ECONOMIC FEASIBILITY OF RAISING BIRDS SEX SEPARATED VS. COMMINGLED WHEN FED MAXIMUM PROFIT DIETARY LYSINE LEVELS

by

MANUEL J. GONÇALVES DA COSTA

(Under the Direction of GENE M. PESTI)

ABSTRACT

Economic benefits of raising birds sex separate vs. straight-run has been a paradigm for the broiler industry over the years. Three experiments were conducted to evaluate the effects of raising birds straight-run vs. sex separate (Experiment 1), and determine optimum digestible lysine (dLys – maintaining the amino acid ratio) levels for net returns (NRML) for the starter (Experiment 2) and grower phases (Experiment 3) for each system. For each of the 3 experiments an economic simulation of net returns of feed cost over whole carcass or cut-up part weights was made for different market weights considering a 1.8 million broiler complex. Experiment 1 revealed economic advantages of sex separation, on 1,344 broilers chicks of two genetic strains processed at 1.7, 2.7, and 3.7 kg MW, of $99,000 for Ross 308, and $254,700 for Ross 708. In addition, bird uniformity was increased in sex separate treatments when compared to straight-run. In experiment 2, 3,240 Ross 708 chicks were fed starter diets (0 to 25d) with 6 dLys levels (1.05% to 1.80% of dLys). A 1.6 kg projected market weight was considered to be sold as whole carcass. Females, males and straight-run birds had 1.07, 1.05, and 1.05 % NRML of dLys respectively. Sex separation was not economically viable (-$13,058) for the light market weight after the cost of sexing chicks was deducted from the returns. Experiment 3 had 2,160

Ross 708 chicks fed grower diets (14 to 32d) with 6 dLys levels (0.90% to 1.30% of dLys). There were 2 projected market weights: 1.7 kg (whole carcass – females and straight-run birds) and 2.9 kg (cut-ups – males and straight-run birds). For the whole carcass, 0.90 and 1.01% were NRML of dLys for females and straight-run birds. The cut-up market had NRML of dLys set at 1.30 and 1.14 % for males and straight-run birds. When combining the two market weights for the complex, sex separation resulted in $112,341 of extra returns. In conclusion, sex separation was shown to result in increased profitability, and NRML of dLys to be dependent on market target weight.

INDEX WORDS: broiler, sex separate, straight-run, economics, maximum profit, lysine, protein, starter, grower

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MANUEL J. GONÇALVES DA COSTA
M.Sc., ICBAS – University of Porto, Portugal, 2010
D.V.M., ICBAS – University of Porto, Portugal, 2010
M.S., North Carolina State University, 2013

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2016

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MANUEL J. GONÇALVES DA COSTA

Major Professor:	Gene M. Pesti
Committee:	Thomas J. Frost
	Greg Colson
	Michael J. Azain
	Woo-Kyun Kim

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
August 2016

DEDICATION

To my brother, Manuel António Da Costa; to my parents, Manuel Fernando Da Costa and Maria de Fátima Gonçalves; to my aunt, Maria de Lourdes Gonçalves; to my grandparents, Julia Teixeira, Adelino Gonçalves, António Da Costa, and Rosalina Moreira. This achievement was only possible because you were there to support me and help me to walk strong through this path of my life.

To Bianca Lourenço, for always being there when needed, for being the best companion that I could have, for the advice, for the friendship, and for all the love. Thank you for everything. You were and you will always be my best friend. I can foretell a bright and happy future for us. We will go and we will see!

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to Dr. Gene Pesti for the amazing learning experiences and professional instruction that he has provided me here at UGA. Thank you for always having an open door to receive me and all the pieces of advice you have given me during the past three years. With no doubt, you left an important stamp on my personal and professional development.

I would also like to thank all Dr. Tom Frost, Dr. John Halley, Dr. Greg Colson, Dr. Michael Azain, and Dr. Woo-Kyun Kim for serving on my committee and for their advice.

I would like to specially thank all the undergraduate students that helped me during my stay at UGA. Without your companionship and hard work this would not have been possible. You definitely made my life easier throughout this process. Thanks to all my graduate student and post-doc fellows for the good times and friendship. Additionally, I would like to acknowledge Dr. Hector Cervantes, Dr. Ivan Alvarado, and Dr. Duarte Neves for all the work and learning opportunities provided, for all of the advice given, and for their friendship.

These years in graduate school were undoubtedly full of joy mainly due to my ΛΠΖ brothers. Thank you Wilmer and Marcelo. Our friendship will last forever my friends.

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CHAPTER 1

Introduction and Literature Review

INTRODUCTION

Considering the importance of the optimization of management and nutrition for maximizing returns regarding poultry companies, the objective of this project first took a stance to evaluate the advantages of raising broilers sex separated when compared with straight-run, and to later determine dietary digestible lysine levels (when maintaining the amino acid ratio) that would maximize returns for various market weights. For that, we hypothesized that raising birds sex separate would result in increased returns and a more uniform product at various market ages, and also that protein level for maximum profit would depend on the gender of the birds. In order to accomplish our research objectives, three experiments were conducted to test the effects of the rearing system and dietary protein level on the production net returns.

As a first approach we decided to evaluate if raising the birds sex separated or straight-run *per se* would result in different performance and consequently different profitability, for two genetic lines:

1. Straight-run *vs.* Sex Separate Rearing for Two Broiler Genetic Lines

Afterwards, considering the results of the first experiment, two experiments were conducted to evaluate optimum digestible lysine levels for the starter and grower phase of birds raised under the two rearing systems:

2. Evaluation of Starter Dietary Digestible Lysine Level on Broilers Raised Under a Sex Separated or Straight-run Housing Regime
3. Evaluation of Grower Dietary Digestible Lysine Level on Broilers Raised under a Sex Separated or Straight-run Housing Regime

LITERATURE REVIEW

The United States of America is responsible for producing around 18,256,844 tons of ready-to-eat poultry meat each yr (USDA, 2016), making it the world's leader in poultry production. Over the past yr, the processing and selling of poultry in cut parts has become a common practice, mainly due to preferences of consumers, but also because of the economics of aggregate that add extra value to the product. One of the reasons that make the poultry industry a success worldwide is because the most economically favorable scenarios are constantly being sought out, with management and nutrition occupying a central role on the costs and profits of poultry companies. Raising broilers sex commingled (straight-run) is still a common practice in the United States of America, whereas broilers are mostly raised sex separate in other parts of the world. Raising broilers straight-run results in potential higher product variability at market age and also does not allow the producer to adapt a diet to benefit each gender. With that being said, the objective of the following review is to evaluate what has been done regarding raising broilers sex separate vs. straight-run, and also the effects of protein/digestible lysine level on broiler performance and economics.

Sex separated vs. straight-run

Proving whether or not there are economic benefits of raising broilers sex separated vs. straight-run (combined genders) has been one of the main dilemmas throughout the years of poultry production. The economic benefits of raising chickens sex separated can be a result in better growth rates, better feed efficiency due to a more efficient design of diets allocated to each gender need, and the reduced variability in the final product which facilitates bird processing. Even though there are potential major benefits that sex separation could have on company finances, very little research has been conducted to this date regarding this topic. Smith, et al. (1954) evaluated the advantages of sex separation under commercial conditions using 6,000 chicks. These authors report that neither BW nor feed efficiency were affected by sex separation, however, they state that males reached market weight two wk sooner than females. At nine wk, males raised separate weighed 1,350 g on average; whereas males raised straight-run weighed 1,360 g. Conversely, females raised sex separate weighed 1,121 g, being heavier than females that were raised straight-run which weighed 1,107 g. At eleven wk, the BW difference between males was less pronounced with sex separate males weighing 1,719 g and straight-run 1,755 g. Therefore, there were some indications that females could benefit from sex separation in terms of gain, whereas males could result in losses. Laseinde and Oluyemi (1994) also evaluated the effect of sex separation at ten wk of age in broilers raised straight-run until four wk. No BW data was reported, and the statistical analysis shown indicates no differences between daily BW gain (g/bird/day) regarding males and females within the rearing system (sex separate *vs* straight-run). Nevertheless, similarly to Smith, et al. (1954), the authors indicate that males raised straight-run tended to be heavier than the males that were sex separate.

Hess, et al. (1960) observed that the advantage of rearing broilers sex separate was dependent on bird age and bird source (ten commercial broiler stock breeders). At eight wk of age, intermingled broilers were heavier than sex separated (1,374 g *vs* 1,338 g for males, and 1,107 g *vs* 1,089 g for females), conversely at nine wk the intermingled broiler showed to be lighter than sex separate (1,564 g *vs* 1,624 g for males, and 1,284 g *vs* 1,302 g for females). Nevertheless, these authors reported a higher variation on the birds tested intermingled than in the ones that were sex separate. The evaluation of genotype and rearing system interaction was also evaluated by Lamoreux and Proudfoot (1969). Contrarily to Hess, et al. (1960), Lamoreux and Proudfoot (1969) did not find an interaction between rearing system and genotype with only the effect of sex and genotype being reported as significant. The authors reported no differences of BW between genders raised in the two systems, however, when looking at the data presented in the paper on average males were heavier when mixed sex when compared to the sex separate (Experiment one: 2,413 g *vs.* 2,383; Experiment two: 2,419 g *vs.* 2,402 g), whereas females barely differ on BW (Experiment one: 1,905 g *vs.* 1,904; Experiment two: 1,913 g *vs.* 1,912 g) at nine wk of age. Regarding BW CVs, males reared in a mixed sexed system had lower values (Experiment one: 8.70 % *vs.* 10.47 %; Experiment two: 8.97 % g *vs.* 9.52 %), while the females' values only differ slightly, this being the difference dependent on the experiment (Experiment one: 8.77 % *vs* 9.61 %; Experiment two: 8.90 % g *vs* 8.76 %).

Recently, Api (2014) evaluated the effects of raising three genetic lines (Cobb, Ross, and Hubbard) using separate or mixed sex rearing. Weekly results were reported with rearing systems yielding different BW gain, feed intake and FCR, at three wk of age. At the end of the experiment (45 d), these differences were the most evident with females presenting the lowest BWG and FI (BWG = 108 g; FI = 540 g), followed by the mixed sex birds (BWG = 182 g; FI = 580 g), and then by the males (BWG = 232 g; FI = 570 g). Similarly for FCR, females had the poorest results (1.74 g:g), followed by mixed sex (1.68 g:g), and males (1.61 g:g) coming after. After finding these results, the author performed a field survey in 141 flocks using the same factors (genetic line and sex separate or mixed rearing system). No information regarding the number of farms for each factor or distribution of treatments by farm complexes was provided; therefore, these results might be confounded. Nevertheless, the study reported the average BW of females to be 2,740 g, males to be 3,007 g, and mixed 2,852 g, at 47, 44, and 46 d of age respectively. For FCR, females presented values of 1.830 g:g, males 1.694 g:g, and mixed birds

1.787 g:g. Despite the results, the differences in slaughter ages and BW make it challenging to create a fair comparison between the rearing systems in terms of efficiency. Therefore, the author presents FCR corrected for BW where females resulted in values of 1.755 g:g, males of 1.551 g:g, and mixed sex of 1.686 g:g. In theory, mixed sex birds should have the average between the males and females FCR. However, when averaging the sex separate birds, the FCR of mixed sex shows to be higher (average = 1.653 g:g; mixed sex = 1.686 g:g). This indicates that raising birds together or sex separate might have an effect on feed efficiency of the birds. Furthermore, mixed sex flocks showed higher mortality rates (5.73 %) when compared with males (4.33 %) and females (3.81 %).

There is also evidence that the benefits of raising broilers sex separate might be dependent on bird stocking density (Deaton, et al., 1973). In one experiment, the interaction of stocking density and rearing system was evaluated and the results showed that males raised in high density (0.073 m^2/bird mixed sex *vs.* 0.079 m^2/bird sex separate) and sex separate were heavier than the mixed (1,633 g *vs.* 1,609 g). However, if males were raised in a lower density (0.051 m^2/bird mixed sex *vs.* 0.055 m^2/bird sex separate), the results were the opposite, where the sex separate males were lighter than the straight-run (1,566 g *vs.* 1,590 g). On females regardless of stocking density (0.073 m^2/bird mixed sex *vs.* 0.067 m^2/bird sex separate; 0.051 m^2/bird mixed sex *vs.* 0.047 m^2/bird sex separate) sex separate birds were always heavier (1,371 g *vs.* 1,340 g; 1,323 g *vs* 1,307 g). Even though not statistically different, on average male CVs were lower in mixed rearing (8.8 % *vs.* 9.85%) while females were higher (9.8 % *vs.* 8.55%). In this experiment, the space in the pen per bird calculated for males and females differ and the number of birds per feeder in each treatment as well. Therefore, this might have a confounded effect on the results. In addition, after five wk of age a protocol of heat stress was used, which might have impacted feed intake and affected the competitive behavior for feed and performance outcomes related with the rearing system. In another study, de Albuquerque, et al. (2006) also evaluated the interaction of rearing type with stocking density. Birds raised sex separate and straight-run were housed according to two stock densities (10 birds/m^2 *vs* 15 birds/m^2) and were allowed to grow up to 45 d of age. Overall, males grew faster and were more feed efficient (BW = 2,402 g; FCR = 1.74 g:g), with straight-run coming after (BW = 2,174 g; FCR = 1.80 g:g), while females performed the worst (BW = 2,101 g; FCR = 1.81 g:g). Theoretically, the straight-run pens should be an average of the female and male results. However, when averaging both BW (average male and female BW = 2,252 g) and FCR (average male and female FCR = 1.78 g:g) it is clear that birds in a straight-run rearing system performed worse than birds raised sex separate, revealing that social interactions between genders might have a role on performance. The interaction of the rearing system with stock density was also evident. Results of kg of chicken BW produced by m^2 showed that the differences between sex separate and straight-run were more evident at lower densities, with females growing more in this density range. The low density range resulted in 21.29, 19.30, and 18.75 kg/m^2, whereas the high density range resulted in 32.60, 29.05, and 29.41 kg/m^2 of live birds for male, female and straight-run birds respectively. When averaging the males and females (low density average = 20.30 kg/m^2; high density average = 30.83 kg/m^2) and comparing them with straight-run birds, it is again discernible that sex separate birds grew more at low bird densities.

Besides effects of the rearing system on bird performance, an advantage of more efficient processing due to less animal size variability has also been suggested by Gehle, et al. (1974). These authors evaluated different lengths of starter and finisher phases for broilers raised sex-separate or straight-run. At 56 d, BW and FCR showed to be the best for male pens (BW = 2,011 g; FCR = 2.00 g:g), followed by straight-run chicks (BW = 1,794 g; FCR = 2.03 g:g), and then females (BW = 1,587 g; FCR = 2.08 g:g). Regarding phase feed allocation for both genders, it was demonstrated that females reared in sex separate pens had different nutritional needs than males, and a consequential adjustment of nutrition for each gender should be considered for the greatest economic return. In addition to performance, differences in the incidence of chondronecrosis with osteomyelitis have been observed between chickens raised straight-run and sex separate (Wideman, et al., 2013). Females raised sex separate have been shown to have lower incidences of osteomyelitis, when comparing with females raised straight-run. It was suggested that these differences were possibly related with higher social/psychological or physical/competitive stress than females who were raised straight-run would be exposed to when mingling with males. Also, even though the authors do not report individual BWs of both genders within the straight-run treatment, it is pointed out that the standard deviation was the lowest for female pens, whereas straight-run had the highest. The authors indicate that this can be advantageous for processing, since the equipment could be adjusted more precisely to a narrower weight range. Furthermore, the condemning and downgrading of carcasses on the processing line indicated that female and straight-run birds tended to be higher than males, since the equipment was previously set to male body size. Nevertheless Wideman, et al. (2014) when trying to reproduce the same effect in another experiment, failed to observe differences in osteomyelitis incidences when raising broilers sex separate or straight-run.

Another concern of growing chicks sex separate or straight-run is the impact that it might have on experimental outcomes. In live poultry experimentation, error can arise and be divided into three main portions: the first is related with the inherent variation of the population used in the test, the second is related with variation induced by the treatments being applied into the population, and the third is the variation induced by non-treatment environmental effects that might be unevenly distributed within the experiment. Becker and Berg (1959) evaluated the effect of raising chicks on these two systems under two different planes of nutrition (medium *vs.* high) for a period of nine wk. Overall, both females and males raised on a mixed sex basis had a higher variance and coefficient of variation than the ones on the sex separate. The exception was the females raised on a medium plane diet, where mixed sexed females had lower variances and coefficients of variation. Chicks on the suboptimal diet also had higher indexes of variation. These authors report that experiments with separated sexes were more sensitive in showing the differences between the treatments. In addition, comparing either males or females within the two rearing systems for both sexes, separated rearing resulted in higher chances of detecting differences. Also between the two genders, males were more sensitive to determining differences between treatments than females. Lang, et al. (1960) reported in a research note of 2 nine wk small experiments that CV of BW of males and females raised separate or together did not differ. However, when looking to the data presented, it is noticeable that females had overall higher CVs when raised mixed than when compared to sex separate (Experiment one: 8.93 % *vs.* 10.33%; Experiment two: 7.94 % *vs.* 8.68%). Males' CVs differ in a lower magnitude with mixed birds showing lower values than males who were sex separate (Experiment one: 8.33 % *vs.* 8.62%; Experiment two: 7.81 % *vs.* 8.26%).

The differences in performance, disease condition, and bird size variation between the two rearing systems can be related with stressful social interactions (Wideman, et al., 2013). Regarding behavior and social hierarchy, chickens present agonistic behavior that includes fighting, pecking, and threatening in addition to submissive responses such as crouching, escaping, and avoiding contact (Guhl, 1968). As a group of chicks age in a group, social order is established gradually. Guhl (1958) reported that from the 2nd to the 6th wk of age of White Leghorns chicks, males expressed higher percentage of aggressive behavior towards other chicks than females, being the aggressiveness more pronounced toward other males. In addition, males established social organization sooner (8 wk) than females (9.5 wk), with the authors reporting that females were under social stress with little opportunity to feed in comparison with the males (Guhl, 1958). Therefore, these differences in "social maturity rate" can potentially explain the differences in performance reported in the literature.

Crude protein, digestible lysine, and ideal amino acid ratio

As a rule of thumb, when formulating diets for broiler chickens, the digestible amino acid levels are expressed as a ratio to digestible lysine level. Baker and Han (1994) stated that the optimum amino acid level can vary according to a multitude of dietary, environmental, and genetic factors, however the ideal ratio of indispensable amino acids to lysine should stay unaffected by the variables. Therefore, when formulating diets using a constant amino acid ratio to lysine, as digestible lysine levels increase the crude protein content will also increase. The effects of increasing crude protein level of isocaloric diets usually lead to improved feed efficiency, increased carcass yield and decreased fat content (Bartov and Plavnik, 1998; Corzo, et al., 2004; Kidd, et al., 2004; Kidd, et al., 2005; Pesti, 2009; Corzo, et al., 2010). However, the increase in dietary lysine levels does not yield a linear response, since if amino acids are in excess the birds will have to metabolize the excess, resulting in decreased utilization and efficiency (D'Mello, 1994). The increase in crude protein will generally guarantee the presence of enough dispensable amino acids, reducing consequently the needs of synthesizing them by usage of indispensable amino acids (Almquist, 1957). If in a diet there is a limitation of protein or a specific indispensable amino acid, there is a chance that the synthesis of new proteins stop. Consequently, this makes the evaluation of a response to a single specific amino acid challenging. It has been shown that lysine requirement levels for chicks varies with the protein content of the diets (Almquist, 1957). There is evidence that as the crude protein level increases, the percentage of essential amino acid required in the protein may decrease (Hurwitz, et al., 1998). In addition, the amino acid requirements vary directly with protein intake, revealing that for the most effective utilization, each essential amino acid should remain in balance with dietary protein and other amino acids (Almquist, 1957; Harper and Benevenga, 2013). This has been shown to be true in several peer-reviewed papers (Surisdiarto and Farrell, 1991; Hurwitz, et al., 1998; Sklan and Noy, 2003; Sterling, et al., 2003; Sterling, et al., 2005; Plumstead, et al., 2007).

Crude protein and amino acid balance. There are several reports in the literature that describe the interaction of lysine with protein levels and the importance of the keeping the amino acid balance. It has been suggested that when comparing the responses of dietary lysine according to various levels of crude protein, the ratio of digestible lysine should be specified in order guarantee a maximum response (Morris, et al., 1987; Abebe and Morris, 1990).

In 3 experiments Hurwitz, et al. (1998) evaluated the response of Cobb males to various levels of protein and lysine for up to four wk of age. The three experiments crossed six total lysine levels (0.69 to 1.37 % of total lysine) with two levels of crude protein (Exp. one: 23% *vs.* 25%; Exp. two: 20% *vs.* 23%; and Exp. three: 18% *vs.* 23% of CP). For experiment two and three, the low protein diets depressed growth and impaired feed efficiency. No differences were observed between protein levels on experiment one. Experiments 2 and 3 revealed that the lysine requirements for the birds on the high protein diets were higher than the ones for the birds on low protein diets; whereas in experiment one, no differences in the requirements were observed between the two levels of protein. This reveals that if protein is reduced, the response to lysine (requirement) might be limited.

In another two experiments, Sklan and Noy (2003) studied the relationship between lysine, other essential amino acids, and crude protein during the first wk of life for male Ross birds. When lysine effect was isolated maintaining the level of crude protein (23% of CP), meaning that there was a different ratio of lysine to other amino acids as lysine increased, BW gain and feed efficiency were maximized at 1.03 and 1.08% of lysine. When three levels of crude protein (20, 23, and 26 % of CP) were fed with either unbalanced or balanced amino acid ratios, results at 7 d showed that both BW and feed efficiency were maximized when high protein diets were fed in conjunction with balanced ratios. Again, these results suggest that there is some required relationship between essential amino acids and non-essential amino acids necessary to attain maximum growth.

The interaction of crude protein and lysine levels for the starter phase has been extensively studied previously (Sterling, et al., 2003; Sterling, et al., 2005). Sterling, et al. (2003) conducted a set of 3 experiments to evaluate performance response of Cobb chicks to various levels of protein and lysine from 9 to 18 d of age. The first experiment tested the combination of 3 protein levels (17, 20, and 23% crude protein) with two levels of lysine (3.5 and 4.8g of lysine/100g of crude protein). The results of this experiment revealed that BW gain and FCR were optimized at the highest levels of protein and lysine. The second and third experiment evaluated three levels of dietary crude protein (17, 18.5, and 23 % of crude protein) combined with 8 levels of lysine (0.5 to 1.2% in 0.1% increments for the 17 and 18.5% CP diets and 0.7 to 1.4% in 0.1% increments for the 23% CP, respectively). Overall, results of both experiments showed that higher levels of crude protein yield heavier broilers with better FCR. In addition, birds in higher protein diets responded to a higher extent to the increased lysine levels for BW gain (experiment 2: 17% of CP – 0.75 % of lysine requirement; 23% of CP – 0.97 of lysine requirement / experiment 3: 18.5 % of CP – 0.90 % of lysine requirement; 23% of CP – 1.04 of lysine requirement), and FCR (experiment 2: 17% of CP – 0.73 % of lysine requirement; 23% of CP – 0.98 of lysine requirement / experiment 3: 18.5 % of CP – 0.74 % of lysine requirement; 23% of CP – 1.06 of lysine requirement). In another paper Sterling, et al. (2005) fed male Cobb 500 chicks 16 dietary treatments coming from a combination of four crude protein levels and four lysine levels (17% CP with 0.6, 0.7, 0.8, or 0.9% lysine; 20% CP with 0.7, 0.8, 0.9, or 1.0% lysine; 23% CP with 0.8, 0.9, 1.0, or 1.1% lysine; and 26% CP with 0.9, 1.0, 1.1, or 1.2% lysine) from 7 to 17 d of age. Results indicated that BW gain increased as crude protein and lysine increased, whereas FCR was only improved as lysine increased. When using regression analysis, an interaction between crude protein and lysine was present, where when birds were fed the 26% of crude protein no further improvement on BW gain was observed after 1.1% of lysine, indicating a possible plateau.

The relationship between dietary crude protein and lysine requirement with or without maintaining the amino acid balance with excess of other essential amino acids provided, has also been studied by Surisdiarto and Farrell (1991) in two experiments. For both experiments, as protein and digestible lysine increased, both BW and FCR were improved. However, diets that had a surplus of amino acids (unbalanced) tended to respond more to digestible lysine increments rather than the ones where the amino acid ratio was kept. These findings suggest that in the diets with surplus of amino acids, the lysine was fairly balanced with other essential amino acids, and that amino acid balance might not be the only factor influencing lysine requirement when increasing dietary crude protein.

Another factor that might affect the response of lysine when increasing crude protein is dietary energy level. Plumstead, et al. (2007) studied the effects of metabolizable energy, digestible lysine, and amino acid balance on bird performance up to 21 d of age. In one experiment, straight-run Cobb 500 chicks were fed diets with three levels of metabolizable energy (3,000, 3100, and 3,200 kcal/kg) combined with four levels of crude protein (21.9, 23.5, 25.2, and 26.9%) with a fixed ratio of digestible lysine to crude protein maintained (1.05, 1.13, 1.21, and 1.29% of digestible lysine respectively). Regardless of the metabolizable energy level, there was an increase in performance (BW and FCR) as digestible lysine levels increased. Feeding 3,100 kcal/kg resulted in optimum BW and FCR with no further improvement when metabolizable energy was increased to 3,200 kcal/kg. On the second experiment, male Ross chicks were fed diets with two levels of protein (22.0 *vs.* 27.0 % of crude protein) combined with increased levels of digestible lysine while the ratio to other essential amino acids may or may not have been maintained. At 20 d, birds fed the low protein diets responded in a diminished relative response fashion to the increments of digestible lysine for BW gain (1.19% digestible lysine estimated to be the requirement). Conversely, when birds were fed either high protein or balanced diets, BW increased in a linear manner as digestible lysine increased. Quentin, et al. (2005), also tested the effect of two nutrient densities (Low: 2,902 kcal/kg, 20.9% CP, 1.10 % total lysine; and High: 3,121 kcal/kg, 22.9% CP, 1.40 % total lysine) fed to broilers up to 7 d of age, followed by a common grower diet (21.2 % CP, 1.15 total lysine) up to 21 d. At the end of the first week, the high density diet resulted in heavier broilers with a lower FCR. Improvement in BW by the high density was still detected after the common grower at 21 d of age.

Bird gender should also be taken into consideration when evaluating the response to different protein levels since males and females have been shown to respond differently. Kidd, et al. (2004) studied the interactions of four dietary phases formulated for low, medium, and high amino acid densities up to 49 d of life for Ross 508 male and females. The authors concluded that males tended to respond better to higher amino acid density than females, and that medium amino acid densities resulted in good feed conversion whereas maximum growth only occurred when high amino acid density diets were fed all way thought the life cycle. In another two experiments, Corzo, et al. (2005), fed two amino acid densities (low and high) to three genetic lines of both males and females from 1 to 56 d of age. Regardless of genetic line, high amino acid density resulted in better FCR and heavier birds, with males consistently out performing females throughout the experiment.

Starter phase lysine level. Most of the studies present in the literature regarding optimum lysine levels to be fed to broilers during the starter phase were done by varying only lysine content by the addition of lysine in synthetic form to the diets. Therefore, the response evaluated is specific to digestible lysine rather than a response to amino acid content. In addition, several factors as sex, age, and genetics have been shown to influence the optimum lysine levels determined. Generally, the results of experiment showed that high levels of lysine result in better performance and carcass yield. However, it is hard to find the maximum safe level that could be fed to broilers during the starter phase in the literature. Baker and Han (1994), evaluated two lysine levels (0.8% *vs.*1.12%) crossed with two amino acid ratio profiles (NRC 1984 *vs.* NRC 1994) from 8 to 17 d of age. Results indicated that the birds fed higher lysine levels gained more weight, and had better gain to feed ratios than the birds fed low lysine levels. Si, et al. (2001) also evaluated the effects of four lysine levels (1.1, 1.2, 1.3, and 1.4%) when combined with four amino acid ratios (100, 110, 120, or 130% of NRC (1994)) for a broiler starter diet (0 to 21 d). Similarly to Baker and Han (1994), there was no interaction of treatments observed with a maximum BW and minimum FCR obtained when the 1.3 % lysine starter diets were fed. These results indicate that birds can respond to lysine level regardless of the ratio to other essential amino acids.

