes were added to the diet. Additionally, there was a genotype x diet interactive effect with Rhode Island Reds having similar ($P > 0.05$) tender weights regardless of diet while broilers had reduced ($P < 0.05$) tender weights when 50% of the CSM-based diet was replaced with a 3:1:1 mixture of field peas, buckwheat, and flax seed. However, this diet x genotype interaction disappears when tender yield is expressed as a percentage of WOG weight. Therefore, tender weights would likely have been similar if the live weights had not been different.

5.4.2.6 Wings

Broilers had heavier wings than Rhode Island Reds (160 vs 145 grams; SEM = 2.5; $P < 0.0001$). However, when expressed as a percentage of the WOG weight, wing yield is lower for broilers than for Rhode Island Reds (10.4 vs 14.0%; SEM = 0.1%; $P < 0.0001$). Males had heavier wings than females and a breed x sex interaction was noted, but the difference and the interaction disappear when wing yield is expressed as a percentage of the WOG weight.

A main effect of diet (*P* < 0.0001) was noted for both wing weight and wing yield as a percentage of chilled WOG weight. Replacing 30% of the CSM-based diet with field peas did not affect (*P* > 0.05) wing weight or yield. However, replacing 50% of the CSM-based diet with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced (*P* < 0.05) wing weight and yield regardless of whether dietary enzyme was added to the diet. No genotype x diet interaction was noted for wing weight or yield.

5.4.2.7 Leg quarters

Broilers had heavier leg quarters than Rhode Island Reds (612 vs 483 grams; SEM = 10*;* *P* < 0.0001). However, as a percentage of the chilled WOG weight, leg quarters made up less of the carcass for broilers than for Rhode Island Reds (39.5 vs 46.2%; SEM = 0.2%*;* *P* < 0.0001). Males had heavier (*P* < 0.0001) leg quarters and higher (*P* < 0.0001) leg quarter yields than females, but a breed x sex interaction was also noted. Leg quarter weights and yields were similar (*P* > 0.05) for male and female broilers, but Rhode Island Red males had heavier (*P* < 0.05) leg quarters than Rhode Island Red females.

A main effect of diet (P < 0.0001) was noted for both leg quarter weight and leg quarter yield as a percentage of chilled WOG weight. Replacing 30% of the CSM-based diet with field peas did not affect (*P* > 0.05) leg quarter weight or yield. However, replacing 50% of the CSM-based diet with a 3:1:1 ratio of field peas, buckwheat and flax seed reduced (*P* < 0.05) leg quarter weight and yield regardless of whether dietary enzymes were added to the diet. No genotype x diet interaction (*P* > 0.05) was noted for leg quarter weight, but an interactive effect was noted for leg quarter yield. Replacing 50% of the CSM-based diet with a 3:1:1 mixture of field peas, buckwheat, and flax seed increased (*P* < 0.05) the percentage of leg quarter in relation to the carcass for broilers, but had no effect (*P* > 0.05) for Rhode Island Reds.

5.4.3 Carcass yield: Black Sex-Link males

Four males from each pen of Black Sex-Links were weighed and processed at 96 days of age. Carcass characteristics were evaluated and compared with broiler males (42 days of age) and Rhode Island Red males (96 days of age). Data from females was excluded from these analyses. The main effects of genotype and diet, and the interactive effect of genotype x diet for carcass and part weights are reported in Table 5.7 and Table 5.8, and the effect for carcass and part yields are reported in Table 5.9.

5.4.3.1 Live weight

Black Sex-Link males had lower live weights than broilers males (1916 vs 2073; SEM = 35; $P < 0.01$), but heavier live weights than Rhode Island Red males (1796 grams). There was no diet x genotype interaction for live weight.

5.4.3.2 Carcass yield

The weight of the chilled carcass without giblets (WOG) followed a similar pattern as live weight. As a percentage of live weight, the chilled WOG yield for Black Sex-Link males was lower than for male broilers (67.6 vs. 74.6%), but was higher than that of Rhode Island Red males (66.8%; SEM = 0.28; $P < 0.0001$). A genotype x diet interaction was noted with the addition of dietary enzymes to the 50% replacement diet improving ($P < 0.05$) chilled WOG yield for Black Sex-Link males and Rhode Island Red males, but not for broiler males.

5.4.3.3 Abdominal fat (fat pad)

Black Sex-Link males had heavier ($P < 0.05$) fat pad weights than either Rhode Island Reds or broiler males. As a percentage of live weight, fat pad yields were higher for Black Sex-Link males than for Rhode Island Red males and broiler males (1.7 vs 1.2%; SEM = 0.1%; $P < 0.05$). There was no interaction between genotype and diet for fat pad weight or yield.

5.4.3.4 Breast filets (pectoralis major)

Broiler males had heavier boneless, skinless breast filets (*pectoralis major)* than Black Sex-Link and Rhode Island Red males (449 vs 193 grams; SEM = 9; $P < 0.05$). As a percentage of the chilled WOG weight, breast filet yield was higher for broiler males than for the other two breeds (28.6 vs 15.5%; SEM = 0.3%; $P < 0.05$). An interactive effect of diet x genotype was noted for breast filet weight and yield with diet having an effect on the breast filet yield of broiler males, but not on Rhode Island Red or Black Sex-Link males.

5.4.3.5 Tenders (pectoralis minor)

Black Sex-Link males had lower tender (p*ectoralis minor)* weights than broiler males (56 vs 84 grams), but both had higher tender weight than Rhode Island Red males (49 grams; SEM = 1.8; $P < 0.0001$). As a percentage of the chilled WOG weight, tender yields were similar ($P > 0.05$) between Black Sex-Link and Rhode Island Red males (4.2%), and both were lower than broiler males (5.4%; SEM = 0.1; $P < 0.0001$). No interactive effects of genotype x diet ($P > 0.05$) were noted for tender weight or yield.

5.4.3.6 Wings

Black Sex-Link males had heavier wings than broiler males and Rhode Island Red males (180 vs 164 grams; SEM = 3; $P < 0.05$). As a percentage of the chilled WOG weight, wing yield was similar for Black Sex-Link males and Rhode Island Red males (14.0%), and both were higher than broiler males (10.4%; SEM = 0.1%; $P < 0.05$). No genotype x diet interaction was noted for wing weight or yield.

5.4.3.7 Leg quarters

Black Sex-Link males and broiler males had heavier leg quarter weights than Rhode Island Red males (611 vs 564 grams; SEM = 12; $P < 0.01$). However, when expressed as a percentage of the chilled WOG weight, Black Sex-Link males and Rhode Island Red males had greater leg quarter yields than broiler males (47.2 vs 39.3%; SEM = 0.3%; $P < 0.05$). No genotype x diet interaction was noted for leg quarter weight or yield.

5.4.4 Meat quality

Samples were taken from one bird per pen for a total of 15 male broilers at 42 days of age, and 15 male Rhode Island Reds and 10 male Black Sex-Links at 96 days of age. Only males were used to eliminate the potential effect of sex on the results. However, it should be noted that the overall sample size was relatively low and that may have affected results.

5.4.4.1 Breast meat color

Breast meat color was measured using L*a*b* coordinates which were recorded in Table 5.11. No breed or diet effects ($P > 0.05$) were noted for lightness. Broiler breast meat was redder ($P < 0.05$) than Rhode Island Red and Black Sex-Link breast meat.

Breast meat of birds fed CSM-based diet was yellower (*P* < 0.05) than those fed other diets.

5.4.4.2 Drip loss

Drip loss was determined for boneless skinless breasts and leg quarters after 3 and 7 days of storage (data not shown). After 3 days of storage, there were no differences (*P* > 0.05) among genotypes or diets for boneless skinless breasts (1.52 ± 0.71%) or leg quarters (0.24 ± 0.11%). After 7 days of storage, there were no differences (*P* > 0.05) among genotypes or diets for boneless skinless breast (3.00 ± 0.97%) or leg quarters (0.45 ± 0.19%).

5.4.4.3 Thirobarbituric Acid Reactive Substances (TBARS)

Boneless skinless breast filets and deboned skinless thighs were individually stored in PVC-overwrapped Styrofoam trays in a retail display cooler at 4°C for 6d. To determine lipid peroxidation, Thirobarbituric Acid Reactive Substances (TBARS), 5 gram samples of each tissue were removed at day 1, 4, and 6. The main and interactive effects of tissue, genotype, and diet for TBARS values are reported in Table 5.12. There was no difference (*P* > 0.05) between TBARS values for breast and thigh. For all meat samples, TBARS increased (*P* < 0.05) over time. At each time point, broilers had lower (*P* < 0.05) TBARS values than Rhode Island Reds and Black Sex-Links. A main effect of diet was noted. Replacing 30% of the CSM-based diet with field peas did not affect TBARS values (*P* > 0.05). On the other hand, replacing 50% of the CSM-based diet with a 3:1:1 mixture of field peas, buckwheat, and flax seed increased (*P* < 0.05) TBARS values. However, birds fed the 50% replacement diet with the addition of dietary enzymes had lower (*P* < 0.05) TBARS values than those fed this diet without dietary enzymes. No interactive effects were noted.

5.4.5 Bone quality

Breaking strength and ash content for humerus and tibia were reported in Table 5.13. Broilers had greater (*P* < 0.05) tibia and humerus breaking strength than Black Sex-Links and Rhode Island Reds. Black Sex-Link bone breaking strength did not differ from that of the Rhode Island Reds. However, Rhode Island Reds and Black Sex-Links had higher (*P* < 0.05) tibia ash content and similar (*P* > 0.05) humerus ash content when compared with broilers. Therefore, the increased breaking strength is not simply a reflection of increased mineral content.

Diet had no effect ($P > 0.05$) on tibia breaking strength, humerus breaking strength, or humerus ash content. However, birds fed the CSM-based diets exhibited greater ($P < 0.05$) tibia ash content than birds fed the other diets. Additionally, birds fed the 30% replacement diet had greater ($P < 0.05$) tibia ash content than birds fed the 50% replacement diet. No interactive effect ($P > 0.05$) between genotype and diet was noted.

5.5 Discussion

This study was conducted to evaluate the replacement of corn and soybean meal with alternative feedstuffs and dietary enzymes on the performance and carcass characteristics of straight-run commercial broilers, straight-run Rhode Island Reds, and males from a Black Sex-Link cross. The commercial broiler strain utilized was the Cobb 700 which is a high-yielding meat type strain commonly used in the industry today. Rhode Island Reds were utilized because they are one of the most common heritage breeds in the United States (Floyd, 2015). The Black Sex-Link cross utilized in this study was created by crossing Rhode Island Red roosters on Barred Plymouth Rock hen. The males from this cross were of particular interest because the females from this type of cross are often used as egg-layers, but the males have no real purpose. While these birds are not currently used for meat production, the backlash against culling of male chicks within the egg industry has created an interest in using egg-type males as meat birds (Lichovnikova et al., 2009; Mench et al., 2011; Bertechini et al., 2014).

5.5.1 Use of alternative genotypes

The initial body weight of the commercial broiler chicks in this study was higher than the initial body weights for either Black Sex-Link male chicks or Rhode Island Red chicks. This is likely a reflection of the genetic potential of these birds because they were hatched from breeder flocks of similar ages maintained under similar management at the University of Kentucky. Based on the limited literature comparing the growth rate of heritage breeds and egg-type chickens with the growth rate of meat-type chickens (Lichovnikova et al., 2009; Bertechini et al., 2014; McCrea et al., 2014) and previous work at the University of Kentucky, the commercial broilers were expected to have better growth performance than Rhode Island Reds. In the present study, this held true with broilers demonstrating 252% faster growth rates with a concurrent 52% improvement in feed conversion when compared with the Rhode Island Reds. The broilers were therefore able to achieve higher body weights in significantly less time. Similarly, the commercial broilers achieved higher average daily gains with better feed conversion ratios than Black Sex-Link males.

The Black Sex-Link males achieved higher average daily gains than the Rhode Island Red birds. However, the Black Sex-Link males also had higher average daily feed intake than the Rhode Island Red birds which resulted in similar feed conversion ratios for the two genotypes. The lower growth performance of the Rhode Island Reds may be partially to that fact that they were placed and raised as hatched. Based on the data presented in previous studies (Chapter 2, Chapter 3), the Rhode Island Red females have slower growth rates than the Rhode Island Red males. This was also noted in the present study with Rhode Island Red males having significantly heavier live weights when compared to Rhode Island Red females of the same age. Therefore, it would be expected that a mixture of males and females would have reduced growth performance when compared with only males. Interestingly, when comparing the body weights of males from the Black Sex-Link cross to male Rhode Island Reds at 96 days of age, the Black Sex-Link males were about 100 grams heavier than Rhode Island Red males. This suggests that there is a difference in growth potential between these two genotypes.

While the intention was to evaluate the carcass and part yields of the different genotypes at a similar body weight, the broilers overshot the target weight before processing. Unfortunately, the heritage breeds could not be housed long enough to reach the body weight achieved by the broilers, so the live weight at processing was different. This adds a limitation to the results, but comparisons of carcass and part yields can still be made.

The commercial broilers in this study had higher chilled WOG yields than either the Black Sex-Links or the Rhode Island Reds. This is consistent with the results of McCrea et al. (2014) which showed lower carcass dressing percent from Delaware chickens (another heritage breed) than for broilers. The chilled WOG yields of the Rhode

Island Reds and Black Sex-Link males in the present study were slightly higher than the carcass yield McCrea et al. (2014) reported for 15-week-old Delaware chickens. However, this may have been due to differences in dietary treatment and bird management. The chilled WOG yield of the Black Sex-Link males in the present study was also higher than the carcass yield Bertechini et al. (2014) reported for egg-layer males. However, the egg-layer males were processed at only 42 days of age and only weighed about 700 grams. Their yields may have been different at a later processing age. Additionally, Collins et al. (2014) showed that the Athens Canadian Random Bred meat-type chickens (representative of 1950's genetics) had lower carcass yields than Cobb 500 high-yielding broilers at 6, 8, and 10 weeks of age.

When compared with Black Sex-Links and Rhode Island Reds, the conformation of the commercial broiler carcass was shifted towards white meat production with higher breast and tender yields, but lower leg and wing yields. This is consistent with the results of Chapter 4 which showed that heritage breeds had lower boneless breast and higher whole leg and wing yields as a percentage of their chilled WOG weights than either fast- (Cornish Cross) or slow-growing (Red Ranger) genotypes. Additionally, these results are consistent with the findings of a study by Fanatico et al. (2008) which showed that slow-growing genotypes had lower breast meat yields, but higher wing and leg yields than fast-growing genotypes. Furthermore, the results make sense in the context of selection pressure placed on broilers which has increased the overall muscle mass of the chicken, with particular emphasis on breast muscle production (Havenstein et al., 2003b; Schmidt et al., 2009; Zuidhof et al., 2014).

Zuidhof et al. (2014) reported that commercial selection pressures have reduced fat deposition in broilers. This is supported by the data from the present study which showed that Rhode Island Reds had higher abdominal fat yields as a percentage of live weight than commercial broilers. However, a genotype x sex interaction was noted with male and female broilers having similar abdominal fat yields, but Rhode Island Red females having higher abdominal fat yields than Rhode Island Red males. When only males were compared, commercial broilers and Rhode Island Reds had similar abdominal fat yields. Additionally, the genotype x diet interaction observed for abdominal fat yield suggests the CSM-based diet and the 30% field peas diet may have oversupplied nutrients for the Rhode Island Reds. When these birds were fed a lower-nutrient density diet where 50% of the CSM-based diet was replaced with a 3:1:1 ratio of field peas, buckwheat, and flaxseed, Rhode Island Reds had similar abdominal fat yields as broilers.

5.5.2 Use of alternative feedstuffs

Poultry feed requires sources of protein, energy, vitamins, and minerals. In conventional chicken diets in the United States, corn serves as the main energy source and soybean meal as the main protein source. When the price of corn and soybeans go up, there is increased interest in alternative feedstuffs. In addition, more than 90% of the corn and soybean crops in the United States are genetically modified organisms (GMO). As a way to differentiate their products from conventional chicken meat or egg production, small- and medium-sized farms may also consider using vegetarian diets that do not include animal products and that are not corn/soybean meal based. However, formulating balanced diets using alternative feedstuffs can be challenging depending on the nutrients available in the feedstuff.

The alternative feedstuffs evaluated in this study included field peas, buckwheat, and flax seed. Field peas were selected as the primary alternative feedstuff because peas are relatively high in protein at 20-29% crude protein. While high inclusion levels of field peas can reduce bird performance (Farrell et al., 1999; Tuunainen et al., 2016), Nalle et al. (2011) found that broilers fed diets containing as much as 20% field peas had similar growth performance as broilers fed a corn-soy control. Based on their experiments, Farrell et al. (1999) suggested field peas inclusion be limited to 30% of the diet for broilers.

Flax seed was selected due to its high protein levels (26% CP) and its use in creating omega-3 enriched meat and eggs (Amini and Ruiz-Feria, 2007; Nanjappan et al., 2013), particularly when utilized with enzyme supplementation (Jia et al., 2008). However, the literature suggests high levels of flax seed inclusion (>10%) lead to decreased product acceptability (Collins et al., 1997). Interest in buckwheat as a poultry feed has increased in some areas of the Midwest (Jacob, 2007). The grain contains 11-13% crude protein and is the best source of lysine among the feed grains, and is the only grain not lysine deficient (Jacob and Carter, 2008). While little data is available on the use of buckwheat, the literature suggests that buckwheat has reasonable feeding value roughly comparable to oats or wheat (Leiber et al., 2009).

In the present study, the use of field peas to replace 30% of the CSM-based diet had no effect on growth performance, carcass and part yields, oxidative stability, or bone breaking strength for any of the genotypes. Therefore, field peas could be a viable alternative feedstuff to partially replace corn and soybean meal in diets for both meat-type and heritage breed chickens. However, the low crude protein content of field peas when compared to soybean meal is limiting. Additionally, breast meat from the birds fed the diet containing 30% field peas was less yellow than breast meat from birds fed the CSM-based diet. Because consumers initially evaluate meat based on color, this difference could impact consumer perception of the product (Kennedy et al., 2005).

Meanwhile, replacing 50% of the CSM-based diet with a 3:1:1 mixture of field peas, buckwheat, and flax seed reduced average daily gain and increased feed intake resulting in poorer feed conversion ratios. However, the addition of dietary enzyme alleviated some of these effects. Specifically, birds fed diets with the enzyme complex exhibited lower feed intake and better feed conversion than birds fed diets without the enzyme complex. At processing, a genotype x diet interaction was noted. For broilers, birds fed the 50% replacement diet had lower body weights, lower chilled WOG yields, and lower breast yields than birds fed the other diets. Conversely, this diet had no effect on live weight, chilled WOG or part yields for Rhode Island Reds or Black Sex-Link males. These results are consistent with the findings of Rack et al. (2009) which found that, while the performance of fast-growing birds was reduced when they were housed on pasture, slower-growing birds did not experience a reduction in performance. The addition of the dietary enzyme complex did not affect carcass or part yields.