Just evaluating the response to increased levels of digestible lysine, Dozier and Payne (2012) determined the optimum digestible lysine levels from 1 to 15 d of age for females of both Ross x Ross 708 and Hubbard x Cobb 500. Treatment diets were obtained by adding synthetic lysine to a basal diet at the expense of sand, showing a marginal change in crude protein. Ross 708 birds showed to have BW maximized when 1.35 and 1.27 % of digestible lysine were fed at 7 and 14 d respectively. FCR was minimized at 7 d at 1.38 % of digestible lysine. Hubbard x Cobb 500 birds had BW maximized when fed 1.26 and 1.18 % of digestible lysine at 7 and 14 d respectively. At 14 d of age, FCR was minimized when 1.26 % digestible lysine diets were fed. For the period right after the one evaluated by Dozier and Payne (2012), 15 to 18 d of age, Mehri, et al. (2010) estimated that BW gain and feed conversion were optimized at 0.95% and 1.08% of digestible lysine respectively for Ross 308 straight-run birds. Also, Abudabos and Aljumaah (2010) evaluated increased digestible lysine levels (100, 110, 120, and 130 % of NRC 1994) for 3 consecutive dietary phases (starter – 1 to 10 d; grower – 11 to 21 d; and finisher – 22 to 42 d) for male Cobb 500. BW was maximized when 110 % diets were fed, whereas minimum feed conversion was obtained with 120 % diets. Labadan, et al. (2001) studied the optimum lysine levels for the first two weeks of post-hatching (0.95 to 1.43% levels of lysine), observing that weight gain, breast muscle, and feed efficiency were maximized at 1.28, 1.32, and 1.21% of lysine respectively.

As mentioned previously, requirement for digestible lysine is dependent on various parameters such as bird gender. In a set of 3 experiments, Garcia, et al. (2006) evaluated the effects of sex on the estimation of optimum digestible lysine levels for Cobb 500 broiler chicks from 7 to 21 d of age. Results indicated digestible lysine levels that optimized BW gain and FCR were very similar between genders. BW gain was maximized at 0.98 and 0.93 % of digestible lysine for males and females respectively, whereas feed to gain was minimized at 1.01 and 0.99 %. On another experiment, the same authors evaluated the same factors (0.73 to 1.13 % of digestible lysine) for the period between 21 and 38 d of age. Males showed to have a higher requirement of digestible lysine than females for maximum growth (0.97% *vs.* 0.93%), and breast meat yield (0.98% *vs.* 0.90%). Both genders had FCR minimized at 0.96% of digestible lysine. In another 2 experiments, Garcia and Batal (2005) estimated the requirements for digestible lysine (experiment 1: 0.88, 0.98, 1.08, 1.18, and 1.28 of digestible lysine; experiment 2: 0.78, 0.88, 0.98, 1.08, and 1.18) for the period between 4 and 21 d of age for Cobb 500 by-product male chicks. Digestible lysine levels that maximized body weight gain and feed efficiency on the first experiment were 1.00 and 1.10% respectively, whereas the values for the experiment 2 were 0.99 and 0.94%. In addition the authors concluded that the levels of digestible lysine required for maximum performance up to 7d of age were lower than the ones required at 21 d, hypothesizing that this could be related to the role of the yolk sack on first week post-hatch nutrition.

Starter lysine level has also been shown to affect bird performance later in life. Kidd and Fancher (2001) evaluated the lysine needs for the starter period (1 to 18 d) and the carryover effect until 42 d of age for Ross x Ross 508 male chicks in two experiments. The levels of lysine tested were 0.88, 0.99, 1.10, 1.21, 1.32, and 1.43% of diet fed as mash and pelleted in experiment one and two respectively. At 18 d, the levels of dietary lysine that maximized growth (95% of maximum quadratic response) were 1.18 and 1.22% for the experiment one and two respectively.

The higher requirement estimated in experiment two might be related with the feed form, where pelleted diets have been shown to result in higher requirements of lysine (Greenwood, et al., 2005). Kidd and Fancher (2001) also concluded that feeding levels of lysine higher than NRC (1994) recommendations (1.10%) did not improve BW or carcass characteristics at 42 d. However, feeding levels below the recommended levels did result in lower BW and carcass weight at marketing age. In another study, with the aim of evaluating starter phase lysine levels interactions with grower/finisher phases, Kidd, et al. (1998) fed male Avian 34 x Avian chicks diets with either 1.04 or 1.21% of lysine from 1 to 18 d, that were posteriorly combined with three grower/finisher lysine levels of 0.88/0.73, 1.05/0.89, and 1.25/1.06 % of the diet from 19 to 49 d. High levels of lysine resulted in better performance (BW gain, and feed gain) at 18 d. An interaction between starter and grower/finisher phases was present on BW at 49 d, where birds fed low lysine levels during the starter phase never recovered the BW gain regardless of the lysine levels fed during the grower/finisher. Birds on the high lysine levels during starter phase, and fed either 1.05/0.89 or 1.25/1.06 % during the grower/finisher phases were the heaviest. There were are also evidence that even if birds are fed high lysine levels during the starter phases, if low levels of lysine during grower/finisher phases are provided, bird performance will be impaired.

Grower and finisher phase lysine level. Similarly to the starter phase, the studies done for later phases were mostly done by varying only lysine content, with the results obtained being specific to digestible lysine and not to overall increase or decrease in crude protein content. Nevertheless, in two experiments Dimova (2012) assessed the effect of digestible lysine levels (0.60 to 1.16 % of digestible lysine) maintaining the ratio to other amino acids (increased levels of protein – 13.28 % to 22.00% of crude protein) from 35 to 48 d of age for straight-run birds of

Cobb 500 x Cobb FF and male chicks of Cobb 500 FF female x Hubbard M99 male cross. The straight-run chicks' optimum digestible lysine levels for BW gain, FCR, and white meat were determined to be 0.96, 0.99, and 0.95 % respectively. For the male chicks BW gain, FCR, and white meat were respectively ideal at 0.86, 0.91, and 0.90% of digestible lysine.

Isolating the effect of lysine, Labadan, et al. (2001) studied the optimum lysine levels for three dietary phases in a set of three experiments. For the period between two to four weeks of age (0.96 to 1.36% of lysine tested) 1.13, and 1.21 maximized weight gain and breast muscle respectively. For the 3-wk period between three to six wk of age (0.75 to 1.15% of lysine tested), both weight gain and breast meat were maximized at 0.99% of lysine, whereas feed efficiency was maximized at 1.00%. For the final stage between 5 and 8 wk (0.66 to 1.06% of lysine tested), both weight gain and breast meat were maximized at 0.81% of lysine. Also carrying the birds to further stages, Si, et al. (2001) fed grower (21 to 42 d – 1.0, 1.1, 1.2, and 1.3 % of Lys) and finisher (42 to 56 d – 0.85, 0.95, 1.05, and 1.15 % of Lys) diets using the same four amino acid ratio treatments (100, 110, 120, or 130% of NRC (1994)). Both BW and FCR were optimized at 42 d when feeding the 1.2 % lysine grower diets. There was no significant effect of lysine level on the finisher diets.

Different bird genetics have also been shown to respond differently to lysine. In two experiments, Dozier, et al. (2010) evaluated the response of Ross x Ross TP16 and Cobb x Cobb 700 to digestible lysine levels from 0.64 to 1.20 % for the period between 28 to 42 d of age, using a quadratic broken linear model. The authors formulated two basal diets, low and high digestible lysine levels that were posteriorly blended to attain 9 treatment diets. The two basal diets were formulated with the same levels of other essential amino acids, having consequently for each dietary treatment, different ratios of digestible amino acids to digestible lysine level.

Nevertheless, the Ross birds added BW gain, feed conversion ratio, and breast weight were optimized at 0.988, 1.053, and 0.962 % of digestible lysine respectively. Additionally, Cobb 700 broilers had the parameters optimized at 0.965, 1.012, and 0.981 of digestible lysine. Similarly to genetics, bird genders seem to have different lysine requirements. Han and Baker (1994) determined that from 22 to 43 d of age, male and female Ross x Ross had BW maximized when fed 0.85% and 0.78% of digestible lysine respectively. In addition, digestible lysine levels that optimized feed efficiency were 0.89% and 0.85% for males and females respectively.

Interaction of dietary crude protein/lysine and energy throughout different phases has also been studied. Quentin, et al. (2005) evaluated the effects of feeding increased levels of protein (4 levels: 16.9 % CP, 0.80 % Lys; 18.2 % CP, 0.90 % Lys; 16.9 % CP, 1.00 % Lys; 16.9 % CP, 1.10 % Lys) from 21 to 42 d, after feeding two density diets (Low: 2,902 kcal/kg, 20.9% CP, 1.10 % total lysine; and High: 3,121 kcal/kg, 22.9% CP, 1.40 % total lysine) from 0 to 7 d, and common grower (21.2 % CP, 1.15 total lysine) from 7 to 21 d. Overall, feeding high density diets resulted in heavier broilers at 42 d with increased breast meat yield. However, an interaction of starter density and protein level from 21 to 42 d was present, where the birds fed low density and high protein diets tended to recover gain when compared with the birds fed high density diets during the first week.

Factors regarding management, as bird density, or feed manufacturing have also been described to interact with dietary lysine level on bird performance. Berri, et al. (2008), evaluated the effects of bird density (13 *vs.* 26 birds/m^2) and 4 levels of lysine (0.83% to 1.13% true digestible lysine) on Ross 308 male birds from 21 to 42 d of age. Results indicated that high density impaired performance (BW gain, FCR, and feed intake), and high lysine levels increased BW and reduced FCR of the birds. An interaction of density and lysine levels on feed intake was present for the 21 to 42 d period. When on low density, feeding different levels of lysine did not have an effect on feed intake, whereas when birds were on high density feeding, 0.93% of lysine resulted in higher intake. Regarding feed form and dietary digestible lysine interaction, Greenwood, et al. (2005) evaluated the optimum digestible lysine levels (0.75, 0.85, 0.95, 1.05, and 1.15% of digestible lysine) when mash and pellet diets were provided from 16 to 30 d of age. The authors concluded that birds fed pelleted diets had a higher growth rate, and therefore had higher digestible lysine levels needed than the ones fed mash diets. Maximum growth and feed efficiency were attained when 0.87% and 0.90% were respectively fed in the mash form, and 1.00% and 0.99% were respectively fed in pellets. Still, to attain the same BW, birds fed pelleted diets needed less digestible lysine levels. In another study, Corzo, et al. (2012) evaluated how 3 feed forms (mash, mash exposed to conditioner steam, and pellets in the form of crumbles) would affect the optimum level of digestible lysine (0.85, 0.95, 1.05, 1.15, and 1.25%) from hatch until 18 d of age for Ross 708 males. Birds fed a pelleted diet responded to a greater extent to lysine accretion in terms of BW gain and feed conversion than the birds fed mashed diets. In addition, birds fed pelleted diets reached maximum growth at lower digestible lysine levels (1.11%) than birds fed mash (1.13%) and mash conditioned (1.15%) diets.

Economics of management and nutrition

Generally, reports present in the literature describe optimum management and nutritional factors that will maximize bird performance. However, for poultry companies, maximum performance might not always be a synonym for maximum return. For instance, high levels of lysine usually result in better performance and carcass yield, however, increased dietary costs will come as lysine is increased, and therefore the question that should always be asked is: where can the line be drawn to show where the costs overcome the returns? There are some economic evaluations in the literature especially related with nutrition, however, this type of analysis is still limited. Nevertheless, it is clear that choosing different nutrient levels when formulating diets will likely result in different returns. As an example, Trevisan, et al. (2014) evaluated the gross margins of feeding diets based on breeder guide or NRC (1994) recommendations for male Cobb 500 slow feathering birds, and concluded that Cobb Vantress recommendations resulted in higher trade gross margins ($0.821) than feeding NRC levels ($0.762).

Regarding overall diet density, Dozier, et al. (2006a) evaluated the economic advantages of two nutrient densities (moderate or high) when feeding Ross 508 (straight-run) 3 or 4 feeding phases up to 56 d of age. The differences in diet costs between the treatments had minimal differences in gross feeding returns. In addition, the authors reported that meat price changes had a greater impact on the gross feeding margins between diets formulated to high or moderate nutrient density than variation in diet cost. In another set of two studies, Dozier, et al. (2006b) evaluated the effects on economic feasibility under twenty-four scenarios of amino acid density (low, moderate, or high) for the withdrawal period (36 to 56 d) of straight-run Ross 708. The authors concluded that the most economic advantages of feeding high amino acid densities come when meat prices were considered the highest. Decreasing meat prices reduced the economic differences between the treatments. Considering a complex of 1 million broilers, the authors estimated that feeding high amino acid density diets under a base price of meat and feed, could result in an additional income of $7,000 to 11,000$/wk when comparing with medium and low amino acid densities.

Effects of dietary protein on returns have also been studied by Eits, et al. (2005). These authors observed that the optimum levels of protein formulated for profit or performance are different, concluding that dietary balanced protein level should be based on how broilers are marketed. In addition, the authors observed that the levels of protein for males and females that maximized profit were very close to each other, with the differences between them being negligible on the gross margin. The setting of nutrient levels according to market weight for maximum return is also well depicted in Basurco, et al. (2015). Evaluating the economic impact of feeding various levels of energy (low, moderate, and high) and amino acid densities (low, moderate, and high) to Cobb 500 females targeted to small whole carcass markets (1.0 kg eviscerated carcass) under high and low feed/meat price scenarios, Basurco, et al. (2015) states that for low market BW the fixed costs (farm and processing) play a major role in the returns, being that the differences on performance induced by changing dietary factors (variable cost) are so diminished that they have little to no impact on the economic returns. Still, the authors observed that high energy density combined with either moderate or high amino acid density resulted in higher gross margins.

Specifically studying the effects of lysine, Aftab (2012) used studies from 1993 to 2010 to evaluate the effect of increasing dietary lysine on minimizing the feed cost per unit of live gain at 42 d of age. The author observed that the level of lysine estimated to maximize performance was not necessarily the same as the level that maximized the economic return. In addition, the economically optimal lysine level varied inversely with the price of the dietary protein source. At high feed prices, the optimum lysine level was 80 % of breeders guide; whereas at low feed prices the optimum was set at 98% of breeder’s recommendations.

Nevertheless, the author disregard the effects of lysine on carcass yield which is a major player on the total returns at the end of the process.

One of the most important parameters that should be taken into account when determining a maximum profit level of a nutrient that sometimes is disregarded, is the methodology used. Choosing the appropriate model to estimate the maximum response is a critical step when determining optimum levels of a nutrient. For example, Pesti and Vedenov (2011) had shown that the usage of different predictive models can result in differences from 1.5 to 3.0 % of CP between the estimated values.

Differences in factors intrinsic to the birds, such as gender, have also been shown to impact economic margins. Groen, et al. (1998) developed a deterministic model for economic evaluations of broiler production and determined that when comparing cost of producing a 1 kg carcass, males had a lower cost ($1.269) than females ($1.370). Even though the differences in cost reported, the authors did not evaluate the differences in profit from raising either of the genders.

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CHAPTER 2

Straight-run vs. Sex Separate Rearing for Two Broiler Genetic Lines

Part 1: Live Production Parameters, Carcass Yield, and Feeding Behavior[1]

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[1] M.J. Da Costa[1], T.J. Frost[2], J. Halley[3], G.M. Pesti[1]
[1] University of Georgia, Athens, GA 30606
[2] Wayne Farms LLC, 4110 Continental Drive, Oakwood, Georgia 30566
[3] Aviagen Inc., 5015 Bradford Drive, Huntsville, AL 35805
To be submitted to Poultry Science

ABSTRACT

The objective of this experiment was to evaluate the effect of raising broilers under sex separate and straight-run conditions for two broiler strains. 1,344 day-old Ross 308 and Ross 708 were separated by sex and placed in 48 pens according to the rearing type: sex separate (28 males or 28 females) or straight-run (14 males + 14 females). There were 3 dietary phases: starter (0 to 17d), grower (17 to 32d), and finisher (32 to 48d). Birds' individual BW and feed intake were taken at 12, 17, 25, 32, 42, and 48d to evaluate performance. At 33, 43, and 49d, four birds per pen were sampled for carcass yield evaluation. Additionally, from 06:00 to 06:30, 13:00 to 13:30, and 22:00 to 22:30, video records were taken to assess bird behavior at 45d. Data were analyzed as CRD with a 2x3 factorial arrangement of treatments over time. Throughout the experiment Ross 308 were heavier than the 708, and after 17d male pens had the heavier birds, followed by straight-run and then females. Straight-run pens had higher BW CV's in comparison with sex separate pens. BW of sex separate males was negatively impacted from 17 to 32d. On the other hand, females raised sex separate were heavier than females raised straight-run with lower CVs from 25 to 41d. Post 25d, FCR was the lowest in male pens whereas feed intake was the highest on these pens after 17d. Overall, males had total carcass cut-up weights higher than straight-run and females at the three processing times. The Ross 708 had higher white meat yields, whereas 308 had higher yields for dark meat. Feeding behavior results were not consistent over time. However, at 13:00 to 13:30 evaluation, birds in female pens spent more time eating followed by straight-run and then males. In conclusion, raising females in a straight-run system negatively impacted performance and CV, whereas males benefited from straight-run rearing, with the differences being possibly related to feeder space competition.

Key words: sex separate, straight-run, genetic line, broiler, performance

INTRODUCTION

The economic benefits of raising broilers sex separate or combined has been a paradigm for poultry production since the early days. The advantages of raising chickens sex separate can be a result of better growth rates, better feed efficiency due to a more efficient design of the diets to allocate each genders need, and the reduced variability in the final product which facilitates bird processing.

Sexual dimorphism of broilers has been shown to start as early as the embryonic phase in respect of weight and muscle development (Burke and Sharp, 1989; Henry and Burke, 1998). Throughout the birds life cycle differences in growth rate, feed intake and feed efficiency are also observed between males and females (Gous, et al., 1999; May and Lott, 2001). Despite these differences and possible opportunities to explore different growth rates and nutritional requirements, there is very little research done on the effects of raising broilers together or sex separate, as well as potential ways to fine-tune nutrition and management for each gender. In addition, most of the data present in the literature regarding effects of management on bird growth rate is done at specific days, not evaluating the effects over time. In nutritional studies, it is common for the usage of various mathematical models to fit data sets, therefore the same approach could be used when doing studies regarding management effects over time (Robbins, et al., 1979; Rogers, et al., 1986; Aggrey, 2002; Robbins, et al., 2006; Vedenov and Pesti, 2008; Aggrey, 2009)

The reports present in the literature, regarding performance of flocks raised straight-run and sex separate, are generally contradictory and were usually done using less selected chicken breeds. In terms of performance, some authors concluded that sex separation of the chicks did not show any benefits (Smith, et al., 1954; Hess, et al., 1960; Lang, et al., 1960; Lamoreux and

Proudfoot, 1969). On the contrary, there are some reports that clearly show benefits in terms of performance and bird uniformity at processing age by sex separation of the chicks (Becker and Berg, 1959; Deaton, et al., 1973; Gehle, et al., 1974; Laseinde and Oluyemi, 1994; de Albuquerque, et al., 2006; Api, 2014). Regardless of the performance results, the effects on CV are very consistent across the reports, where overall CVs are higher in straight-run flocks when comparing with sex separate (Becker and Berg, 1959; Hess, et al., 1960; Lamoreux and Proudfoot, 1969; Deaton, et al., 1973).

Considering the contradicting data and the lack of information in the literature regarding the effects of rearing broilers sex separate or straight-run using modern broiler strains, the objective of this experiment was to evaluate the impact of each rearing system on the growth performance, processing yields, and bird uniformity of two modern genetic lines using several models to determine which best described the data. In addition, bird feeding behavior was evaluated.

MATERIAL AND METHODS

There were six experimental treatments that consisted of a factorial combination of two genetic lines with three broiler rearing types.

Strain treatments

Two genetic lines were evaluated in the present experiment. One-day-old chicks of Ross 308 and Ross 708 strains were sexed in order to obtain 336 chicks per sex and strain, with a total of 1,344 chicks used.

Sex separate vs. Straight-run treatments

Chicks were allocated and raised in pens according to one of the three following treatments: male, female, and straight-run. At placing for the male and female treatments, 28 chicks of the respective sex treatments were randomly selected, weighed individually, and identified with a neck tag; for the straight-run treatment, 14 males and 14 females were used instead. From this point forward, these treatments will be called rearing systems.

Birds and Husbandry

All practices regarding animal management were approved by the Institutional Animal Care and Use Committee of the University of Georgia. The experiment was performed in a window-less room with 48 pens that were 1.22 x 1.52 m in dimension. Each pen had one hanging tubular feeder with 170 cm of feeder space (6 cm / bird), 10 nipple drinkers, and the floor covered with 0.05 m of used pine shavings as litter. For the first three d of brooding, one cardboard tray with feed was placed in each pen to ease the access to the feed for the chickens. The diets fed in the present experiment were provided by a local integrator, being corn-soybean meal-based with three dietary phases: starter – 0 to 17 d, grower – 17 to 32 d, and finisher – 32 to 48 d. The starter diets were fed as crumble, and the grower and finisher diets were fed as pellets. Both water and feed were consumed *ad libitum*. Temperature, ventilation, and lighting programs were checked twice a day and followed commercial practices. Chicks were housed at 34°C and the temperature was gradually reduced by 3°C every wk, until the temperature reached 20°C. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing 24 h of light at 30 lux at the floor levelfor the first 7 d, 16 h of light at 3.5 lux with 8 h of dark from 7 to 28 d of age, and 20 h of light at 3.5 lux with 6 h of dark from 28 d until the end of the trial.

Performance data

Chickens were weighed individually at hatch, 12, 17, 25, 32, 42, and 48 d. Afterwards, BW CVs were calculated for bird variability per pen, per treatment evaluation. Feed was also weighed at the same time points. Group feed intake, individual BW gain, and adjFCR (adjusted FCR for mortality and sampling) were calculated for each age for performance analysis.

Processing data

At 33, 43, and 49 d the four birds that had the lowest numbered neck tags were selected for processing. In the straight-run pens, two birds of each sex were selected also based on the lowest neck tag number. Birds were withdrawn from feed for eight hours over night. Birds were individually weighed before processing, immediately following evisceration (pre-chill/hot carcass weight), and after chilling (cold carcass weight). Paws were taken and weighed prior to hot carcass weighing. Carcasses were chilled in water and ice at 1°C for 240 min. Subsequently, carcasses were deboned and then the *pectoralis major*, *pectoralis minor*, wings, and legs weighed for carcass yield.

Behavior data

Behavioral data was collected using a security system that consisted of eight cameras (Night Owl® TL-168). Video records were obtained from 06:00 to 06:30, 13:00 to 13:30, and 22:00 to 22:30 at 45 d of age. Behavioral measurements consisted of time spent at the feeder and time spent eating, and also how birds accessed (free access *vs.* fight) and left the feeder (voluntary exit *vs.* pushed out).

Data Analysis

At first, all data were tested for homogeneity of variance using Levene's test and for normality using the Shapiro-Wilk test. The BW, feed intake, adjFCR (adjusted feed conversion for mortality and sampling), BW CV, and carcass weights over time did not show homogeneity of variances and normality, therefore data were transformed to the natural logarithm. In addition, percentage data were arcsine transformed for analysis. For these data, the true means are presented with the P-values coming from the analysis of the transformed data. There were two separate analysis of the data, both considering a completely randomized design with a factorial arrangement of the treatments over time. At first the factorial arrangement of the three rearing treatments, two strains and age were considered; secondly, an analysis of gender within each rearing treatment, male and female reared sex separated *vs.* straight-run, was considered as the first factor, which was then crossed with strain and age factors. The data by rearing system and strain of all the response variables, were fitted with age as the independent variable using the following six models:

Quadratic

$$y = intercept + \beta_1 \times age + \beta_2 \times age^2$$

Logistic 3 parameters

$$y = \frac{asymptote}{(1 + \ e^{(-growth\, rate\, \times (age\, - inflection\, point)})}$$

Logistic 4 parameters

$$y = \frac{(upper\ asymptote - lower\ asymptote)}{(1 + \ e^{(-growth\, rate\, \times (age\, - inflection\, point)})}$$

Gompertz

$$y = asymptote\ \times\ e^{\left(-\ e^{(-\ growth\, rate\, \times\, (age\, -\, inflection\, point))}\right)}$$

Mechanistic growth

$$y = asymptote \times (1 - scale \times e^{(-\,growth\,rate\,\times age)})$$

Michaelis Menten

$$y = \frac{(maximum\,reaction\,rate \times age)}{(inverse\,affinity + age)}$$

For all the equations *y* represents the dependent/response variable, and for the quadratic model the β_1 and β_2 are the parameters associated with linear and quadratic effects respectively. After fitting the data with all the previous models, the models were ranked using the Akaike information criterion, and the model with the lowest value was chosen as the one that best described the data.

The data for the length of time eating and time spent in the feeder were transformed to the natural logarithm to attain normality, and were analyzed by hour. Similarly to the data described previously, these data were analyzed as a complete randomized design with the factorial arrangement of the treatments but herein the birds were considered the experimental unit and nested within the pen. Meal frequency was analyzed by the same design using an ordinal logistic model (chi-square test). All the previous data were analyzed and modeled using JMP Pro 11 (SAS Inst. Inc., Cary, NC) software. The behavioral data for the access and exit from the feeder was analyzed using Proc GLIMMIX of SAS 9.4 (SAS Institute Inc., Cary, NC), considering a binomial distribution of data and using logit as a link function. Birds were considered the experimental unit and nested within the pen (random factor), with the fixed effects of strain and rearing system arranged in a factorial fashion and hour as a random block effect.

RESULTS

Performance

The BW and BW CV data is presented in Table II – 1.1 At hatch, no differences (*P*>0.05) on BW and BW CV were observed between genders. Ross 308 birds were 1.1g heavier on average (*P*<0.001) than Ross 708 at the moment of placing. Throughout the experimental period the Ross 308 birds were always heavier than the Ross 708 (main effect: *P*<0.001). The interaction of strain by gender (*P*=0.001) on BW indicates that the strains will benefit differently on the usage of the three rearing systems. Nevertheless, the main effect of gender (*P*<0.001) demonstrated that overall, males were heavier, followed by the straight-run birds and then females. There was also a significant interaction of rearing system with age (*P*<0.001). According to the result Table II – 1.1 and Figure II – 1.1 and 1.2, it is observed that the difference in BW by rearing system is present around 17 d for the Ross 308 and 25 d for the Ross 708. The model that was shown to fit BW data the best was the Gompertz function (Table II – 1.5). For the Ross 308 (Figure II – 1.1) birds, females had the higher growth rate/maturity coefficient (0.0484), followed by the straight-run birds (0.0471), and then the males (0.0457). The growth rate/maturity parameter represents the rate of exponential decay of the initial growth rate, or the rate of decline in the growth rate (Tzeng and Becker, 1981). Consequently, the females presented an inflection point early in life (34.2 d), succeeding by straight-run birds (35.4), and then males (37.228). Similarly, the Ross 708 (Figure II – 1.2) females had the highest growth rate coefficient (0.0476), however, for this strain the males resulted in having the intermediate growth rate coefficient (0.0472) followed by the straight-runs (0.0461). Females reached the maximal absolute growth rate at 34.5 d, males at 36.4 d, and straight-runs at 36.3 d.

For the BW CV there was an interaction (*P*<0.001) between rearing system and age, where it was observed that for sex separate birds (both male and female) the BW CV decreased as birds aged, and for the straight-run birds the BW CV increased with age (Table II – 1.1). The model shown to fit the best BW CV data was the Michaelis and Menten function (Table II – 1.5). Overall as birds aged, the CV of males and females decreased whereas the straight-run birds increased. The lower maximum reaction rate observed in females indicated that females tended to be more uniform than males.

Evaluating BW of each sex within each rearing system (Table II – 1.2 and 1.3), male birds were shown to grow bigger (*P*<0.001) when raised under the straight-run system, while females were negatively impacted (*P*<0.001) when raised straight-run. The Gompertz equation coefficients for birds of same sex reared sex separated or straight-run revealed that for the Ross 308, males straight-run had a higher growth rate coefficient (0.0473 vs. 0.0457) with a respective maximal absolute growth happening earlier in life (35.9 vs. 37.228 d). Conversely, for the female birds, sex separated rearing resulted in a higher growth rate coefficient (0.0465 *vs* 0.0484) with an inflection point occurring earlier in life (34.2 vs. 35.1 d) than straight-run females. Conversely, the Ross 308, sex separated rearing resulted in higher growth and lower inflection points for both males and females of the Ross 708. Sex separated males were found to have a coefficient of growth rate of 0.047 and an inflection point of 36.4 d, whereas straight-run had values of 0.0458 and 37.0 d respectively. Similarly, females sex separated had higher values of growth rate (0.0476) and lower maximal absolute growth age at 34.5 d, with straight-run females having values of 0.0459 and 35.742 d respectively. The Gompertz growth curves (Figures II – 1.5 and 1.6) indicated that differences in BW between birds raised sex separate or straight-run were more evident and pronounced for females than males. Even though there was the presence of a main effect of rearing system for male BW, the trend for an interaction between rearing system and age (*P*=0.077) and the growth curve shapes revealed that the difference between rearing systems was minimal and varied with time for this gender. On the other hand, it was clear that females raised straight-run were significantly lighter than the sex separated females.

No differences (*P*>0.05) in BW CV were observed between males raised straight-run and sex separate. On the other hand, females raised under a straight-run system had higher (*P*=0.057) BW CV when compared with sex separate females. For both strains, the Michaelis and Menten function was shown to fit the data best, with the sex separated females having lower maximum reaction rates, revealing that this rearing system resulted in more uniform birds than straight-run.

On feed intake and adjFCR (Table II – 1.4), Ross 308 showed higher values (*P*<0.001) for both parameters. There was a difference between rearing systems on feed intake, where birds raised in the male pens had a higher intake, followed by the straight-run, and then the females. An interaction between rearing system (*P*<0.001) and age was apparent on adjFCR. Overall, adjFCR differences tended to be more evident with age with males presenting the lowest adFCR, followed by the straight-run birds, and then females. There was also a significant interaction (*P*=0.023) between strain and age, where Ross 308 had the best adjFCR early in life but performed poorly later on when comparing with Ross 708 birds. For both feed intake and adjFCR data, the mechanistic growth models were shown to fit the data best (Table II – 1.5 and Figure II – 1.9 to II – 1.12).

Processing

Results of carcass cut-up weights and yields for the six treatment combinations are presented in the tables II – 1.7 and II – 1.9. As birds aged, *pectoralis major* and *minor* cut-up weights and yields increased. A main effect (*P*<0.001) of rearing system was observed on *pectoralis major* and *minor* weights where males had heavier breast muscles, with straight-run birds with intermediate weights, and females with lower weights. Regarding the yields, there was a significant interaction (*P*=0.027) of rearing system and strain on *pectoralis major* percentage. For the Ross 308, the straight-run rearing system resulted in higher *pectoralis major* yields in comparison with the males and females at the three processing ages. Contrarily, at 49 d of age, the Ross 708 straight-run birds showed lower *pectoralis major* percentage than the males and females. There was also an interaction (*P*<0.001) of strain and age. Overall, males had the lower yields, whereas straight-run birds had the higher yields at 33 and 49d and females at 43 d. Strain of the birds also resulted in differences (*P*<0.001) in breast meat weight and yields. Ross 708 birds had heavier and higher percentages of breast muscle than the Ross 308. Contrarily to breast meat yield, wings and legs percentages decreased (*P*<0.001) as birds aged. On wings, legs, and paw weights, there was as significant interaction of rearing system and age. Males had the heaviest cut-ups, followed by the straight-runs and females, with the differences between the groups being more pronounced as birds aged. There was an interaction (*P*=0.035) of strain and age on wing yield, where Ross 308 had higher percentages than the Ross 708 with the differences becoming more accentuated as birds aged. The CV of the cut-up weights (Table II – 1.9) of *pectoralis major*, wings, and legs were significantly affected by the rearing system (main effect). The straight-run cut up CV weights were overall higher than the sex separate birds. Females showed to have more uniform cut-ups, followed by the males and then the straight-run birds. A three-way interaction (*P*=0.024) was observed on *pectoralis minor* CV weights. On the Ross 308, during the first two processing ages, the straight-run birds had higher CVs, whereas at 49 d males were the rearing system with higher CVs. On the Ross 708, males had higher CVs at the first two processing ages followed by straight-run birds; females had lowest CVs at 33 and 43 d, however at 49 d this rearing system resulted in the highest CV. Age had a significant but distinct effect on *pectoralis major* and wing CV. *Pectoralis* major showed to become more uniform with age, while wings tended to increase in variability when birds aged. No effect (P<0.05) of strain was observed on the cut-up CV weights.

When comparing the cut-up weights of each gender within the rearing systems (Table II – 1.10 and II – 1.11) for both males and females, there was a main effect of strain where the Ross 708 had heavier breast meat (*pectoralis major* and *minor*), but had lower weights of wings, legs and paws than the Ross 308 birds. For both males and females, there were no significant differences observed on the cut-up weights between sex separated and straight-run birds.

Behavior

For the three time periods within a d (45 d of age), there was a significant interaction (P<0.001) between strain and gender on the number of times that the birds visit the feeder from 6:00 to 6:30 (Table II – 1.12). At this time of the day, birds in male Ross 308 pens did not go to feeder (n=6) as much as birds in female (n=25) and straight-run (n=28) pens. Conversely, birds in straight-run pens had the lowest amount of visits to the feeder (n=5) when compared with the female (n=16), and male (n=21) pens for the Ross 708 strain. In addition, from 13:00 to 13:30 there was a significant main effect (P=0.05) of gender on time spent at the feeder and eating. Birds raised on female pens spent more time in the feeder (total=249 s; eating=234 s) than the birds in male pens (total=113 s; eating=96 s). The birds in straight-run pens spent on average 167 s in the feeder with the 165 s spent eating. There were no statistical differences (P>0.05) between the treatments on the percent of aggressive behavior at the time of entering and leaving the feeder (Table II – 1.13).

DISCUSSION

The data presented herein allowed a comparison on performance and carcass parameters of two broilers strains when raised sex separate or straight-run. None or little research has been published where growth rate of birds raised sex separated or straight-run is compared over time. Indeed, most of the studies performed previously tend to evaluate and estimate growth curves for birds raised sex separate. Not surprisingly, in the data presented here, males were heavier followed by straight-run birds, and then females, which is consistent to most of the data present in the literature (Smith, et al., 1954; Hess, et al., 1960; Brake, et al., 1993; Gous, et al., 1999; May and Lott, 2001; Aggrey, 2002; de Albuquerque, et al., 2006; Aggrey, 2009; Shim, et al., 2012; Api, 2014; Zuidhof, et al., 2014). The growth curve analysis revealed a higher maturity rate and an earlier in life inflection point for the females in comparison with males. These results were consistent with the findings reported by Scheuermann, et al. (2003) and Gous, et al. (1999), where females had a higher rate of maturity and an inflection point 2 d earlier on average than the males. In addition, male BW plateaued at heavier weights, which was consistent with the literature (Gous, et al., 1999; Scheuermann, et al., 2003). Though, care should be taken when looking to the plateau weights in the data present herein, since the plateau weight and age at which it occurs were out of the data range evaluated in the experiment, and an extrapolation of data might result in inaccurate estimation of values.

The interaction of genetic strains and rearing system on growth observed in the present experiment has been described previously in the literature (Hess, et al., 1960; Lamoreux and

Proudfoot, 1969; Api, 2014). Overall for both strains, males grew heavier and faster than straight-run and females. However, the magnitude of BW difference between birds raised in male, straight-run, and female pens were different between strains. Ross 308 birds had bigger differences in BW between rearing systems throughout the experiment, having these differences become noticeable earlier in life than the Ross 708 birds. Similarly, Hess, et al. (1960) reported that effects of raising birds sex separate or straight-run on BW, were dependent on genetic strain of the birds. On the contrary, Lamoreux and Proudfoot (1969) did not observe any interaction of genetics and rearing system on BW, showing that the rearing system affected equally the genotypes evaluated (three genetic strains). Furthermore, no significant differences were observed by these authors on FCR when they averaged pens of males and females reared sex separate with pens reared straight-run. In a field survey using 141 flocks, Api (2014) evaluated the effects of raising birds of three genetic lines (Cobb, Ross, and Hubbard) under sex separate and straight-run regime. No interaction of the genetic line and rearing system was observed on BW, however, the interaction of treatments showed to be significant when FCR was the criteria evaluated, which is the complete opposite of the outcomes of the current experiment. In Api (2014)'s survey, neither information regarding the number of farms for each treatment combination nor treatment distribution of treatments by farm complexes were provided, consequently some results might be confounded which might explain the differences in results. The effects on adjFCR were consistent across the two genetic strains where males had the lowest values, followed by straight-run birds, and females (Table II – 1.4). Gehle, et al. (1974), and de Albuquerque, et al. (2006) reported similar results of sex separate and straight-run rearing on FCR on birds raised up to 56 d (FCR: male = 2.00 g:g; straight-run = 2.03 g:g; and female = 2.08

g:g) and 45 d (FCR: male = 1.74 g:g; straight-run = 1.80 g:g; and female = 1.81 g:g) respectively.

When the BW of each gender was evaluated within each rearing type (sex separate vs. straight-run), it was interesting to observe that females were positively affected whereas males were negatively affected by sex separation. The growth curve parameters for the Ross 308 showed that straight-run males had a higher growth rate coefficient and an earlier inflection point, with the straight-run female parameters having lower and later values for the two parameters respectively. Therefore, the growth curve parameters for the Ross 308 reinforced that males were negatively affected by sex separation while females benefited from it. Indeed, when modeling the Ross 708 data, the Gompertz growth curve parameters clearly indicated that sex separation resulted in higher growth rate and earlier inflection points for both genders. Even though, most of the time, the results of differences in BW of each gender reared sex separate vs. straight-run are presented as non-significantly different, there is a trend across several papers in the literature that reflect the same findings detected herein. Smith, et al. (1954), reported no advantages in sex separation. However, looking to the results at 9 wk of age, males raised sex separate averaged at 1,350 g of BW, whereas straight-run males weighed 1,360 g. Conversely, females raised sex separate weighed 1,121 g, being heavier than straight-run females that weighed 1,107 g. Similarly, Lamoreux and Proudfoot (1969) did not observe significant differences of BW of genders raised in the two systems, however, when looking to the data, on average males were heavier on the mixed sex when comparing with the sex separate (Experiment 1: 2,413 g vs. 2,383; Experiment 2: 2,419 g vs. 2,402 g), whereas females barely differ on BW (Experiment 1: 1,905 g vs. 1,904; Experiment 2: 1,913 g vs. 1,912 g). In addition, Hess, et al.

(1960) showed that at 9 wk intermingled broilers were lighter than sex separate regardless of the gender (1,564 g vs. 1,624 g for males, and 1,284 g vs. 1,302 g for females).

Effects on BW CV were consistent among strains, where females and males pens were more uniform and straight-run birds more variable. These outcomes are unanimous in the literature (Hess, et al., 1960; Lang, et al., 1960; Gehle, et al., 1974), and were expected since in the straight-run pens both genders were present creating *per se* an increased variability inherent to a different growth potential between genders as shown in the growth curve parameter results. The results of carcass cut-ups on the processing side were consistent with the live production results. Again, and as suggested by Gehle, et al. (1974), it was shown herein that one of the main advantages of rearing birds sex separate was the reduction on CV weights of the final carcass products. Lower CV's allow an easier calibration of the machinery at the processing plant for a narrower weight range. This can potentially result in lower amount of carcass downgrades and better product allocation based on weight (Gehle, et al., 1974).

The behavior data did not show any consistent effects on feeding behavior. The differences on feeder visit frequency and time spent at the feeder observed from 6:00 to 6:30 and 13:00 to 13:30 respectively, suggesting that there were differences in feeding behavior among rearing systems. That being said, it would have been interesting to evaluate the behavior throughout several d of the flock, to track the feeding behavior of males and females within straight-run pens and compare with sex separate birds. When establishing social hierarchy, chickens present agonistic behavior as fighting, pecking, threatening, and submissive responses as crouching, escaping and avoiding contact (Guhl, 1968). As a flock ages, social order is established gradually among the birds. In an experiment conducted with White Leghorns, Guhl (1958) reported that from the 2nd to the 6th wk of age, males expressed a higher percentage of aggressive behavior towards other chicks than females, the aggressiveness being more pronounced toward other males. Furthermore, males established social organization sooner (8 wk) than females (9.5 wk), with the authors reporting that females were under social stress with little opportunity to feed in comparison with the males. This might help explain the results observed on the differences in BW of both male and female reared straight-run and sex separate in the present experiment. When the females were reared straight-run, it is plausible that the competition for feeder space was higher. This could have resulted in lower feed intake, and consequently resulted in straight-run females being lighter than sex separate females, which is something that was observed in the data presented herein. In addition, straight-run females also showed higher BW CVs than sex separate females, which might be a result of increased social stress exposure. Conversely, males reared under a sex separate regime can easily exclude smaller birds as females from the feeders, allowing them to increase feed intake and grow faster. However, when with other males, the competition for feeder space will be higher and growth rate slower in comparison with straight-run males. The bird number per pen planned for the present experiment was based on projection of 38 kg/m^2 (approximately 0.07 m^2/bird) of live weight for males at 42 and 48 d (Estevez, 2007) with a feeder space above the genetic line recommendations (70 birds per a 38.5 cm diameter feeder). Therefore, female and straight-run pens ended with lower density since females grew smaller than males. There is evidence in the literature stating that benefits of raising broilers sex separate might be dependent on bird stocking density (Deaton, et al., 1973). In one experiment, the interaction of stocking density and rearing system was evaluated and the results showed that males raised in a high density (0.073 m^2/bird mixed sex vs. 0.079 m^2/bird sex separate) and sex separate were heavier than the mixed (1,633 g vs. 1,609 g). However, if males were raised in a lower density (0.051 m^2/bird mixed sex vs. 0.055 m^2/bird sex separate), the results were the opposite, where the sex separate males were lighter than the straight-run (1,566 g vs. 1,590 g). With the females, regardless of stocking density (0.073 m^2/bird mixed sex vs. 0.067 m^2/bird sex separate; 0.051 m^2/bird mixed sex vs. 0.047 m^2/bird sex separate) sex separate birds were always heavier. In the Deaton, et al. (1973) experiment, the space in the pen per bird calculated for males and females differed and the number of birds per feeder in each treatment did as well. Therefore, this might have confounded effects in the results. In addition, after 5 wk of age a protocol of heat stress was used, which might have impacted feed intake and affected the competition behavior for feed and performance outcomes related with the rearing system. In addition, Zuowei, et al. (2011) observed that high bird density resulted in poorer BW and FCR regardless of the gender, and also that females needed more stocking space than males with similar BW per square meter. These two reports show that each gender might have a different optimum stock density, and also that bird density might play a role in the advantages of raising the birds sex separate or straight-run.

In conclusion, sex separating birds resulted in heavier females but lighter males, with this effect being most likely related with feeder space competition. Still, sex separating birds resulted in an increased uniformity of bird BW and consequent cut-up weights. For further research and analysis, it would be interesting to evaluate the economic impact based on feed intake to body weight gain ratio of raising flocks sex separate vs straight-run.

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Table II – 1.1. Effect of broiler strain, and rearing system throughout a 48 d period time on BW and BW CV

Strain	Rearing system	0 d		BW (g)						BW CV (%)					
		BW (g)	CV (%)	12 d	17 d	25 d	32 d	42 d	48 d	12 d	17 d	25 d	32 d	42 d	48 d
308		42.1	7.66	315	547	1236	1937	2902	3635	10.52	9.48	8.88	9.27	9.45	9.05
708		41.0	7.42	292	518	1175	1846	2741	3459	10.63	9.91	9.23	8.84	8.80	9.36
	Female	41.4	7.50	301	522	1156	1793	2613	3259	10.66	8.99	8.03	7.79	7.73	7.37
	Male	41.7	7.82	306	541	1255	1987	3049	3841	10.46	9.51	8.20	8.04	8.09	7.78
	Straight-run	41.5	7.29	303	535	1205	1895	2802	3540	10.60	10.59	10.93	11.34	11.55	12.46
	Female	42.0±0.3	7.21	308±5	529±8	1173±13	1834±22	2674±21	3329±31	10.95	9.19	8.24	7.94	7.89	7.19
308	Male	42.2±0.4	8.33	322±5	562±7	1293±14	2036±25	3155±30	3963±60	9.90	9.18	7.69	8.53	9.01	7.71
	Straight-run	42.0±0.5	7.45	316±4	551±4	1241±9	1942±16	2877±28	3612±29	10.71	10.08	10.71	11.34	11.44	12.26
	Female	40.8±0.4	7.80	295±3	516±4	1138±7	1752±8	2552±17	3189±29	10.38	8.79	7.83	7.64	7.58	7.56
708	Male	41.3±0.4	7.31	290±5	520±5	1218±9	1937±24	2943±24	3719±25	11.02	9.84	8.71	7.55	7.16	7.86
	Straight-run	40.9±0.3	7.14	291±6	520±3	1169±8	1848±21	2728±21	3467±26	10.50	11.11	11.15	11.35	11.65	12.65
Source of variation				------------------------ *P*–values ------------------------											
Rearing System		<.001	0.450	<0.001						0.970					
Strain		0.288	0.412	<0.001						<0.001					
Strain x RS		0.798	0.134	0.001						0.513					
Age		-	-	<0.001						<0.001					
RS x Age		-	-	<0.001						<0.001					
Strain x Age		-	-	0.213						0.619					
RS x S x A		-	-	0.789						0.790					

RS – rearing system
S – strain
Age – age

Table II – 1.2. Effect of broiler strain, and rearing system on male BW and BW CV throughout a 48 d period time

Strain	Rearing system	BW (g)						BW CV (%)					
		12 d	17 d	25 d	32 d	42 d	48 d	12 d	17 d	25 d	32 d	42 d	48 d
308		322	564	1303	2064	3140	3957	10.34	9.29	7.97	8.12	8.05	7.61
708		293	527	1229	1960	2950	3757	10.14	9.83	8.72	8.13	7.54	7.98
	Male	306	541	1255	1987	3049	3841	10.46	9.51	8.20	8.04	8.09	7.78
	SR Male	310	551	1277	2037	3041	3872	10.03	9.61	8.48	8.21	7.50	7.80
308	Male	322±5	562±7	1293±14	2036±25	3155±30	3963±60	9.90±0.58	9.18±0.81	7.69±0.74	8.53±0.95	9.01±1.42	7.71±0.53
	SR Male	323±4	567±7	1314±13	2092±27	3126±37	3950±49	10.78±1.56	9.40±1.41	8.25±1.06	7.71±0.85	7.09±0.64	7.51±0.78
708	Male	290±5	520±5	1218±9	1937±24	2943±25	3719±25	11.02±0.76	9.84±0.55	8.71±0.32	7.55±0.25	7.16±0.50	7.86±0.86
	SR Male	296±6	535±5	1241±11	1983±24	2957±21	3794±32	9.27±0.42	9.81±0.35	8.72±0.66	8.70±0.97	7.92±1.18	8.10±1.20
Source of variation								------------------------- *P*–values -------------------------					
Rearing System					0.006						0.696		
Strain					<0.001						0.529		
Strain x RS					0.212						0.653		
Age					<0.001						<0.001		
RS x Age					0.077						0.882		
Strain x Age					0.650						0.976		
RS x S x A					0.967						0.440		

SR – straight-run
RS – rearing system
S – strain
Age – age

Table II – 1.3. Effect of broiler strain, and rearing system on female BW and BW CV throughout a 48 d period time

Strain	Rearing system	BW (g)						BW CV (%)					
		12 d	17 d	25 d	32 d	42 d	48 d	12 d	17 d	25 d	32 d	42 d	48 d
308		308	531	1170	1814	2656	3311	10.26	9.31	8.68	8.23	7.84	7.82
708		291	510	1119	1733	2528	3175	10.57	10.08	8.90	7.91	7.61	7.72
	Female	301	522	1156	1793	2613	3259	10.66	8.99	8.03	7.79	7.73	7.38
	SR Female	298	519	1133	1753	2571	3227	10.17	10.41	9.54	8.36	7.71	8.17
308	Female	308±5	529±8	1173±13	1833±22	2674±21	3328±31	10.95±0.70	9.19±0.46	8.23±0.24	7.94±0.34	7.88±0.61	7.19±0.34
	SR Female	308±5	534±5	1167±12	1794±12	2637±27	3294±25	9.57±0.39	9.44±0.62	9.12±0.94	8.52±0.82	7.79±0.87	8.45±1.09
708	Female	295±3	515±4	1138±7	1752±8	2552±17	3189±29	10.38±0.65	8.79±0.66	7.83±0.58	7.63±0.58	7.58±0.77	7.56±0.77
	SR Female	287±7	504±6	1099±10	1713±20	2504±28	3161±33	10.77±1.40	11.38±0.64	9.96±0.47	8.19±0.60	7.63±0.51	7.88±1.45
Source of variation		------------------------- *P*–values -------------------------											
Rearing System		0.002						0.057					
Strain		<0.001						0.871					
Strain x RS		0.077						0.225					
Age		<0.001						<0.001					
RS x Age		0.922						0.923					
Strain x Age		0.906						0.334					
RS x S x A		0.771						0.662					

SR – straight-run
RS – rearing system
S – strain
Age – age

Table II – 1.4. Effect of broiler strain, and rearing system throughout a 48 d period time on feed intake and adjFCR

Strain	Rearing system	Feed intake (g)						adjFCR (g:g)					
		0-12 d	0-17 d	0-25 d	0-32 d	0-42 d	0-48 d	0-12 d	0-17 d	0-25 d	0-32 d	0-42 d	48 d
308		351	692	1769	3045	5043	7266	1.288	1.372	1.483	1.607	1.741	1.929
708		331	663	1676	2914	4723	6877	1.317	1.389	1.481	1.615	1.727	1.918
	Female	338	667	1679	2882	4653	6877	1.301	1.388	1.507	1.646	1.780	2.011
	Male	346	689	1770	3063	5155	7281	1.312	1.382	1.458	1.573	1.693	1.843
	Straight-run	339	677	1719	2992	4840	7056	1.295	1.371	1.481	1.614	1.728	1.918
	Female	344±9	674±7	1716±13	2946±28	4784±30	6992±71	1.296±0.027	1.386±0.013	1.518±0.018	1.645±0.008	1.789±0.013	2.009±0.019
308	Male	359±6	709±6	1829±23	3144±28	5376±68	7606±143	1.287±0.025	1.366±0.012	1.462±0.016	1.574±0.012	1.704±0.016	1.860±0.015
	Straight-run	351±5	693±4	1762±10	3044±12	4968±49	7199±108	1.281±0.011	1.363±0.007	1.470±0.013	1.601±0.016	1.729±0.016	1.919±0.023
	Female	332±8	660±9	1642±12	2819±26	4522±70	6762±106	1.306±0.019	1.390±0.012	1.496±0.007	1.647±0.016	1.772±0.025	2.012±0.025
708	Male	332±7	668±7	1711±22	2983±47	4934±63	6956±127	1.338±0.019	1.398±0.015	1.454±0.019	1.572±0.013	1.683±0.015	1.827±0.022
	Straight-run	327±7	660±8	1676±13	2940±22	4713±54	6912±125	1.309±0.028	1.378±0.014	1.493±0.015	1.627±0.017	1.728±0.009	1.916±0.018
Source of variation								------------------------- *P*–values -------------------------					
Rearing System					<0.001						<0.001		
Strain					<0.001						0.008		
Strain x RS					0.353						0.322		
Age					<0.001						<0.001		
RS x Age					0.224						<0.001		
Strain x Age					0.440						0.023		
RS x S x A					0.985						0.912		

RS – rearing system
S – strain
Age – age

Table II – 1.5. Estimated parameters for body weight, feed intake, feed conversion ratio, and body weight coefficient of variation predictive models of female, male and straight-run birds Ross 308 and Ross 708

Response	Model	Equation coefficients	308			708		
			Female	Male	Straight-run	Female	Male	Straight-run
Body weight	Gompertz	Asymptote	5547.8	7305.3	6256.7	5369.0	6616.10	6173.01
		Growth rate	0.0484	0.0457	0.0471	0.0476	0.0472	0.0461
		Inflection point	34.245	37.228	35.416	34.476	36.385	36.250
		R^2	0.998	0.996	0.998	0.998	0.998	0.998
		RMSE	55.01	84.10	53.75	43.80	52.07	51.04
Feed intake	Mechanistic growth	Asymptote	-1882.7	-2201.2	-2021.6	-1559.7	-2283.6	-1892.2
		Scale	0.7407	0.7229	0.7346	0.7489	0.7400	0.7365
		Growth rate	-0.0387	-0.0381	-0.0382	-0.0411	-0.0357	-0.0386
		R^2	0.998	0.995	0.997	0.995	0.994	0.995
		RMSE	112.61	193.34	140.09	168.46	184.16	171.32
Feed conversion ration	Mechanistic growth	Asymptote	1.1700	1.2033	1.1241	1.3393	1.4915	1.3021
		Scale	-0.1579	-0.1166	-0.1687	-0.0552	-0.0070	-0.0766
		Growth rate	-0.0317	-0.0325	-0.0301	-0.0464	-0.0740	-0.0382
		R^2	0.866	0.829	0.918	0.882	0.772	0.835
		RMSE	0.0823	0.0762	0.0576	0.0741	0.0669	0.0756
BW coefficient of variation	Michaelis and Menten	Maximum reaction	6.7468	7.6387	12.2735	6.7126	6.7852	12.6528
		Inverse affinity	-4.5942	-2.6665	2.5388	-4.1683	-4.7393	2.6191
		R^2	0.477	0.058	0.084	0.2427	0.404	0.098
		RMSE	1.2937	2.458	1.746	1.8258	1.619	1.726

RMSE – root-mean-square error

Table II – 1.6. Estimated parameters for body weight and body weight coefficient of variation predictive models of male and female Ross 308 and Ross 708, reared sex separated or straight-run

Response	Model	Equation coefficients	308				708			
			Male SS	Male SR	Female SS	Female SR	Male SS	Male SR	Female SS	Female SR
Body weight	Gompertz	Asymptote	7305.3	6925.3	5547.9	5690.8	6616.1	6911.3	5369.0	5563.0
		Growth rate	0.0457	0.0473	0.0484	0.0465	0.0472	0.0458	0.0476	0.0459
		Inflection point	37.228	35.923	34.245	35.138	36.385	37.041	34.476	35.742
		R^2	0.996	0.997	0.998	0.998	0.998	0.998	0.998	0.997
		RMSE	84.10	79.84	55.01	48.49	52.07	59.01	43.80	57.98
BW coefficient of variation	Michaelis and Menten	Maximum reaction	7.6386	6.6126	6.7468	7.9176	6.7853	7.8907	6.7129	7.5512
		Inverse affinity	-2.6667	-4.7158	-4.5944	-2.2940	-4.7390	-2.2239	-4.1674	-4.1295
		R^2	0.058	0.155	0.477	0.243	0.403	0.045	0.054	0.172
		RMSE	2.4581	2.9905	1.2935	1.8257	1.6189	2.3823	2.2423	2.687

SS – sex separate

SR – straight-run

RMSE – root-mean-square error

Table II – 1.7. Effect of broiler strain, and rearing system on *pectoralis major* and *minor* weight and yield at 33, 43 and 49 d

Strain	Rearing system	Pectoralis major						Pectoralis minor					
		Weight (g)			Percentage (%)			Weight (g)			Percentage (%)		
		33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d
308		295	487	640	20.33	21.61	22.49	68	111	139	4.69	4.89	4.90
708		325	547	728	23.10	24.97	26.49	72	120	147	5.12	5.45	5.38
	Female	294	480	631	21.69	23.45	24.52	68	111	139	5.03	5.36	5.37
	Male	322	551	743	21.58	23.10	24.41	71	120	149	4.76	4.96	4.89
	Straight-run	313	519	678	21.87	23.32	24.54	70	116	142	4.93	5.18	5.17
	Female	282±6	445±10	590±14	20.29±0.33	21.57±0.38	22.30±0.33	66±1	105±2	137±3	4.76±0.07	5.04±0.09	5.18±0.08
308	Male	303±6	525±17	687±19	20.05±0.17	21.53±0.35	22.08±0.36	69±1	117±3	144±4	4.55±0.07	4.75±0.04	4.62±0.09
	Straight-run	300±8	491±10	643±15	20.64±0.26	21.75±0.29	23.08±0.19	69±3	110±2	136±4	4.74±0.10	4.87±0.07	4.91±0.09
	Female	306±6	515±11	673±12	23.08±0.25	25.34±0.23	26.73±0.24	70±2	116±2	140±3	5.30±0.12	5.68±0.11	5.55±0.08
708	Male	341±7	578±7	799±9	23.11±0.32	24.67±0.21	26.75±0.14	73±2	122±2	154±3	4.96±0.11	5.17±0.10	5.17±0.08
	Straight-run	327±10	547±12	713±20	23.10±0.45	24.90±0.31	25.99±0.26	72±3	122±3	147±4	5.11±0.14	5.50±0.07	5.42±0.11
Source of variation						------------------------- *P*–values -------------------------							
Rearing System			<0.001			0.385			<0.001			<0.001	
Strain			<0.001			<0.001			<0.001			<0.001	
Strain x RS			0.620			0.027			0.837			0.934	
Age			<0.001			<.0001			<0.001			<0.001	
RS x Age			0.204			0.947			0.708			0.666	
Strain x Age			0.435			0.008			0.600			0.558	
RS x S x A			0.719			0.278			0.590			0.492	