5.6 Conclusions

The results also suggest field peas can be used with or without dietary enzyme to replace 30% of the corn and soybean meal in diets for meat-type birds and heritage breeds without sacrificing growth performance or carcass yield. However, replacing 50% of the corn and soybean meal with a 3:1:1 ratio of field peas, buckwheat, and flaxseed negatively impacted growth performance for both meat-type and heritage breeds. Furthermore, this dietary formulation reduced chilled WOG and breast yields for commercial broilers, but not for the heritage breed studied. The use of a dietary enzyme complex may improve some performance parameters; however, it did not appear to affect carcass and part yields.

The results of the present study provide further evidence that heritage breeds such as the Rhode Island Red demonstrate poor growth parameters when compared with meat-type birds. Additionally, while the Black Sex-Link cross demonstrated better performance than the Rhode Island Reds, their growth rate was still significantly slower and they demonstrated poorer feed conversion than that of the commercial broiler. However, as noted by Bertechini et al. (2014) the abundant potential supply of males from this type of cross due to practices within the laying industry may make them useful in certain situations. Ultimately, the findings of this study provides further evidence that their nutrient requirements are lower than those of fast-growing meat-type strains, and suggests heritage breeds are better able to utilize lower nutrient density diets. However, further research is needed to determine the extent to which alternative ingredients can be used to replace corn and soybean meal in diets for these breeds.

5.7 Tables

Table 5.1. Diet composition and analyzed nutrient content for the corn-soybean meal based diet (CSM) and the peas and mix diets with or without an enzyme complex added

	CSM	Peas	Peas +SSF	Mix	Mix +SSF
Corn, %	65.83	43.86	43.86	29.56	29.56
Soybean meal, %	31.00	18.50	18.50	13.77	13.77
Buckwheat, %	-	-	-	10.00	10.00
Field peas, %	-	30.00	30.00	30.00	30.00
Flaxseed, %	-	-	-	10.00	10.00
Vegetable oil, %	1.18	3.57	3.57	2.77	2.77
Limestone, %	1.33	1.32	1.32	1.40	1.40
Dicalcium phosphate, %	1.82	1.85	1.85	1.63	1.63
Salt, %	0.42	0.4	0.4	0.38	0.38
Vitamin-mineral mix[1], %	0.25	0.25	0.25	0.25	0.25
DL-Methionine, %	0.17	0.25	0.25	0.24	0.24
Enzyme complex[2], %	-	-	0.02	-	0.02
Integral® [3], %	0.10	0.10	0.10	0.10	0.10
Energy, kcal ME/kg (calculated)	3000	3000	3000	3000	3000
Crude protein, %	18.99	19.82	20.92	18.52	19.86
Methionine, %	0.42	0.39	0.49	0.41	0.43
Cysteine, %	0.32	0.28	0.30	0.28	0.28
Lysine, %	1.16	1.20	1.31	1.21	1.20
Crude fat, %	3.71	5.37	5.19	5.96	6.81
Crude fiber, %	3.06	3.83	3.85	7.00	5.94
Calcium, (calculated)	1.00	1.00	1.00	1.00	1.00
Phosphorus, available (calculated)	0.45	0.45	0.45	0.45	0.45

[1] Akey Layer Starter Breeder Premix (Akey, Lewisburg, OH)
[2] Allzyme-SSF® (Alltech Inc., Nicholasville, KY)
[3] Integral® (Alltech Inc., Nicholasville, KY)

Table 5.2. Average daily gain, average daily feed intake, and feed:gain for birds from 1 through 98 days of age*

		Average Daily Gain (grams/bird/day)	Average Daily Feed Intake (grams/bird/day)	Average Feed to Gain (g feed/g gain)
Genotype main effects				
Broiler (straight-run)		37.5 ± 0.8 [a]	82.9 ± 2.8 [a]	2.31 ± 0.16 [b]
Black Sex-Link (male)		17.6 ± 1.0 [b]	75.8 ± 3.7 [a]	4.21 ± 0.21 [a]
Rhode Island Red (straight-run)		14.9 ± 0.8 [c]	65.6 ± 2.8 [b]	4.44 ± 0.16 [a]
P-value		<0.0001	0.0007	<0.0001
Diet main effects				
Corn-Soy		24.4 [a]	70.5 [b]	3.40 [bc]
Peas		24.8 [a]	67.8 [b]	3.05 [c]
Peas +SSF		24.6 [a]	72.5 [b]	3.39 [bc]
Mix		21.0 [b]	87.1 [a]	4.56 [a]
Mix + SSF		21.8 [ab]	75.6 [b]	3.83 [b]
SEM		1.1	3.9	0.23
P-value		0.0459	0.0172	0.0011
Interactive effects				
Genotype	Diet			
Broiler	Corn-Soy	41.9	80.7	1.93
Broiler	Peas	40.3	79.6	1.98
Broiler	Peas +SSF	39.8	72.9	1.83
Broiler	Mix	31.7	100.7	3.44
Broiler	Mix + SSF	33.8	80.5	2.36
BSL	Corn-Soy	16.3	71.2	4.24
BSL	Peas	18.2	66.1	3.55
BSL	Peas +SSF	19.1	88.6	4.43
BSL	Mix	17.2	76.7	4.35
BSL	Mix + SSF	17.2	78.4	4.45
RIR	Corn-Soy	14.9	59.7	4.04
RIR	Peas	16.0	57.7	3.62
RIR	Peas +SSF	14.8	58.0	3.93
RIR	Mix	14.2	83.7	5.90
RIR	Mix + SSF	14.5	67.7	4.69
SEM		1.81	6.7	0.39
P-value		0.0888	0.3202	0.3736

RIR = Rhode Island Red, BSL = Black Sex-Link

*Mean values are pen averages (genotype, n = 15 for broilers and RIR, n = 10 for BSL; diet main effects, n = 8; interactive effects, n = 3 for broilers and RIR and n = 2 for BSL for each diet)

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)

Table 5.3. Main effects of genotype, sex, and diet on live weight, chilled carcass weight without giblets (WOG), abdominal fat (fat pad) weight, and part weights for Rhode Island Reds and broilers*

	Live weight, g	Chilled WOG weight, g	Fat pad weight, g	Boneless, skinless breast weight, g	Tender weight, g	Wing weight, g	Leg quarter weight, g
Genotype main effects							
Broiler	2070 ^{a}	1559 ^{a}	24.1	442 ^{a}	84.4 ^{a}	160 ^{a}	612 ^{a}
Rhode Island Red	1562 ^{b}	1042 ^{b}	25.8	166 ^{b}	44.8 ^{b}	145 ^{b}	483 ^{b}
SEM	31	26	1.2	8.7	1.7	2.5	10.3
P-value	<0.0001	<0.0001	0.2943	0.0309	<0.0001	<0.0001	<0.0001
Sex main effects							
Female	1697 ^{b}	1226 ^{b}	25.6	290 ^{b}	62.5	141 ^{b}	509 ^{b}
Male	1934 ^{a}	1375 ^{a}	24.3	317 ^{a}	66.6	164 ^{a}	586 ^{a}
SEM	31	26	1.2	8.7	1.7	2.5	10.3
P-value	<0.0001	<0.0001	0.4441	<0.0001	0.0899	<0.0001	<0.0001
Diet main effects							
Corn-Soy	1868 ^{a}	1356 ^{a}	27.9 ^{a}	326 ^{a}	69.1 ^{a}	157 ^{a}	562 ^{a}
Peas	1938 ^{a}	1411 ^{a}	28.0 ^{a}	347 ^{a}	71.5 ^{a}	161 ^{a}	587 ^{a}
Peas +SSF	1946 ^{a}	1422 ^{a}	31.5 ^{a}	344 ^{a}	68.7 ^{a}	161 ^{a}	593 ^{a}
Mix	1693 ^{b}	1178 ^{b}	20.0 ^{b}	262 ^{b}	58.9 ^{b}	143 ^{b}	503 ^{b}
Mix + SSF	1634 ^{b}	1135 ^{b}	17.4 ^{b}	240 ^{b}	54.8 ^{b}	141 ^{b}	494 ^{b}
SEM	50	41	1.9	13.8	2.7	3.9	16.2
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001

Interactive effects were reported in Table 5.4.

*Mean values are averages (genotype main effects, n = 30; sex main effects, n = 30; diet main effects, n = 12)

^{a,b,c} Means within the same column without common letters are different (P < 0.05)

Table 5.4. Interactive effect of genotype, sex, and diet the chilled carcass weight without giblets (WOG), abdominal fat (fat pad) weight, and part weights for Rhode Island Reds (RIR) and broilers*

	Live weight, g	Chilled WOG weight, g	Fat pad weight, g	Boneless, skinless breast weight, g	Tender weight, g	Wing weight, g	Leg quarter weight, g
Genotype x Sex							
Broiler Female	2067 ^{a}	1565 ^{a}	24.4	434	84.8 ^{a}	159 ^{a}	617 ^{a}
Broiler Male	2073 ^{a}	1552 ^{a}	23.7	449	84.0 ^{a}	160 ^{a}	608 ^{a}
RIR Female	1328 ^{c}	886 ^{c}	26.8	146	40.2 ^{c}	123 ^{b}	402 ^{c}
RIR Male	1796 ^{b}	1199 ^{b}	24.9	185	49.3 ^{b}	167 ^{a}	564 ^{b}
SEM	44	37	1.7	12.4	2.4	3.5	15
P-value	<0.0001	<0.0001	0.7000	0.3385	0.0406	<0.0001	<0.0001
Genotype x diet							
Broiler Corn-Soy	2130 ^{a}	1641 ^{a}	24.5	484 ^{a}	92.9 ^{a}	166	628
Broiler Peas	2299 ^{a}	1760 ^{a}	27.9	521 ^{a}	96.0 ^{a}	175	683
Broiler Peas +SSF	2221 ^{a}	1725 ^{a}	29.2	506 ^{a}	90.3 ^{a}	170	668
Broiler Mix	1919 ^{b}	1386 ^{b}	21.7	370 ^{b}	75.3 ^{b}	148	558
Broiler Mix + SSF	1779 ^{bc}	1280 ^{bc}	17.0	327 ^{b}	67.5 ^{b}	140	525
RIR Corn-Soy	1605 ^{cde}	1071 ^{d}	31.3	167 ^{c}	45.3 ^{c}	148	497
RIR Peas	1577 ^{de}	1062 ^{d}	28.1	172 ^{c}	47.0 ^{c}	147	491
RIR Peas +SSF	1670 ^{cd}	1119 ^{cd}	33.8	182 ^{c}	47.1 ^{c}	152	518
RIR Mix	1467 ^{de}	970 ^{d}	18.2	155 ^{c}	42.5 ^{c}	138	448
RIR Mix + SSF	1489 ^{e}	989 ^{d}	17.8	152 ^{c}	42.0 ^{c}	143	462
SEM	70	58	2.6	20	3.8	5.6	23
P-value	0.0474	0.0058	0.3279	<0.0001	0.0088	0.0851	0.0810
Diet x sex	0.8064	0.8593	0.2364	0.6491	0.8292	0.8913	0.9679
Genotype x diet x sex	0.5604	0.6376	0.3356	0.8095	0.6732	0.5087	0.5430

Main effects were reported in Table 5.3

*Mean values are pen averages (genotype x sex interaction, n = 15; genotype x diet interaction, n = 6; diet x sex interaction, n = 6; genotype x sex x diet interaction, n = 3)

^{a,b,c} Mean values within the same column without common letters are different ($P < 0.05$)

Table 5.5. Main effects of genotype, sex, and diet on carcass, fat, and part yields for broilers and Rhode Island Reds*

	% of live weight		% of chilled carcass without giblets			
	Chilled carcass without giblets	Abdominal fat pad	Breasts (boneless, skinless)	Tenders	Wings	Leg quarters
Genotype main effects						
Broiler	74.8 [a]	1.15 [b]	27.9 [a]	5.39 [a]	10.4 [b]	39.5 [b]
Rhode Island Red	66.7 [b]	1.67 [a]	15.9 [b]	4.32 [b]	14.0 [a]	46.2 [a]
SEM	0.24	0.06	0.25	0.07	0.09	0.17
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sex main effects						
Female	70.8	1.58 [a]	21.8	4.95 [a]	12.1	42.6 [b]
Male	70.7	1.24 [b]	22.0	4.76 [b]	12.2	43.2 [a]
SEM	0.24	0.06	0.25	0.07	0.09	0.17
P-value	0.5658	0.0003	0.5538	0.0404	0.6506	0.0081
Diet main effects						
Corn-Soy	71.8 [a]	1.60 [a]	22.6 [a]	4.94	12.0 [b]	42.3 [b]
Peas	71.9 [a]	1.54 [a]	22.9 [a]	4.99	11.9 [b]	42.4 [b]
Peas +SSF	72.3 [a]	1.68 [a]	22.7 [a]	4.75	11.7 [b]	42.4 [b]
Mix	68.9 [b]	1.17 [b]	21.1 [b]	4.87	12.5 [a]	43.3 [a]
Mix + SSF	68.9 [b]	1.07 [b]	20.2 [b]	4.74	12.7 [a]	44.0 [a]
SEM	0.38	0.10	0.39	0.10	0.13	0.28
P-value	<0.0001	<0.0001	<0.0001	0.3257	<0.0001	<0.0001

Interactive effects are reported in Table 5.6.

*Mean values are averages (genotype main effects, n = 30; sex main effects, n = 30; diet main effects, n = 12)

[a,b,c] Mean values within the same column without common letters are different ($P < 0.05$)

Table 5.6. Interactive effect of genotype, sex, and diet on carcass, fat, and part yields for broilers and Rhode Island Reds (RIR) *

	% of live weight		% of chilled carcass without giblet			
	Chilled carcass without giblets	Abdominal fat pad	Breasts (boneless, skinless)	Tenders	Wings	Leg quarters
Genotype x Sex						
Broiler Female	75.0	1.18 ^{b}	27.2 ^{b}	5.37 ^{a}	10.3	39.7 ^{c}
Broiler Male	74.6	1.12 ^{b}	28.6 ^{a}	5.41 ^{a}	10.4	39.3 ^{c}
RIR Female	66.7	1.98 ^{a}	16.5 ^{c}	4.54 ^{b}	14.0	45.4 ^{b}
RIR Male	66.8	1.36 ^{b}	15.4 ^{d}	4.11 ^{c}	14.0	47.1 ^{a}
SEM	0.34	0.09	0.35	0.09	0.12	0.25
P-value	0.4267	0.0021	0.0005	0.0124	0.6904	<0.0001
Genotype x diet						
Broiler Corn-Soy	77.0 ^{a}	1.15 ^{b}	29.9 ^{a}	5.66	10.2	39.3 ^{c}
Broiler Peas	76.3 ^{a}	1.22 ^{b}	30.0 ^{a}	5.78	10.0	39.9 ^{c}
Broiler Peas +SSF	77.5 ^{a}	1.31 ^{b}	29.6 ^{a}	5.27	9.9	39.8 ^{c}
Broiler Mix	71.8 ^{b}	1.12 ^{b}	26.6 ^{b}	5.35	10.8	41.6 ^{b}
Broiler Mix + SSF	71.4 ^{b}	0.96 ^{b}	25.4 ^{b}	5.21	11.1	42.6 ^{b}
RIR Corn-Soy	66.7 ^{c}	2.04 ^{a}	15.8 ^{c}	4.23	13.9	48.1 ^{a}
RIR Peas	67.4 ^{c}	1.86 ^{a}	16.4 ^{c}	4.50	13.8	47.8 ^{a}
RIR Peas +SSF	67.0 ^{c}	2.05 ^{a}	16.4 ^{c}	4.24	13.6	48.0 ^{a}
RIR Mix	66.0 ^{c}	1.21 ^{b}	16.1 ^{c}	4.40	14.3	48.0 ^{a}
RIR Mix + SSF	66.4 ^{c}	1.18 ^{b}	15.4 ^{c}	4.27	14.5	48.5 ^{a}
SEM	0.54	0.14	0.56	0.15	0.19	0.43
P-value	<0.0001	0.0207	0.0006	0.4020	0.6900	0.0040
Diet x sex	0.9769	0.1150	0.3716	0.8597	0.2400	0.1258
Genotype x diet x sex	0.5347	0.0519	0.9363	0.4115	0.9280	0.8290

Main effects were reported in Table 5.5.