RS – rearing system
S – strain
Age – age

Table II – 1.8. Effect of broiler strain, and rearing system on wings, legs and paw weight and wings and legs yield at 33, 43 and 49 d

Strain	Rearing system	Wings						Legs						Paws		
		Weight (g)			Percentage (%)			Weight (g)			Percentage (%)			Weight (g)		
		33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d
308		146	217	245	10.10	9.57	8.63	408	620	763	28.12	27.29	26.77	75	100	114
708		139	202	236	9.93	9.13	8.58	382	587	708	27.26	26.45	25.74	68	90	105
	Female	137	193	218	10.08	9.35	8.46	374	547	664	27.56	26.43	25.77	64	80	90
	Male	149	225	262	10.00	9.30	8.61	413	661	811	27.73	27.34	26.62	79	110	129
	Straight-run	142	210	242	9.97	9.38	8.75	397	603	731	27.80	26.86	26.36	71	96	110
308	Female	141±2	200±3	220±8	10.12±0.09	9.61±2.63	8.33±0.28	394±5	561±8	693±8	28.40±0.22	26.90±0.18	26.25±0.27	67±2	83±1	95±1
	Male	153±3	233±3	265±6	10.12±0.07	9.48±7.03	8.56±0.17	425±10	683±12	843±13	28.14±0.23	27.75±0.24	27.19±0.11	84±2	119±2	134±3
	Straight-run	146±2	217±3	250±4	10.08±0.07	9.61±8.79	8.99±0.18	403±6	617±6	752±22	27.83±0.21	27.22±0.22	26.86±0.29	74±1	100±1	115±2
708	Female	133±1	187±2	215±5	10.04±0.10	9.10±6.91	8.59±0.13	354±4	533±9	635±13	26.72±0.25	25.95±0.29	25.30±0.20	61±1	76±1	85±1
	Male	145±3	216±2	259±7	9.89±0.07	9.13±8.16	8.66±0.22	401±7	639±9	778±15	27.31±0.18	26.92±0.24	26.06±0.36	74±1	102±4	124±2
	Straight-run	139±3	203±3	234±7	9.86±0.07	9.15±6.41	8.50±0.18	391±8	589±10	711±15	27.76±0.33	26.49±0.27	25.85±0.20	69±2	93±1	105±2
Source of variation								------------------------ *P*–values ------------------------								
Rearing System			<0.001			0.604			<0.001			<0.001			<0.001	
Strain			<0.001			<0.001			<0.001			<0.001			<0.001	
Strain x RS			0.803			0.152			0.167			0.113			0.211	
Age			<0.001			<0.001			<0.001			<0.001			<0.001	
RS x Age			0.005			0.296			0.001			0.197			<0.001	
Strain x Age			0.382			0.035			0.649			0.735			0.893	
RS x S x A			0.813			0.191			0.626			0.172			0.313	

RS – rearing system
S – strain
Age – age

Table II – 1.9. Effect of broiler strain, and rearing system on carcass cut-up coefficient of variation at 33, 43 and 49 d

Strain	Rearing system	Coefficient of Variation (%)											
		Pectoralis major			Pectoralis minor			Wings			Legs		
		33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d
308		13.76	13.86	11.84	13.07	11.86	13.10	9.28	7.38	14.46	10.73	10.60	11.21
708		14.87	10.69	10.67	14.65	11.13	11.80	9.71	8.08	11.93	11.15	9.94	10.74
	Female	12.60	11.31	9.74	11.38	11.43	12.57	9.41	6.98	12.79	10.45	9.09	8.05
	Male	14.14	10.16	10.95	14.42	10.31	12.49	7.51	6.99	11.36	9.31	9.10	8.58
	Straight-run	16.22	15.35	13.09	15.79	12.76	12.28	11.57	9.21	15.44	13.07	12.62	16.29
	Female	12.43	11.19	9.78	10.75	12.67	11.53	9.48	5.48	16.38	10.37	8.82	8.69
308	Male	13.10	11.15	13.39	12.03	8.66	16.11	6.19	6.74	12.57	8.98	8.66	9.01
	Straight-run	15.75	19.24	12.37	16.44	14.26	11.66	12.15	9.92	14.43	12.85	14.32	15.93
	Female	12.77	11.43	9.70	12.01	10.18	13.62	9.33	8.48	9.20	10.53	9.37	7.42
708	Male	15.17	9.16	8.51	16.80	11.96	8.87	8.82	7.25	10.15	9.64	9.54	8.15
	Straight-run	16.68	11.47	13.82	15.15	11.26	12.91	10.99	8.51	16.45	13.28	10.92	16.65
Source of variation							------------------------- *P*–values -------------------------						
Rearing System			0.001			0.266			0.003			<0.001	
Strain			0.247			0.970			0.821			0.760	
Strain x RS			0.607			0.877			0.844			0.891	
Age			0.014			0.154			<0.001			0.698	
RS x Age			0.701			0.280			0.932			0.066	
Strain x Age			0.218			0.362			0.379			0.792	
RS x S x A			0.122			0.024			0.155			0.582	

RS – rearing system
S – strain
Age – age

Table II – 1.10. Effect of broiler strain, and rearing system on male carcass cut-up weights at 33, 43 and 49 d

Strain	Rearing system								Male Carcass Cut Weights							
		Pectoralis Major (g)			Pectoralis minor (g)			Wings (g)			Legs (g)			Paws (g)		
		33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d
308		316	534	689	72	118	142	155	233	269	433	683	837	84	117	135
708		349	577	787	74	124	153	146	216	260	414	635	788	76	104	124
	Male	322	551	743	71	120	149	149	225	262	413	661	811	79	110	129
	SR Male	342	560	733	75	122	146	153	224	267	434	657	814	81	111	130
308	Male	303	525	687	69	117	144	153	233	265	425	683	843	84	119	134
	SR Male	328	543	690	75	119	140	157	233	272	441	682	831	85	116	136
708	Male	341	578	799	73	122	154	145	216	259	401	639	778	74	102	124
	SR Male	357	576	775	76	125	152	148	215	262	426	632	798	78	106	125
Source of variation									------------------------- *P*–values -------------------------							
Rearing System			0.1963			0.429			0.257			0.373			0.210	
Strain			<0.001			0.010			<0.001			<0.001			<0.001	
Strain x RS			0.2357			0.848			0.657			0.549			0.241	
Age			<0.001			<0.001			<0.001			<0.001			<0.001	
RS x Age			0.153			0.267			0.614			0.282			0.808	
Strain x Age			0.363			0.720			0.343			0.765			0.427	
RS x S x A			0.993			0.866			0.994			0.763			0.552	

SR – straight-run
RS – rearing system
S – strain
Age – age

Table II – 1.11. Effect of broiler strain, and rearing system on female carcass cut-up weights at 33, 43 and 49 d

Strain	Rearing system	Female Carcass Cut Weights														
		Pectoralis Major (g)			Pectoralis minor (g)			Wings (g)			Legs (g)			Paws (g)		
		33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d	33 d	43 d	49 d
308		276	442	593	64	104	135	137	200	224	380	557	684	65	84	94
708		301	509	662	69	117	141	131	187	210	355	535	630	60	77	85
	Female	294	480	631	68	111	139	137	193	218	374	547	664	64	80	90
	SR Female	284	470	623	65	110	138	132	194	216	361	544	649	61	81	89
308	Female	282	445	590	66	105	137	141	200	221	394	561	693	67	83	95
	SR Female	271	439	595	63	102	132	134	201	227	365	552	674	63	84	94
708	Female	306	515	673	70	116	140	133	187	215	354	533	635	61	76	85
	SR Female	297	502	650	68	117	143	129	188	205	357	537	624	60	77	85
Source of variation									------------------------- *P*–values -------------------------							
Rearing System			0.125			0.167			0.313			0.040			0.303	
Strain			<0.001			<0.001			<0.001			<0.001			<0.001	
Strain x RS			0.615			0.226			0.496			0.051			0.451	
Age			<0.001			<0.001			<0.001			<0.001			<0.001	
RS x Age			0.830			0.639			0.495			0.497			0.108	
Strain x Age			0.416			0.177			0.824			0.276			0.498	
RS x S x A			0.823			0.901			0.334			0.321			0.582	

SR – straight-run
RS – rearing system
S – strain
Age – age

Table II – 1.12. Effect of broiler strain, and rearing system on meal frequency, meal length and time spent in the feeder at 3 time points on the 45th d of age

		Time of the evaluation								
Strain	Rearing System	6:00 to 6:30 AM			1:00 to 1:30 PM			10:00 to 10:30 PM		
		Eating	Feeder	n	Eating	Feeder	n	Eating	Feeder	n
		------ seconds ------			------ seconds ------			------ seconds ------		
308		270	271	59	185	186	142	254	299	135
708		262	264	42	145	166	116	247	308	136
	Female	290	295	41	234	249	86	208	253	97
	Male	234	235	27	96	113	106	281	346	70
	Straight-run	272	272	33	165	167	66	263	310	104
	Female	232 ± 47	236 ± 47	25	239 ± 51	242 ± 53	47	202 ± 81	248 ± 93	33
308	Male	324 ± 88	324 ± 86	6	119 ± 56	119 ± 58	58	258 ± 64	276 ± 73	49
	Straight-run	252 ± 36	253 ± 35	28	198 ± 52	198 ± 54	37	300 ± 59	371 ± 68	53
	Female	349 ± 50	354 ± 48	16	228 ± 52	255 ± 54	39	213 ± 57	259 ± 65	64
708	Male	145 ± 43	146 ± 41	21	73 ± 51	108 ± 54	48	304 ± 86	416 ± 99	21
	Straight-run	292 ± 99	292 ± 98	5	133 ± 62	137 ± 64	29	225 ± 59	248 ± 67	51
Source of variation		------- *P*–values -------		-- χ^2 --	------- *P*–values -------		-- χ^2 --	------- *P*–values -------		-- χ^2 --
Strain		0.606	0.611	0.166	0.167	0.432	0.339	0.762	0.596	0.730
Rearing System		0.315	0.306	0.180	0.052	0.056	0.336	0.318	0.374	0.247
Strain x Rearing System		0.149	0.145	0.001	0.715	0.628	0.807	0.689	0.322	0.988

Table II – 1.13. Frequency of feeder access behaviors (free *vs* fight) of Ross 308 and Ross 708 raised sex separated or straight-run at 3 time points on the 45th d of age

Strain	Rearing System	Access to feeder		Leaving the feeder	
		Free	Fight	Free	Fight
		-------------- % --------------			
	Female	93.33	6.67	86.67	13.33
308	Male	97.35	2.65	90.27	9.73
	Straight-run	93.22	6.78	83.05	16.95
	Female	96.64	3.36	87.39	12.61
708	Male	94.44	5.56	87.78	12.22
	Straight-run	94.47	3.53	88.24	11.76
Time of the evaluation (Block)	6:00 to 6:30 AM	92.08	7.92	91.09	8.91
	1:00 to 1:30 PM	94.96	5.04	87.60	12.40
	10:00 to 10:30 PM	96.68	3.32	85.24	14.76
Source of variation		-------------- *P*–values --------------			
Strain		0.608		0.651	
Rearing System		0.694		0.890	
Strain x Rearing System		0.658		0.475	
Hour		0.415		0.099	

Figure II – 1.1. Growth curve of Ross 308 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks.

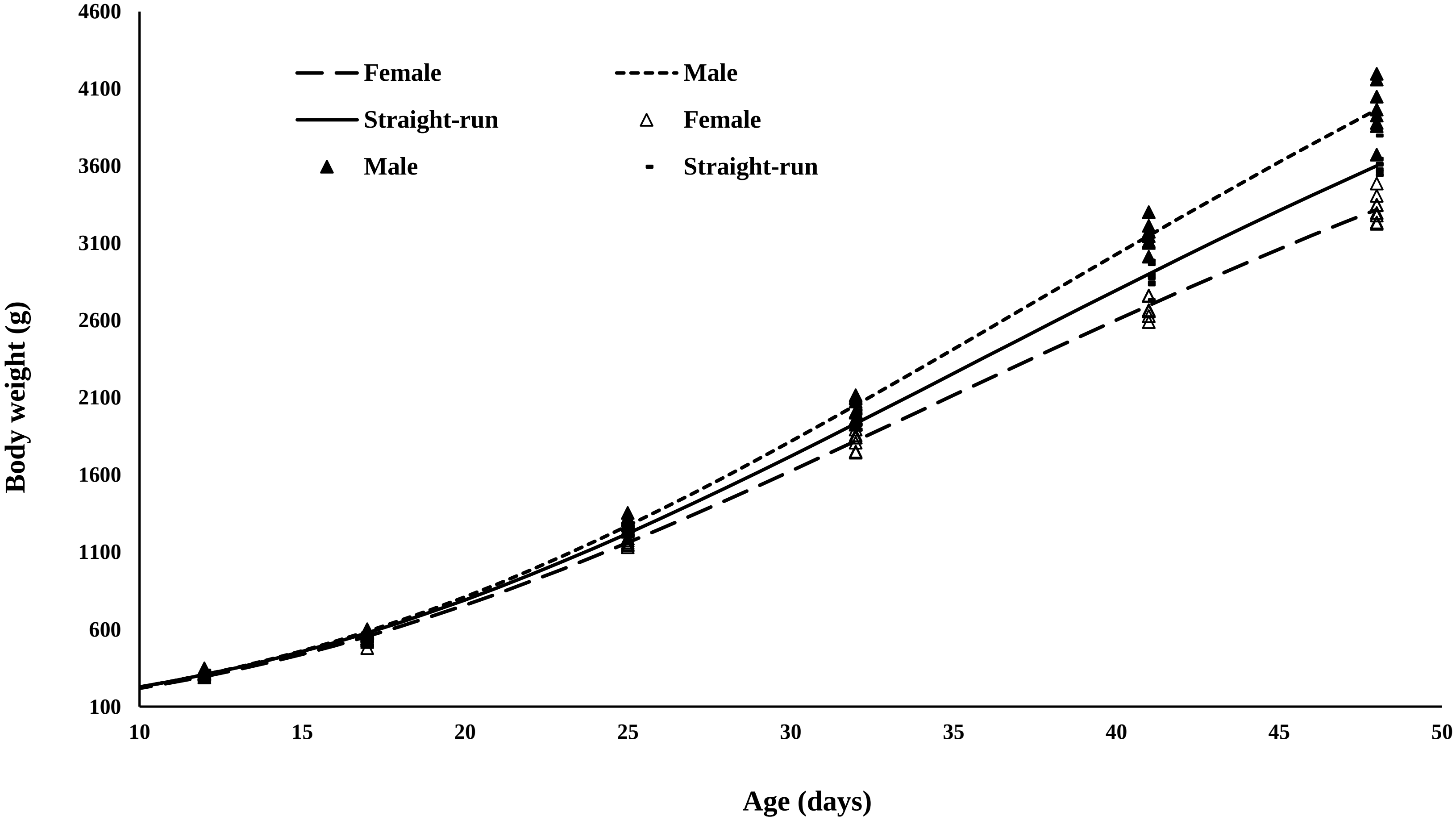


Figure II – 1.2. Growth curve (Gompertz curve) of Ross 708 broilers raised sex separated or straight –run. Each point represents the mean of 28 chicks.

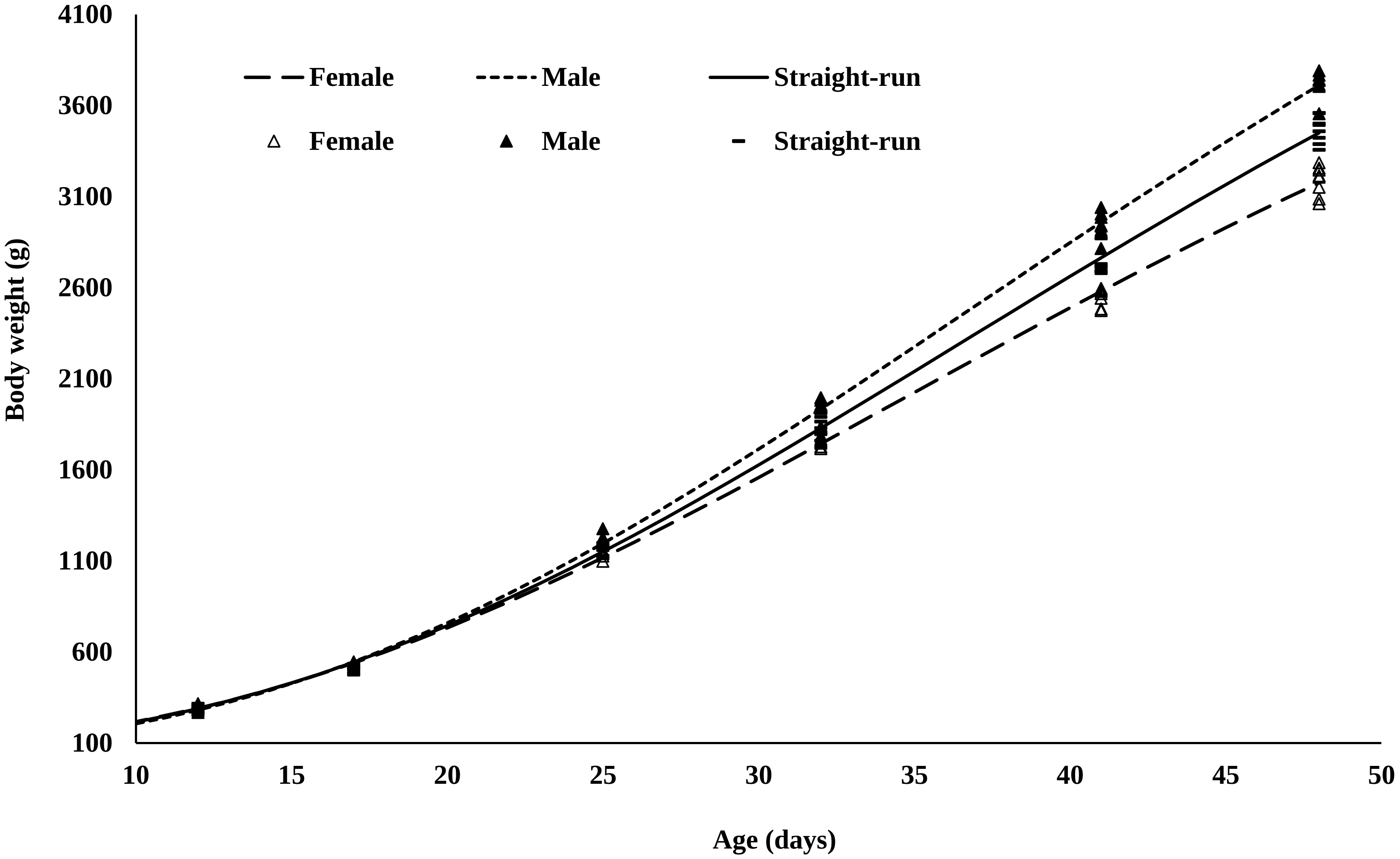


Figure II – 1.3. Body weight coefficient curve (Michaelis and Menten function) of Ross 308 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks.

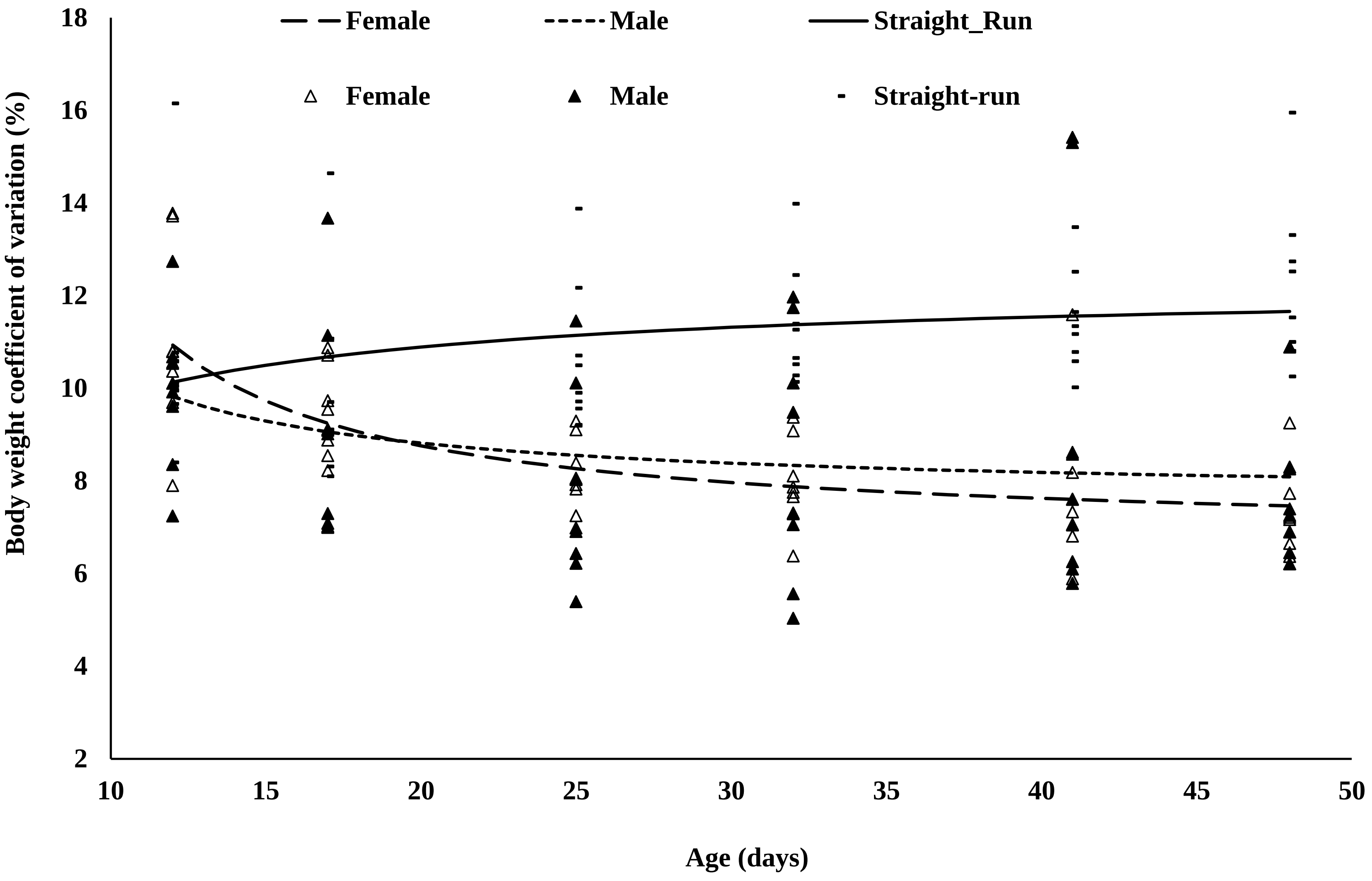


Figure II – 1.4. Body weight coefficient curve (Michaelis and Menten function) of Ross 708 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks.

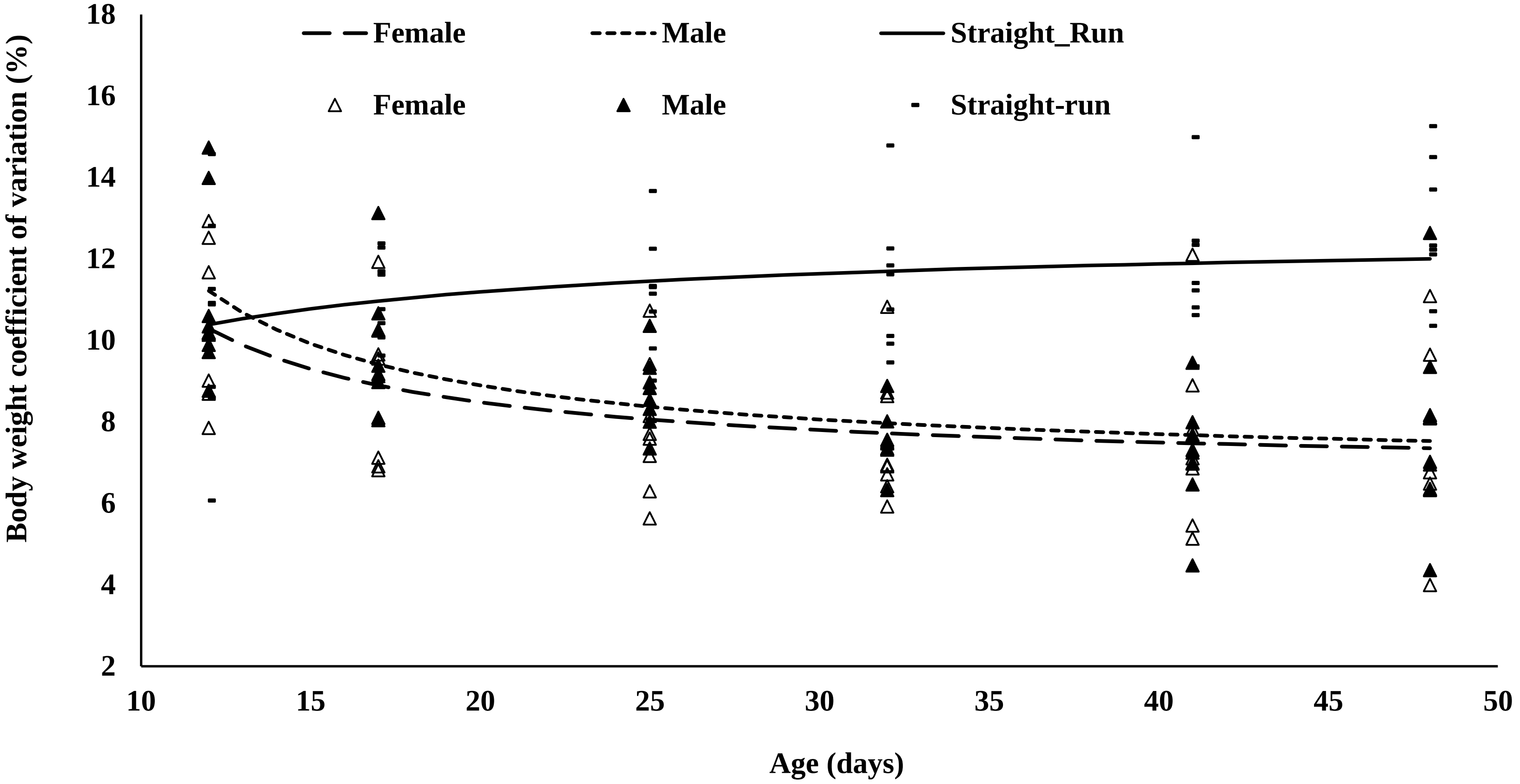


Figure II – 1.5. Growth curve (Gompertz function) of male and female Ross 308 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks (sex separated) or 14 chicks (straight-run).

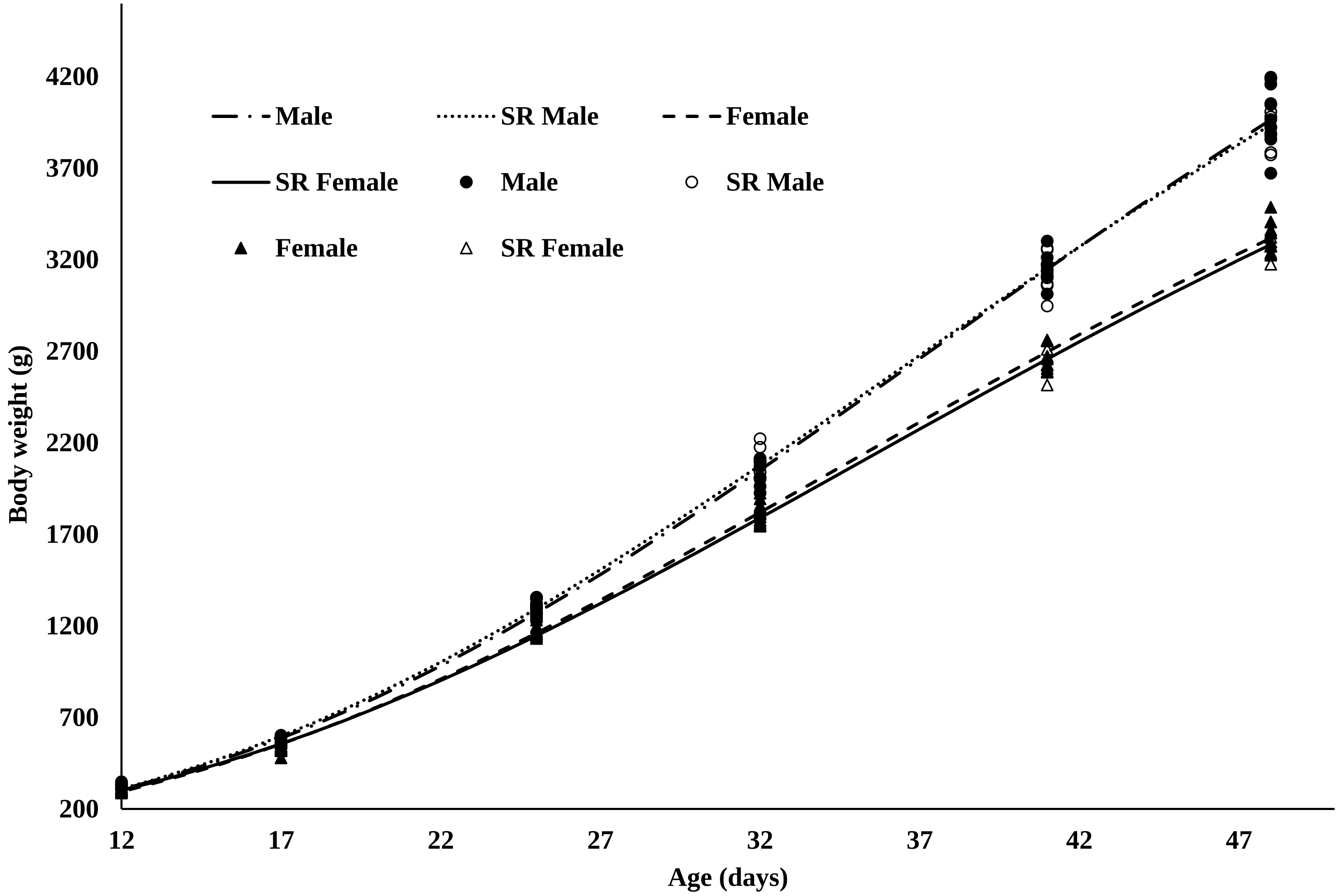


Figure II – 1.6. Growth curve (Gompertz function) of male and female Ross 708 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks (sex separated) or 14 chicks (straight-run).

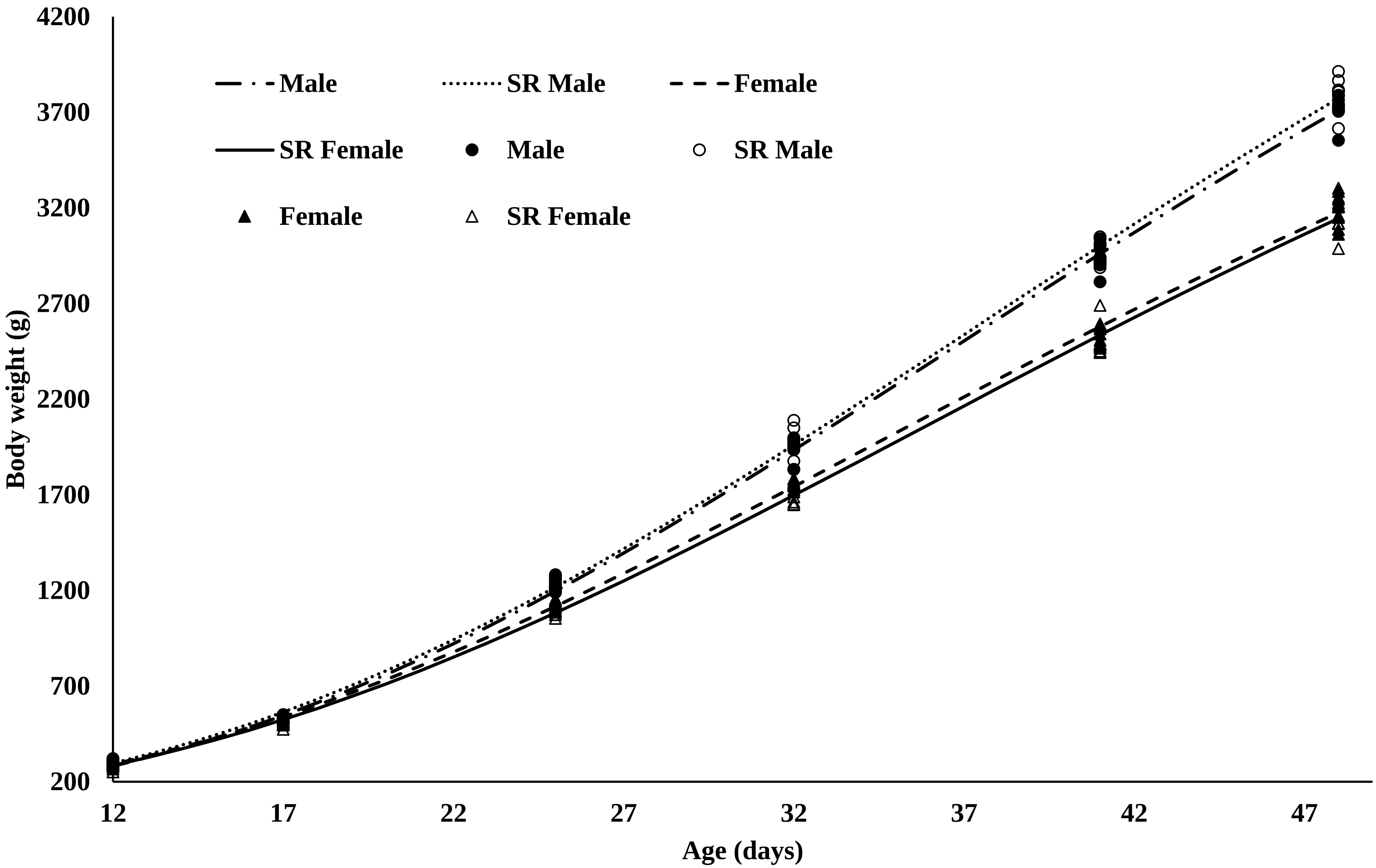


Figure II – 1.7. Body weight coefficient curve (Michaelis and Menten function) of Ross 308 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks (sex separated) or 14 chicks (straight-run).

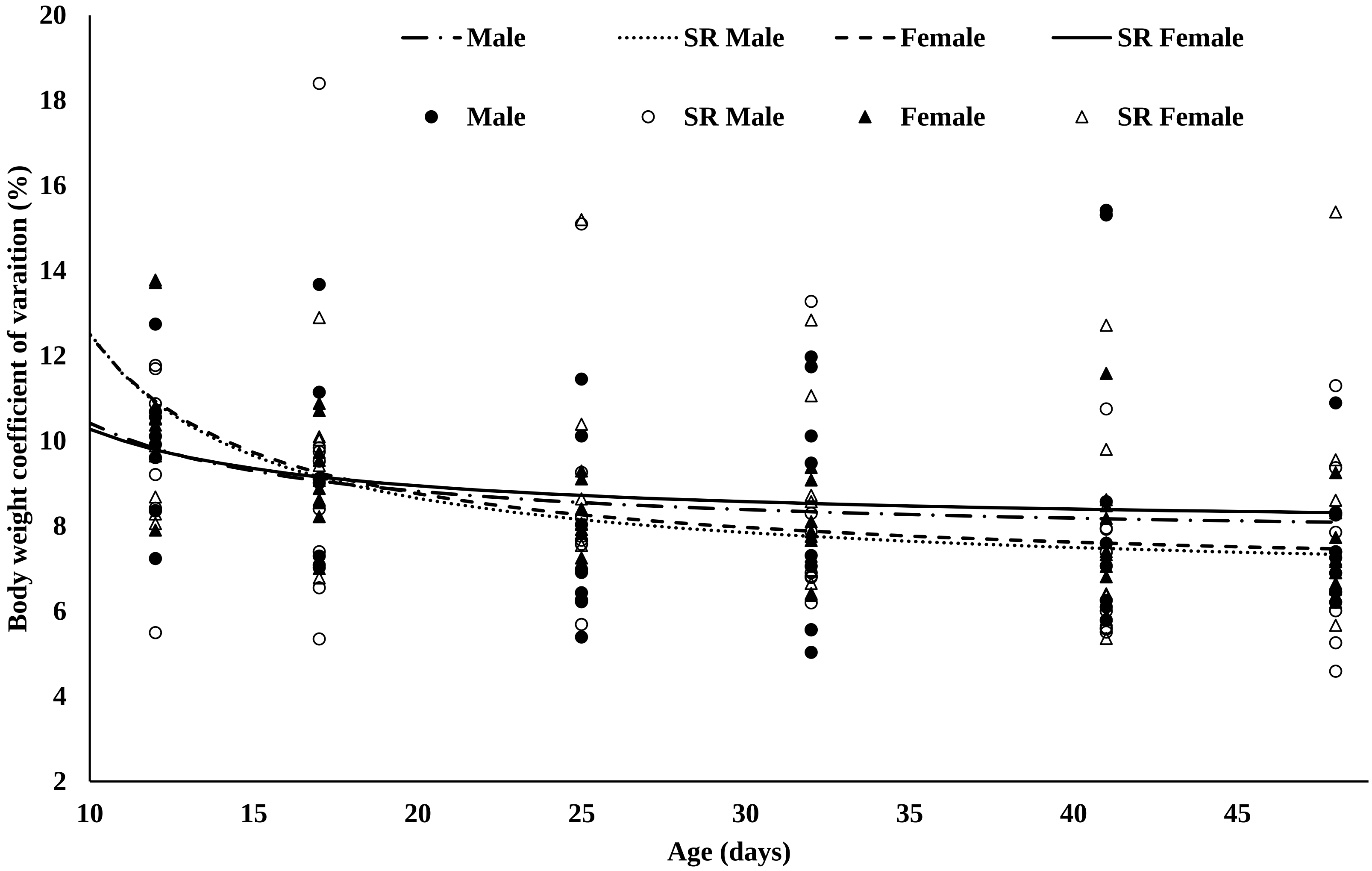


Figure II – 1.8. Body weight coefficient curve (Michaelis and Menten function) of Ross 708 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks (sex separated) or 14 chicks (straight-run).

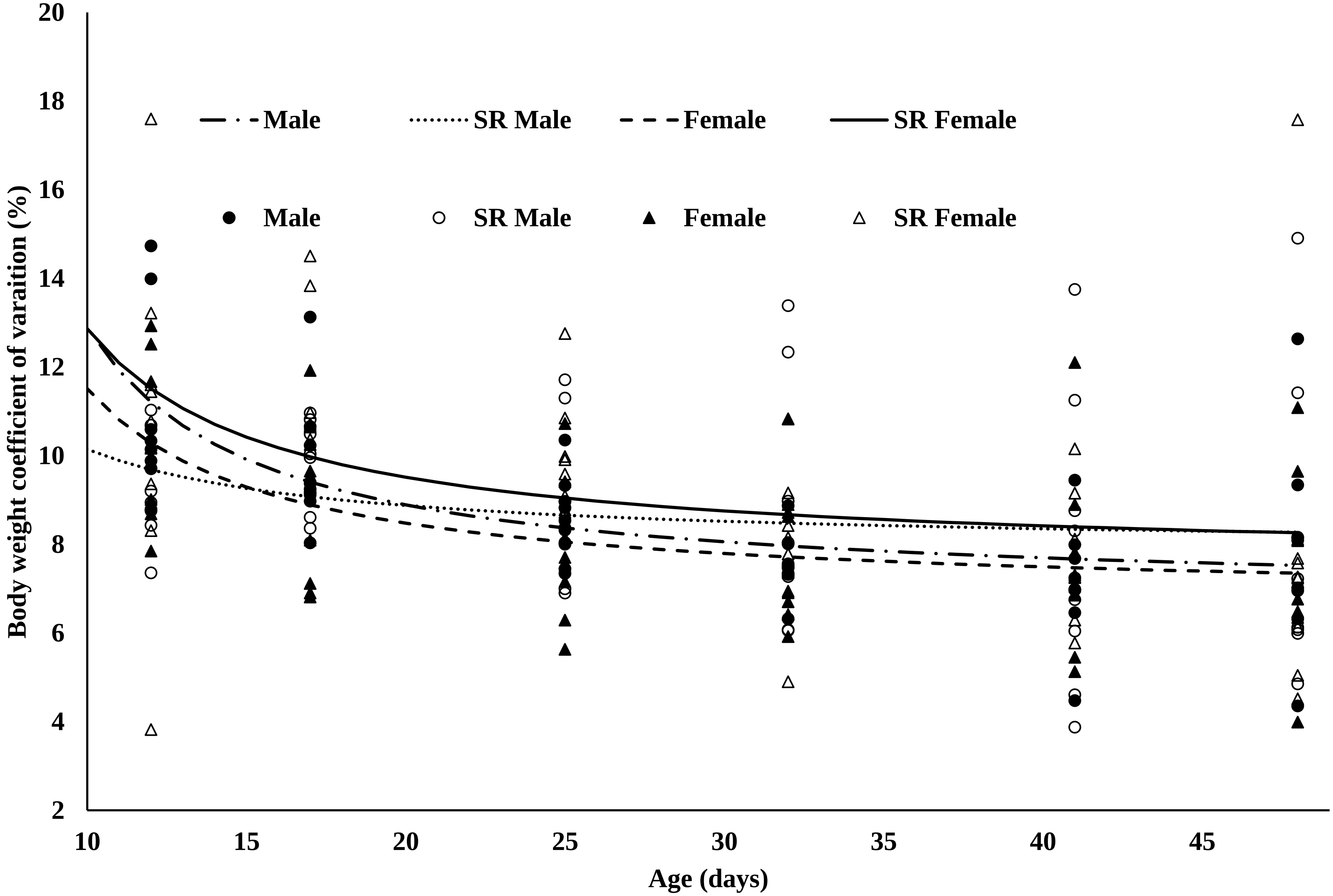


Figure II – 1.9. Feed intake (Mechanistic growth function) of Ross 308 broilers raised sex separated or straight-run Each point represents the mean of 28 chicks

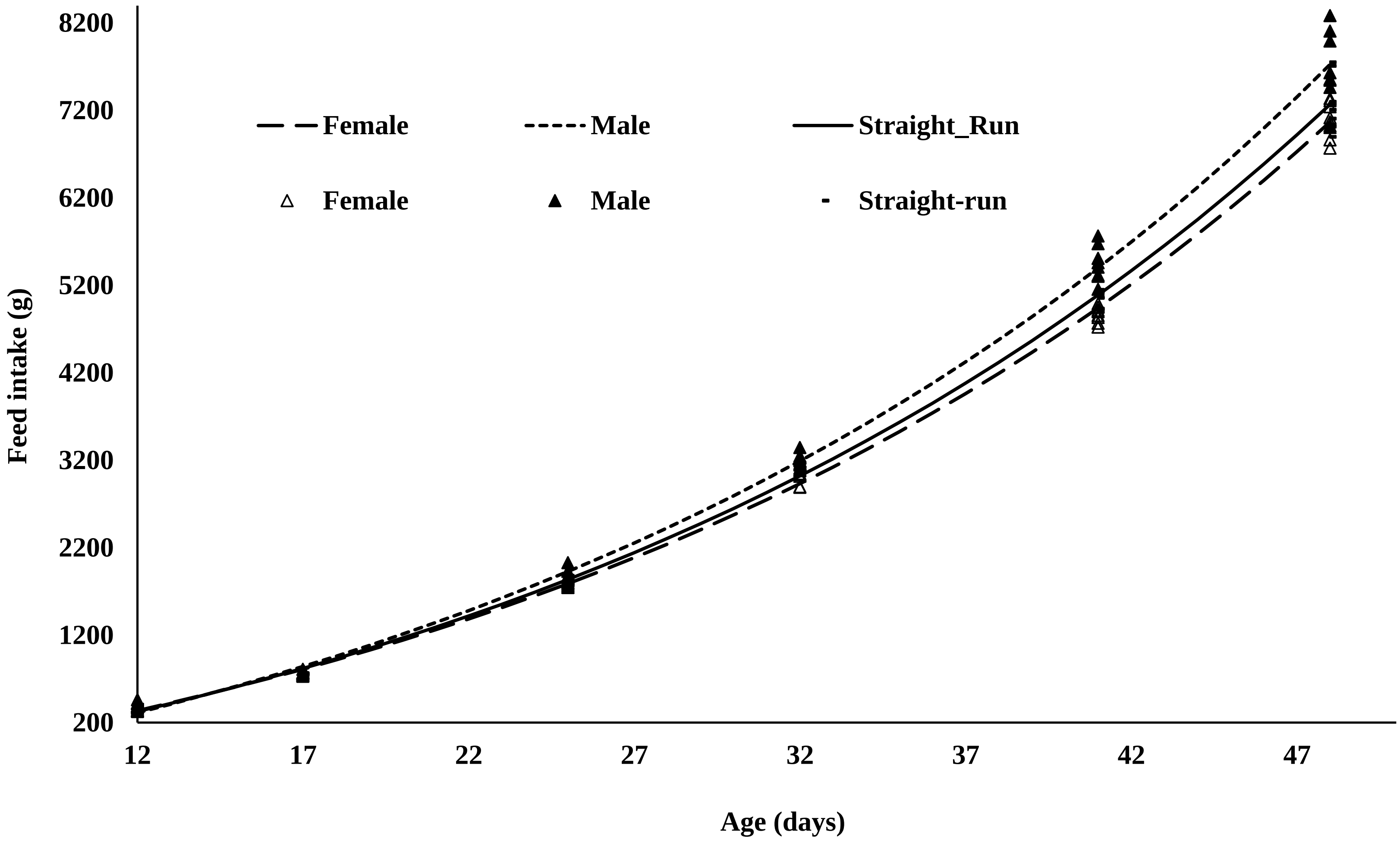


Figure II – 1.10. Feed intake (Mechanistic growth function) of Ross 708 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks.

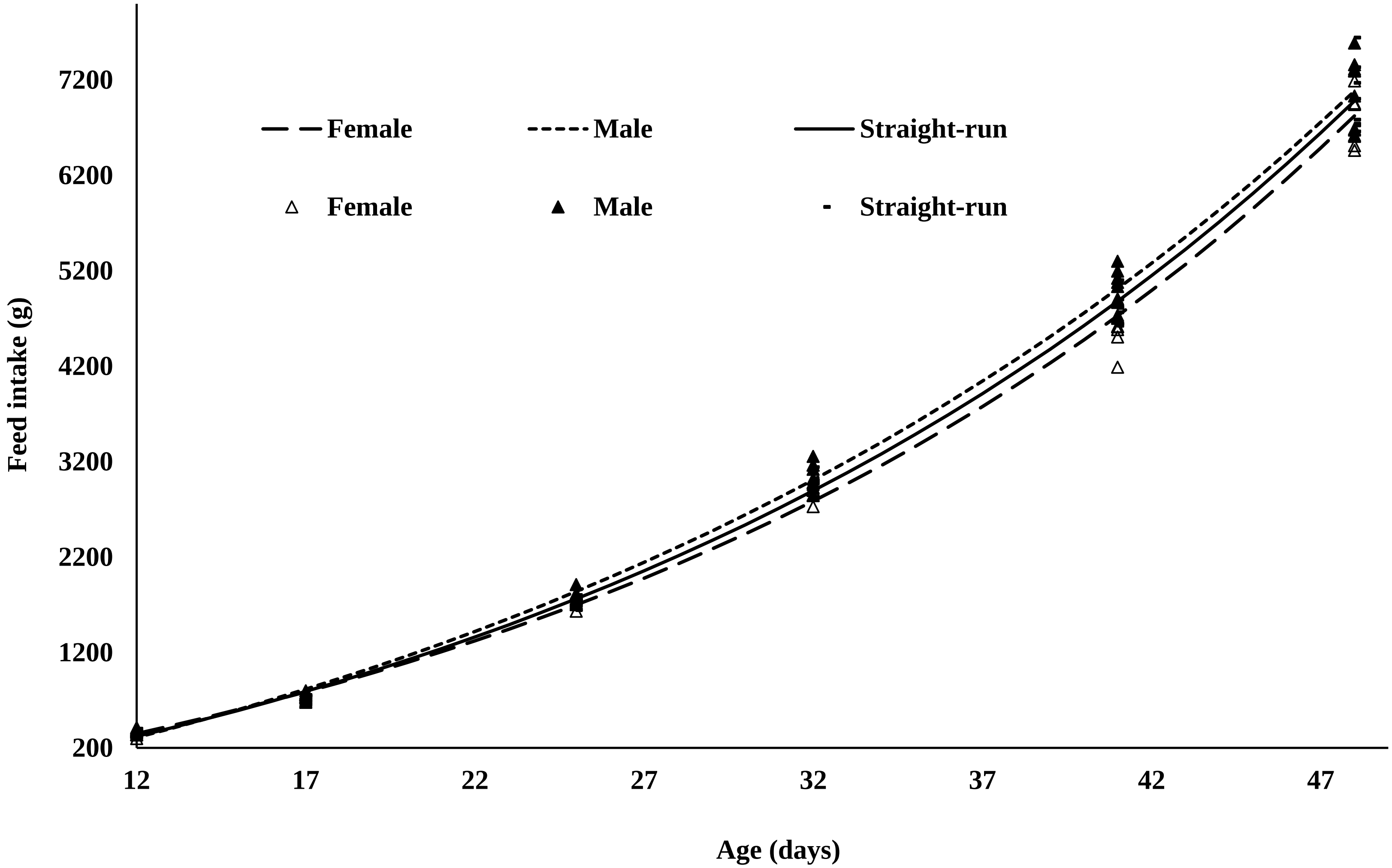


Figure II – 1.11. Adjusted feed conversion ratio (Mechanistic growth function) of Ross 308 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks.

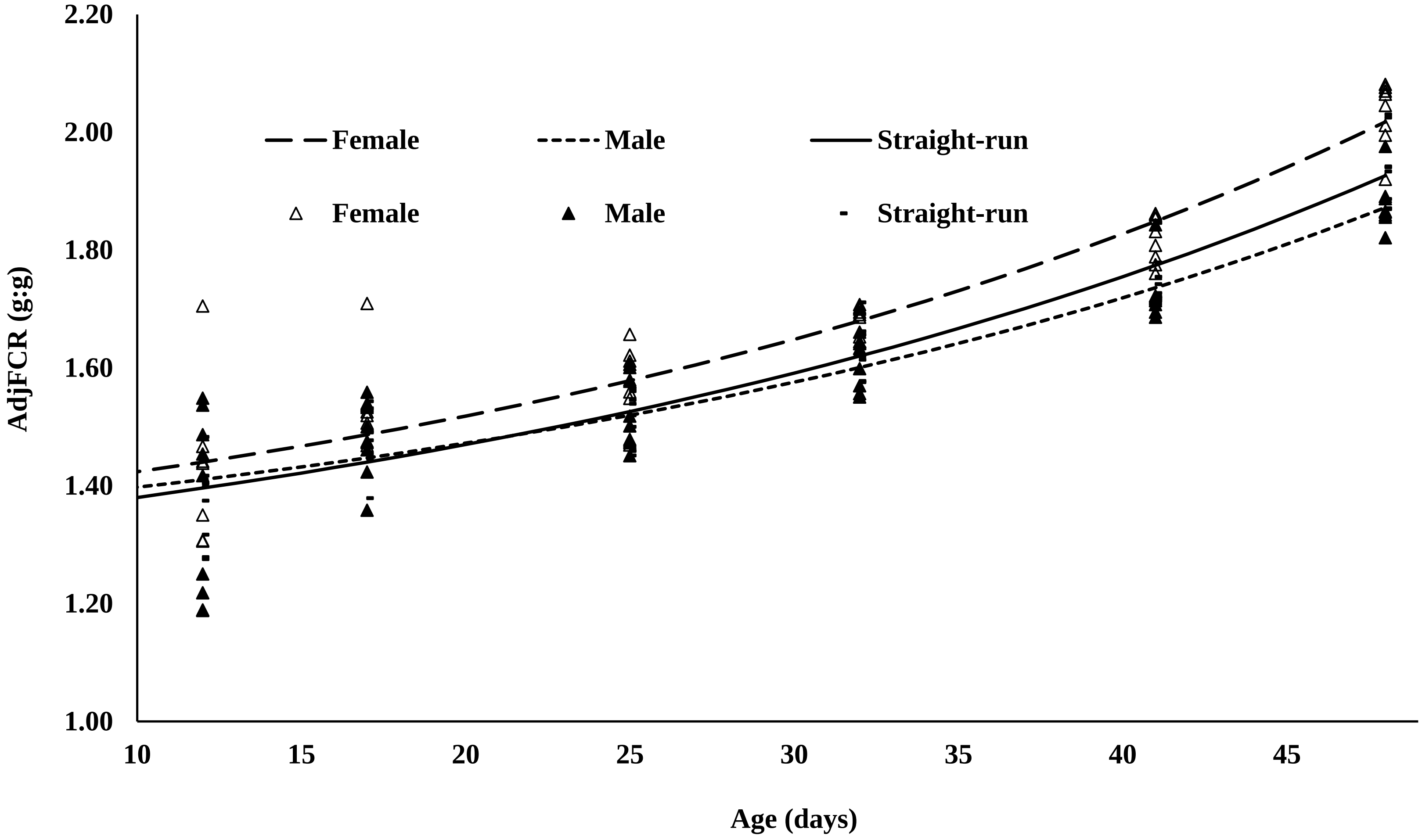
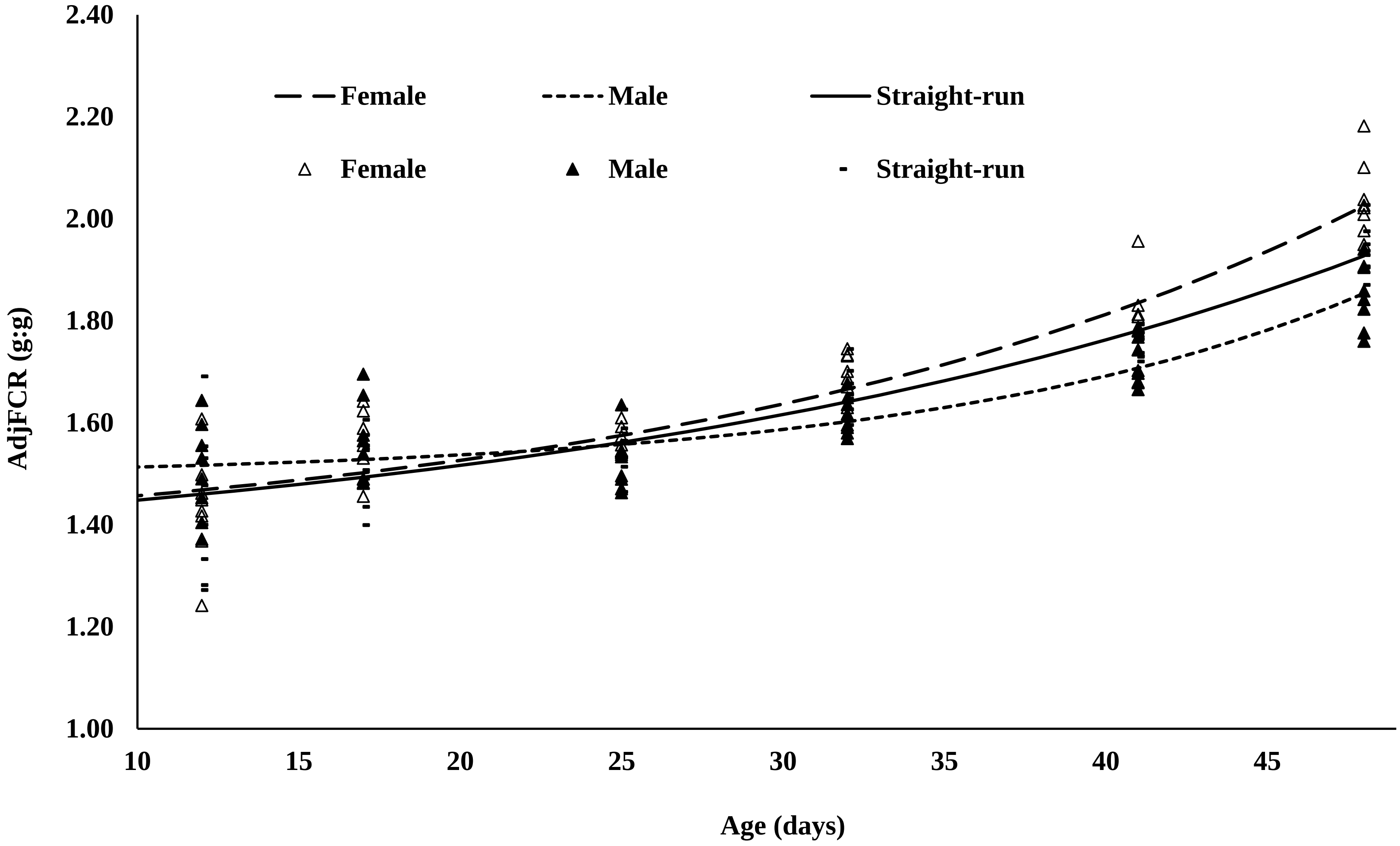


Figure II – 1.12. Adjusted feed conversion ratio (Mechanistic growth function) of Ross 708 broilers raised sex separated or straight-run. Each point represents the mean of 28 chicks.