*Mean values are pen averages (genotype x sex interaction, n = 15; genotype x diet interaction, n = 6; diet x sex interaction, n = 6; genotype x sex x diet interaction, n = 3)

^{a,b,c} Means within the same column without common letters are different ($P < 0.05$)

Table 5.7. Effect of genotype and diet on live weight, chilled carcass weight without giblets (WOG), and abdominal fat (fat pad) weight for male Black Sex-Links, Rhode Island Red birds, and broilers*

		Live weight, g	Chilled WOG weight, g	Fat pad weight, g
Genotype main effects				
Broiler		2073 [a]	1552 [a]	23.7 [b]
Black Sex-Link (BSL)		1916 [b]	1296 [b]	33.7 [a]
Rhode Island Red (RIR)		1796 [c]	1199 [c]	24.9 [b]
SEM		35	27	2.6
P-value		<0.0001	<0.0001	0.0062
Diet main effects				
Corn-Soy		1988 [a]	1404 [a]	27.5 [abc]
Peas		1995 [a]	1415 [a]	29.6 [ab]
Peas +SSF		2049 [a]	1461 [a]	34.6 [a]
Mix		1867 [b]	1271 [b]	25.5 [bc]
Mix + SSF		1740 [c]	1194 [c]	20.0 [c]
SEM		43	33	3.2
P-value		<0.0001	<0.0001	0.0281
Interactive effects				
Genotype	Diet			
Broiler	Corn-Soy	2122	1619	23.2
Broiler	Peas	2193	1673	27.0
Broiler	Peas +SSF	2241	1741	30.4
Broiler	Mix	1978	1414	20.1
Broiler	Mix + SSF	1828	1315	18.0
BSL	Corn-Soy	2004	1361	33.1
BSL	Peas	1963	1342	38.0
BSL	Peas +SSF	1979	1353	37.3
BSL	Mix	1902	1256	34.5
BSL	Mix + SSF	1731	1169	25.8
RIR	Corn-Soy	1839	1231	26.2
RIR	Peas	1830	1231	23.7
RIR	Peas +SSF	1928	1290	36.3
RIR	Mix	1722	1144	22.0
RIR	Mix + SSF	1661	1099	16.2
SEM		77	60	5.8
P-value		0.8703	0.3458	0.9695

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)
Broilers were 42 days of age at processing, while Black Sex-Link and Rhode Island Reds were 96 days of age.
*Mean values are average of 2 birds per pen for broilers and Rhode Island Reds and 4 birds/pen for Black Sex-Links (genotype main effects, n = 15 for broilers and Rhode Island Reds and n = 10 for Black Sex-Links; diet main effects, n = 8; interactive effects, n = 3 for Rhode Island Reds and broilers and n = 2 for Black Sex-Links)

Table 5.8. Effect of genotype and diet on carcass part weights for male broilers, Black Sex-Links, Rhode Island Reds*

		Boneless, skinless breast weight, g	Tender weight, g	Wing weight, g	Leg quarter weight, g
Genotype main effects					
Broiler		449 [a]	84 [a]	160 [b]	608 [a]
Black Sex-Link (BSL)		201 [b]	56 [b]	180 [a]	613 [a]
Rhode Island Red (RIR)		185 [b]	49 [c]	167 [b]	564 [b]
SEM		8.9	1.8	3.0	12
P-value		<0.0001	<0.0001	<0.0001	0.0055
Diet main effects					
Corn-Soy		294 [a]	67 [a]	175 [a]	615 [a]
Peas		297 [a]	67 [a]	174 [a]	627 [a]
Peas +SSF		318 [a]	67 [a]	176 [a]	630 [a]
Mix		251 [b]	61 [b]	163 [b]	565 [b]
Mix + SSF		232 [b]	54 [c]	157 [b]	539 [b]
SEM		11.0	2.2	3.6	15
P-value		<0.0001	0.0001	0.0006	<0.0001
Interactive effects					
Genotype	Diet				
Broiler	Corn-Soy	487 [a]	90	169	624
Broiler	Peas	198 [a]	92	167	649
Broiler	Peas +SSF	532 [a]	91	169	661
Broiler	Mix	384 [b]	77	151	565
Broiler	Mix + SSF	345 [b]	71	147	540
BSL	Corn-Soy	216 [c]	59	187	640
BSL	Peas	201 [c]	58	184	649
BSL	Peas +SSF	216 [c]	59	187	625
BSL	Mix	188 [c]	56	177	600
BSL	Mix + SSF	183 [c]	49	164	554
RIR	Corn-Soy	180 [c]	51	170	582
RIR	Peas	191 [c]	51	171	582
RIR	Peas +SSF	207 [c]	52	174	604
RIR	Mix	182 [c]	49	162	531
RIR	Mix + SSF	167 [c]	44	161	522
SEM		20	4.0	6.6	26
P-value		0.0004	0.5203	0.9718	0.9084

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)
Broilers were 42 days of age at processing, while Black Sex-Link and Rhode Island Reds were 96 days of age.
*Mean values are average of 2 birds per pen for broilers and Rhode Island Reds and 4 birds/pen for Black Sex-Links (genotype main effects, n = 15 for broilers and Rhode Island Reds and n = 10 for Black Sex-Links; diet main effects, n = 8; interactive effects, n = 3 for Rhode Island Reds and broilers and n = 2 for Black Sex-Links)

Table 5.9. Effect of genotype and diet on carcass without giblets (WOG) yield and abdominal fat (fat pad) yield as a percentage of live weight for male broilers, Black Sex-Links, Rhode Island Reds*

		Chilled WOG	Fat Pad
Genotype main effects			
Broiler		74.6 [a]	1.12 [b]
Black Sex-Link (BSL)		67.6 [b]	1.73 [a]
Rhode Island Red (RIR)		66.8 [c]	1.36 [b]
SEM		0.28	0.12
P-value		<0.0001	0.0013
Diet main effects			
Corn-Soy		70.4 [a]	1.38
Peas		70.6 [a]	1.48
Peas +SSF		71.0 [a]	1.70
Mix		68.0 [b]	1.37
Mix + SSF		68.4 [b]	1.11
SEM		0.34	0.15
P-value		<0.0001	0.1121
Interactive effects			
Genotype	Diet		
Broiler	Corn-Soy	76.2 [a]	1.10
Broiler	Peas	76.1 [a]	1.23
Broiler	Peas +SSF	77.6 [a]	1.35
Broiler	Mix	71.4 [b]	1.01
Broiler	Mix + SSF	71.7 [b]	0.95
BSL	Corn-Soy	67.9 [cd]	1.64
BSL	Peas	68.4 [c]	1.90
BSL	Peas +SSF	68.4 [c]	1.88
BSL	Mix	66.0 [e]	1.83
BSL	Mix + SSF	67.5 [cde]	1.43
RIR	Corn-Soy	67.0 [cde]	1.41
RIR	Peas	67.3 [cde]	1.31
RIR	Peas +SSF	66.9 [cde]	1.87
RIR	Mix	66.5 [de]	1.28
RIR	Mix + SSF	66.1 [cde]	0.95
SEM		0.62	0.28
P-value		<0.0001	0.9663

[a,b,c,d,e] Means within the same column without common letters are different ($P < 0.05$)
Broilers were 42 days of age at processing, while Black Sex-Link and Rhode Island Reds were 96 days of age.
*Mean values are average of 2 birds per pen for broilers and Rhode Island Reds and 4 birds/pen for Black Sex-Links (genotype main effects, n = 15 for broilers and Rhode Island Reds and n = 10 for Black Sex-Links; diet main effects, n = 8; interactive effects, n = 3 for Rhode Island Reds and broilers and n = 2 for Black Sex-Links)

Table 5.10. Effect of genotype and diet on part yields as a percentage of the chilled carcass weight without giblets for male broilers, Black Sex-Links, Rhode Island Reds*

		Breasts (boneless, skinless)	Tenders	Wings	Leg quarters
Genotype main effects					
Broiler		28.6 ^{a}	5.41 ^{a}	10.4 ^{b}	39.3 ^{b}
Black Sex-Link (BSL)		15.5 ^{b}	4.33 ^{b}	13.9 ^{a}	47.3 ^{a}
Rhode Island Red (RIR)		15.4 ^{b}	4.11 ^{b}	14.0 ^{a}	47.1 ^{a}
SEM		0.29	0.09	0.11	0.27
P-value		<0.0001	<0.0001	<0.0001	<0.0001
Diet main effects					
Corn-Soy		20.1 ^{ab}	4.68	12.7 ^{bc}	44.3 ^{bc}
Peas		20.0 ^{ab}	4.63	12.5 ^{c}	44.8 ^{ab}
Peas +SSF		20.9 ^{a}	4.55	12.3 ^{c}	43.6 ^{c}
Mix		19.3 ^{bc}	4.71	13.0 ^{ab}	44.7 ^{ab}
Mix + SSF		18.8 ^{c}	4.50	13.3 ^{a}	45.4 ^{a}
SEM		0.35	0.11	0.13	0.34
P-value		0.0016	0.6374	<0.0001	0.0071
Interactive effects					
Genotype	Diet				
Broiler	Corn-Soy	30.0 ^{a}	5.56	10.4	38.6
Broiler	Peas	29.7 ^{a}	5.51	10.0	38.9
Broiler	Peas +SSF	30.5 ^{a}	5.24	9.7	38.0
Broiler	Mix	27.1 ^{b}	5.42	10.7	40.0
Broiler	Mix + SSF	25.9 ^{b}	5.33	11.3	41.3
BSL	Corn-Soy	15.8 ^{c}	4.33	13.7	47.0
BSL	Peas	15.0 ^{c}	4.29	13.7	48.3
BSL	Peas +SSF	16.0 ^{c}	4.36	13.8	46.1
BSL	Mix	14.9 ^{c}	4.42	14.1	47.8
BSL	Mix + SSF	15.6 ^{c}	4.23	14.1	47.3
RIR	Corn-Soy	14.6 ^{c}	4.17	13.8	47.2
RIR	Peas	15.5 ^{c}	4.10	13.8	47.3
RIR	Peas +SSF	16.1 ^{c}	4.05	13.4	46.8
RIR	Mix	15.9 ^{c}	4.29	14.2	46.4
RIR	Mix + SSF	15.0 ^{c}	3.95	14.6	47.5
SEM		0.65	0.20	0.24	0.61
P-value		0.0012	0.9862	0.2733	0.0706

^{a,b,c} Means within the same column without common letters are different ($P < 0.05$)
Broilers were 42 days of age at processing, while Black Sex-Link and Rhode Island Reds were 96 days of age.
*Mean values are average of 2 birds per pen for broilers and Rhode Island Reds and 4 birds/pen for Black Sex-Links (genotype main effects, n = 15 for broilers and Rhode Island Reds and n = 10 for Black Sex-Links; diet main effects, n = 8; interactive effects, n = 3 for Rhode Island Reds and broilers and n = 2 for Black Sex-Links)

Table 5.11. Effect of genotype and diet on breast meat color for broilers, Black Sex-Links, Rhode Island Reds*

	Lightness (L*)	Redness (a*)	Yellowness (b*)
Genotype main effects			
Broiler	60.3 ± 0.4	11.6 ± 0.3 [a]	12.6 ± 0.3
Black Sex-Link	61.8 ± 0.7	7.9 ± 0.5 [b]	13.5 ± 0.5
Rhode Island Red	62.1 ± 0.6	8.0 ± 0.4 [b]	12.9 ± 0.4
P-value	0.1255	<0.0001	0.3311
Diet main effects			
Corn-Soy	62.7	8.1	14.4 [a]
Peas	61.0	9.5	12.1 [b]
Peas +SSF	60.6	9.3	13.6 [ab]
Mix	61.7	9.3	12.3 [b]
Mix + SSF	60.9	9.5	12.5 [b]
SEM	0.7	0.5	0.5
P-value	0.2722	0.3468	0.0183

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)
No interactive effect of genotype x diet ($P > 0.05$)
Broilers were 42 days of age at processing, while Black Sex-Link and Rhode Island Reds were 96 days of age.
*Mean values are average of 1 breast per pen (genotype main effects, n = 15 for broilers and Rhode Island Reds and n = 10 for Black Sex-Links; diet main effects, n = 8; interactive effects, n = 3 for Rhode Island Reds and broilers and n = 2 for Black Sex-Links)

Table 5.12. Effect of tissue, genotype, and diet on thiobarbituric acid reactive substances (TBARS) of breast and thigh meat from broilers, Black Sex-Links, Rhode Island Reds*

	TBARS (mg MDA/kg meat)		
	Day 1	Day 4	Day 6
Tissue main effects			
Breast	0.041	0.102	0.161
Thigh	0.039	0.091	0.181
SEM	0.003	0.004	0.015
P-value	0.6016	0.0795	0.3339
Genotype main effects			
Broiler	0.025 [b]	0.071 [b]	0.113 [b]
Black Sex-Link	0.052 [a]	0.109 [a]	0.211 [a]
Rhode Island Red	0.043 [a]	0.112 [a]	0.190 [a]
SEM	0.004	0.005	0.016
P-value	<0.0001	<0.0001	<0.0001
Diet main effects			
Corn-Soy	0.033 [c]	0.084 [b]	0.157 [b]
Peas	0.030 [c]	0.085 [b]	0.122 [b]
Peas +SSF	0.027 [c]	0.078 [b]	0.131 [b]
Mix	0.063 [a]	0.120 [a]	0.277 [a]
Mix + SSF	0.048 [b]	0.118 [a]	0.181 [b]
SEM	0.005	0.007	0.023
P-value	<0.0001	<0.0001	<0.0001

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)
TBARS were higher ($P < 0.05$) on day 4 than day 1
TBARS were higher ($P < 0.05$) on day 6 than day 1 or day 4
No interactive effect between tissue, genotype, or diet were noted for any days ($P > 0.05$)
Broilers were 42 days of age at processing, while Black Sex-Link and Rhode Island Reds were 96 days of age.
*Mean values are average of 1 sample per pen (tissue main effect, n = 40; genotype main effects, n = 30 for broilers and Rhode Island Reds and n = 20 for Black Sex-Links; diet main effects, n = 16; interactive effects, n = 3 for Rhode Island Reds and broilers and n = 2 for Black Sex-Links)

Table 5.13. Effect of genotype and diet on the tibia and humerus breaking strength and ash content of broilers, Black Sex-Links, Rhode Island Reds*

	Tibia breaking strength, kg force	Tibia Ash, %	Humerus breaking strength, kg force	Humerus Ash, %
Genotype main effects				
Broiler	40.3 ± 1.2 [a]	51.8 ± 0.3 [b]	41.0 ± 1.2 [a]	57.3 ± 1.2
Black Sex-Link	32.2 ± 1.6 [b]	54.8 ± 0.3 [a]	28.9 ± 1.6 [b]	58.8 ± 1.3
Rhode Island Red	28.1 ± 1.2 [b]	54.4 ± 0.3 [a]	27.9 ± 1.2 [b]	59.4 ± 1.2
P-value	<0.0001	<0.0001	<0.0001	0.6153
Diet main effects				
Corn-Soy	37.4	55.7 [a]	36.1	57.1
Peas	32.0	53.8 [b]	34.5	59.8
Peas +SSF	30.5	53.7 [b]	32.6	60.5
Mix	34.0	52.8 [bc]	29.8	59.4
Mix + SSF	33.8	52.5 [c]	30.1	55.8
SEM	0.18	0.39	1.7	1.7
P-value	0.0845	<0.0001	0.0513	0.2574

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)

No interaction of genotype x diet ($P > 0.05$)

Broilers were 42 days of age at processing, while Black Sex-Link and Rhode Island Reds were 96 days of age.

*Mean values are average of 2 birds per pen (genotype main effects, n = 15 for broilers and Rhode Island Reds and n = 10 for Black Sex-Links; diet main effects, n = 8; interactive effects, n = 3 for Rhode Island Reds and broilers and n = 2 for Black Sex-Links)

CHAPTER 6: Use of sorghum and field peas to replace corn and soybean meal in diets for heritage chicken breeds

6.1 Abstract

This study evaluated the use of sorghum and field peas as replacements for corn and soybean meal (CSM) in diets for two heritage breeds: Rhode Island Red (RIR) and Barred Plymouth Rock (BPR). A 2 x 5 factorial arrangement of breeds and dietary treatments was used with the following diets: 1) a CSM-based control, 2) 100% of corn and 20 of soybean meal in CSM diet replaced with sorghum (SSM), 3) SSM diet with a dietary enzyme complex (Allzyme® SSF, Alltech Inc., Nicholasville, KY) added (SSM+), 4) complete replacement of CSM with a 2:1 ratio of field peas to sorghum (SFP), and 5) SFP diet with an enzyme complex added (SFP+). Replacement of soy limited dietary protein levels; therefore, CSM contained 20% CP, SSM/SSM+ contained 18.5% CP, and SFP/SFP+ contained 15.3% CP. Three replicate groups of 11 straight-run chicks per treatment were housed in floor pens with 0.2 square meters per bird. Diets and water were provided on an *ad libitum* basis and birds were grown to 98 days of age. Before analysis, average daily gain and feed intake values were corrected for the ratio of males:females in the pen. RIR birds exhibited higher ($P < 0.01$) average daily gain than BPR, and achieved a higher ($P < 0.05$) final body weight. Additionally, a breed x diet interaction was noted for average daily gain with RIR birds fed SSM diets being heavier ($P < 0.05$) than BPR birds fed those same diets. ADFI (70.5 ± 1.5 g/bird/d) and feed:gain (4.2 ± 0.1 g feed/g gain) were similar between the breeds. To account for differences in diet composition, dietary effects were analyzed on a nutrient intake to gain basis. Birds fed CSM had better ($P < 0.05$) feed:gain than birds fed SSM or SSM+ (3.3 vs 4.0 g feed/g gain), and all three had better feed:gain than birds fed SFP or SFP+ (4.8 g feed/g gain, SEM = 0.2; $P < 0.01$). At 98 days of age, two male birds per pen were processed and the carcasses were chilled for at least two hours. The chilled carcass without giblets (WOG) yields averaged 64.7 ± 0.5% of live weight and were similar ($P > 0.05$) among breeds and diets. As a percentage of chilled WOG weight, there were no differences ($P > 0.05$) in relative parts weights. Breast meat of RIR birds was yellower ($P < 0.05$) than BPR breast meat, but there was no difference ($P > 0.05$) between breeds for lightness or

redness. A dietary effect was also noted. As corn and soybean meal were reduced in the diet, lightness and yellowness of the breast meat decreased ($P < 0.05$) while redness increased ($P < 0.05$). In conclusion, the use of sorghum and field peas with or without a dietary enzyme complex to replace corn and soybean meal may impair growth performance and alter breast meat color of heritage breeds, but it does not affect their carcass or part yields. Additionally, the breed x diet interaction for growth performance indicates a possible difference in dietary requirements between breeds.

6.2 Introduction

Growing interest in small flocks, urban poultry, and general alternatives to conventional chicken has led to an increase in interest in heritage breed chickens. Unfortunately, there is very little published data regarding the production parameters of these breeds. While the nutrient requirements of heritage breed chickens are not known, the results of previous experiments suggest that they are lower than those of commercial broilers. This suggests the potential for the utilization of less common feedstuffs that may be lower in nutrient density than the typical corn- and soy- based diets.

In a previous study (Chapter 5), Rhode Island Reds and commercial broilers were able to consume at least 30% field peas in place of corn and soybean meal in their diets without a corresponding reduction in growth rate or feed intake. Additionally, while the carcass and breast yields of Rhode Island Reds were lower than those of commercial broilers, they were also less affected by the use of alternative feed ingredients. Therefore, this experiment aims to take a step further and completely replace corn and soybean meal with alternative ingredients. Field peas contain anywhere from 20-29% crude protein which makes them suitable as a potential protein-energy source. While this is significantly lower crude protein than is found in soybean meal, the use of a higher protein grain than corn may offset the reduction. Sorghum has been shown to have similar energy value to corn, but it has a higher protein content which may make it a suitable complement to field peas.

The objective of this study was to evaluate the growth performance, carcass yield, bone strength, and meat color of Rhode Island Reds and Barred Plymouth Rocks fed complete diets formulated using alternative feed ingredients (sorghum and field peas) to replace corn and soybean meal.

6.3 Materials and methods

Experiments were conducted at the Alltech-University of Kentucky Research Alliance Poultry Farm. All procedures for this study were conducted under protocols approved by the University of Kentucky Institutional Animal Care and Use Committee (IACUC). This trial was conducted from July 2014 through October 2014.