Straight-run vs. Sex Separate Rearing for Two Broiler Genetic Lines

Part 2: Economic Analysis and Processing Advantages[1]

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[1] M.J. Da Costa[1], G. Colson[1], T.J. Frost[2], J. Halley[3], G.M. Pesti[1]
[1]University of Georgia, Athens, GA 30606
[2]Wayne Farms LLC, 4110 Continental Drive, Oakwood, Georgia 30566
[3]Aviagen Inc., 5015 Bradford Drive, Huntsville, AL 35805
To be submitted to Poultry Science

ABSTRACT

The objective of these analysis was to evaluate the effects of raising broilers under sex separate and straight-run conditions for two broiler genetic lines. 1,344 day-old Ross 308 and Ross 708 birds were sex separated and placed in 48 pens according to rearing type: sex separate (28 males or 28 females) or straight-run (14 males + 14 females). There were three dietary phases: starter (0 to 17d), grower (17 to 32d), and finisher (32 to 48d). Bird individual BW and feed intake were taken at 12, 17, 25, 32, 42, and 48d to evaluate performance. At 33, 43, and 49 d four birds per pen (straight-run pens 2 males + 2 females) were sampled for carcass yield evaluation. Data were analyzed using linear and non-linear regression in order to estimate feed intake and cut-up weights at three separate market weights (1,700, 2,700, and 3,700g). Returns over feed cost were estimated for a 1.8 million broiler complex of each rearing system and under nine feed/meat price scenarios. Overall, rearing birds that were sex separated resulted in extra income that ranged from $48,824 to $330,300, depending on the market targeted and feed and meat price scenarios. Sex separation was shown to be especially important in disadvantageous scenarios where feed prices were high. Gains from sex separation were markedly higher for the Ross 708 than for the Ross 308 birds. Bird variability was also evaluated at the three separate market ages under a narrow range of BW that was targeted. Straight-run birds decreased the number of birds present in the desired range. Depending on market weight, straight-run rearing resulted in 9.1 to 16.6 % less estimated birds than sex separate rearing. It was concluded that sex separation can result in increased company profitability, and also have possible beneficial effects at the processing plant due to increased bird uniformity.

Key words: sex separate, straight-run, genetic line, economics, uniformity

INTRODUCTION

The poultry industry worldwide is driven by economic feasibility and optimization. Nevertheless, there are still some practices that seem paradoxical to companies' maximum return strategies. One of the most controversial policies is the decision on rearing broilers sex separate or comingled (straight-run). On one hand, there are several indications in the literature showing no beneficial effect of sex separation (Smith, et al., 1954; Hess, et al., 1960; Lang, et al., 1960; Lamoreux and Proudfoot, 1969) on bird performance. On the other hand, there are other studies that concluded the existence of beneficial effects on performance of birds that were sex separated (Becker and Berg, 1959; Deaton, et al., 1973; Gehle, et al., 1974; Laseinde and Oluyemi, 1994; de Albuquerque, et al., 2006; Api, 2014). Despite the conflicting results, the reports are consistent on the advantages of sex separation on bird uniformity at market age (Becker and Berg, 1959; Hess, et al., 1960; Lamoreux and Proudfoot, 1969; Deaton, et al., 1973). In addition, it is important to note that most of the studies in this regard were performed using less selected chicken breeds. Broiler production is a dynamic industry where changes in bird genetics are evident yearly (Zuidhof, et al., 2014), so there is a need to reassess the advantages of the two rearing systems when using modern broiler strains.

Most of the studies done on poultry production profitability are related with nutrition, since it represents a rough estimate of 70% of the production costs (Eits, et al., 2005; Dozier, et al., 2006a; Dozier, et al., 2006b; Aftab, 2012; Trevisan, et al., 2014; Basurco, et al., 2015). Very little research was done on the economics of management factors (Groen, et al., 1998; Verspecht, et al., 2011), and to the authors best knowledge there is no work done on the economic feasibility of sex separate rearing *vs.* straight-run. Therefore, the objective of this study was to evaluate the economic returns of rearing broilers sex separate or straight-run using modern broiler strains and the effects of the rearing system on bird uniformity at market age.

MATERIAL AND METHODS

There were six experimental treatments consisting of a factorial combination of two genetic lines with three broiler rearing types.

Strain treatments

Two genetic lines were evaluated in the present experiment. One-d-old chicks of Ross 308 and Ross 708 strains were sexed in order to obtain 336 chicks per sex and strain, with a total of 1,344 chicks used.

Sex separate vs. Straight-run treatments

Chicks were allocated and raised in pens according to one of the three following treatments: male, female, and straight-run. At placing, for the male and female treatments, 28 chicks of the respective sex treatment were randomly selected, weighed individually, and identified with a neck tag; for the straight-run treatment 14 males and 14 females were used instead. From this point forward, this treatment will be called as rearing system.

Birds and Husbandry

All practices regarding animal management were approved by the Institutional Animal Care and Use Committee of the University of Georgia. The experiment was performed in a window-less room with 48 pens that were 1.22 x 1.52 m in dimension. Each pen had one hanging tubular feeder with 170 cm of feeder space (6 cm / bird), 10 nipple drinkers, and the floor was covered with 0.05 m of used pine shaving as litter. For the first three days of brooding, one cardboard tray with feed was placed in each pen to ease the access to feed by the chickens. The diets fed in the present experiment were provided by a local integrator, being corn-soybean meal-based with three dietary phases: starter – 0 to 17 d, grower – 17 to 32 d, and finisher, 32 to 48 d. The starter diets were fed as crumble and the grower and finisher diets were fed as pellet. Both water and feed were consumed *ad libitum*. Temperature, ventilation and lighting programs were checked twice a day and followed commercial practices. Chicks where housed at 34°C and then the temperature was gradually reduced 3°C every wk until the temperature reached 20°C. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing 24 h of light at 30 lux for the first 7 d, 16 h of light at 3.5 lux with 8 h of dark from 7 to 28 d of age, and 20 h of light at 3.5 lux with 6 h of dark from 28 d until the end of the trial.

Performance data

Chickens were weighed individually at hatch, 12, 17, 25, 32, 42, and 48 d. Afterwards, BW CVs were calculated for bird variability per pen, per treatment evaluation. Feed was also weighed at the same time points. Group feed intake, individual BW gain, and adjFCR (adjusted FCR for mortality and sampling) were calculated for each age for performance analysis.

Processing data

At 33, 43, and 49 d the four birds that had the lowest number of neck tag were selected for processing. In the straight-run pens, two birds of each sex were selected also based on the neck tag number. Birds were withdrawn from feed for eight hours over night. Birds were individually weighed before processing, immediately following evisceration (pre-chill/hot carcass weight) and after chilling (cold carcass weight). Paws were taken and weighed prior to hot carcass weighing. Carcasses were chilled in water and ice at 1°C for 240 min. Subsequently, carcasses were deboned and *pectoralis major*, *pectoralis minor*, wings, and legs were weighed for carcass yield.

Data Analysis

The data analysis was comprised of two separate parts, where economic feasibility of rearing birds sex separate *vs.* straight-run and the impact of these rearing systems on bird variability were evaluated. Economic feasibility was based on an input (feed) output (meat) base under different scenarios of feed and meat prices. For all these scenarios, two or three market BW were considered (1,700, 2,700, and 3,700 g). The first economic simulation was projected to a broiler complex producing 1,800,000 birds (a wk of production roughly) with an allocation of 600,000 birds for each market weight (Table II. 2.1) to be sold as whole birds or cut-ups. For the sex separate rearing, females were targeted to the 1,700 g market BW, males to the 3,700g, and for the 2,700g market straight-run birds were used. The straight-run rearing system had straight-run birds for all three of the processing ages. The second simulation just considered the 1,700 g birds to be sold as whole birds, and the 3,700 g birds to be sold as cut-ups. Afterwards, an estimate of feed intake for each market BW of each rearing system was determined using regression analysis. Feed intake data for each gender were fitted using seven models (quadratic, cubic, logistic 3 parameters, logistic 4 parameters, Gompertz, mechanistic growth, and Michaelis Menten), considering BW as the independent variable. The models were selected based on the lowest Akaike information criterion, lowest root-mean-square error, and highest R^2 to better describe the data (data not shown). This analysis revealed that the model to best fit the data set was the third order polynomial:

$$Feed\ intake = intercept + \beta_1 \times BW + \beta_2 \times BW^2 + \beta_3 \times BW^3$$

Consequently this model was used to predict the feed intake at each market BW. Subsequently, using the same set of models, cut-up parts (whole carcass, *pectoralis major*, *pectoralis minor*, whole wings, whole legs, and paws) were expressed in function of BW to determine parts' weight for each market BW. Weights were better predicted using both linear or quadratic regressions depending on the cut-up part evaluated:

$$Linear \rightarrow Cut - up\ weight = intercept + \beta_1 \times BW$$

$$Quadratic \rightarrow Cut - up\ weight = intercept + \beta_1 \times BW + \beta_2 \times BW^2$$

Pectoralis major of Ross 308 showed to have a linear relationship with BW; whereas for Ross 708 birds, the relationship was better fit by the second order polynomial model. *Pectoralis minor*, legs, and paws had a linear relationship with BW. Wings of Ross 308 had a quadratic relationship with BW, and Ross 708 a linear one.

There were nine price scenarios formulated, considering a combination of three feed prices (low – \$250, medium – \$350, and high – \$450) with three meat prices (low – 80% of medium, medium, and high 120% of medium). The cut-up parts were based on the Urner Barry weekly insider's poultry report from May 26th 2016. Net returns were calculated based on the return from meat selling over feed cost. An associated fixed cost of \$0.009/bird was considered when chicks were sex separated (Personal communication, Dr. Thomas Frost, Wayne Farms LLC).

To evaluate bird variability within each rearing system, normal distribution curves were determined at each weighing day. Herein, birds were considered the experimental unit for each rearing system. True mean, standard deviation and 95% CI were determined. In addition, bird BW SD were expressed in function of BW using all weight data, in order to determine estimated SD observed at each market BW. Afterwards, 1,440,000 bird BW for each rearing system were generated using Microsoft Excel (2013) according to Alhotan, et al. (2014). Using the values generated, the cumulative distribution function was used to determine the percentage of individuals observed within a narrow weight range at the three market BW. For the 1,700g, 2,700g, and 3,700 a ± range of 50g, 100g, and 150g was considered respectively. All the previous data were analyzed and modeled using JMP Pro 11 (SAS Inst. Inc., Cary, NC) software.

RESULTS AND DISCUSSION

Bird performance data regarding the specific differences of strains and rearing system throughout life cycle were not evaluated herein and were presented elsewhere. The estimates and respective predictive models for bird individual feed intake needed to reach each of the three market BW are present on Table II – 2.2. Overall, estimates revealed males needing less feed to reach market weight, followed by straight-run, and then female birds. This is in agreement with Groen, et al. (1998) who, when comparing the cost of producing 1 kg carcass, observed that males had a lower cost ($1.269) than females ($1.370). The cut-up part estimates and regressions are presented on Tables II 2.3 and 2.4. Females were shown to have a larger increase in breast meat yield than males at same BW, which has been shown by other authors (Gous, et al., 1999).

For the scenario where birds were being sold as whole carcasses at the three market weights, both Ross 308 (Table II – 2.5) and Ross 708 (Table II – 2.6) profits were shown to benefit from sex separation. Even though the returns from sex separation were positive for both strains, Ross 708 had higher net returns than Ross 308. The higher net returns were mainly related with the higher yields presented by the Ross 708, which compensated the higher estimated feed intake also shown by this strain. Evaluating the beneficial effects of sex separating, it was evident that as feed prices increase the returns from sex separation would also increase regardless of meat price. As expected, as meat prices increased net returns also increased; however, it was noteworthy that in the worst case scenario where feed prices are high and meat prices are low, the returns from sex separation were shown to be higher (Ross 308 = $120,202; Ross 708 = $219,560) than in a case where the feed prices were low with low meat prices (Ross 308 = $77,304; Ross 708 = $124,430).

The simulation for the cut-up market at the three processing weights also revealed that sex separation resulted in higher returns under any feed and meat price scenario (Table II – 2.7). Once again, Ross 708 birds resulted in total higher net returns and higher sex separation returns when compared with Ross 308. Similarly, with the whole carcass data, high feed prices mitigated the least when sex separation rearing was performed. Remarkably, it was shown that advantages of sex separation resulted in an extra return up to $203,673 (Ross 708 at high feed and high meat prices) when compared with a straight-run complex (a wk of production).

Despite the results for the three market weights being sold as whole carcass or cut-up parts, it is likely that a company would produce lighter birds to be sold as a whole carcass and heavier birds to be sold as cut-ups. This scenario is depicted in Table II – 2.8, where females (half of the complex) were allocated to be sold as whole carcasses and males were set to be sold as cut-up parts. This simulation revealed to be the scenario where a company could take the most advantage from sex separation, this being especially evident under unfavorable feed prices. Under high feed price returns for the Ross 308 sex separated showed to be at least $130,000 higher than Ross 308 straight-run birds, regardless of meat price. The sex separation advantage was again notably evident for the Ross 708 birds, where the extra return of sex separation ranged from $179,100 to $330,300, depending on the feed/meat price scenario. It should be considered that this economic simulation was performed for a production period of roughly a wk. Therefore, if the net returns for the year are considered, it is observed that the extra returns from sex separation could range from $9,313,200 to $17,175,600 yearly. Even though, there is a clear economic advantage of sex separating birds, one could argue that if the sexing cost increased it might turn sex separation to not be feasible. Therefore, it was determined how much sexing cost would be allowed to increase, for a medium meat and low feed price scenario (scenario with the lowest returns from sex separation), in order to make the returns from both systems equal. Results revealed that under the worst case scenario, sex separation would start to be economically unfavorable if sexing cost increased to $0.046/bird, which is roughly five times the cost used here ($0.009). Consequently, it is evident that there is a large margin for sexing cost to vary and still be economically favorable.

Evaluating bird distribution throughout birds' life cycle, it was evident that as birds aged dispersion from the average flock BW increased (Figures II – 2.1 and 2.2). Nevertheless, the population of birds raised sex separated showed a normal distribution across the experiment. The same was not observed on the straight-run birds where a normal mixture distribution was patented at 32 d. This results from the presence of two populations (each gender) with two different average BW and normal distributions within the same flock. The increased SD and CI range observed on straight-run birds when compared with sex separate, clearly reveals that at any of the processing ages mentioned previously, bird variability will be increased in the former ones. Considering that the average BW of each rearing system was targeted at that age, we can have a better understanding of the implication of raising birds straight-run at the time of processing. So the question we can raise is: in a scenario where a company is targeting a market BW at 48 d within 100 g lower and above the means obtained, what percentage of the population would fall in this range? In the case of Ross 308 birds, the percentage of birds would fall in the range of 3228g – 3428g, 3852g – 4052g, and 3514g – 3714g for female, male, and straight-run flocks. Using a cumulative distribution function, it was determined that 31.2, 23.2, and 17.7% of birds would be observed for the respective ranges of females, males, and straight-run birds. Even though, it is clear that sex separate flocks would have more likelihood of having birds falling into the specific range, one can argue that different BW would have different variances and therefore the comparisons would not be fair. Therefore, SD were estimated for each market weight (Table II – 2.9) and normal distribution curves generated for each rearing system. Using the cumulative distribution function, the percentage of birds estimated for the specified ranges were determined (Table II – 2.10). For both genetics, sex separate birds had a higher percentage of birds estimated to be within each market BW range. Furthermore, as birds aged this discrepancy increased. At a lighter weight (1,700 g), the average difference of the percentage of individuals observed within the ranges between sex separate and straight-run was 10 % in favor of sex separate, whereas at heavier weights (3,700 g) this difference increased to 15.2 %. These values allow us to infer that at any market age straight-run flocks will have higher bird BW variability at the processing plant that can result in increased losses. Wideman, et al. (2013) observed lower standard deviations of sex separate flocks when comparing with straight-run. The authors indicated that this could be advantageous for processing, since the equipment could be adjusted more precisely to a narrower weight range. Furthermore, the condemning and downgrading of carcasses on the processing line during the experiment indicated that female and straight-run birds tended to be higher than males, since the equipment was previously set to male body size.

One of the limitations of this report is to consider that all the birds present in a flock would have the same value. The pay per bird or cut-up used here was obtained from an average price from a report (Urner Barry weekly insider's poultry report from May 26th 2016), but in reality the pay to the companies will vary according to the products falling within a weight range stipulated by the buyer. For example, for *pectoralis major*, it can be stipulated that the company will be payed $2.640/kg for every cut that are within the range of 500 to 580 g. Anything that will fall outside of this range (lower or higher) will get a pay lower than the one set for the range. Considering the results of the bird BW distribution within a population, it is clear that for the flocks with straight-run birds there is higher probability of birds falling outside of the desired range resulting in economic losses. These economical losses where not considered here, therefore the economic advantage of sex separation shown in the present experiment might actually be an underestimation.

In conclusion, sex separation was shown to result in higher profitability under any scenario price evaluated, being especially economically important in disadvantageous scenarios where feed prices were high. In addition, reduced bird variability at market age of sex separate birds indicated potential gains (or fewer losses) at the processing plant.

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Table II – 2.1 Simulation of a two production scenarios in a 1,800,000 broiler complex when using a sex separate *vs.* straight-run regime

		Production strategy for 3 market BW (1,800,000 birds complex)			
		Number of birds allocated per market BW			
Market targets	Market weight (g):	1,700	2,700[1]	3,700	Cost of sexing ($/bird)
3 market BW	Female	600,000	600,000	0	0.009
	Male	0		600,000	
	Straight-run	600,000	600,000	600,000	0
2 market BW	Female	900,000	0	0	0.009
	Male	0	0	900,000	0.009
	Straight-run	900,000	0	900,000	0

[1] For the 2,700 g market BW, sex separate birds would still be raised straight-run

Table II – 2.2 Predictive models and estimated feed intake (FI) based on BW of Ross 308 and Ross 708 raised straight-run or sex separate at three market ages

Strain	Rearing system	R^2	Linear *P*-value	Quadratic *P*-value	Cubic *P*-value	Equations	Market BW (g)		
							1,700	2,700	3,700
							Estimated feed intake (g)		
380	Female	0.996	<0.001	<0.001	0.004	$FI = -437.0071 + 1.8621461\times BW + 0.0002716\times(BW-1640.9)^2 + 0.00000010244\times(BW-1640.9)^3$	2,730	5,017	8,499
	Male	0.998	<0.001	<0.001	0.008	$FI = -411.6742 + 1.762338\times BW + 0.0001526\times(BW-1846.6)^2 + 0.000000033212\times(BW-1846.6)^3$	2,587	4,478	6,845
	Straight-run	0.997	<0.001	<0.001	0.051	$FI = -420.2102 + 1.7952551\times BW + 0.0001813\times(BW-1677.91)^2 + 0.000000040682\times(BW-1677.91)^3$	2,632	4,660	7,300
780	Female	0.995	<0.001	<0.001	<0.001	$FI = -346.3998 + 1.8051315\times BW + 0.0002964\times(BW-1573.6)^2 + 0.00000015039\times(BW-1573.6)^3$	2,727	5,118	9,119
	Male	0.996	<0.001	<0.001	0.038	$FI = -317.3247 + 1.7227482\times BW + 0.000161\times(BW-1771.02)^2 + 0.000000048148\times(BW-1771.02)^3$	2,612	4,512	7,002
	Straight-run	0.998	<0.001	<0.001	<0.001	$FI = -299.1108 + 1.7506251\times BW + 0.0002052\times(BW-1670.45)^2 + 0.000000097217\times(BW-1670.45)^3$	2,677	4,751	7,836

Table II – 2.3 Predictive models and estimated whole carcass, *pectoralis major*, and *pectoralis minor* weight outputs based on BW of Ross 308 and Ross 708 raised straight-run or sex separate at three market ages

Parameter (g)	Strain	Rearing system	R^2	Linear *P*-value	Quadratic *P*-value	Equations	Market BW (g)		
							1,700	2,700	3,700
							Estimated cut-up weight (g)		
Whole carcass (WOG[1])	380	Female	0.998	<0.001	-	$Y = -101.8584 + 0.8634866 \times BW$	1,366	2,230	3,093
		Male	0.998	<0.001	-	$Y = -173.9066 + 0.8846657 \times BW$	1,330	2,215	3,099
		Straight-run	0.997	<0.001	-	$Y = -152.3226 + 0.8771947 \times BW$	1,339	2,216	3,093
	780	Female	0.998	<0.001	-	$Y = -99.57115 + 0.8773327 \times BW$	1,392	2,269	3,147
		Male	0.998	<0.001	-	$Y = -119.592 + 0.8792949 \times BW$	1,375	2,255	3,134
		Straight-run	0.997	<0.001	-	$Y = -127.6572 + 0.8820594 \times BW$	1,372	2,254	3,136
Pectoralis major	380	Female	0.989	<0.001	-	$Y = -78.47452 + 0.207519 \times BW$	274	482	689
		Male	0.981	<0.001	-	$Y = -114.3807 + 0.2157972 \times BW$	252	468	684
		Straight-run	0.988	<0.001	-	$Y = -115.0906 + 0.2233819 \times BW$	265	488	711
	780	Female	0.994	<0.001	0.049	$Y = -143.9757 + 0.2671576 \times BW + 0.00002522 \times (BW-2332.58)^2$	320	581	892
		Male	0.992	<0.001	0.002	$Y = -173.7674 + 0.2658474 \times BW + 0.000035 \times (BW-2739.58)^2$	316	544	842
		Straight-run	0.991	<0.001	0.024	$Y = -147.2865 + 0.2598901 \times BW + 0.000025622 * (BW-2562.1)^2$	314	555	847
Pectoralis minor	380	Female	0.983	<0.001	-	$Y = -20.33053 + 0.0492049 \times BW$	63	113	162
		Male	0.985	<0.001	-	$Y = -14.0895 + 0.0434248 \times BW$	60	103	147
		Straight-run	0.988	<0.001	-	$Y = -19.02399 + 0.0468732 \times BW$	61	108	154
	780	Female	0.965	<0.001	-	$Y = -14.26443 + 0.0521314 \times BW$	74	126	179
		Male	0.976	<0.001	-	$Y = -12.50003 + 0.0472751 \times BW$	68	115	162
		Straight-run	0.967	<0.001	-	$Y = -18.6456 + 0.0514848 \times BW$	69	120	172

[1] Whole chicken without giblets

Table II – 2.4 Predictive models and estimated wings, whole legs, and paws weight outputs based on BW of Ross 308 and Ross 708 raised straight-run or sex separate at three market ages

Parameter (g)	Strain	Rearing system	R^2	Linear *P*-value	Quadratic *P*-value	Equations	Market BW (g)		
							1,700	2,700	3,700
							Estimated cut-up weight (g)		
Wings	380	Female	0.965	<0.001	<0.001	$Y = 47.664521 + 0.0601715 \times BW - 0.0000235 \times (BW-2459.47)^2$	136	209	234
		Male	0.988	<0.001	<0.001	$Y = 41.17698 + 0.0645874 \times BW - 0.00001517 \times (BW-2836.54)^2$	131	215	269
		Straight-run	0.982	<0.001	0.001	$Y = 33.589353 + 0.0665542 \times BW - 0.0000148 \times (BW-2653)^2$	133	213	264
	780	Female	0.973	<0.001	-	$Y = 33.350046 + 0.0613019 \times BW$	138	199	260
		Male	0.956	<0.001	-	$Y = 26.637159 + 0.0657066 \times BW$	138	204	270
		Straight-run	0.992	<0.001	-	$Y = 21.896178 + 0.066841 \times BW$	136	202	269
Legs (whole)	380	Female	0.993	<0.001	-	$Y = 34.771763 + 0.2066898 \times BW$	386	593	800
		Male	0.993	<0.001	-	$Y = -20.67542 + 0.2338323 \times BW$	377	611	845
		Straight-run	0.994	<0.001	-	$Y = -25.04869 + 0.232888 \times BW$	371	604	837
	780	Female	0.987	<0.001	-	$Y = 11.556265 + 0.209849 \times BW$	368	578	788
		Male	0.987	<0.001	-	$Y = 4.3762629 + 0.2196916 \times BW$	378	598	817
		Straight-run	0.990	<0.001	-	$Y = 15.684331 + 0.2138229 \times BW$	379	593	807
Paws	380	Female	0.936	<0.001	-	$Y = 30.454984 + 0.0203258 \times BW$	65	85	106
		Male	0.964	<0.001	-	$Y = 28.885889 + 0.0292935 \times BW$	79	108	137
		Straight-run	0.976	<0.001	-	$Y = 24.853308 + 0.0268724 \times BW$	71	97	124
	780	Female	0.965	<0.001	-	$Y = 30.229826 + 0.0184329 \times BW$	62	80	98
		Male	0.981	<0.001	-	$Y = 21.633093 + 0.0290123 \times BW$	71	100	129
		Straight-run	0.972	<0.001	-	$Y = 23.67165 + 0.0253063 \times BW$	67	92	117

Table II – 2.5 Net returns simulation from selling whole chicken carcasses (WOG) at 3 market weights on a production scenario of a 1,800,000 Ross 308 broiler complex when using a sex separate *vs.* straight-run regime

	Respective whole carcass weight (g) at market BW			Bird Individual feed intake (g) at market BW		
Rearing system	1,700	2,700	3,700	1,700	2,700	3,700
Female	1,366	2,216	0	2,730	4,660	0
Male	0		3,099	0		6,845
Straight-run	1,339	2,216	3,093	2,632	4,660	7,300

Simulation of a production scenario in a 1,800,000 broiler complex for 3 market BW

Price Scenario	Meat price	Feed Price ($/ton)	Rearing system	Net Return ($)/ market BW				Returns from sex separation ($)
				1,700	2,700	3,700	Complex	
Low meat/ Low Feed	$1.73	$250	Female	1.672	2.669	0	4,789,520	77,304
			Male	0		3.642	4,712,216	
			Straight-run	1.658	2.669	3.526		
Low meat/ Medium Feed	$1.73	$350	Female	1.399	2.203	0	3,935,477	98,753
			Male	0		2.957		
			Straight-run	1.395	2.203	2.796	3,836,724	
Low meat/ High Feed	$1.73	$450	Female	1.126	1.737	0	3,081,434	120,202
			Male	0		2.273		
			Straight-run	1.132	1.737	2.066	2,961,232	
Medium meat/ Low Feed	$2.16	$250	Female	2.259	3.622	0	6,513,354	85,875
			Male	0		4.974		
			Straight-run	2.234	3.622	4.857	6,427,480	
Medium meat/ Medium Feed	$2.16	$350	Female	1.986	3.156	0	5,659,311	107,324
			Male	0		4.290		
			Straight-run	1.971	3.156	4.127	5,551,988	
Medium meat/ High Feed	$2.16	$450	Female	1.713	2.690	0	4,805,269	128,773
			Male	0		3.606		
			Straight-run	1.708	2.690	3.397	4,676,496	
High meat/ Low Feed	$2.59	$250	Female	2.847	4.575	0	8,237,188	94,445
			Male	0		6.307		
			Straight-run	2.810	4.575	6.187	8,142,743	
High meat/ Medium Feed	$2.59	$350	Female	2.574	4.109	0	7,383,146	115,894
			Male	0		5.623		
			Straight-run	2.547	4.109	5.457	7,267,252	
High meat/ High Feed	$2.59	$450	Female	2.301	3.643	0	6,529,103	137,343
			Male	0		4.938		
			Straight-run	2.283	3.643	4.727	6,391,760	

Table II – 2.6 Net returns simulation from selling whole chicken carcasses (WOG) at 3 market weights on a production scenario of a 1,800,000 Ross 708 broiler complex when using a sex separate *vs.* straight-run regime