6.3.1 Animals and dietary treatments

The ten experimental treatments utilized a 2 x 5 factorial arrangement which consisted of 2 breeds and 5 diets. The breeds utilized were Rhode Island Red and Barred Plymouth Rock. The diets utilized were: 1) a corn- and soybean meal-based control (CSM), 2) 100% of corn and 20% of soybean meal in CSM diet replaced with sorghum (SSM), 3) SSM diet with a dietary enzyme complex (Allzyme® SSF, Alltech Inc. Nicholasville, KY) added (SSM+SSF), 4) complete replacement of CSM with a 2:1 ratio of field peas to sorghum (SFP), and 5) SFP diet with an enzyme complex added (SFP+SSF). Field peas contained only 20.5% crude protein compared with the 49.9% crude protein content of the soybean meal utilized. Therefore, replacement of soybean meal limited the dietary protein levels that could be achieved; resulting in the CSM-based diet containing 20% CP, the SSM and SSM+SSF diets containing 18.5% CP, and SFP and SFP+SSF diets containing 15.3% CP. The diet formulation and analyzed nutrient content of the diets are reported in Table 6.1.

Chicks were produced from the University of Kentucky's breeder flocks. For each breed and diet combination, three replicate groups of 11 straight-run chicks were placed. Chicks were housed in floor pens bedded with dried pine shavings. The floor pen dimensions were 1.22 x 1.83 meters which provided 0.20 square meters of space to each bird. Birds were brooded at 29.4°C for two weeks with temperature reduced incrementally until reaching ambient outdoor temperatures. The average temperature experienced was 22.8°C. The lighting program provided 22 hours of light per day throughout the experiment. Feed was provided on an *ad libitum* basis in a hanging tube feeder. Water was provided on an *ad libitum* basis via a nipple drinking system with three nipples per pen. Birds were raised to 98 days of age.

6.3.2 Growth performance measurements

Chicks were weighed at the time of placement (1 day of age) and then weekly through processing at 98 days of age. Average daily gain was calculated on a pen basis. Feed intake was recorded weekly on a pen basis. The feed conversion ratio was calculated as grams of feed consumed per gram of gain. At the conclusion of the experiment, the number of males and females in each pen was counted and the ratio of males to females was used to adjust gain and feed data. Daily mortality was monitored and accounted for in gain and feed intake calculations.

6.3.3 Carcass yield and sample collection

Birds were processed at 98 days of age. At processing, two male birds per pen were euthanized via electrical stunning followed by exsanguination in accordance with University of Kentucky IACUC approved procedures. After euthanasia, birds were immersed in hot water bath and then de-feathered using a semi-automated chicken plucker. The digestive tract, giblets (heart, liver, gizzard, and neck), lungs, feet, and shanks were removed. Abdominal fat (fat pad) weights were recorded (expressed as a percentage of live weight). Following a 3-hour chill, the chilled carcass weight without giblets (WOG) was recorded (expressed as a percentage of live weight) and then breast filets (*pectoralis major* – deboned, skinless), breast tenders (*pectoralis minor*), wings, and leg quarters were removed from each carcass and weighed to determine part yields. Breast filets were retained and stored on ice for color score analysis.

6.3.4 Breast filet color score analysis

Breast filet color was measured objectively for the Commission Internationale de l'Eclairage (CIE) values of lightness (L*), redness (a*), and yellowness (b*) using CR-310 Chroma Meter (Minolta Co, Ltd., Osaka, Japan) calibrated against a white tile. Color measurements were measured in duplicate on the ventral surface of each breast filet.

6.3.5 Bone quality analysis

At 98 days of age, two birds per pen were randomly selected and euthanized by argon gas asphyxiation followed by cervical dislocation. Left tibae and humeri were collected and pooled by pen for breaking strength analysis via Instron Testing Instrument (Model 4301). Excess soft tissue was removed from the bone shaft prior to analysis of breaking strength. Bones were placed flat on a raised platform where a stainless steel wedge probe aligned perpendicular to the center of the bone shafts applied 100 kilograms force at a speed of 40 millimeters per second until the bones fractured. Right tibae and humeri were collected and pooled by pen for percent ash analysis. Bones were defrosted overnight, then boiled in deionized water for 15 minutes to remove flesh and dried at 105°C for a minimum of 12 hours. Bones were then de-fatted in changes of petroleum ether until petroleum ether solution appeared to be free of fat residues. De-fatted bones were dried overnight at 105°C in a forced air oven and then ashed at 600°C for 6 hours in a muffler furnace. Ash percent was calculated on a dry matter basis.

6.3.6 Statistical analysis

Analysis of variance for a 2 x 5 factorial arrangement of treatments was conducted using the general linear model procedures of SAS® (SAS v. 9.3, Cary, NC). This analysis allowed for the determination of the main effect of breed, the main effect of dietary treatment, and the interactive effects of breed and dietary treatment. Fisher's least significant difference test was used to determine significant differences between means with a significance set at $P < 0.05$.

6.4 Results

6.4.1 Average body weight

Average body weights at 1 and 98 days of age are reported in Table 6.2. At placement, initial body weight of chicks average 37.8 ± 0.3 grams and was similar ($P > 0.05$) between breeds and among dietary treatments. However, final body weights at 98 days of age differed ($P < 0.01$) between breeds and among diets. Rhode Island Red birds were heavier than Barred Plymouth Rock birds (1624 vs 1518 grams, SEM = 21, $P < 0.05$). Birds fed CSM and SSM+SSF were heavier ($P < 0.05$) than birds fed SFP or

SFP+SSF. No breed x diet interaction ($P > 0.05$) was noted for initial or final body weights.

6.4.2 Growth performance

Growth performance data was normalized using the ratio of males to females in the pen because birds were raised straight-run and reported in Table 6.3.

6.4.2.1 Average daily gain

Average daily gain from 1 to 98 days of age differed by breed and diet. Rhode Island Red birds exhibited higher average daily gain than Barred Plymouth Rock birds (17.7 vs 16.5 grams/bird/day, SEM = 0.2, $P < 0.01$). A main effect of diet was noted. Birds fed the SSM-based diet were lighter ($P < 0.05$) than birds fed the CSM-based diet, but both were heavier ($P < 0.05$) than birds fed the SFP-based diet. However, the addition of dietary enzyme partially alleviated the reduction in average daily gain for birds on the SSM-based diet. An additional interaction of breed on diet was noted for average daily gain ($P < 0.05$). For Barred Plymouth Rocks, birds fed the CSM-based diet exhibited higher ($P < 0.05$) average daily gain than all of the other diets. On the other hand, Rhode Island Red birds fed SSM and SSM+SSF exhibited similar ($P > 0.05$) average daily gain to birds fed CSM, and birds on all three diets had higher ($P < 0.05$) average daily gain than birds fed SFP and SFP+SSF.

6.4.2.2 Average daily feed intake

Average daily feed intake from 1 to 98 days of age was similar between breeds (70.5 ± 1.5 grams/bird/day; $P > 0.05$), but differed among diets. Birds fed the CSM-based diet exhibited lower average daily feed intake (60.9 grams/bird/day) than birds fed SSM with or without SSF (69.3 grams/bird/day). The highest average daily feed intake was exhibited by birds fed SFP-based diets with or without SSF (76.7 grams/bird/day, SEM = 2.4; $P < 0.01$). No interaction of breed and diet was noted for average daily feed intake ($P > 0.05$).

6.4.2.3 Feed to gain

Barred Plymouth Rock birds exhibited poorer feed to gain than Rhode Island Red birds (4.38 vs 3.99 grams feed/grams gain, SEM = 0.12, $P < 0.05$). A main effect of diet was also noted. Birds fed CSM-based diets had better feed to gain (3.32 grams feed/gram gain) than birds fed SSM or SSM+SSF (4.04 grams feed/gram gain). Birds fed SFP or SFP+SSF had the poorest feed to gain (4.78 grams feed/gram gain, SEM = 0.18; $P < 0.0001$). While there were dietary differences in average daily gain, the effect of diet on feed to gain reflected the increased ADFI of these diets. No breed x diet interaction were noted for feed to gain ratio ($P > 0.05$).

6.4.3 Carcass characteristics

6.4.3.1 Live weight of processed birds

The two male birds selected for processing were within 10% of the average individual body weight for the males in their respective pens (Table 6.4). The live weight of the processed birds did not differ between the two breeds, but there were differences among live weights for the birds processed from each diet. For the birds selected for processing, the live weight of birds fed CSM was similar ($P > 0.05$) to those fed SSM or SSM+SSF (2017 grams). However, birds fed CSM were heavier than birds fed SFP or SFP+SSF (2088 vs. 1860 grams, $P < 0.01$).

6.4.3.2 Chilled carcass weight without giblets (WOG)

The average chilled carcass weight without giblets (WOG) were reported in Table 6.4. Chilled WOG weight followed a similar pattern to the live weight with no difference ($P > 0.05$) between breeds, but a main effect of diet. Birds fed the SFP diet had lighter ($P < 0.01$) chilled WOG weights than birds fed the CSM diet or the SSM+SSF diet with the chilled WOG weights for birds fed the SSM diet being intermediate. However, when expressed as a percentage of the live weight (Table 6.5), no differences were noted between breeds or among diets for either WOG (61.9 ± 0.3%, $P > 0.05$) or chilled WOG (64.7 ± 0.5%, $P > 0.05$).

6.4.3.3 Abdominal fat (fat pad)

The average weight of the abdominal fat (fat pad) for each treatment was reported in Table 6.4, and fat pad yield as a percentage of the live weight was reported in Table 6.5. There was no difference ($P > 0.05$) in fat pad weight or yields as a percentage of the live weight between breeds or among diets. While there was an interactive effect of breed x diet ($P < 0.05$) for both fat pad weight and yield, no clear pattern could be discerned.

6.4.3.4 *Cut-up part weights and yields*

As reported in Table 6.6, there were no differences (P > 0.05) on a weight basis between breeds for deboned skinless breast filets, tenders, wings, or leg quarters. However, there were differences (P < 0.05) in the weights of these parts among diets. These differences tended to follow the same trend as the differences in live weight. Therefore, the part weights were expressed as a percentage of the chilled WOG and reported in Table 6.7. When expressed as a percentage of the chilled WOG, there were no differences (P > 0.05) in deboned skinless breast filet yield (11.4 ± 0.2%), tender yield (4.7 ± 0.1%), wing yield (14.1 ± 0.2%), or leg quarter yield (49.1 ± 0.4%). No interactive effect of breed on diet was noted on either a weight- or yield-basis ($P > 0.05$).

6.4.4 Breast meat color

As reported in Table 6.8, there were significant treatment effects on the lightness (L*), redness (a*), and yellowness (b*) of breast meat. The breast meat of Rhode Island Red birds was yellower than the Barred Plymouth Rock breast meat (2.82 vs. 1.92, SEM = 0.14; P < 0.0001), but there was no difference (P > 0.05) between breeds for lightness or redness. A dietary effect was also noted – as corn and soybean meal were reduced in the diet, lightness and yellowness of the breast meat decreased while redness increased (P < 0.0001). No breed x diet interactions were observed ($P > 0.05$).

6.4.5 Bone quality

Bone breaking strength and ash content for humerus and tibia were reported in Table 6.9. The average breaking strength for tibae was 23.3 ± 0.7 kg force with no effect (P > 0.05) of breed or diet. The average breaking strength for humeri differed (P < 0.05) between breeds and among diets. Rhode Island Red birds had higher humerus breaking strength than Barred Plymouth Rock birds (20.7 vs 19.1, SEM = 0.5; P < 0.05). Birds fed CSM-based diets exhibited higher (P < 0.01) humerus breaking strength than birds fed SFP with or without SSF, with birds fed SSM and SSM+SSF intermediate. However, there was no effect (P > 0.05) of breed or diet for tibia or humerus bone ash content.

Tibia ash averaged 58.5 ± 0.4% and humerus ash averaged 61.0 ± 0.4%. Therefore, the difference in strength is not a simple reflection of mineral content.

6.5 Discussion

Poultry diets in the United Sates typically utilize corn as the main energy source and soybean meal as the main protein source. However, there is increasing interest in the use of alternative feedstuffs, particularly in organic production where the use of genetically modified organisms (GMO) is not permitted (USDA 2012a; USDA 2012b). With more than 90% of the corn and soybean crops in the United States coming from GMO varieties, organic varieties demand a premium price which can be prohibitive for producers of small- and medium-size flocks. The use of alternative feedstuffs to partially or completely replace corn and soybean meal may reduce feed costs. It also provides a way for their producers to differentiate their products from conventional chicken meat or eggs. Unfortunately, formulating balanced diets using alternative feedstuffs can be challenging depending on the nutrients available in the feedstuff.

Therefore, this study was conducted to evaluate the growth performance, carcass yield, bone strength, and meat color of Rhode Island Reds and Barred Plymouth Rocks fed complete diets formulated using alternative feed ingredients to replace corn and soybean meal. The alternative feedstuffs evaluated in this study were field peas and sorghum. Field peas were selected as the primary alternative feedstuff because peas are relatively high in protein at 20-29% crude protein. While high inclusion levels of field peas can reduce bird performance (Farrell et al., 1999; Tuunainen et al., 2016), Nalle et al. (2011) found that broilers fed diets containing as much as 20% field peas had similar growth performance as broilers fed a corn-soy control. Based on their experiments, Farrell et al. (1999) suggested field peas inclusion be limited to 30% of the diet for broilers. Additionally, the results of Chapter 5 indicated field peas can be used to replace 30% of the corn and soybean meal in a diet with no effect on growth performance, or carcass and part yields. Sorghum was selected because it has similar digestible energy as corn, but more crude protein. Some studies have shown that sorghum-based diets had no effect on feed intake, but decreased growth performance when compared with corn-based diets (Batonon-Alavo et al., 2015). However, sorghum-based diets supplemented with enzymes showed no negative effects, suggesting the combination is a viable strategy to improve the nutritional value of the diets and performance results (Leite et al., 2012)

Based on the results of the study described in Chapter 3, Rhode Island Reds and Barred Plymouth Rocks were expected to demonstrate similar growth performance to one another. However, some differences between the two breeds were noted in the present study. While Rhode Island Reds and Barred Plymouth Rocks exhibited similar average daily feed intakes during the present study, the Rhode Island Reds exhibited higher average daily gain and therefore better feed efficiency than the Barred Plymouth Rocks. One reason for this discrepancy is the breed x diet interaction noted for average daily gain. Both breeds had lower average daily gain when fed the SFP and SFP+SSF diets. However, for the Barred Plymouth Rocks, birds fed the SSM and SSM+SSF diets also had lower average daily gain than birds fed the CSM-based diet. On the other hand, Rhode Island Reds fed the SSM and SSM+SSF diets maintained growth performance at a level similar to that of birds on the CSM-based diet. This suggests that Rhode Island Reds were somehow better equipped to adapt to the sorghum-soy-based diet than Barred Plymouth Rocks were.

As expected based on the results of the study described in Chapter 4, Rhode Island Reds and Barred Plymouth Rocks had similar carcass and part yields. However, there were some differences noted among the dietary treatments. Birds fed the SSM or SSM+SSF diets demonstrated similar live weights, similar carcass and part weights, and similar carcass and part yields when compared with birds fed the CSM-based diet. This suggests that sorghum is a viable replacement for corn in diets for heritage breeds even when it reduces the crude protein level of the diet. However, reducing the level at which corn is included in the diet reduced yellowness of the breast meat. Because consumers rely primarily on color when they initially evaluate meat (Kennedy et al., 2005), this difference in color may impact consumer perception of the product. Whether this impact is positive or negative would depend on the consumer's knowledge and experience.

On the other hand, the birds fed the SFP or SFP+SSF diets had lower live weights at 98 days of age than birds fed the CSM-based diets. Birds fed the SFP or SFP+SSF diets also exhibited lower carcass and part weights than CSM-fed birds, the chilled WOG yield (as a percentage of the live weight) and the part weights (as a percentage of the chilled WOG weight) were similar among the dietary treatments. Therefore, the lower nutrient density of the SFP and SFP+SSF diets does not seem to have altered body conformation. Based on these results, sorghum and field peas can be used to completely replace corn and soybean meal in diets for heritage breeds if the producer is willing to grow the birds longer and provide more feed. However, the effect on meat color is also something to consider with these diets because feeding the SFP and SFP+SSF diets resulted in darker breast meat that was more red and less yellow than the meat of birds fed the CSM-based diet.

6.6 Conclusions

The results of this study suggest that sorghum can be used with a dietary enzyme complex to completely replace corn and partially replace soybean meal in diets for heritage breeds without sacrificing average daily gain or carcass yields. However, this replacement may increase feed intake, reduce feed conversion, and alter breast meat color. Completely replacing corn and soybean meal with a combination of sorghum and field peas depressed growth, increased feed intake, and worsened feed conversion when compared with both the CSM- and SSM-based diets. In both cases, it is worth noting that supplemental amino acids were provided to fortify the diets. Data from previous studies and the literature suggest that heritage breeds have lower nutrient requirements than fast-growing meat-type birds, so this fortification may not be necessary. However, additional trials are needed to determine the optimal nutrient levels for heritage breeds. Furthermore, the breed x diet interaction observed for growth performance indicates a possible difference in dietary requirements between breeds which could warrant further investigation. Additionally, further research is needed to determine how these alternative ingredients affect meat quality parameters (flavor, texture, water holding capacity, and oxidative stability) of heritage breeds.

6.7 Tables

Table 6.1. Diet composition and analyzed nutrient content of a corn-soybean meal based diet (CSM), and sorghum-soy-based diets (SSM) or sorghum-field peas-based diets (SFP) with or without dietary enzyme (SSF).

	CSM	SSM	SSM + SSF	SFP	SFP +SSF
Corn, %	64.1	-	-	-	-
Soybean meal, %	30.7	24.7	24.7	-	-
Sorghum, %	-	70.6	70.6	32.4	32.4
Field peas, %	-	-	-	60.2	60.2
Vegetable oil, %	1.13	0.55	0.55	3.10	3.10
Limestone, %	1.33	1.37	1.37	1.37	1.37
Dicalcium phosphate, %	1.82	1.75	1.75	1.81	1.81
Salt, %	0.42	0.38	0.38	0.38	0.38
Vitamin-mineral premix [1], %	0.25	0.25	0.25	0.25	0.25
DL-Methionine, %	0.17	0.23	0.23	0.40	0.40
Threonine, %	0.11	0.17	0.17	0.08	0.08
Tryptophan, %	-	-	-	0.10	0.10
Enzyme complex [2], %	-	-	0.02	-	0.02
Integral® [3], %	0.10	0.10	0.10	0.10	0.10
Energy, kcal ME/kg (calculated)	3000	3000	3000	2900	2900
Crude protein, %	20.32	18.74	18.19	15.34	15.28
Methionine, %	0.49	0.39	0.37	0.48	0.47
Cysteine, %	0.31	0.26	0.23	0.22	0.21
Lysine, %	1.12	0.87	0.80	1.07	1.04
Crude fat, %	3.49	2.47	2.53	4.29	4.27
Crude fiber, %	3.34	3.17	3.23	5.05	4.66
Calcium	0.98	0.96	0.97	1.02	0.81
Phosphorus, total	0.74	0.67	0.69	0.61	0.54

[1] Akey Layer Starter Breeder Premix (Akey, Lewisburg, OH)
[2] Allzyme-SSF® (Alltech Inc., Nicholasville, KY)
[3] Integral® (Alltech Inc., Nicholasville, KY)

Table 6.2. Effect of breed and diet on body weights at 1 and 98 days of age for straight-run Rhode Island Reds and Barred Plymouth Rocks*

		Average body weight at 1 day of age (grams)	Average body weight at 98 days of age (grams)
Breed main effects			
Barred Plymouth Rock (BPR)		37.3	1518 [b]
Rhode Island Red (RIR)		37.9	1624 [a]
SEM		0.3	21
P-value		0.1797	0.0070
Diet main effects			
CSM		37.9	1678 [a]
SSM		37.6	1594 [ab]
SSM +SSF		37.3	1658 [a]
SFP		37.7	1437 [c]
SFP + SSF		37.5	1489 [bc]
SEM		0.4	33
P-value		0.9314	0.0032
Interactive effects			
Breed	Diet		
BPR	CSM	37.6	1707
BPR	SSM	37.7	1485
BPR	SSM +SSF	36.8	1537
BPR	SFP	37.1	1417
BPR	SFP + SSF	37.2	1446
RIR	CSM	38.2	1650
RIR	SSM	37.4	1703
RIR	SSM +SSF	37.9	1779
RIR	SFP	38.2	1458
RIR	SFP + SSF	37.7	1532
SEM		0.6	47
P-value		0.8110	0.0588

*Mean values are pen averages (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)

CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets

+SSF = enzyme complex added to the diet

Table 6.3. Effect of breed and diet on average daily gain, average daily feed intake, and feed to gain from 1 to 98 days of age (corrected for male:female ratio within pen) for straight-run Rhode Island Reds and Barred Plymouth Rocks*

		Average daily gain (gram/bird/day)	Average daily feed intake (gram/bird/day)	Feed to Gain (grams of feed per gram gain)
Breed main effects				
Barred Plymouth Rock (BPR)		16.5 [b]	71.3	4.38 [a]
Rhode Island Red (RIR)		17.7 [a]	69.9	3.99 [b]
SEM		0.24	1.5	0.12
P-value		0.0020	0.5137	0.0279
Diet main effects				
CSM		18.4 [a]	60.9 [c]	3.32 [c]
SSM		17.2 [b]	69.8 [b]	4.13 [b]
SSM +SSF		17.6 [ab]	68.8 [b]	3.94 [b]
SFP		15.9 [c]	75.5 [a]	4.75 [a]
SFP + SSF		16.3 [c]	77.9 [a]	4.80 [a]
SEM		0.34	2.43	0.18
P-value		0.0005	0.0011	<0.0001
Interactive effects				
Breed	Diet			
BPR	CSM	18.6 [a]	60.5	3.25
BPR	SSM	16.1 [b]	73.3	4.62
BPR	SSM +SSF	16.2 [b]	70.1	4.32
BPR	SFP	15.5 [b]	76.4	4.92
BPR	SFP + SSF	15.9 [b]	76.3	4.81
RIR	CSM	18.1 [a]	61.3	3.38
RIR	SSM	18.3 [a]	66.4	3.64
RIR	SSM +SSF	19.0 [a]	67.6	3.55
RIR	SFP	16.3 [b]	74.5	4.58
RIR	SFP + SSF	16.6 [b]	79.5	4.80
SEM		0.48	3.44	0.26
P-value		0.0242	0.6619	0.1992

*Mean values represent pen averages corrected for male:female ratio within the pen (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)
[a,b,c] Means within the same column without common letters are different ($P < 0.05$)
CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets
+SSF = enzyme complex added to the diet

Table 6.4. Effect of breed and diet on live weight, chilled carcass weight without giblets (WOG), and abdominal fat (fat pad) weight for Barred Plymouth Rocks and Rhode Island Reds at 98 days of age

		Live weight, g	Chilled WOG weight, g	Fat pad weight, g
Breed main effects				
Barred Plymouth Rock (BPR)		1960	1279	35.8
Rhode Island Red (RIR)		1976	1268	39.0
SEM		32	23	3.3
P-value		0.718	0.7196	0.4901
Diet main effects				
CSM		2088 [a]	1371 [a]	46.5
SSM		1971 [ab]	1276 [ab]	29.3
SSM +SSF		2062 [a]	1335 [a]	44.0
SFP		1833 [b]	1188 [b]	29.5
SFP + SSF		1887 [b]	1198 [b]	37.6
SEM		50	36	5.1
P-value		0.0024	0.0016	0.0619
Interactive effects				
Breed	Diet			
BPR	CSM	2112	1400	48.5 [ab]
BPR	SSM	1913	1247	22.0 [c]
BPR	SSM +SSF	2037	1333	31.3 [bc]
BPR	SFP	1859	1224	30.3 [bc]
BPR	SFP + SSF	1879	1195	46.7 [ab]
RIR	CSM	2063	1342	44.5 [ab]
RIR	SSM	2029	1306	36.5 [abc]
RIR	SSM +SSF	2087	1338	56.7 [a]
RIR	SFP	1808	1152	28.7 [bc]
RIR	SFP + SSF	1894	1202	28.5 [bc]
SEM		70	50	7.3
P-value		0.7351	0.7002	0.0406

Mean values are averages of two birds per pen (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)

[a,b,c] Means within the same column without common letters are different (P < 0.05)

CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets

+SSF = enzyme complex added to the diet

Table 6.5. Effect of breed and diet on chilled carcass yield without giblets (WOG), and abdominal fat (fat pad) yield as a percentage of live weight for Barred Plymouth Rocks and Rhode Island Reds at 98 days of age

		% of live weight	
		Chilled WOG yield	Fat pad yield
Breed main effects			
Barred Plymouth Rock (BPR)		65.31	1.79
Rhode Island Red (RIR)		64.07	1.95
SEM		0.47	0.15
P-value		0.0771	0.4500
Diet main effects			
CSM		65.61	2.24
SSM		64.70	1.43
SSM +SSF		62.72	2.11
SFP		64.96	1.6
SFP + SSF		63.44	1.97
SEM		0.75	0.24
P-value		0.4146	0.1075
Interactive effects			
Breed	Diet		
BPR	CSM	66.26	2.30 [abc]
BPR	SSM	65.14	1.06 [d]
BPR	SSM +SSF	65.39	1.48 [cd]
BPR	SFP	66.20	1.63 [bcd]
BPR	SFP + SSF	63.55	2.46 [ab]
RIR	CSM	64.96	2.17 [abc]
RIR	SSM	64.26	1.80 [abcd]
RIR	SSM +SSF	64.06	2.73 [a]
RIR	SFP	63.72	1.58 [bcd]
RIR	SFP + SSF	63.33	1.47 [cd]
SEM		1.05	0.34
P-value		0.8455	0.0198

Mean values are averages of two birds per pen (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)
[a,b,c] Means within the same column without common letters are different ($P < 0.05$)
CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets
+SSF = enzyme complex added to the diet

Table 6.6. Effect of breed and diet on average part weights for Barred Plymouth Rocks (BPR) and Rhode Island Reds (RIR) at 98 days of age

		Boneless, skinless breast weight, g	Tender weight, g	Wing weight, g	Leg quarter weight, g
Breed main effects					
BPR		148	60.5	179	627
RIR		142	58.8	178	623
SEM		3.7	1.4	2.9	12.2
P-value		0.2244	0.3807	0.9219	0.7976
Diet main effects					
CSM		159 [a]	65.8 [a]	187 [a]	673 [a]
SSM		149 [ab]	61.8 [a]	180 [ab]	619 [ab]
SSM +SSF		148 [ab]	62.7 [a]	186 [a]	660 [a]
SFP		134 [b]	53.8 [b]	167 [b]	592 [b]
SFP + SSF		135 [b]	54.3 [b]	173 [b]	581 [b]
SEM		5.8	2.2	4.5	19.2
P-value		0.0206	0.0008	0.0135	0.0035
Interactive effects					
Breed	Diet				
BPR	CSM	164	67.7	189	680
BPR	SSM	148	58.8	176	603
BPR	SSM +SSF	153	65.2	191	655
BPR	SFP	139	55.8	171	614
BPR	SFP + SSF	137	55.2	168	584
RIR	CSM	153	63.8	184	667
RIR	SSM	150	64.7	184	635
RIR	SSM +SSF	143	60.2	182	664
RIR	SFP	129	51.7	164	569
RIR	SFP + SSF	133	53.5	178	577
SEM		8.2	3.20	6.40	27.2
P-value		0.9271	0.4266	0.3912	0.7090

Mean values are averages of two birds per pen (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)

CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets

+SSF = enzyme complex added to the diet

Table 6.7. Effect of breed and diet on part yields as a percentage of live weight for Barred Plymouth Rocks (BPR) and Rhode Island Reds (RIR) at 98 days of age

		% of live weight			
		Boneless, skinless breast yield	Tender yield	Wing yield	Leg quarter yield
Breed main effects					
BPR		11.57	4.74	14.02	49.01
RIR		11.13	4.62	14.12	49.12
SEM		0.16	0.08	0.16	0.36
P-value		0.0522	0.2600	0.6508	0.8578
Diet main effects					
CSM		11.55	4.80	13.65	49.17
SSM		11.65	4.87	14.16	48.47
SSM +SSF		11.06	4.68	13.97	49.47
SFP		11.25	4.51	14.13	49.75
SFP + SSF		11.23	4.52	14.45	48.47
SEM		0.25	0.12	0.26	0.57
P-value		0.4293	0.1390	0.2782	0.3967
Interactive effects					
Breed	Diet				
BPR	CSM	11.71	4.85	13.54	48.65
BPR	SSM	11.88	4.78	14.18	48.27
BPR	SSM +SSF	11.45	4.89	14.37	49.22
BPR	SFP	11.36	4.57	13.97	50.11
BPR	SFP + SSF	11.45	4.61	14.05	48.82
RIR	CSM	11.39	4.76	13.76	49.68
RIR	SSM	11.43	4.96	14.15	48.67
RIR	SSM +SSF	10.66	4.48	13.56	49.72
RIR	SFP	11.15	4.46	14.28	49.40
RIR	SFP + SSF	11.02	4.43	14.86	48.12
SEM		0.35	0.17	0.36	0.81
P-value		0.9433	0.5383	0.2686	0.7644

Mean values are averages of two birds per pen (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)

CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets; +SSF = enzyme complex added to the diet

Table 6.8. Effect of breed and diet on breast meat color of Rhode Island Reds (RIR) and Barred Plymouth Rocks (BPR) at 98 days of age

		Lightness (L*)	Redness (a*)	Yellowness (b*)
Breed main effects				
BPR		59.62	9.74	1.92 [b]
RIR		60.02	9.61	2.82 [a]
SEM		0.31	0.16	0.14
P-value		0.3593	0.5625	<0.0001
Diet main effects				
CSM		62.71 [a]	8.30 [b]	4.96 [a]
SSM		62.71 [a]	8.88 [b]	1.55 [c]
SSM +SSF		62.19 [a]	8.96 [b]	1.25 [c]
SFP		56.52 [b]	11.10 [a]	2.36 [b]
SFP + SSF		54.97 [c]	11.14 [a]	1.72 [c]
SEM		0.49	0.25	0.22
P-value		<0.0001	<0.0001	<0.0001
Interactive effects				
Breed	Diet			
BPR	CSM	62.24	8.71	4.49
BPR	SSM	62.97	8.81	1.35
BPR	SSM +SSF	62.38	9.07	0.94
BPR	SFP	55.96	10.85	1.73
BPR	SFP + SSF	54.54	11.26	1.09
RIR	CSM	63.17	7.89	5.42
RIR	SSM	62.47	8.94	1.75
RIR	SSM +SSF	62.01	8.86	1.57
RIR	SFP	57.08	11.34	3.00
RIR	SFP + SSF	55.40	11.02	2.35
SEM		0.70	0.35	0.31
P-value		0.6518	0.4370	0.5564

Mean values are averages of two birds per pen (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)

[a,b,c] Means within the same column without common letters are different *(P* < 0.05)

CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets

+SSF = enzyme added to the diet

Table 6.9. Effect of breed and sex on the bone breaking strength and ash content of tibia and humerus for two Rhode Island Reds (RIR) and Barred Plymouth Rocks (BPR) at 98 days of age

		Tibia breaking strength, kg force	Tibia Ash, %	Humerus breaking strength, kg force	Humerus Ash, %
Breed main effects					
BPR		22.8	58	19.1 [b]	61
RIR		23.7	59	20.7 [a]	61
SEM		0.7	0.4	0.5	0.4
P-value		0.3820	0.0352	0.0356	0.7745
Diet main effects					
CSM		23.7	59	22.0 [a]	61
SSM		22.3	58	20.7 [ab]	61
SSM +SSF		25.6	60	20.3 [abc]	60
SFP		22.8	57	18.1 [c]	61
SFP + SSF		21.8	59	18.4 [bc]	61
SEM		1.1	0.6	0.8	0.7
P-value		0.1310	0.0498	0.0074	0.8124
Interactive effects					
Breed	Diet				
BPR	CSM	22.4	59	22.5	61
BPR	SSM	23.5	58	19.4	62
BPR	SSM +SSF	25.8	58	18.7	60
BPR	SFP	21.8	57	16.8	60
BPR	SFP + SSF	20.7	59	18.0	61
RIR	CSM	25.0	59	21.5	61
RIR	SSM	21.1	58	21.9	61
RIR	SSM +SSF	25.4	61	21.9	61
RIR	SFP	23.9	58	19.3	62
RIR	SFP + SSF	23.0	59	18.8	61
SEM		1.5	0.8	1.2	1.0
P-value		0.4282	0.7691	0.3958	0.7484

Mean values are averages of two birds per pen (Breed main effects, n = 10; Diet main effects, n = 6; Interactive effects, n = 3)

[a,b,c] Means within the same column without common letters are different ($P < 0.05$)

CSM = corn/soy diet; SSM = sorghum/soybean diet; SFP = sorghum/field peas diets

+SSF = enzyme added to the diet

CHAPTER 7: Summary and conclusions

The objective of this research was to examine the effect of feed strategies, alternative feedstuffs, and dietary enzyme on the growth and performance of heritage breeds of chickens used for either egg- or meat-production.

The first study (Chapter 2) utilized a self-selection feeding method to determine the growth performance of pullets from three heritage breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp) and two sex-link strains (Black Star and Red Star). Pullets from all five genotypes demonstrated similar growth rates to those of commercial ISA Brown pullets. Overall feed and nutrient intake was similar among genotypes with pullets selected a diet that consisted of 3098 kcal ME/kg, 15.3% crude protein, 0.26% methionine, 0.70% lysine, 0.51% calcium, and 0.29% phosphorus. Therefore, self-selection resulted in diets that were sufficient in protein, methionine, lysine, and phosphorus, but lower in calcium and higher in energy than National Research Council (1994) recommendations. This indicated that heritage breed pullets likely have similar nutrient requirements to pullets from brown-egg-laying strains. However, a subsequent study showed that the heritage breed hens and the sex-link strains produced smaller eggs and had poor hen day production when compared with the ISA Brown hens (Jacob, 2014).

The second study (Chapter 3) utilized a self-selection feeding method to determine the growth performance of males from three heritage breeds (Rhode Island Red, Barred Plymouth Rock, and Black Australorp) and a slow-growing meat-type strain (Red Ranger). Average daily gain for Red Rangers was lower than that of Cornish Cross males and females, but higher than that of the heritage breeds. Therefore, Red Ranger males and heritage breed males took about 1.3 and 2.8 times longer, respectively, than Cornish Cross males to reach a live weight of 2300 grams. Additionally, while heritage breeds consumed less feed per day than meat-type birds, they also exhibited poor feed efficiency which resulted in higher overall feed intake to reach the same body weight.

The third study (Chapter 4) evaluated the carcass characteristics of the birds from the second study. At a common live weight of 2300 grams, Cornish Cross males and females had higher chilled WOG yields than Red Rangers or heritage breeds (74.8 vs 67.4%). Additionally, there was a conformational difference observed for the carcasses of

Red Rangers and heritage breeds when compared with Cornish Cross carcasses. The Cornish Cross birds had higher boneless breast yields, and lower leg and wing yields, than the Red Rangers and heritage breeds. On the self-selection diet, heritage breeds had larger gizzards than the Cornish Cross birds which could allow the birds to better process larger feedstuffs.

The fourth study (Chapter 5) evaluated the use of alternative feedstuffs (field peas, buckwheat, and flax seed) to partially replace corn and soybean meal (CSM) in diets for three genotypes (straight-run Cornish Crosses, males from a Black Sex-Link cross, and straight-run Rhode Island Reds). As expected based on previous research, Cornish Crosses had better growth performance and carcass yield than Black Sex-Link males and Rhode Island Reds. Percent carcass and breast filet yields of Rhode Island Reds were lower and more affected by sex, but less affected by feed ingredients, than commercial broilers. For all three breeds, field peas replaced 30% of the CSM-based diet without reducing performance. However, a 50% replacement of CSM-based diet with a 3:1:1 mixture of field peas, buckwheat, and flax seed resulted in reduced performance. Additionally, the use of alternative breeds and feed ingredients was found to impact meat color and negatively affect lipid peroxidation, but the inclusion of dietary enzymes mitigated the effect on lipid peroxidation.

The fifth study (Chapter 6) evaluated the use of sorghum and field peas as replacements for corn and soybean meal in diets for two heritage breeds: Rhode Island Reds and Barred Plymouth Rocks. While Rhode Island Reds and Barred Plymouth Rocks exhibited similar average feed intake, Rhode Island Reds exhibited higher average daily gain and therefore better feed efficiency. Additionally, Rhode Island Reds were better able to adapt to a sorghum- and soybean meal-based diet with or without dietary enzyme than Barred Plymouth Rocks. For both breeds, the use of sorghum and field peas with or without dietary enzymes did not affect carcass or part yields relative to live weight. However, lightness and yellowness of the breast meat decreased when the levels of corn and soybean meal were reduced in the diet. This could be a benefit or a concern depending on the market.