	Respective whole carcass weight (g) at market BW			Bird Individual feed intake (g) at market BW		
Rearing system	1,700	2,700	3,700	1,700	2,700	3,700
Female	1,392	2,254	0	2,727	4,751	0
Male	0		3,134	0		7,002
Straight-run	1,372	2,254	3,136	2,677	4,751	7,836

Simulation of a production scenario in a 1,800,000 broiler complex for 3 market BW

Price Scenario	Meat price	Feed Price ($/ton)	Rearing system	Net Return ($)/ market BW				Returns from sex separation ($)
				1,700	2,700	3,700	Complex	
Low meat/ Low Feed	$1.73	$250	Female	1.717	2.711	0	4,854,414	125,430
			Male	0		3.662		
			Straight-run	1.704	2.711	3.466	4,728,985	
Low meat/ Medium Feed	$1.73	$350	Female	1.444	2.236	0	3,985,611	172,495
			Male	0		2.962		
			Straight-run	1.436	2.236	2.683	3,813,117	
Low meat/ High Feed	$1.73	$450	Female	1.172	1.761	0	3,116,808	219,560
			Male	0		2.262		
			Straight-run	1.169	1.761	1.899	2,897,249	
Medium meat/ Low Feed	$2.16	$250	Female	2.316	3.681	0	6,603,550	130,045
			Male	0		5.010		
			Straight-run	2.294	3.681	4.815	6,473,506	
Medium meat/ Medium Feed	$2.16	$350	Female	2.043	3.206	0	5,734,747	177,110
			Male	0		4.309		
			Straight-run	2.026	3.206	4.031	5,557,638	
Medium meat/ High Feed	$2.16	$450	Female	1.770	2.730	0	4,865,944	224,175
			Male	0		3.609		
			Straight-run	1.758	2.730	3.247	4,641,770	
High meat/ Low Feed	$2.59	$250	Female	2.914	4.650	0	8,352,686	134,659
			Male	0		6.357		
			Straight-run	2.884	4.650	6.163	8,218,027	
High meat/ Medium Feed	$2.59	$350	Female	2.641	4.175	0	7,483,883	181,725
			Male	0		5.657		
			Straight-run	2.616	4.175	5.379	7,302,159	
High meat/ High Feed	$2.59	$450	Female	2.369	3.700	0	6,615,080	228,790
			Male	0		4.957		
			Straight-run	2.348	3.700	4.596	6,386,291	

Table II – 2.7 Net returns simulation from selling Ross 308 and Ross 708 broilers as cut-ups at 3 market weights on a production scenario of a 1,800,000 broiler complex, using a sex a sex separate *vs.* straight-run regime

Price Scenario\ cut-up price	*Pectoralis major*	*Pectoralis minor*	Wings	Legs	Paws
Low (80% medium)	$2.112	$3.336	$2.720	$1.472	$1.056
Medium	$2.640	$4.170	$3.400	$1.840	$1.320
High (120% medium)	$3.168	$5.004	$4.080	$2.208	$1.584

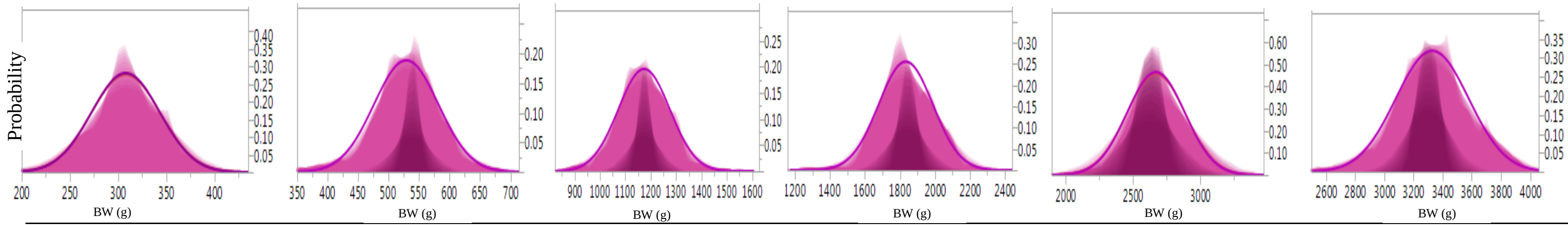
Meat price	Feed Price	Production type		Market BW	Ross 308			Ross 708		
					Net Return		Sex separation return	Net Return		Sex separation return
					$/bird	Complex		$/bird	Complex	
Low (80 % medium price)	Low ($250)	Sex separated	Female	1700	$1.107	$3,141,775	$48,824	$1.215	$3,453,085	$108,650
			Straight-run	2700	$1.796			$1.906		
			Male	3700	$2.333			$2.634		
		Sex comingled	Straight-run	1700	$1.086	$3,092,951		$1.220	$3,344,436	
			Straight-run	2700	$1.796			$1.906		
			Straight-run	3700	$2.272			$2.448		
	Medium ($350)	Sex separated	Female	1700	$0.834	$2,287,732	$70,273	$0.942	$2,584,283	$155,715
			Straight-run	2700	$1.330			$1.431		
			Male	3700	$1.648			$1.934		
		Sex comingled	Straight-run	1700	$0.823	$2,217,459		$0.952	$2,428,568	
			Straight-run	2700	$1.330			$1.431		
			Straight-run	3700	$1.542			$1.664		
	High ($450)	Sex separated	Female	1700	$0.561	$1,433,689	$91,722	$0.670	$1,715,480	$202,780
			Straight-run	2700	$0.864			$0.956		
			Male	3700	$0.964			$1.234		
		Sex comingled	Straight-run	1700	$0.560	$1,341,967		$0.685	$1,512,700	
			Straight-run	2700	$0.864			$0.956		
			Straight-run	3700	$0.812			$0.881		
Medium	Low ($250)	Sex separated	Female	1700	$1.557	$4,463,695	$50,324	$1.691	$4,862,059	$109,096
			Straight-run	2700	$2.536			$2.680		
			Male	3700	$3.346			$3.732		
		Sex comingled	Straight-run	1700	$1.522	$4,413,371		$1.692	$4,752,962	
			Straight-run	2700	$2.536			$2.680		
			Straight-run	3700	$3.297			$3.550		
	Medium ($350)	Sex separated	Female	1700	$1.284	$3,609,652	$71,773	$1.419	$3,993,256	$156,161
			Straight-run	2700	$2.070			$2.205		
			Male	3700	$2.662			$3.032		
		Sex comingled	Straight-run	1700	$1.259	$3,537,879		$1.425	$3,837,094	
			Straight-run	2700	$2.070			$2.205		
			Straight-run	3700	$2.567			$2.766		
	High ($450)	Sex separated	Female	1700	$1.011	$2,755,610	$93,222	$1.146	$3,124,453	$203,227
			Straight-run	2700	$1.604			$1.729		
			Male	3700	$1.977			$2.332		
		Sex comingled	Straight-run	1700	$0.996	$2,662,387		$1.157	$2,921,226	
			Straight-run	2700	$1.604			$1.729		
			Straight-run	3700	$1.837			$1.982		
High (120 % medium price)	Low ($250)	Sex separated	Female	1700	$2.007	$5,785,615	$51,824	$2.168	$6,271,032	$109,543
			Straight-run	2700	$3.277			$3.453		
			Male	3700	$4.359			$4.831		
		Sex comingled	Straight-run	1700	$1.958	$5,733,791		$2.165	$6,161,489	
			Straight-run	2700	$3.277			$3.453		
			Straight-run	3700	$4.321			$4.651		
	Medium ($350)	Sex separated	Female	1700	$1.734	$4,931,573	$73,274	$1.895	$5,402,229	$156,608
			Straight-run	2700	$2.811			$2.978		
			Male	3700	$3.675			$4.130		
		Sex comingled	Straight-run	1700	$1.695	$4,858,299		$1.897	$5,245,621	
			Straight-run	2700	$2.811			$2.978		
			Straight-run	3700	$3.591			$3.868		
	High ($450)	Sex separated	Female	1700	$1.461	$4,077,530	$94,723	$1.622	$4,533,426	$203,673
			Straight-run	2700	$2.345			$2.503		
			Male	3700	$2.991			$3.430		
		Sex comingled	Straight-run	1700	$1.432	$3,982,808		$1.629	$4,329,753	
			Straight-run	2700	$2.345			$2.503		
			Straight-run	3700	$2.861			$3.084		

Table II – 2.8 Net returns simulation from selling Ross 308 and Ross 708 broilers as whole birds (1,700 g) or cut-ups (3,700 g) on a production scenario of a 1,800,000 broiler complex, using a sex separate *vs.* straight-run regime

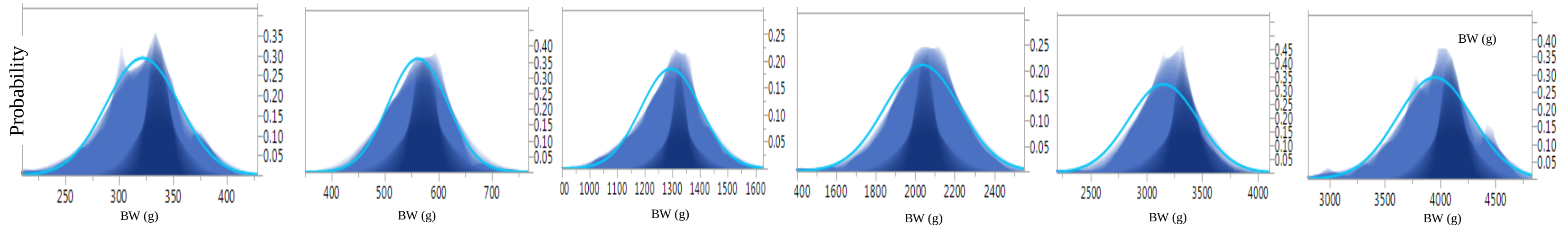
Price Scenario\ cut-up price	Whole carcass	*Pectoralis major*	*Pectoralis minor*	Wings	Legs	Paws
Low (80% medium)	$1.730	$2.112	$3.336	$2.720	$1.472	$1.056
Medium	$2.160	$2.640	$4.170	$3.400	$1.840	$1.320
High (120% medium)	$2.590	$3.168	$5.004	$4.080	$2.208	$1.584

Strain	Meat price	Feed price	Sex Separate			Sex comingled			Returns from sex separation
			Female	Male	Net return complex	Straight-run		Net return complex	
			1,700g	3,700g		1,700g Whole carcass	3,700g Cut-ups parts		
			Whole carcass	Cut-ups parts					
Ross 308	Low	Low	$1.672	$2.333	$3,604,500	$1.658	$2.272	$3,537,000	$67,500
	Low	Medium	$1.399	$1.648	$2,742,300	$1.395	$1.542	$2,643,300	$99,000
	Low	High	$1.126	$0.964	$1,881,000	$1.132	$0.812	$1,749,600	$131,400
	Medium	Low	$2.259	$3.346	$5,044,500	$2.234	$3.297	$4,977,900	$66,600
	Medium	Medium	$1.986	$2.662	$4,183,200	$1.971	$2.567	$4,084,200	$99,000
	Medium	High	$1.713	$1.977	$3,321,000	$1.708	$1.837	$3,190,500	$130,500
	High	Low	$2.847	$4.359	$6,485,400	$2.810	$4.321	$6,417,900	$67,500
	High	Medium	$2.574	$3.675	$5,624,100	$2.547	$3.591	$5,524,200	$99,900
	High	High	$2.301	$2.991	$4,762,800	$2.283	$2.861	$4,629,600	$133,200
Ross 708	Low	Low	$1.717	$2.634	$3,915,900	$1.704	$2.448	$3,736,800	$179,100
	Low	Medium	$1.444	$1.934	$3,040,200	$1.436	$1.664	$2,790,000	$250,200
	Low	High	$1.172	$1.234	$2,165,400	$1.169	$0.881	$1,845,000	$320,400
	Medium	Low	$2.316	$3.732	$5,443,200	$2.294	$3.550	$5,259,600	$183,600
	Medium	Medium	$2.043	$3.032	$4,567,500	$2.026	$2.766	$4,312,800	$254,700
	Medium	High	$1.770	$2.332	$3,691,800	$1.758	$1.982	$3,366,000	$325,800
	High	Low	$2.914	$4.831	$6,970,500	$2.884	$4.651	$6,781,500	$189,000
	High	Medium	$2.641	$4.130	$6,093,900	$2.616	$3.868	$5,835,600	$258,300
	High	High	$2.369	$3.430	$5,219,100	$2.348	$3.084	$4,888,800	$330,300

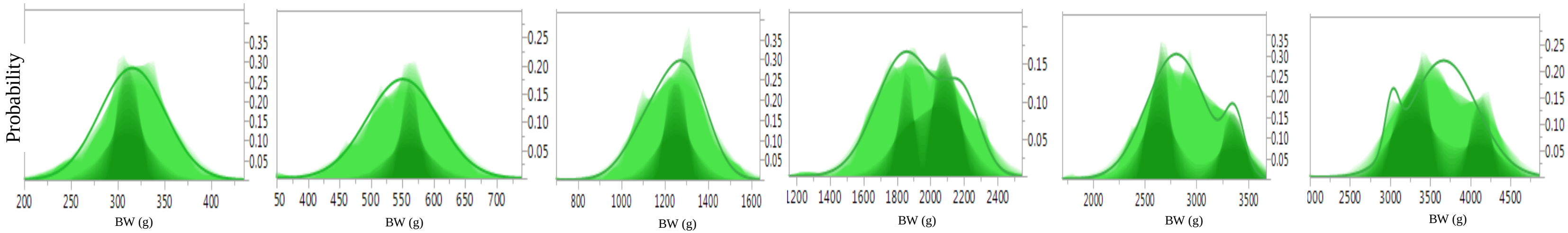
Figure II – 2.1 Ross 308 BW distribution[1] of birds raised sex separate *vs.* straight-run at 12, 17, 25, 32, 42, and 48 d of age



Females Ross 308																	
12 d			17 d			25 d			32 d			42 d			48 d		
μ: 308g	CI 95%		μ: 529g	CI 95%		μ: 1173g	CI 95%		μ: 1833g	CI 95%		μ: 2674g	CI 95%		μ: 3328g	CI 95%	
SD: 35.9	303g	313g	SD: 52.8	552g	536g	SD: 102	1160g	1187g	SD: 156	1813g	1854g	SD: 218	2642g	2705g	SD: 250	3289g	3367g



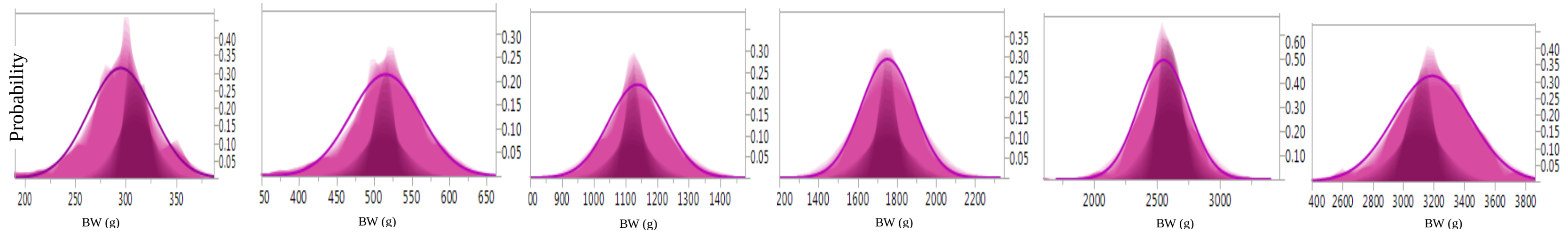
Males Ross 308																	
12 d			17 d			25 d			32 d			42 d			48 d		
μ: 322g	CI 95%		μ: 562g	CI 95%		μ: 1293g	CI 95%		μ: 2035g	CI 95%		μ: 3152g	CI 95%		μ: 3952g	CI 95%	
SD: 34.0	317g	326g	SD: 55.5	554g	569g	SD: 108	1279g	1307g	SD: 190	2010g	2061g	SD: 309	3106g	3198g	SD: 343	3895g	4009g



Straight-run Ross 308																	
12 d			17 d			25 d			32 d			42 d			48 d		
μ: 316g	CI 95%		μ: 551g	CI 95%		μ: 1240g	CI 95%		μ: 1942g	CI 95%		μ: 2877g	CI 95%		μ: 3614g	CI 95%	
SD: 35.1	311g	320g	SD: 56.7	543g	558g	SD: 134	1223g	1258g	SD: 223	1912g	1972g	SD: 335	2828g	2925g	SD: 447	3542g	3686g

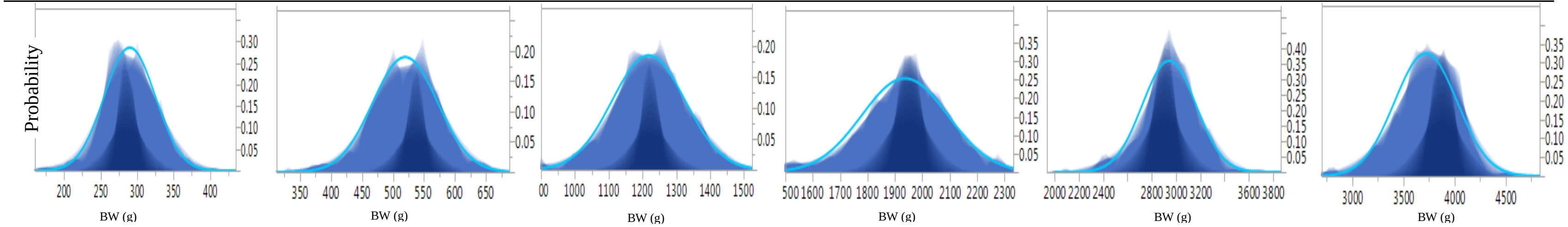
[1] Normal distribution histogram with respective density curve for the total birds obtained from the simulation (1,440,000 birds' BW)

Figure II – 2.2 Ross 708 BW distribution[1] of birds raised sex separate *vs.* straight-run at 12, 17, 25, 32, 42, and 48 d of age



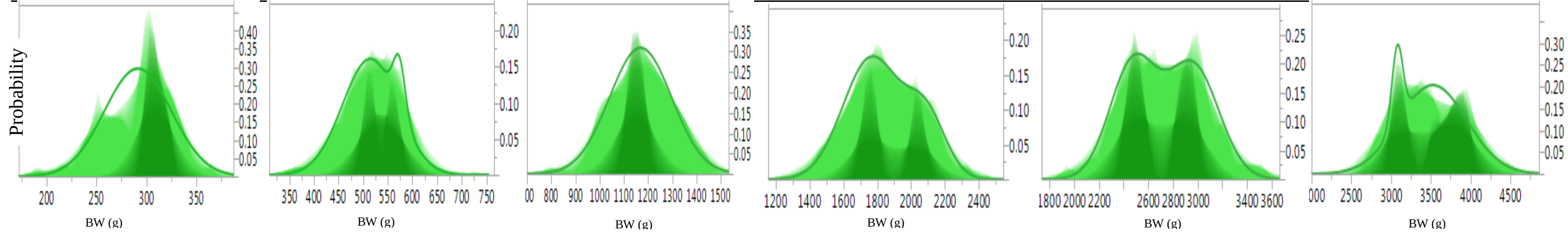
Females Ross 708

12 d			17 d			25 d			32 d			42 d			48 d		
μ: 294g	CI 95%		μ: 515g	CI 95%		μ: 1138g	CI 95%		μ: 1752g	CI 95%		μ: 2552g	CI 95%		μ: 3190g	CI 95%	
SD: 31.8	291g	299g	SD: 46.6	509g	521g	SD: 91	1126g	1150g	SD: 136	1734g	1770g	SD: 201	2523g	2580g	SD: 252	3150g	3230g



Males Ross 708

12 d			17 d			25 d			32 d			42 d			48 d		
μ: 290g	CI 95%		μ: 520g	CI 95%		μ: 1218g	CI 95%		μ: 1936g	CI 95%		μ: 2943g	CI 95%		μ: 3718g	CI 95%	
SD: 35.0	285g	294g	SD: 52.5	513g	527g	SD: 108	1203g	1232g	SD: 157	1915g	1957g	SD: 221	2911g	2975g	SD: 306	3669g	3767g



Straight-run Ross 708

12 d			17 d			25 d			32 d			42 d			48 d		
μ: 291g	CI 95%		μ: 520g	CI 95%		μ: 1169g	CI 95%		μ: 1848g	CI 95%		μ: 2729g	CI 95%		μ: 3468g	CI 95%	
SD: 33.6	287g	296g	SD: 58	512g	527g	SD: 131	1152g	1186g	SD: 215	1819g	1877g	SD: 319	2682g	2775g	SD: 437	3398g	3539g

[1] Normal distribution histogram with respective density curve for the total birds obtained from the simulation (1,440,000 birds' BW)

Table II – 2.9 Predictive models and estimated SD based on BW of Ross 308 and Ross 708 raised straight-run or sex separate at three market ages

Strain	Rearing system	R^2	*P*-value	Equations	Market BW (g) 1,700	 2,700	 3,700
					Estimated SD (g)		
	Female	0.96	<0.001	SD = 9.5368334 + 0.0704495*BW	129.30	199.75	270.20
308	Male	0.90	<0.001	SD = 7.7842601 + 0.0731704*BW	132.17	205.34	278.51
	Straight-run	0.98	<0.001	SD = -7.203381 + 0.1181268*BW	193.61	311.74	429.87
	Female	0.85	<0.001	SD = 6.1521949 + 0.0728947*BW	130.07	202.97	275.86
708	Male	0.92	<0.001	SD = 11.522767 + 0.0688725*BW	128.61	197.48	266.35
	Straight-run	0.95	<0.001	SD = -8.942489 + 0.1241377*BW	202.09	326.23	450.37

Table II – 2.10 Estimated percentage of Ross 308 and Ross 708 broilers observed within a strict range at 3 market BW for birds raised straight-run or sex separate

Strain	Rearing system	Estimated percentage of birds within a range at each market BW					
		1,700 g		2,700		3,700	
		1,650 g	1,750 g	2,600 g	2,800 g	3,550 g	3,850 g
	Female	30.2		38.4		42.2	
308	Male	29.5		37.5		41.1	
	Straight-run	20.4		25.2		27.3	
	Female	30.0		37.8		41.4	
708	Male	30.3		38.8		42.7	
	Straight-run	19.6		24.1		26.1	

CHAPTER 3

Evaluation of Starter Dietary Digestible Lysine Level on Broilers Raised under a Sex Separated or Straight-run Housing Regime

Part 1: Live Production and Carcass Yield Parameters[1]

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[1] M.J. Da Costa[1], T.J. Frost[2], J. Halley[3], G.M. Pesti[1]
[1]University of Georgia, Athens, GA 30606
[2]Wayne Farms LLC, 4110 Continental Drive, Oakwood, Georgia 30566
[3]Aviagen Inc., 5015 Bradford Drive, Huntsville, AL 35805
To be submitted to Poultry Science

ABSTRACT

The objective of this experiment was to model dietary digestible lysine (dLys) levels in starter diets when raising broilers sex separate or commingled (straight-run) to provide the basis for profit maximizing strategies. 3,240 Ross 708 chicks were separated by sex and placed in 90 pens by two rearing types: sex separate (36 males or 36 females) or straight-run (18 males + 18 females). Each rearing type was fed six starter diets (25d) formulated to have dLys levels between 1.05 and 1.80%. A common grower with 1.02% of dLys was fed from 25 to 32d. Body weight gain (BWG) and feed intake were assessed at 25 and 32d for performance evaluation. Additionally at 26 and 33d, 4 birds per pen were sampled for carcass yield evaluation. Data were analyzed using a factorial arrangement of treatments and non-linear regression, where linear and quadratic effects of dLys were fitted. At 25d, males were the heaviest, followed by straight-run and then females. There was a quadratic effect of dLys with BWG being maximized at 1.419, 1.471, and 1.537% for males, straight-run, and females respectively. Males, straight-run, and females adjFCR were minimized at dLys levels of 1.339, 1.562, and 1.540% respectively. *Pectoralis major* was affected by dLys levels with 1.456, 1.508, and 1.417% (quadratic effect) resulting in heavier muscles for male, straight-run, and female birds. At 32d, males were the heaviest followed by straight-run and then females. There was a quadratic effect of dLys on BWG and adjFCR at 32d. BWG was maximized at 1.319, 1.453, and 1.470%, and adjFCR minimized at 1.297, 1.562, and 1.463% of dLys for males, straight-run, and females respectively. *Pectoralis major* weight was maximized at 1.478, 1.467, and 1.423% of dLys for male, straight-run and female. It was evident throughout the experiment that birds raised straight-run were less efficient and had the highest feed intake. In conclusion, females were shown to have performance that maximized at higher dLys levels than males.

Keywords: sex separate, straight-run, lysine, protein, starter

INTRODUCTION

Raising broiler flocks sex separate *vs.* straight-run has been a controversial subject over the years for the American poultry industry. This uncertainty is mainly related with the disparity of results on the research done so far, regarding the performance parameters for birds and also any economic advantages. There are several pieces of evidence in the literature showing no beneficial effect on sex separation (Smith, et al., 1954; Hess, et al., 1960; Lang, et al., 1960; Lamoreux and Proudfoot, 1969). However, these studies were performed using less selected chicken breeds. On the other hand, there are some reports that did observe beneficial effects on performance and bird uniformity when chicks were sex separated (Becker and Berg, 1959; Deaton, et al., 1973; Gehle, et al., 1974; Laseinde and Oluyemi, 1994; de Albuquerque, et al., 2006; Api, 2014). The rationale behind the advantages of raising birds sex separate are related to the sexual dimorphism observed between the genders. The differences between males and females start as early as the embryonic stages (Burke and Sharp, 1989; Henry and Burke, 1998), extending throughout the life cycle of the birds with observed differences in growth rate, feed intake, and feed efficiency (Gous, et al., 1999; May and Lott, 2001). These differences open a potential opportunity to explore specific nutritional needs for each gender.

One of the nutrients that impacts the most birds regarding their performance and carcass yield, is dietary protein level. Currently, diets are formulated on a digestible amino acid level basis, where lysine is considered the reference amino acid, with the other amino acids being expressed in a ratio to lysine. There are several reports that show that bird performance varies with digestible lysine level inclusion, being that the amino acid ratio was kept or not (Sterling, et al., 2003; Kidd, et al., 2004; Corzo, et al., 2005; Sterling, et al., 2005; Plumstead, et al., 2007). In addition, it has been shown that males and females respond differently to dietary lysine levels, presenting different technical response maximum levels (TRML). Furthermore, it has been reported that lysine nutrition early on in life (starter phase) can affect bird performance, with effects that carry over throughout the birds life cycle, impacting carcass yield at processing age (Kidd, et al., 1998; Kidd and Fancher, 2001; Labadan, et al., 2001; Sterling, et al., 2003; Garcia and Batal, 2005; Sterling, et al., 2005; Garcia, et al., 2006; Plumstead, et al., 2007; Dozier and Payne, 2012).

Taking into consideration the absence of information on potential advantages of raising broilers sex separate when using modern genetic strains, and also the possible differences that genders might have on lysine for TRML early in life, the objective of this experiment was to evaluate the effects on performance and carcass characteristics of graded lysine levels maintaining the ideal amino acid ratio during the starter phase for broilers raised sex separate *vs.* straight-run.

MATERIAL AND METHODS

There were 18 experimental treatments consisting of a factorial combination of 3 broiler rearing types with 6 dietary protein levels.

Sex separate vs. Straight-run treatments

A total of 3,240 day old sexed Ross 708 chicks were placed and raised in 90 pens according to one of the three following treatments: male, female, and straight-run. At placing, for the male and female treatments, 36 chicks of the respective sex treatment were randomly selected, weighed, and identified with a neck tag; for the straight-run treatment 18 males and 18 females were used instead. From this point forward, this treatment will be called a rearing system.

Dietary treatments

The diets fed in the present experiment were corn-soybean meal based with two dietary phases used: starter – 0 to 25 d (experimental phase), and grower – 15 to 32 d (common diet). The starter diets were fed as crumble and grower diets were fed as pellet. There were 6 dietary starter treatments based on digestible lysine inclusion level with the ideal amino acid ratios maintained (Table III 1.1). The dietary digestible lysine levels were obtained by formulating a base (1.05% dLys) and summit (1.80% dLys) diets, which were blended in different proportions, resulting in 6 digestible lysine treatments (1.05, 1.20, 1.35, 1.50, 1.65, and 1.85 % of dLys). The calculated digestible amino acid values used were based on Ajinomoto Heartland LLC. (2004) values.