7.1 Use of heritage breeds and slow-growing meat-type strains

Despite increased interest in the use of heritage breeds and slow-growing meat-type strains for meat production, neither of these types are truly viable alternatives to the fast-growing genetics used today. Based on the results of the presented studies, the poultry industry cannot afford to go back to slower-growing chickens if it wants to continue to meet consumer demand for chicken meat. The issue is not simply that heritage breeds grow slower, but also that they have poorer feed conversion which requires more feed per gram of gain than a fast-growing meat-type bird would.

The fast-growing meat-type strains utilized in these studies achieved 3.6x higher growth rates while consuming half as much feed per gram of gain than the heritage breed males. While the slow-growing meat-type strain (Red Ranger) utilized in these studies had better growth rates and feed conversion ratios than the heritage breeds, the fast-growing meat-type strain still achieved 1.5x higher growth rates and consumed 15% less feed per gram of gain than these birds. For both heritage breeds and slow-growing meat-type strains, this issue is compounded by relatively low carcass yields when compared with fast-growing meat-type strains. While these studies did not evaluate where the weight goes, visual appraisal of these birds suggest it is in longer limbs and increased feather coverage. However, this did not translate to stronger bones. In fact, the results of Chapter 5 showed that commercial broilers had higher bone breaking strength when compared with heritage breeds at the same body weight.

As a result of their slow growth rates and low carcass yields, producing the same amount of meat using slow-growing genotypes would require more time, more feed, more land (for chicken houses and to grow feed), more trucks (to transport birds and feed), more fuel, more birds, more manpower, etc. While this may create new jobs, the additional resources required and the additional waste produced would have a catastrophic impact on both the economy and the environment. Therefore, the use of slower-growing breeds for meat production is neither economically nor environmentally sustainable except on a very small scale for premium niche markets. This is particularly true if these birds are being provided with high-nutrient-density diets which are formulated for fast-growing meat-type birds. While more work still needs to be done to determine their precise nutrient requirements, heritage breeds seem to have lower nutrient requirements than fast-growing meat-type strains.

Based on these findings, alternatives genotypes such as slow-growing meat-type birds and heritage breed chickens will remain a niche market in the United States. Producers interested in raising heritage breeds must take into consideration the increased feed costs and decreased yield when pricing their products. Additionally, sex-separate management where only males are used for meat production is advised due to the low growth rates of female heritage breeds. To this end, birds produced from sex-linked crosses offer a unique opportunity to easily divert males and females to different production streams. However, their growth performance and carcass yields are similar to that of heritage breeds, so raising these birds poses the same challenges as heritage breeds when it comes to production costs.

7.2 Use of self-selection feeding program for heritage breeds

Significant research has been conducted to determine the nutrient requirements of poultry species used in the commercial production of meat and eggs. The data from this research is used to formulate complete diets designed to meet the bird's needs and maximize production. For producers interested in raising heritage breeds, the only recommendations available are the National Research Council (1994) recommendations for meat-type and egg-type chickens. However, these recommendations may not be appropriate for heritage breeds. Therefore, one of the goals of this project was to produce data to begin to determine the nutrient requirements of heritage breeds.

With no nutritional standards specifically designed for heritage breeds, formulating a complete diet for these breeds with any accuracy would be difficult. Therefore, the first studies used a self-selection feeding program to determine the nutrient intake of heritage breed pullets and cockerels. Steinruck and Kirchgessner (1992, 1993a, 1993b) and others suggest that pullets and laying hens are capable of balancing their own diets when given a choice of feeds with either a deficient or excessive supply of protein. Self-selection feeding has also been used in meat-type birds with varying degrees of success. While self-selection-fed birds had similar growth performance to birds fed complete diets in some studies, others showed decreased performance. Additionally, some studies have shown reduced carcass yields for self-selection-fed birds (Cerrate et al., 2007), while others show no effect (Ozek et al., 2012). However, self-selection feeding programs have not been extensively studied in heritage breeds.

7.2.1 Use of self-selection feeding program for pullets

The results of the pullet study showed that Black Australorp, Barred Plymouth Rock, Black Star, and Red Star pullets were able to use a self-selection feeding program to achieve weights consistent with the expected body weights published by the National Research Council (1994) for brown-egg-laying pullets. However, the Rhode Island Reds and ISA Browns fell short of the expected body weights published for both brown-egg-laying strain pullets (National Research Council, 1994) and for ISA Brown pullets (Institut de Sélection Animale). This begs the question as to whether these pullets were selecting diets that met their requirements.

Based on the results of the self-selection feeding program, the average daily feed and nutrient intake for the heritage breeds was similar to that for the ISA Browns. Additionally, the nutrient composition of the self-selected diets resulted in diets that were sufficient in protein, methionine, lysine, and phosphorus, but lower in calcium and higher in energy than National Research Council (1994) recommendations. The higher than expected energy consumption is consistent with the literature on self-selection feeding which shows that self-selection-fed birds tend to consume more energy and less protein than birds fed complete diets (Leeson and Caston, 1993; Sahin, 2003; Cerrate et al., 2007; Syafwan et al., 2012; Fanatico et al., 2013; Catanese et al., 2015). Therefore, these results suggest that heritage breed pullets likely have similar nutrient requirements to pullets from commercial brown-egg-laying strains during the rearing phase. Consequently, the National Research Council (1994) recommendations for brown-egg-laying strain pullets should also be appropriate for heritage breed pullets.

7.2.2 Use of self-selection feeding program for cockerels

When a self-selection feeding program was used for heritage breed males, the birds showed a preference for higher energy, but lower protein diets than those selected by meat-type birds. The heritage breeds selected diets containing 16.2% crude protein and 3068 kcal ME/kg, while the fast-growing meat-type males selected diets containing 20.8% crude protein and 2887 kcal ME/kg. Because feed intake in birds is heavily driven by energy appetite, this difference in appetite for energy should be considered when formulating diets for heritage breeds.

No signs of deficiency were noted which indicates the self-selected diet was not deficient. However, when some birds were switched on to a broiler starter diet (22% CP; 3084 kcal ME/kg) part way through the study, their average daily gain was improved when compared with the bird remaining on self-selection. Additionally, the birds had similar average daily feed intake, but improved feed conversion. This suggests that the self-selected diet (16.2% CP; 3068 kcal ME/kg) was not sufficient to maximize growth.

Rhode Island Reds were used in all of the studies presented. Therefore, they provide an interesting point of comparison between studies. On the self-selection feeding program, the Rhode Island Red males reached a live weight of 1814 grams at 105 days of age. However, in a another trial where Rhode Island Reds were provided with formulated diets (~19% CP; 3000 kcal ME/kg), this same weight was achieved at 96 days of age. While this difference could be attributed to the higher protein content of the formulate diet, a similar weight (1851 grams) was also achieved in 98 days with a lower crude protein diet (15.3% CP and 2900 kcal ME/kg) in another study. Lastly, in the final trial, Rhode Island Red males achieved an average body weight of 2060 grams at 98 days of age while receiving either a corn-soy diet (20% CP; 3000 kcal ME/kg) or a sorghum-soy based diet (18.4% CP; 3000 kcal ME/kg). This weight was not achieved in the self-selection trial until around 119 days of age.

The differences in growth rates observed in these trials provide further evidence that, while the self-selection feeding program were adequate to prevent nutritional deficiency, the resulting diets were not sufficient to maximize growth. However, other factors such as lighting program and stocking density differed in these trials and may be responsible for some of the difference observed.

Finally, while the heritage breeds' tendency to select diets higher in energy and lower in protein than meat-type birds could result in lower cost per pound of feed, the amount of extra feed required by these birds overall will undoubtedly exceed any potential savings. Therefore, the recommendation is to use complete diets for heritage breeds. Unfortunately, specific nutrient recommendations cannot be made based on these results, so further research is needed to determine the nutrient requirements of heritage breed cockerels.

7.3 Use of alternative feed ingredients and dietary enzymes

Poultry feed requires sources of protein, energy, vitamins, and minerals. In conventional chicken diets in the United States, corn serves as the main energy source and soybean meal as the main protein source. However, more than 90% of the corn and soybean crops in the United States are genetically modified organisms (GMO). In some production systems, such as organic production, GMO ingredients products are not allowed (USDA 2012a; USDA 2012b). Additionally, there is a trend in the industry moving towards all vegetarian diets which do not utilize animal by products. Therefore, there is interest in finding alternative feed ingredients, particularly those with relatively high levels of protein. While some alternative protein sources have been identified, all present major challenges which limit their use (Burley et al., 2015). There is some early research looking at the suitability of individual feedstuffs as substitutes for corn or soybean meal in poultry diets, but there is very little research into the use of combinations of these alternative crops as the sole ingredients in a complete poultry feed. Some of the proposed feed ingredients contain anti-nutritive factors (e.g., β-glucans, pentosans) which may limit their use when feed enzymes are not included. Organic feed regulations allow for the use of non-GMO feed enzymes (USDA 2012a; USDA 2012b).

In these studies, the alternative feed ingredients evaluated included pearl millet, naked oats, field peas, sorghum, buckwheat, and flax seed. These ingredients were selected because they contain higher levels of protein than corn and have previously been used in poultry diets. However, many of these ingredients have anti-nutritive factors which limit their utility beyond a certain inclusion level. Based on the literature, pearl millet, sorghum, and field peas showed the greatest potential utility as complete replacements for either corn or soybean meal. During the self-selection trials, birds readily accepted pearl millet as a stand-alone feed ingredient. While most of the birds showed a strong preference for corn over the other grains, the ingredient consumption pattern for the slow-growing meat-type bird (Red Ranger) showed a preference for pearl millet over corn. However, pearl millet is a relatively expensive feed ingredient, so it was not utilized in subsequent studies. Naked oats have been successfully used in some studies (Burley et al., 2015), but they were not readily accepted by the birds in the present studies.

Based on the results of these studies, field peas can be used with or without dietary enzyme to replace 30% of the corn and soybean meal in diets for meat-type birds and heritage breeds without sacrificing growth performance or carcass yield. Due to the limited protein value of field peas (20 to 29% CP), field peas could not be included at higher levels without significant amino acid supplementation. Therefore, a diet where 50% of the corn and soybean meal was replaced with a 3:1:1 ratio of field peas, buckwheat, and flax seed was evaluated. This diet negatively affected growth performance for both meat-type and heritage breeds. Furthermore, this dietary formulation reduced chilled WOG and breast yields for commercial broilers, but not for the heritage breed studied. The use of a dietary enzyme complex was able to improve some performance parameters; however, it did not appear to affect carcass and part yields.

In the final trial, sorghum was used to completely replace corn and a combination of sorghum and field peas was evaluated to completely replace corn and soybean meal. The results of this study suggested that sorghum can be used with a dietary enzyme complex to completely replace corn and partially replace soybean meal in diets for heritage breeds without sacrificing average daily gain or carcass yields. However, this replacement increased feed intake, reduced feed conversion, and altered breast meat color. Completely replacing corn and soybean meal with a combination of sorghum and field peas depressed growth, increased feed intake, and worsened feed conversion when compared with both the corn-soy and sorghum-soy diets.

Based on the combined results, alternative ingredients can be utilized in the diets of heritage breeds. However, the utility of a particular ingredient is limited by its nutrient composition. Ultimately, none of the alternative ingredients evaluated were able to completely replace corn and soybean meal. Therefore, these studies reconfirmed the reason why we feed corn and soybean meal to chickens. Using corn and soybean meal, it is very easy to formulate a wide variety of well-balanced diets to meet birds' with minimal supplementation. Field peas provide a promising avenue for replacing soybean meal in the diets of heritage breeds, but the amino acid balance presents a challenge when using it at higher inclusion levels. Finally, dietary enzymes can help birds overcome poor quality diets, but they will not alleviate all negative effects.

7.4 Future directions

When taken together, the results of this research indicate that the slow growth rate and poor feed efficiency of heritage breeds limit their utility as meat birds. However, the lower nutrient intakes of the heritage breeds suggest lower nutrient requirements when compared with meat-type birds which may enable heritage breeds to perform better in marginal environments where lower-nutrient-density diets are provided. Finally, through documentation of the growth performance and carcass characteristics of three heritage breeds, this research should provide producers interested in raising heritage breeds with some of the information needed to calculate potential expenses and determine the price needed to profit on their products.

Further research needs to be done to determine the nutrient requirements for males from heritage breeds and slow-growing meat-type birds which optimize production characteristics. Particular attention should be given to improving feed conversion if these birds are going to be used. Additionally, while the results of these studies suggest heritage breed pullets have similar requirements as brown-egg-laying strain pullets, additional studies would need to evaluate their performance and nutrient needs during lay.

APPENDIX A: Nutrient specifications for brown-egg-laying strain pullets from hatch to 18 weeks of age

Age	0 to 6 weeks	6 to 12 weeks	12 to 18 weeks	18 weeks to first egg
ME (kcal/kg)	2800	2800	2850	2850
CP (%)	17.0	15.0	14.0	16.0
Met (%)	0.28	0.23	0.19	0.21
Met + Cys (%)	0.59	0.49	0.39	0.44
Lys (%)	0.80	0.56	0.42	0.49
Thr (%)	0.64	0.53	0.35	0.44
Trp (%)	0.16	0.13	0.10	0.11
Ca (%)	0.90	0.80	0.80	1.8
Non-phytate P (%)	0.40	0.35	0.30	0.35
Cl (min %)	0.12	0.11	0.11	0.11
Na (min %)	0.15	0.15	0.15	0.15

Adapted from National Research Council (1994)

APPENDIX B: Nutrient specifications for ISA Brown pullet diets from 1 day of age through beginning of lay

	Starter	Grower	Pullet	Pre-lay
Days of Age	1 to 28 days	28 to 70 days	70 to 112 days	112 days to 2 lay
ME (kcal/kg)	2950	2850	2750	2750
CP (%)	20.5	19.0	16.0	17.0
Met (%)	0.52	0.45	0.35	0.36
Met + Cys (%)	0.86	0.76	0.62	0.65
Lys (%)	1.16	0.98	0.74	0.80
Thr (%)	0.78	0.66	0.50	0.54
Trp (%)	0.21	0.19	0.16	0.17
Ca (%)	1.08	1.10	1.10	2.05
P (available)	0.48	0.42	0.40	0.45
Cl (min %)	0.15	0.15	0.15	0.15
Na (min %)	0.17	0.17	0.17	0.17

Adapted from ISA Brown Management Guide (Institut de Sélection Animale)

APPENDIX C: Average hen day egg production for heritage breed hens (Jacob, 2014)

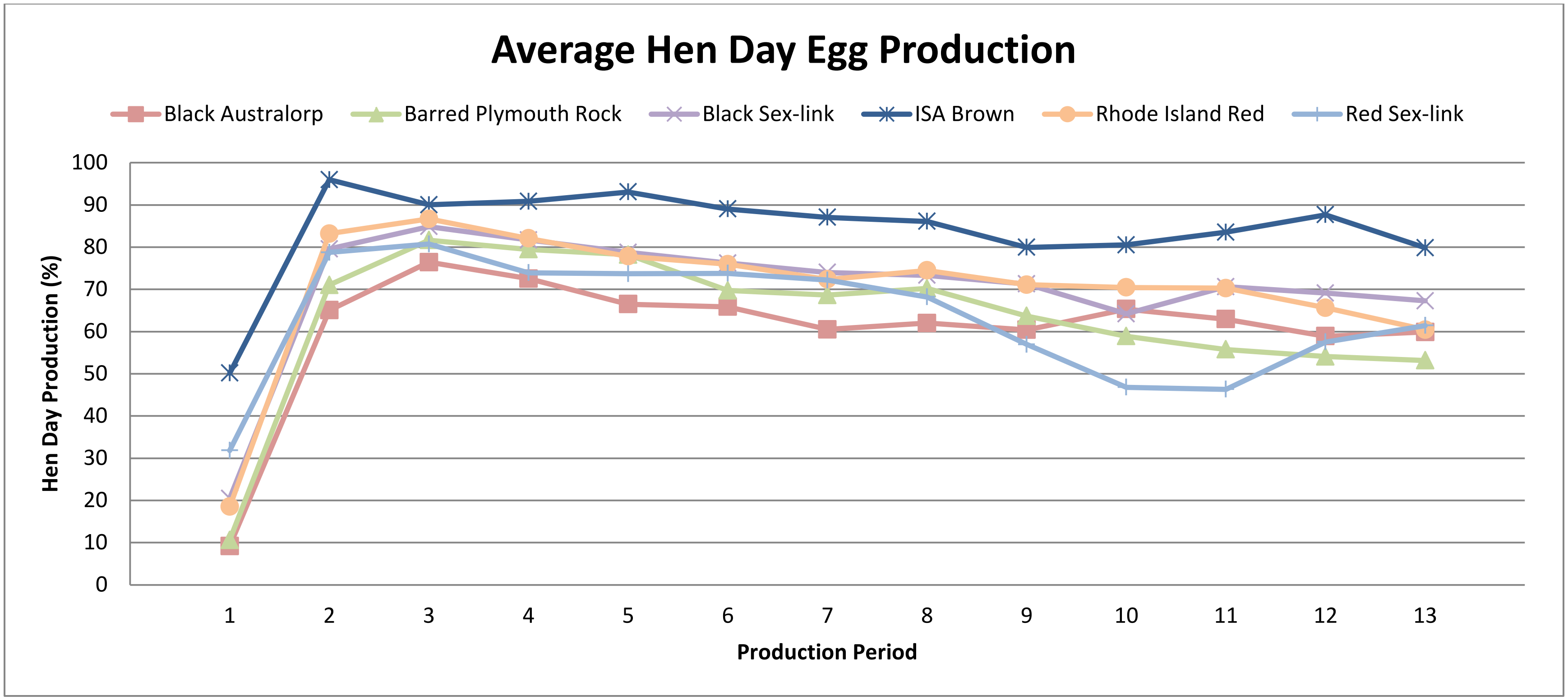

Figure C.1. Average hen day egg production from beginning of lay through 13 four-week production periods

APPENDIX D: Average egg weight for heritage breed hens (Jacob, 2014)

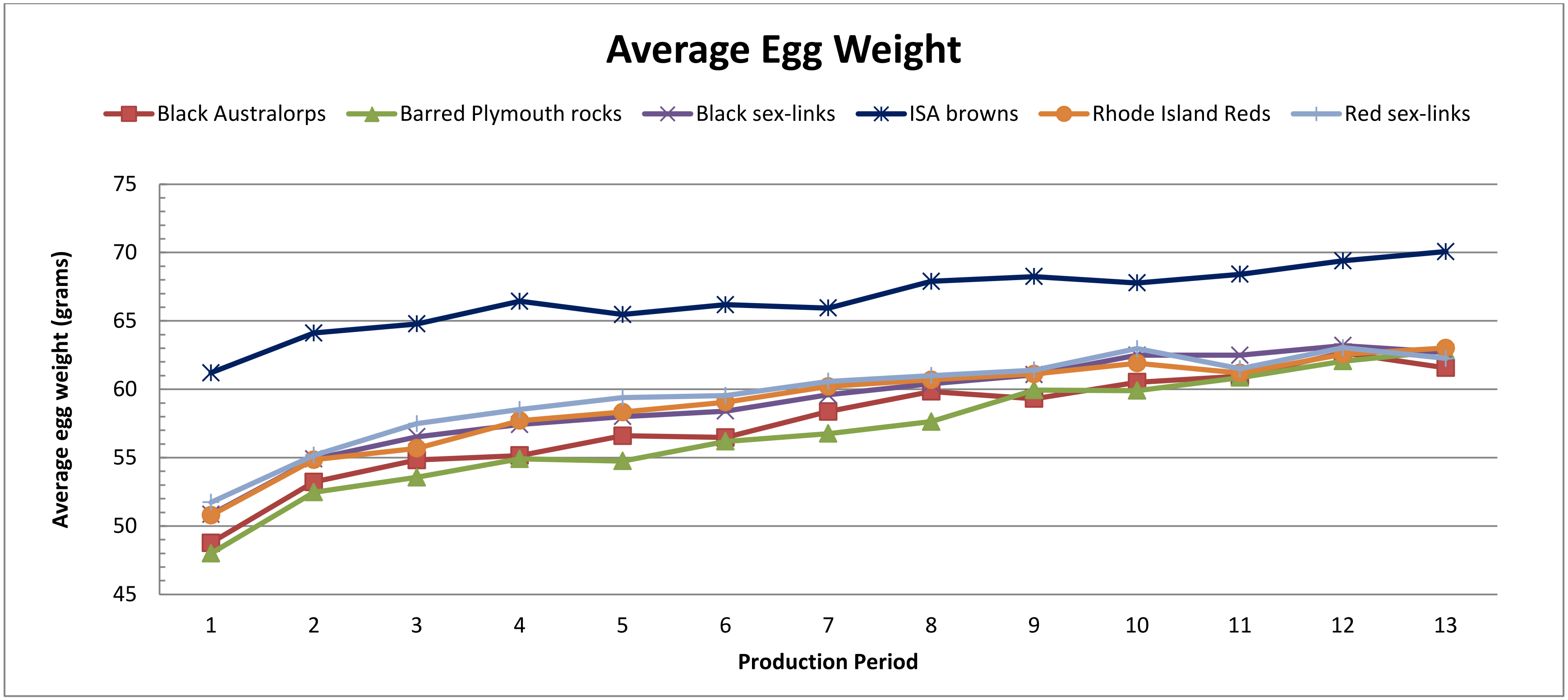

Figure D.1. Average egg weight from beginning of production through 13 four-week production periods

APPENDIX E: Nutrient specifications for broiler diets from 0 to 8 weeks of age

Age	0 to 3 weeks	3 to 6 weeks	6 to 8 weeks
ME (kcal/kg)	3200	3200	3200
CP (%)	23	20	18
Met (%)	0.50	0.38	0.32
Met + Cys (%)	0.90	0.72	0.60
Lys (%)	1.10	1.00	0.85
Thr (%)	0.80	0.74	0.68
Trp (%)	0.20	0.18	0.16
Ca (%)	1.00	0.90	0.80
Non-phytate P (%)	0.45	0.35	0.30
Cl (min %)	0.20	0.15	0.12
Na (min %)	0.20	0.15	0.12

Adapted from National Research Council (1994)

REFERENCES

Adeola, O., J. C. Rogler, and T. W. Sullivan. 1994. Pearl-millet in diets of white pekin ducks. Poultry science 73: 425-435.

Afsharmanesh, M., N. Ghorbani, and Z. Mehdipour. 2016. Replacing corn with pearl millet (raw and sprouted) with and without enzyme in chickens' diet. Journal of Animal Physiology and Animal Nutrition 100: 224-228.

Amerah, A. M., and V. Ravindran. 2008. Influence of method of whole-wheat feeding on the performance, digestive tract development and carcass traits of broiler chickens. Animal Feed Science and Technology 147: 326-339.

Amini, K., and C. A. Ruiz-Feria. 2007. Evaluation of pearl millet and flaxseed effects on egg production and n-3 fatty acid content. British Poultry Science 48: 661-668.

Anderson, K. L., M. T. Brewer, M. A. Rasmussen, and S. A. Carlson. 2015. Identification of heritage chicken breeds with diminished susceptibility to intestinal colonization by multiple antibiotic-resistant Salmonella spp. Livest. Sci. 182: 34-37.

Angel, C., W. Saylor, S. Vieira, and N. Ward. 2011. Effects of a monocomponent protease on performance and protein utilization in 7-to 22-day-old broiler chickens. Poultry science 90: 2281-2286.

Applegate, T. J., and R. Angel. 2014. Nutrient requirements of poultry publication: History and need for an update. The Journal of Applied Poultry Research: japr980.

Aydilek, N. et al. 2012. Effect of Free Choice Feeding as to Protein Levels on Oxidative Status in the Broilers Exposed to Heat Stress. Kafkas Universitesi Veteriner Fakultesi Dergisi 18: 1049-1054.

Azahan, E. E., and J. Forbes. 1989. Growth, food intake and energy balance of layer and broiler chickens offered glucose in the drinking water and the effect of dietary protein content. British poultry science 30: 907-917.

Bailey, R. A., K. A. Watson, S. Bilgili, and S. Avendano. 2015. The genetic basis of pectoralis major myopathies in modern broiler chicken lines. Poultry science: pev304.

Balog, J. M., and R. I. Millar. 1989. Influence of the sense of taste on broiler chick feed consumption. Poultry science 68: 1519-1526.

Batonon-Alavo, D. I., M. U. Faruk, P. Lescoat, G. M. Weber, and D. Bastianelli. 2015. Inclusion of sorghum, millet and cottonseed meal in broiler diets: a meta-analysis of effects on performance. Animal 9: 1120-1130.

Baurhoo, N., B. Baurhoo, A. F. Mustafa, and X. Zhao. 2011a. Comparison of corn-based and Canadian pearl millet-based diets on performance, digestibility, villus morphology, and digestive microbial populations in broiler chickens. Poultry science 90: 579-586.

Baurhoo, N., B. Baurhoo, and X. Zhao. 2011b. Effects of exogenous enzymes in corn-based and Canadian pearl millet-based diets with reduced soybean meal on growth performance, intestinal nutrient digestibility, villus development, and selected microbial populations in broiler chickens. Journal of Animal Science 89: 4100-4108.

Bedford, M. R., and G. G. Partridge. 2001. Enzymes in farm animal nutrition. CABI.

Bergoug, H. et al. 2015. Relationships between hatch time and egg weight, embryo sex, chick quality, body weight and pododermatitis severity during broiler rearing. European Poultry Science 79.
Bertechini, A. G., H. Mazzuco, E. C. Rodrigues, and E. M. Ramos. 2014. Study of the utilization of light egg-type males: a proposal for the sustainability of the egg industry. Poultry science 93: 755-761.
Burley, H. K., P. H. Patterson, and K. E. Anderson. 2015. Alternative ingredients for providing adequate methionine in organic poultry diets in the United States with limited synthetic amino acid use. Worlds Poultry Science Journal 71: 493-504.
Burton, G. W., K. O. Rachie, and A. R. Wallace. 1972. Chemical composition and nutritive-value of pearl millet (pennisetum-typhoides (burm) stapf and hubbard,ec) grain. Crop Science 12: 187.
Carrasco, S., G. Bellof, and E. Schmidt. 2014. Nutrients deposition and energy utilization in slow-growing broilers fed with organic diets containing graded nutrient concentration. Livest. Sci. 161: 114-122.
Casey-Trott, T. et al. 2015. Methods for assessment of keel bone damage in poultry. Poultry science 94: 2339-2350.
Castellini, C., C. Berri, E. Le Bihan-Duval, and G. Martino. 2008. Qualitative attributes and consumer perception of organic and free-range poultry meat. Worlds Poultry Science Journal 64: 500-512.
Catanese, F., H. R. Ganduglia, J. J. Villalba, and R. A. Distel. 2015. Free availability of high-energy foods led to energy over-ingestion and protein under-ingestion in choice-fed broilers. Animal Science Journal 86: 1000-1009.
Cerrate, S., Z. Wang, C. Coto, F. Yan, and P. W. Waldroup. 2007. Choice feeding as a means of identifying nutritional needs with two methods of amino acid formulation. International Journal of Poultry Science 6: 846-854.
Cheema, M. A., M. A. Qureshi, and G. B. Havenstein. 2003. A comparison of the immune response of a 2001 commercial broiler with a 1957 randombred broiler strain when fed representative 1957 and 2001 broiler diets. Poultry science 82: 1519-1529.
Chen, X. et al. 2013. Effects of outdoor access on growth performance, carcass composition, and meat characteristics of broiler chickens. Poultry science 92: 435-443.
Clark, P., K. Behnke, and A. Fahrenholz. 2009. Effects of feeding cracked corn and concentrate protein pellets on broiler growth performance. The Journal of Applied Poultry Research 18: 259-268.
Collins, K. E., B. H. Kiepper, C. W. Ritz, B. L. McLendon, and J. L. Wilson. 2014. Growth, livability, feed consumption, and carcass composition of the Athens Canadian Random Bred 1955 meat-type chicken versus the 2012 high-yielding Cobb 500 broiler. Poultry science 93: 2953-2962.
Collins, V. P., A. H. Cantor, A. J. Pescatore, M. L. Straw, and M. J. Ford. 1997. Pearl millet in layer diets enhances egg yolk n-3 fatty acids. Poultry science 76: 326-330.
Corr, S. A., M. J. Gentle, C. C. McCorquodale, and D. Bennett. 2003. The effect of morphology on the musculoskeletal system of the modern broiler. Animal Welfare 12: 145-157.

Covasa, M., and J. M. Forbes. 1996. Effects of prior experience and training on diet selection of broiler chickens using wheat. Applied Animal Behaviour Science 46: 229-242.

Dale, K. 2003. 'Heritage' beasts facing extinction Few are aware of the risks to many domesticated breeds of our past. Activists call for protection of American 'heritage' breeds Philadelphia Inquirer, Philadelphia, Pa.

De Jong, I., and D. Guémené. 2011. Major welfare issues in broiler breeders. World's Poultry Science Journal 67: 73-82.

Del Castilho, C. C., T. T. Santos, C. A. F. Rodrigues, and R. A. Torres. 2013. Effects of sex and genotype on performance and yield characteristics of free range broiler chickens. Arquivo Brasileiro De Medicina Veterinaria E Zootecnia 65: 1483-1490.

Denbow, D. M. 1999. Food intake regulation in birds. Journal of Experimental Zoology 283: 333-338.

Deniz, G. et al. 2013. Effects of feeding corn distiller's dried grains with solubles with and without enzyme cocktail supplementation to laying hens on performance, egg quality, selected manure parameters, and feed cost. Livest. Sci. 152: 174-181.

Dozier, W. A., W. Hanna, and K. Behnke. 2005. Grinding and pelleting responses of pearl millet-based diets. Journal of Applied Poultry Research 14: 269-274.

Ebadi, M. R., M. Sedghi, A. Golian, and H. Ahmadi. 2011. Prediction of the true digestible amino acid contents from the chemical composition of sorghum grain for poultry. Poultry science 90: 2397-2401.

Evvard, J. M. 1915. The “Free-choice” System of Feeding Swine. Proceedings of the American Society of Animal Nutrition 1915: 50-64.

Fanatico, A., L. C. Cavitt, P. Pillai, J. Emmert, and C. Owens. 2005a. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: meat quality. Poultry science 85: 1785-1790.

Fanatico, A. et al. 2006a. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: sensory attributes. Poultry science 85: 337-343.

Fanatico, A., P. Pillai, T. O'Connor-Dennie, and J. Emmert. 2006b. Methionine requirements of alternative slow-growing genotypes. Poultry science 85: 110-110.

Fanatico, A., P. Pillai, C. Owens, and J. Emmert. 2005b. Impact of alternative broiler genotype and production system on growth performance and carcass yield. Poultry science 84: 34-34.

Fanatico, A. C., V. B. Brewer, C. M. Owens-Hanning, D. J. Donoghue, and M. Donoghue. 2013. Free-choice feeding of free-range meat chickens. Journal of Applied Poultry Research 22: 750-758.

Fanatico, A. C., C. M. Owens, and J. L. Emmert. 2009. Organic poultry production in the United States: Broilers. Journal of Applied Poultry Research 18: 355-366.

Fanatico, A. C., P. B. Pillai, L. C. Cavitt, C. M. Owens, and J. L. Emmert. 2005c. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: Growth performance and carcass yield. Poultry science 84: 1321-1327.

Fanatico, A. C. et al. 2007a. Sensory attributes of slow- and fast-growing chicken genotypes raised indoors or with outdoor access. Poultry science 86: 2441-2449.

Fanatico, A. C., P. B. Pillai, J. L. Emmert, and C. M. Owens. 2007b. Meat quality of slow- and fast-growing chicken genotypes fed low nutrient or standard diets and raised indoors or with outdoor access. Poultry science 86: 2245-2255.

Fanatico, A. C. et al. 2008. Performance, livability, and carcass yield of slow- and fast-growing chicken genotypes fed low-nutrient or standard diets and raised indoors or with outdoor access. Poultry science 87: 1012-1021.

Farrell, D. J., R. A. Perez-Maldonado, and P. F. Mannion. 1999. Optimum inclusion of field peas, faba beans, chick peas and sweet lupins in poultry diets. II. Broiler experiments. British Poultry Science 40: 674-680.

Floyd, A. 2015. So You Want to Raise Chickens? Flagpole No. 29. p 10. Flagpole, Inc., Athens.

Forbes, J. M., and M. Covasa. 1995. Application of diet selection by poultry with particular reference to whole cereals. Worlds Poultry Science Journal 51: 149-165.

Gabriel, I., S. Mallet, M. Leconte, G. Fort, and M. Naciri. 2003. Effects of whole wheat feeding on the development of coccidial infection in broiler chickens. Poultry science 82: 1668-1676.

Garcia, A. R., and N. M. Dale. 2006. Feeding of unground pearl millet to laying hens. Journal of Applied Poultry Research 15: 574-578.

Gee, K. 2016. Demand Swells for Chickens That Grow More Slowly --- Companies like Whole Foods and Starbucks are betting customers will be willing to pay higher prices for unhurried maturing of birds Wall Street Journal, New York, N.Y.

Golian, A., T. A. Woyengo, C. Bennett, W. Guenter, and H. Muc. 2007. Carcass yield of modern vs 1970's heritage broilers fed drug free recommended and low protein diets. Poultry science 86: 524-524.

Gracia, M., M. J. Aranibar, R. Lazaro, P. Medel, and G. Mateos. 2003. Alpha-amylase supplementation of broiler diets based on corn. Poultry science 82: 436-442.

Graham, J. C. 1934. Individuality of Pullets in Balancing the Ration. Poultry science 13: 34-39.

Havenstein, G. B., P. R. Ferket, and M. A. Qureshi. 2003a. Carcass composition and yield of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. Poultry science 82: 1509-1518.

Havenstein, G. B., P. R. Ferket, and M. A. Qureshi. 2003b. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. Poultry science 82: 1500-1508.

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

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and D. V. Rives. 1994b. Carcass composition and yield of 1991 vs 1957 broilers when fed typical 1957 and 1991 broiler diets. Poultry science 73: 1795-1804.

Heinrichs, C., and D. Schrider. 2005. Enjoy heritage chickens. Mother Earth News: 57-63.

Hidalgo, M. A., A. J. Davis, N. M. Dale, and W. A. Dozier. 2004. Use of whole pearl millet in broiler diets. Journal of Applied Poultry Research 13: 229-234.

Hooge, D., J. Pierce, K. McBride, and P. Rigolin. 2010a. Meta-analysis of broiler chicken trials using diets with or without Allzyme® SSF enzyme complex. Int. J. Poult. Sci 9: 819-823.

Hooge, D., J. Pierce, K. McBride, and P. Rigolin. 2010b. Meta-analysis of laying hen trials using diets with or without allzyme® SSF enzyme complex. International Journal of Poultry Science 9: 824-827.

Hulet, R., G. Gladys, D. Hill, R. Meijerhof, and T. El-Shiekh. 2007. Influence of egg shell embryonic incubation temperature and broiler breeder flock age on posthatch growth performance and carcass characteristics. Poultry science 86: 408-412.

Innes, B., and J. Cranfield. 2009. Consumer preference for production-derived quality: analyzing perceptions of premium chicken production methods. Agribusiness 25: 395-411.

Institut de Sélection Animale. ISA Brown Commercial Management Guide.

Jackson, S., and J. Diamond. 1996. Metabolic and digestive responses to artificial selection in chickens. Evolution 50: 1638-1650.

Jacob, J. 2007. Nutrient content of organically grown feedstuffs. The Journal of Applied Poultry Research 16: 642-651.

Jacob, J. 2014. Unpublished data.

Jacob, J. P., and C. A. Carter. 2008. Inclusion of Buckwheat in Organic Broiler \Diets. Journal of Applied Poultry Research 17: 522-528.

Jacobs, H. L., and M. Scott. 1957. Factors Mediating Food and Liquid Intake in Chickens 1. Studies on the Preference for Sucrose or Saccharine Solutions. Poultry science 36: 8-15.

Jia, W., B. A. Slominski, W. Guenter, A. Humphreys, and O. Jones. 2008. The effect of enzyme supplementation on egg production parameters and omega-3 fatty acid deposition in laying hens fed flaxseed and canola seed. Poultry science 87: 2005-2014.

Jones, D., P. Curtis, K. Anderson, and F. Jones. 2004. Microbial contamination in inoculated shell eggs: II. Effects of layer strain and egg storage. Poultry science 83: 95-100.

Jones, D. R., K. E. Anderson, and G. S. Davis. 2001. The effects of genetic selection on production parameters of single comb white leghorn hens. Poultry science 80: 1139-1143.

Kaur, R., B. M. Rathgeber, K. L. Thompson, and J. MacIsaac. 2013. Uterine fluid proteins and egg quality characteristics for 2 commercial and 2 heritage laying hen lines in response to manipulation of dietary calcium and vitamin D3. Poultry science 92: 2419-2432.

Kempster, H. 1917. Food selection by laying hens. Poultry science 2: 26-29.

Kennedy, O. B., B. J. Stewart-Knox, P. C. Mitchell, and D. I. Thurnham. 2005. Flesh colour dominates consumer preference for chicken. Appetite 44: 181-186.

Kestin, S., T. Knowles, A. Tinch, and N. Gregory. 1992. Prevalence of leg weakness in broiler chickens and its relationship with genotype. The Veterinary Record 131: 190-194.

Khattak, F., T. Pasha, Z. Hayat, and A. Mahmud. 2006. Enzymes in poultry nutrition. Journal of Animal and Plant Sciences 16: 1-7.

Kronsberg, M. 2014. Will 2015 Be the Year of the Chicken? Wall Street Journal (Online): 1.
Kutlu, H. R., and J. M. Forbes. 1993. Self-selection of ascorbic-acid in colored foods by heat-stressed broiler chicks. Physiology & Behavior 53: 103-110.
Leenstra, F., J. Ten Napel, J. Visscher, and F. Van Sambeek. 2016. Layer breeding programmes in changing production environments: a historic perspective. World's Poultry Science Journal 72: 21-36.
Leeson, S., and L. Caston. 1993. Production and carcass yield of broiler using free-choice cereal feeding. The Journal of Applied Poultry Research 2: 253-258.
Leeson, S., and J. Summers. 2001. Scoot's Nutrition of the Chicken. University Book. Guelph, Canada.
Leiber, F., R. Messikommer, and C. Wenk. 2009. Buckwheat: a feed for broiler chicken? Agrarforschung 16: 448-453.
Leite, P. et al. 2012. Intestinal microflora and broiler performance fed with sorghum or pearl millet with enzymatic complexes. Arquivo Brasileiro De Medicina Veterinaria E Zootecnia 64: 1673-1681.
Lemme, A., V. Ravindran, and W. L. Bryden. 2004. Heal digestibility of amino acids in feed ingredients for broilers. Worlds Poultry Science Journal 60: 423-437.
Lichovnikova, M., J. Jandasek, M. Juzl, and E. Drackova. 2009. The meat quality of layer males from free range in comparison with fast growing chickens. Czech Journal of Animal Science 54: 490-497.
Lilburn, M. S. 1994. Skeletal growth of commercial poultry species. Poultry science 73: 897-903.
Loetscher, Y., A. R. Hospenthal, M. Kreuzer, and R. E. Messikommer. 2014. Do antioxidants induce feed selection behavior in laying hens? Preference for, and palatability of, different antioxidant sources. European Poultry Science 78.
MacLeod, M. G. et al. 2008. Naked oats: metabolisable energy yield from a range of varieties in broilers, cockerels and turkeys. British Poultry Science 49: 368-377.
Madiya, A. T., C. M. E. McCrindle, C. M. Veary, and S. P. R. Bisschop. 2003. The use of dried bakery products in a free-choice feeding method for small-scale broiler production. Journal of the South African Veterinary Association-Tydskrif Van Die Suid-Afrikaanse Veterinere Vereniging 74: 111-116.
Malheiros, R., V. Moraes, A. Collin, E. Decuypere, and J. Buyse. 2003. Free diet selection by broilers as influenced by dietary macronutrient ratio and corticosterone supplementation. 1. Diet selection, organ weights, and plasma metabolites. Poultry science 82: 123-131.
Mathlouthi, N., S. Mallet, L. Saulnier, B. Quemener, and M. Larbier. 2002. Effects of xylanase and $\ beta $-glucanase addition on performance, nutrient digestibility, and physico-chemical conditions in the small intestine contents and caecal microflora of broiler chickens fed a wheat and barley-based diet. Animal Research 51: 395-406.
Mbajiorgu, C. A., and N. O. Ramaphala. 2014. Insight into egg weight and its impact on chick hatch-weight, hatchability and subsequent growth indices in chickens- a review. Indian Journal of Animal Research 48: 209-213.

McCrea, B. A., A. F. Mills, K. Matthews, and J. Hutson. 2014. Performance and carcass characteristics of Delaware chickens in comparison with broilers. Journal of Applied Poultry Research 23: 586-592.
Mench, J., D. Sumner, and J. Rosen-Molina. 2011. Sustainability of egg production in the United States—The policy and market context. Poultry science 90: 229-240.
Min, Y. N., F. Yan, F. Z. Liu, C. Coto, and P. W. Waldroup. 2009. Effect of various dietary enzymes on energy digestibility of diets high in distillers dried grains with solubles for broilers. Journal of Applied Poultry Research 18: 734-740.
Murai, A., T. Kobayashi, T. Okada, and J. Okumura. 2002. Improvement of growth and nutritive value in chicks with non-genetically modified phytase product from Aspergillus niger. British poultry science 43: 687-695.
Nalle, C. L., V. Ravindran, and G. Ravindran. 2011. Nutritional value of peas (Pisum sativum L.) for broilers: apparent metabolisable energy, apparent ileal amino acid digestibility and production performance. Animal Production Science 51: 150-155.
Nangsuay, A. et al. 2015. Development and nutrient metabolism of embryos from two modern broiler strains. Poultry science 94: 2546-2554.
Nanjappan, K., P. Selvaraj, S. Jayachandran, P. Visha, and R. Mathivanan. 2013. Enriching chicken eggs with omega-3 fatty acids for improving human health. Indian Journal of Animal Sciences 83: 825-828.
Napolitano, F. et al. 2013. Consumer preference for chicken breast may be more affected by information on organic production than by product sensory properties. Poultry science 92: 820-826.
Noble, D. O. et al. 1993. Food-intake adjustments of chicks - short-term reactions of genetic stocks to deficiencies in lysine, methionine or tryptophan. British Poultry Science 34: 725-735.
National Research Council. 1994. Nutrient Requirements of Poulty. 9th rev. ed. Natl. Acad. Press, Washington, DC.
Olver, M. D., and D. D. Malan. 2000. The effect of choice-feeding from 7 weeks of age on the production characteristics of laying hens. South African Journal of Animal Science-Suid-Afrikaanse Tydskrif Vir Veekunde 30: 110-114.
Ozek, K., Y. Konca, A. U. Catli, and K. T. Wellmann. 2012. The effects of free choice feeding based on whole triticale on growth, meat quality, carcass characteristics and gastrointestinal traits in broilers. Revue De Medecine Veterinaire 163: 621-627.
Passos, A. A., C. Andrade, C. E. Phillips, M. T. Coffey, and S. W. Kim. 2015. Nutrient value of spray field forages fed to pigs and the use of feed enzymes to enhance nutrient digestibility. Journal of Animal Science 93: 1721-1728.
Paul, M. A. 2015. Effects of Post-hatch Holding Time and Early Nutrition Strategies on Growth Performance, Carcass and Skeletal Characteristics of Young Chickens. Theses and Dissertations--Animal and Food Sciences. Paper 50. http://uknowledge.uky.edu/animalsci_etds/50
Paxton, H., M. A. Daley, S. A. Corr, and J. R. Hutchinson. 2013. The gait dynamics of the modern broiler chicken: a cautionary tale of selective breeding. Journal of Experimental Biology 216: 3237-3248.

Pearl, R., and T. E. Fairchild. 1921. Studies on the physiology of reproduction in the domestic fowl. Xix. Of the influence of free choice of food matrials on winter egg production and body weight. American Journal of Epidemiology 1: 253-277.
Petersen, V. E. 1969. A Comparison of the Feeding Value for Broilers of Corn, Grain Sorghum, Barley, Wheat, and Oats, and the Influence of the Various Grains on the Composition and Taste of Broiler Meat. Poultry science: 2006-2013.
Phillips, C. J. C., and S. T. Strojan. 2007. The ability of chickens to select nutritive and avoid toxic concentrations of heavy metals in feeds. Journal of Sustainable Agriculture 30: 31-45.
Rack, A. L., K. G. S. Lilly, K. R. Beaman, C. K. Gehring, and J. S. Moritz. 2008. The effect of genotype, choice-feeding and season on organically reared broilers fed diets devoid of synthetic methionine. Poultry science 87: 9-9.
Rack, A. L., K. G. S. Lilly, K. R. Beaman, C. K. Gehring, and J. S. Moritz. 2009. The effect of genotype, choice feeding, and season on organically reared broilers fed diets devoid of synthetic methionine. Journal of Applied Poultry Research 18: 54-65.
Rao, S. V. R., M. Raju, M. R. Reddy, and A. K. Panda. 2004. Replacement of yellow maize with pearl millet (Pennisetum typhoides), foxtail millet (Setaria italica) or finger millet (Eleusine coracana) in broiler chicken diets containing supplemental enzymes. Asian-Australasian Journal of Animal Sciences 17: 836-842.
Rao, S. V. R., M. R. Reddy, N. K. Prarharaj, and G. S. Sunder. 2000. Laying performance of broiler breeder chickens fed various millets or broken rice as a source of energy at a constant nutrient intake. Tropical Animal Health and Production 32: 329-338.
Rath, N. C., G. R. Huff, W. E. Huff, and J. M. Balog. 2000. Factors regulating bone maturity and strength in poultry. Poultry science 79: 1024-1032.
Rathgeber, B. M., P. McCarron, and K. L. Budgell. 2013. Salmonella penetration through eggshells of chickens of different genetic backgrounds. Poultry science 92: 2457-2462.
Raubenheimer, D., and S. J. Simpson. 1997. Integrative models of nutrient balancing: application to insects and vertebrates. Nutrition research reviews 10: 151-179.
Ravindran, V., L. I. Hew, G. Ravindran, and W. L. Bryden. 2005. Apparent ileal digestibility of amino acids in dietary ingredients for broiler chickens. Animal Science 81: 85-97.
Richardson, J., J. Burgener, R. Winterfield, and A. Dhillon. 1980. Deep pectoral myopathy in seven-week-old broiler chickens. Avian diseases: 1054-1059.
Richter, C. P., L. E. Holt Jr, and B. Barelare Jr. 1938. Nutritional requirements for normal growth and reproduction in rats studied by the self-selection method. American Journal of Physiology.
Rooney, L. W. 1978. Sorghum and pearl millet lipids. Cereal Chemistry 55: 584-590.
Roura, E., B. Humphrey, G. Tedo, and I. Ipharraguerre. 2008. Unfolding the codes of short-term feed appetence in farm and companion animals. A comparative oronasal nutrient sensing biology review. Canadian Journal of Animal Science 88: 535-558.
Rovee-Collier, C., H. Hayne, G. Collier, P. C. Griesler, and G. B. Rovee. 1996. Diet selection by chicks. Developmental Psychobiology 29: 241-272.

Rugg, W. 1925. Feeding experiments, free choice of feeds. Victoria Department of Agriculture Bulletin 54: 36-56.
Sahin, A. 2003. Cereals in choice feeding of finishing broiler chickens. Journal of Applied Animal Research 24: 213-217.
Sapkota, A. R., L. Y. Lefferts, S. McKenzie, and P. Walker. 2007. What do we feed to food-production animals? A review of animal feed ingredients and their potential impacts on human health. Environmental Health Perspectives 115: 663-670.
Schmidt, C. J., M. E. Persia, E. Feierstein, B. Kingham, and W. W. Saylor. 2009. Comparison of a modern broiler line and a heritage line unselected since the 1950s. Poultry science 88: 2610-2619.
Scholz, B., S. Rönchen, H. Hamann, M. Hewicker-Trautwein, and O. Distl. 2007. Keel bone condition in laying hens: a histological evaluation of macroscopically assessed keel bones. Berliner und Munchener Tierarztliche Wochenschrift 121: 89-94.
Scott, T., and D. Balnave. 1988. Comparison between concentrated complete diets and self-selection for feeding sexually-maturing pullets at hot and cold temperatures. British Poultry Science 29: 613-626.
Scott, T., and D. Balnave. 1989. Responses of sexually-maturing pullets to self-selection feeding under different temperature and lighting regimens. British poultry science 30: 135-150.
Sedghi, M., M. R. Ebadi, A. Golian, and H. Ahmadi. 2011. Estimation and modeling true metabolizable energy of sorghum grain for poultry. Poultry science 90: 1138-1143.
Siller, W. G. 1985. Deep pectoral myopathy: A penalty of successful selection for muscle growth. Poultry science 64: 1591-1595.
Sirri, F., C. Castellini, A. Roncarati, A. Franchini, and A. Meluzzi. 2010. Effect of feeding and genotype on the lipid profile of organic chicken meat. European Journal of Lipid Science and Technology 112: 994-1002.
Smith, N. 2004. Saving Rare Breeds Mother Earth News. p 57-63. Ogden Publications, Inc., Topeka.
Steinruck, U., and M. Kirchgessner. 1992. Regulation of protein-intake of hens with high laying performance by self-selecting diets with different protein-levels. Archiv Fur Geflugelkunde 56: 163-171.
Steinruck, U., and M. Kirchgessner. 1993a. The effects of color and flavor experience on the ability of laying hens to select an adequate dietary-protein level. Archiv Fur Geflugelkunde 57: 125-130.
Steinruck, U., and M. Kirchgessner. 1993b. Protein requirement, n-balance and protein-utilization of layers during self-selecting of different protein rations. Journal of Animal Physiology and Animal Nutrition-Zeitschrift Fur Tierphysiologie Tierernahrung Und Futtermittelkunde 69: 44-56.
Steinruck, U., and M. Krichgessner. 1993. The origin of the specific protein hunger of layers by investigating their responses in dietary self-selection. Archiv Fur Geflugelkunde 57: 42-47.
Syafwan, S., G. J. D. Wermink, R. P. Kwakkel, and M. W. A. Verstegen. 2012. Dietary self-selection by broilers at normal and high temperature changes feed intake behavior, nutrient intake, and performance. Poultry science 91: 537-549.

Tahir, M., F. Saleh, A. Ohtsuka, and K. Hayashi. 2008. An effective combination of carbohydrases that enables reduction of dietary protein in broilers: importance of hemicellulase. Poultry science 87: 713-718.
Torres, T. R. et al. 2013. Performance of Broilers Fed During 21 Days on Mash or Pellet Diets Containing Whole or Ground Pearl Millet Grain. Brazilian Journal of Poultry Science 15: 371-378.
Tuunainen, P. et al. 2016. Effects of dietary rapeseed meal and peas on the performance and meat quality of broilers. Agricultural and Food Science 25: 22-33.
USDA. 2012a. USDA AMS National Organic Program. http://www.ams.usda.gov/nop
USDA. 2012b. National list of allowed and prohibited substances. Electronic Code of Federal Regulations: Part 205 – National Organic Program.
Ussery, H. 2008. Incredible Homestead Chickens Mother Earth News. p 81-85. Ogden Publications, Inc., Topeka.
Van Horne, P., and N. Bondt. 2013. Competitiveness of the EU poultry meat sector. LEI Report 68: 1-67.
Weerd, H. A. v. d., R. Keatinge, and S. Roderick. 2009. A review of key health-related welfare issues in organic poultry production. World's Poultry Science Journal 65: 649-684.
Wilkinson, S. J., P. H. Selle, M. R. Bedford, and A. J. Cowieson. 2014. Separate feeding of calcium improves performance and ileal nutrient digestibility in broiler chicks. Animal Production Science 54: 172-178.
Will, O. H., III. 2014. Heritage backyard chickens. Mother Earth News. p 56-58,60,62. Ogden Publications, Inc., Topeka.
Wu, Y., V. Ravindran, D. Thomas, M. Birtles, and W. Hendriks. 2004. Influence of phytase and xylanase, individually or in combination, on performance, apparent metabolisable energy, digestive tract measurements and gut morphology in broilers fed wheat-based diets containing adequate level of phosphorus. British poultry science 45: 76-84.
Yadava, P. K., P. S. Niranjan, S. K. Udeybir, and D. N. Verma. 2009. Performance of Broiler Chicken as Affected by Varying Levels of Multi Enzyme Supplementation. Animal Nutrition and Feed Technology 9: 103-108.
Yo, T., P. B. Siegel, H. Guerin, and M. Picard. 1997. Self-selection of dietary protein and energy by broilers grown under a tropical climate: Effect of feed particle size on the feed choice. Poultry science 76: 1467-1473.
Zakaria, A. H., and O. H. Omar. 2013. Egg laying pattern, egg weight, body weight at hatch, and sex ratio bias relative to oviposition time of young-and mid-age broiler breeders. Animal Reproduction Science 141: 80-85.
Zhao, H. G. et al. 2015. Impact of feed additives on surface mucosal health and columnaris susceptibility in channel catfish fingerlings, Ictalurus punctatus. Fish & Shellfish Immunology 46: 624-637.
Zubair, A. K., and S. Leeson. 1996. Compensatory growth in the broiler chicken: A review. Worlds Poultry Science Journal 52: 189-201.
Zuberbuehler, C. A., R. E. Messikommer, and C. Wenk. 2002. Choice feeding of selenium-deficient laying hens affects diet selection, selenium intake and body weight. Journal of Nutrition 132: 3411-3417.

Zuidhof, M. J., B. L. Schneider, V. L. Carney, D. R. Korver, and F. E. Robinson. 2014. Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 2005. Poultry science 93: 2970-2982.

VITA

Tatijana Fisher was born and raised in Lexington, KY. She was selected to participate in the Kentucky Governor's Scholars Program in 2007, and graduated from Henry Clay High School in 2008. Tatijana was awarded a full tuition scholarship to attend the University of Kentucky for her undergraduate degree. As an undergraduate, Tatijana actively participated in a variety of research programs across campus. Her favorite was a project which involved using a molecular fingerprinting technique to compare the gastrointestinal bacteria of horses to those of phylogenetically related zoo species (zebras, rhinoceroses, and tapirs) and an unrelated species (goats) living in close proximity to the horses .In May 2012, Tatijana graduated from the University of Kentucky with a Bachelor's of Science in Animal Science and a Bachelor's of Science in Agricultural Biotechnology.

After graduation, Tatijana participated in the nutrigenomics research internship program at Alltech Inc. in Nichollasville, KY. This experience inspired her to pursue a graduate degree in poultry nutrition with Dr. Anthony Pescatore which she began in August 2008. Throughout graduate school, Tatijana was involved in research, teaching, and extension. Tatijana received the Poultry Science Association Certificate of Excellence for presentations on her research in 2014 and 2016. In addition to her research, Tatijana was heavily involved with ASC 101, the departments' 300-student introductory animal science course. She served as a teaching assistant in the fall of 2013, and as an instructor for the course in the fall of 2014. Tatijana earned her Graduate Certificate in College Teaching & Learning in 2015. Tatijana served as secretary of the Animal and Food Sciences Graduate Student Association from 2013 to 2014. In 2015, Tatijana was elected to serve as the Student Director for the Poultry Science Association.