Birds and Husbandry

All the practices regarding animal management were approved by the Institutional Animal Care and Use Committee of the University of Georgia. The experiment was performed in a window-less room with 48 pens that were 1.22 x 1.52 m in dimension. Each pen had 1 hanging tubular feeder with 170 cm of feeder space (4.7 cm/bird), 10 nipple drinkers, and the floor covered with 0.05 m of used pine shavings as litter. For the first 3 days of brooding, one cardboard tray with feed was placed in each pen to ease the access to feed by the chickens. Both water and feed were consumed *ad libitum*. Temperature, ventilation and lighting programs were checked twice a day and followed commercial practices. Chicks where housed at 34°C and then the temperature was gradually reduced 3°C every wk until the temperature reached 20°C. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing 24 h of light at 30 lux for the first 7 d, 16 h of light at 3.5 lux with 8 h of dark from 7 to 28 d of age, and 20 h of light at 3.5 lux with 6 h of dark from 28 until the end of the trial.

Performance data

The chickens' group BW per pen was evaluated at hatch, 13, 25, and 32 d of age. Additionally, feed consumption was recorded to calculate feed intake and FCR. Mortality was checked twice a d and BW recorded to calculate adjFCR.

Processing data

At 14, 26, and 33 d, the 4 birds that had the lowest number on their neck tag were selected for processing. In the straight-run pens, 2 birds of each sex were selected also based on the lowest neck tag number. Birds were withdrawn off of feed for 8 hours over night. Birds were individually weighed prior to processing, immediately following evisceration (pre-chill/hot carcass weight), and after chilling (cold carcass weight). Paws were taken and weighed prior to weighing the hot carcass. Carcasses were chilled in water and ice at 1°C for 240 min. Subsequently carcasses were deboned and pectoralis major, pectoralis minor, wings, and legs weighed for carcass yield. For the 14 d cut-ups, wings were not deboned and were considered part of the shell weight.

Data Analysis

Data were analyzed as a completely randomized design in a 3x6 factorial arrangement of treatments. Before analysis, percentage data had to be transformed to arcsine in order to obtain normality. For these data, the true means are presented with the *P*-values coming from the analysis of the transformed data. The factorial analysis was first run considering the arrangement of the 3 rearing treatments with the 6 digestible lysine levels. Then an analysis of gender within each rearing treatment, male and female reared sex separated *vs.* straight-run, was considered, which was then crossed with the digestible lysine levels. Interactions and main effects were evaluated, and when the rearing system was significant at $P \leq 0.05$, means were separated using orthogonal contrasts. Afterwards, all the response data for each gender, were fitted using six models (quadratic, logistic 3 parameters, logistic 4 parameters, Gompertz, mechanistic growth, and Michaelis Menten), using the digestible lysine levels as the independent variable. The models were ranked using the Akaike information criterion, and the model with the lowest value was chosen as the one that better described the data (data not shown). This analysis revealed that the model that fitted the best the data set was the second order polynomial. Therefore, regression reports with linear and quadratic effects, maximum/minimum response, and digestible lysine level at which maximum/minimum response was observed (TRML – technical response maximum level) for each rearing system are presented. All the previous data were analyzed and modeled using JMP Pro 11 (SAS Inst. Inc., Cary, NC) software.

RESULTS

Performance

The BW and BW gain results are presented in Table III – 1.2. A main effect of rearing system was present for both BW and BW gain throughout the experiment, however this effect impacted growth differently over time. At 13 d, females and straight-run birds were the heaviest ($P<0.001$). Though, at 25 ($P=0.005$) and 32 d ($P<0.001$) males were the heaviest with higher gains, followed by the straight-run birds, and then the females. The outcomes for the BW and BW gain comparison of each sex within each rearing system are presented in the tables III – 1.3 and 4. When comparing the growth of males raised either sex separated or straight-run, straight-run males were heavier ($P<0.05$) at 13 and 32 d of age, while no effects were observed at the end of the starter phase (25 d). On the other hand, females raised on both systems only showed to be significantly different on growth at 25 d, with sex separate females being heavier than the straight-run. A significant ($P<0.001$) main effect of digestible lysine level was observed across the experiment. Moreover, it was interesting to observe an interaction between the rearing system and digestible lysine levels on growth at 13 ($P=0.042$) and 32d ($P=0.039$), and for the grower ($P=0.024$) period (25 to 32 d). This indicates that digestible lysine levels will differently impact the growth of birds raised sex separate and straight-run. In addition, the significant treatment interaction was also present when the growth of males raised sex separate or straight-run was compared at 13 ($P=0.066$) and 32d ($P=0.042$). Such interaction reveals that males raised in both rearing systems, might respond differently to the same level of dietary digestible lysine. For the evaluation of the treatment interaction effects, and main effect of digestible lysine levels, a second order polynomial model was fitted to the growth data.

The models for BW and BW gain for each rearing system are presented on the Table III – 1.5 and 1.6. At 13 d, both male and female growth was maximized at 1.489 % of dLys and straight-run birds at 1.436%. Even though both males and females had the same TRML, females were heavier (302 g) than males (291 g) at this age. At 25 and 32 d, males had a consistently lower TRML for growth (1.419 and 1.319 % of dLys for 25 and 32 d respectively) than females (1.537 and 1.470 % of dLys for 25 and 32 d respectively). Additionally, males presented higher weight gain than females both at 25 (1020 g *vs.* 986 g), and 32 d(1717 g *vs.* 1583 g). The straight-run birds had an intermediate maximum weight gain between males and females at 25 (996 g), and 32d (1651 g), with a respective of 1.471 and 1.453 % of dLys TRML. Looking at each gender within the straight-run pens, similarly to the sex separated pens, females were shown to have a higher TRML than males at 13 (1.449 % *vs.* 1.399 % of dLys), 25d (1.529 % *vs.* 1.406 % of dLys).

Feed intake and adjFCR results are presented on Table III – 1.7. Similarly to the growth data, a main effect of the rearing systems was present on feed intake seeing that treatment made different impacts throughout the experimental period. Birds on sex separate female and straight-run pens had the highest ($P<0.001$) feed intake at 13 d. Noteworthy, straight-run runs birds had the highest ($P<0.001$) feed intake at 25 (1440 g), and 32 d (2654 g), this higher feed intake not being congruent with the highest growth observed in the data presented herein. This is well depicted by the adjFCR results, where straight-run birds had the highest ($P<0.05$) adjFCR at 13 (P=1.257 g:g), and 32d (P=1.570 g:g). Female pens had the lowest feed intake at 13 (1436 g) and 32d (2521 g). Males presented an intake non-statistically different than straight-run birds at 25 and 32 d, though these birds showed to be more efficient with the lowest adjFCR at 13 (1.240 g:g), and 32 d (1.570 g:g). A main effect of digestible lysine level was also present at 13 d, however it tends to disappear at 25 (*P*=0.070), and was absent at 32 d (*P*=0.504). On the contrary, digestible lysine did not have an effect on adjFCR at 13 d (*P*<0.062), but did impact adjFCR at 25 (*P*<0.001) and 32d (*P*<0.001). No treatment interactions (*P*>0.05) were observed on feed intake across the experiment. Conversely, a treatment interaction was present on adjFCR at 25 (*P*<0.029) and 32d (*P*=0.042), indicating that the adjFCR yielded to the digestible lysine levels was different between the rearing systems.

The regression reports for feed intake and adjFCR are presented on Table III 1.8. Feed intake was shown to be affected quadratically by lysine levels early on in life, however this effect tended to disappear as birds aged. At 13 d, all the 3 rearing systems were affected quadratically as digestible lysine levels increased. Females showed the highest (1.519 % dLys) feed intake TRML, followed by males (1.483 % dLys), and then straight-run birds (1.437 % dLys). At 25 d, females and straight-run birds were still affected quadratically by digestible lysine levels with a respective maximum TRML attained at 1.558 % and 1.437, whereas male feed intake was not affected by lysine. It was interesting to observe that at 32 d both male and female feed intake were affected linearly but in a totally opposite fashion by digestible lysine. For males, as digestible lysine increased the feed intake increased; whereas for females, as digestible lysine increased feed intake was suppressed. Regarding the adjFCR at 13 d, females were affected quadratically by digestible lysine with a TRML at 1.480 % of digLys. Conversely, males were affected linearly with adjFCR increasing as lysine increased. At 25 and 32 d, all three rearing systems had adjFCR affected quadratically by digestible lysine. Female, male, and straight-run birds had TRML at 1.50, 1.339, and 1.562 % of dLys respectively at 25 d, whereas at 32 d the TRML was obtained at 1.463, 1.297, and 1.562 % digLys.

The figures III – 1.1, 1.2, and 1.3 represent the BW gain quadratic response (*P*<0.001) according to digestible lysine intake for each rearing system at 13, 23, and 32 d respectively. At 13 d females presented the highest (5.66 g) digestible lysine intake needed to maximize gain (298 g). At this age, males needed an intake of 5.37 g to attain maximum BW gain of 288 g, and straight-run birds needed 5.18 g for a maximum gain of 297 g. On the contrary, at 25 and 32 d the birds that required the highest lysine intake were the ones raised in straight run pens. For a gain of 1002 g an intake of 23.20 g was needed at 25 d, and for a gain of 1644 g an intake of 37.69 g of digestible lysine was required. When comparing male and female birds raised sex separate, it was observed that males required less lysine intake to attain maximum growth. For a maximum gain of 1019 g at 25 and 1716 g at 32 d, males needed 20.39 and 31.21 g of digestible lysine. Female birds revealed a higher lysine need than males, with an intake of 22.31 and 32.73 g of digestible lysine needed, to maximize BW at 25 (986 g) and 32 (1579 g) d respectively.

Processing

The BW and respective cold carcass yields for the birds sampled for processing are presented in Table III – 1.9. The live BW results and cold carcass weights are shown to be affected by a main effect of rearing at 14 and 33 d, and a main effect of lysine across the 3 processing ages. At 14 and 26 d there was a significant interaction of treatments. Total carcass yield was only affected by both the rearing system (*P*<0.001), and lysine levels (*P*<0.036) at 13 d. On the cut-up weights, both the *pectoralis major* weight and yield were significantly affected (*P*<0.001) by digestible lysine levels at all three ages (Table III – 1.10). In addition, there was treatment interaction present at the end of the starter phase (26 d) on *pectoralis major* weight. *Pectoralis minor* weight (Table III – 1.10) was also affected by lysine levels throughout the experiment, whereas relative weight was only affected by lysine levels at 26 and 33 d. Interaction of treatments was observed at 14 and 33 d on muscle weight. At the end of the experiment, females also showed to have higher *pectoralis minor* yield (5.82%) in comparison with males (5.58%), and straight-run birds (5.60%). Leg weight was affected by a treatment interaction (*P*=0.002) at 14 d, with a main effect of rearing system that was shown at 14 and 33 d, and by a main effect of digestible lysine at 26 and 33 d (Table III – 1.11). At the market age (33 d) males had the higher leg weights (320 g), followed by straight-run birds (302 g), and then females (292 g). Leg yield data revealed that males had higher values at 14 and 33 d. Wing weight was affected by digestible lysine levels and the rearing system both at 26 and 33 d (Table III – 1.11). Males were shown to have a higher wing weight (118 g) at 33 d. Paw weights were affected by a main effect of both rearing system and digestible lysine at 26 and 33 d (Table III – 1.11). Overall, males had higher paws weights, followed by straight-run birds, and then females.

The regression equations for cold carcass parameters are presented in Table III – 1.12. At 26 and 33 d, cold carcass weights of both females and males were affected quadratically by lysine inclusion. At both ages, the TRML for females (26 d = 1.324 % of digestible lysine; 33d = 1.407 % of digestible lysine) was lower than the one for the males (26 d = 1.423 % of dLys; 33d = 1.413 % of dLys). However, males also showed heavier weights at 26 d (811 g *vs.*774 g), and 33 d (1356 g *vs.*1254 g). It was interesting to observe that straight-run birds showed to only be affected quadratically at 33 d, with a TRML (1.477 % of dLys) higher than males and females. Cold carcass weight was maximized for females at 1.452 % of dLys at 33 d of age. *Pectoralis major* weight results (Table III – 1.13) at 26 d revealed that both females and males attained TRML at 1.511 and 1.489 % of dLys, with a maximum response of 165 and 172 g respectively. At market age (33 d), all rearing systems were affected quadratically, with straight-run birds needing more digestible lysine (1.508 % of dLys), than males (1.456 % of dLys), and females (1.417 % of dLys). Regarding *pectoralis major* percentage, at the end of the starter phase both female and straight-run birds' *pectoralis major* increased linearly as digestible lysine increased, whereas male birds had TRML at 1.571 % of dLys. At market age (33 d), *pectoralis major* percentage was affected by a quadratic effect for the 3 rearing systems, with TRML achieved at 1.423, 1.478, and 1.467 % of dLys for females (26.21 %), males (26.26 % g), and straight-run birds (26.42 %) respectively. The *pectoralis minor* weight results at 26 and 33 d revealed that females responded linearly to the increments of digestible lysine, while males and straight-run birds reached TRML at 1.536, and 1.609 % dLys at 26 d, and 1.510, and 1.517 % dLys at 33 d. Results of the *pectoralis minor* percentages showed similar trends as the weights at 26 d, where females had muscle percentage increasing as digestible lysine increased, and males and straight-run birds hit TRML at 1.651, and 1.630 % of digestible lysine, respectively. At market age, both males and females had *pectoralis minor* percentage increase as digestible lysine increased whereas straight-run birds showed no significant response. Regarding wing weights at the end of starter phase (26 d), female and males hit TRML at 1.404, and 1.435 % of dLys whereas straight-run birds did not show any significant response to digestible lysine. At 33 d, males had the lowest TRML (1.398 % of dLys), followed by females (1.436 % dLys), and then by straight-run birds (1.516 % of dLys) birds. No significant effects were observed on wing yield. Leg weights were only increased linearly by digestible lysine on sex separate female birds at the end of starter phase. However, at market age all the rearing systems were affected quadratically by digestible lysine, with TRML obtained at 1.447, 1.446, and 1.516 % of digestible lysine for females, males, and straight-run birds respectively. Maximum response at these levels were 295, 341, and 319 g respectively. Leg yield (%) was not affected to a great extent by digestible lysine with females showing a decrease in leg relative weight as digestible lysine increased at 26 d, and straight-run birds with a TRML of 1.485 of digestible lysine at 33 d. Effects on paw weights were mainly observed at 33 d, where TRML for female, males, and straight-run birds were achieved at 1.537, 1.441, and 1.644 % of digestible lysine respectively.

DISCUSSION

Regarding the effects of rearing system on growth, as expected, males out-performed females and were followed by the straight-run birds, which is consistent with most results present in the literature (Smith, et al., 1954; Hess, et al., 1960; Brake, et al., 1993; Gous, et al., 1999; May and Lott, 2001; Aggrey, 2002; de Albuquerque, et al., 2006; Aggrey, 2009; Shim, et al., 2012; Api, 2014; Zuidhof, et al., 2014). The effects of the straight-run rearing system impacted males and females distinctively when comparing BW of these with each respective gender that was reared sex separate. The fact that males raised in the straight-run rearing system grew heavier than sex separate males at 13 and 32 d, and females in the straight-run rearing system grew less at 25 d than females sex separate, suggests that sex separation might favor female growth rate and impair male gains. It is possible that this difference of benefiting from sex separation can be related with agonistic behavior and feeder space competition. When females were raised straight-run, they had to compete with males. The males were significantly heavier than females and could out-compete females easily. The fact that males that were raised straight-run were heavier also points to the same conclusion. When males had to compete with other males, feeder access could have been deterred and feed intake could have been restricted. On the other hand, if males had to compete with females, the access could have been easier resulting in the birds growing bigger. It has been shown that this competition is especially important from the 2nd to the 6th wk of age, where males tend to express high percentage of aggressive behavior towards other males, and also females being under social stress with little opportunity to feed in comparison with the males (Guhl, 1958). The results of feed intake and adjFCR (Table III – 1.7) also depict a possible negative effect of raising the genders together that could be related with feed competition and stress. It was evident, that straight-run pens had higher feed consumption when compared with male and female pens. Furthermore, this higher feed intake did not concur with the growth rate of the birds, which was reflected on adjFCR. Birds that were raised in male pens were the heaviest, followed by the straight-run birds. However, birds raised in these two rearing systems presented the same feed intake. Also, females were the lightest birds at the end of the trial, with the respective lowest feed intake. So the question that is raised is: what is the real net gain to feed intake of birds raised sex separate *vs.* straight-run? Putting together the growth, feed intake, and adjFCR data, there is a strong indication that birds raised straight-run might use more feed to gain the same amount of weight. It has to be considered, that both feed intake and adjFCR are highly correlated with body size, so an interpretation of the results for these parameters *per se* might be misleading. Therefore, an approach where the output (BW gain) is expressed in function of input (feed intake) throughout the birds life, is more appropriate to determine the optimum levels of digestible lysine level for a specific bird size. In the present experiment, bird density was based on a projection of 38 kg/m^2 (approximately 0.07 m^2/bird) of live weight for males at 32 d (Estevez, 2007) with a feeder space above the genetic line recommendations (70 birds per a 38.5 cm diameter feeder). Since male and females grew at different rates, each rearing system pen ended up with different bird stocking density, which might have impacted the final results.

Regarding the lysine effect on growth, there was significant quadratic effect throughout the birds' lives. It was interesting to observe that among the models tested, the quadratic model was the one that fit the best because it showed that bird performance did not plateau, but rather was diminished by high lysine levels. The present experiment was designed to evaluate the response of birds to high levels of lysine, and to the best of our knowledge, there are no reports that did an extensive evaluation of digestible lysine levels, while still maintaining the ideal amino acid ratio, at levels as high as the ones used here. One of the consequences of formulating diets using a constant amino acid ratio to lysine, is a consistent increase of crude protein as digestible lysine levels increase. It is well recognized that increasing protein level of iso-caloric diets results in improved feed efficiency, increased carcass yield, and decreased fat content (Bartov and Plavnik, 1998; Corzo, et al., 2004; Kidd, et al., 2004; Kidd, et al., 2005; Pesti, 2009; Corzo, et al., 2010). However, it is also true that increasing the protein level does not yield a linear response due to the fact that if amino acids are in excess the birds will have to metabolize the excess, resulting in decreased utilization and efficiency (D'Mello, 1994), and this might be the case happening herein (Table III 1.12).

Experimentally there are two main approaches when determining optimum lysine levels. The first one, and most used, is done by varying just the lysine level by adding extra lysine in the synthetic form to a basal diet. This methodology has the limitation that crude protein does not follow lysine increments (amino acid ratios not maintained), and therefore the presence of enough dispensable amino acids are not guaranteed. This might lead to a usage of indispensable amino acids for synthesis of the dispensable ones (Almquist, 1957). Furthermore, there is a chance that after lysine reaches the TRML, another amino acid can turn into the one limiting the response. This phenomenon has been shown in several experiments (Morris, et al., 1987; Abebe and Morris, 1990; Hurwitz, et al., 1998; Sklan and Noy, 2003; Sterling, et al., 2003; Sterling, et al., 2005; Plumstead, et al., 2007). In the second methodology, which is the one used in the present experiment, the response to lysine is evaluated maintaining the amino acid ratio. The drawback of this methodology is that the response obtained is related to the increase of protein and not to the isolated amino acid. Therefore, the responses to digestible lysine in the present experiment should be taken as a response to a balanced protein increase, as well as lysine.

The interactions of digestible lysine level with the rearing system indicate that the digestible lysine levels will differently impact males, females, and birds raised in the straight-run pens. It was also interesting to observe that this interaction was present when comparing males raised sex separated with the males raised straight-run, indicating that even the same gender might benefit from different levels of lysine depending on the rearing system. It was evident that males had a lower TRML for BW gain than females at 25 and 32 d. This was an interesting find since the values present in the literature for TRML for BW for males are usually higher than the ones for females (Kidd, et al., 2004; Garcia, et al., 2006). Kidd, et al. (2004), observed that males tended to respond better to higher amino acid density (starter phase, 0 – 14 d: 23.35 % CP / 1.38 % Lysine; grower, 14 – 28 d: 21.77 % CP / 1.19 % Lysine) than females at 28 d. Also, Garcia, et al. (2006) in a set of 3 experiments evaluated the effect of sex on digestible lysine (0.7 to 1.12 % of dLys) requirement from 7 to 21 d of age on Cobb 500 birds. Results indicated digestible lysine levels that optimized BW gain and FCR were very similar between genders, with BW gain maximized at 0.98 and 0.93 % of digestible lysine for males and females respectively. It is noticeable that the TRMLs for BW gain for both genders in Garcia, et al. (2006) are significantly lower, than the ones observed herein (males: 1.419 and 1.319 % of dLys at 25 and 32 d respectively; females: 1.537 and 1.470 % of dLys for 25 and 32 d respectively), even though the genetics are different. Still, in Dozier and Payne (2012) Ross x Ross 708 females were reported to have BW maximized at 1.35 and 1.27 % of digestible lysine at 7 and 14 d respectively. Also in a set of 2 experiments, Kidd and Fancher (2001) evaluated the response of Ross x Ross 508 males to 0.88, 0.99, 1.10, 1.21, 1.32, and 1.43% of lysine and determined that maximum BW was at attained at 18 d, when 1.18 and 1.22 % of lysine was fed in the first and second experiment respectively. It is interesting to observe that all the TRMLs for BW maximization present in the literature are lower than the ones estimated herein. It is possible that this discrepancy is related with the differences in methodology used to determine TRML. Besides Kidd, et al. (2004), all of the reports mentioned above evaluated response to lysine not maintaining the amino acid ratio. Therefore, it is possible that the responses observed might have been limited by a shortage of another amino acid. It was also interesting to observe, that even when evaluating the response of the genders to lysine within the straight-run pens, females showed TRML higher than males (1.529 % *vs.* 1.406 % of dLys). Likewise when BW gain was expressed in function of digestible lysine intake, it was evident that straight-run birds need more digestible lysine intake to attain maximum gain.

The digestible lysine level of the diets barely affected feed intake. Nevertheless, lysine levels did impact adjFCR at 25 and 32 d when interacting with the rearing system, which indicates that same levels of digestible lysine can yield different adjFCR, depending on the rearing system. The regression reports for feed intake and adjFCR portray accurately the results observed in the factorial analysis. Regression analysis revealed significant effects of digestible lysine on feed intake early in life, however, those tended to fade with age. It was interesting to observe that TRMLs for adjFCR were the highest for straight-run birds, followed by females, and then by males. This is likely related with the higher feed intake observed by the straight-run birds that was not followed by the highest weight gain.

The TRMLs for BW gain are generally described in the literature to be lower than the TRMLs for adjFCR (Garcia and Batal, 2005; Abudabos and Aljumaah, 2010; Mehri, et al., 2010; Dozier and Payne, 2012). The results presented here are in agreement with this for females (Dozier and Payne, 2012), and straight-run birds (Mehri, et al., 2010). However, the same was not observed on the TRMLs for the male pens (Garcia and Batal, 2005; Abudabos and Aljumaah, 2010), where TRMLs for maximum BW gain were higher than the TRMLs for optimum FCR.

The treatment interaction observed for total carcass yield and breast muscle (*pectoralis major* + *pectoralis minor*) weight reveals again that each rearing system can have a different TRML. It was interesting to observe that the TRMLs estimated for cold carcass weight for females were lower than the ones estimated for males at 26 and 33 d. This reveals the opposite of what was observed on the live performance parameters, suggesting that females fed higher levels of protein can grow bigger. However, this weight gain might be related with fat deposition rather than lean mass. This was also present on *pectoralis major* TRMLs results, where females had a lower TRML for maximum *pectoralis major* when compared with the TRML for BW gain. Conversely, both male and straight-run rearing systems had higher TRML for *pectoralis major* than TRML for maximum growth, which is consistent to what is described in the literature (Labadan, et al., 2001). In a study where levels from 0.95 to 1.43% of lysine were fed for the first two weeks of post-hatching, Labadan, et al. (2001) reported that body weight gain, breast muscle and feed efficiency were maximized at 1.28, 1.32, and 1.21% of lysine respectively.

In conclusion, it was shown that the straight-run rearing system result in higher feed consumption when compared with the sex separated rearing system. Also, it was clear that females had a higher TRML for growth even though feeding high levels of digestible lysine resulted in decreased carcass yield parameters. Nevertheless, it was evident that genders have specific TRMLs with the addition that rearing systems can affect the optimum value of digestible lysine to be fed. At last, an important conclusion from these results is that each producer needs to know how their birds respond in their environment (e.g. rearing system, temperatures, bird density, etc.) in order to determine the appropriate nutrient levels for their diets.

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Table III – 1.1. Ingredient composition (%) and formulated nutrient contents of the starter diets with differing levels of digestible lysine and grower diet

Diet blend	Low	80%Low 20%High	60%Low 40%High	40%Low 60%High	20%Low 80%High	High	Grower
% dLys	1.05	1.2	1.35	1.5	1.65	1.8	1.02
				----------------------------------- % -----------------------------------			
Corn	62.39	57.55	52.70	47.85	43.02	38.18	62.97
Soybean Meal, 48%	25.97	29.91	33.85	37.78	41.72	45.66	20.63
Distillers dried grains/solubles	4.00	4.00	4.00	4.00	4.00	4.00	6.00
Poultry by-product meal	3.00	3.00	3.00	3.00	3.00	3.00	6.34
DL-Methionine	0.22	0.30	0.39	0.47	0.55	0.63	0.24
L-Lysine-HCl, 78%	0.18	0.25	0.33	0.40	0.48	0.55	0.20
L-Threonine, 98.5%	0.07	0.12	0.17	0.23	0.28	0.33	0.06
Poultry Fat	1.52	2.25	2.97	3.70	4.42	5.15	2.00
Limestone	0.54	0.53	0.53	0.53	0.52	0.52	0.34
Defluorinated phosphate, 18%	1.28	1.26	1.23	1.21	1.18	1.15	0.39
Salt (NaCl)	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin Premix[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix[2]	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Nicarbazin[3]	0.04	0.04	0.04	0.04	0.04	0.04	0.04
BMD[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutrient composition							
ME, kcal/g	3,050	3,050	3,050	3,050	3,050	3,050	3,120
CP, %	20.09	21.72	23.35	24.97	26.60	28.22	20.01
Calcium, %	0.96	0.96	0.96	0.96	0.96	0.96	0.87
Total phosphorus, %	0.72	0.73	0.74	0.74	0.75	0.75	0.69
Available phosphorus, %	0.48	0.48	0.48	0.48	0.48	0.48	0.44
Potassium, %	0.75	0.81	0.88	0.94	1.01	1.07	0.66
Chloride, %	0.34	0.35	0.37	0.38	0.39	0.41	0.36
Sodium, %	0.27	0.27	0.27	0.27	0.27	0.27	0.25
Choline, mg/kg	1.60	1.68	1.76	1.83	1.91	1.99	1.71
dArg, %	1.17	1.27	1.38	1.49	1.60	1.70	1.12
dIle, %	0.73	0.79	0.85	0.91	0.97	1.04	0.70
dLeu, %	1.57	1.65	1.74	1.82	1.90	1.98	1.57
dLys, %	1.05	1.20	1.35	1.50	1.65	1.80	1.02
dMet, %	0.51	0.60	0.70	0.80	0.90	0.99	0.53
dTSAA, %	0.78	0.89	1.00	1.11	1.22	1.34	0.80
dThr, %	0.71	0.81	0.91	1.01	1.11	1.21	0.68
dTrp, %	0.20	0.21	0.23	0.25	0.27	0.29	0.18
dVal, %	0.82	0.88	0.94	1.00	1.06	1.12	0.82

[1] Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B12 (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[2] Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO4.H2O), 101 mg; iron (FeSO4.7H2O), 20 mg; zinc (Zn)), 80 mg; copper (CuSO4.5H2O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

[3] Nicarb® 25% (Nicarbazine – Type A) – 100 ppm of nicarbazin provided in the final feed

[4] BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

Table III – 1.2. Effect of rearing system and digestible lysine level on BW and BW gain of Ross 708 chicks

Rearing system	Lysine level (%)	BW (g)			BW gain (g)			
		13	25	32	0 to 13	0 to 25	0 to 32	25 to 32
Female		331 ± 2^{a}	1006 ± 6^{b}	1601 ± 9^{c}	293 ± 2^{a}	968 ± 6^{b}	1563 ± 9^{c}	590 ± 4^{c}
Male		319 ± 2^{b}	1032 ± 8^{a}	1705 ± 13^{a}	281 ± 2^{b}	993 ± 8^{a}	1666 ± 13^{a}	675 ± 9^{a}
Straight-run		330 ± 2^{a}	1019 ± 5^{ab}	1672 ± 7^{b}	292 ± 2^{a}	980 ± 5^{ab}	1633 ± 7^{b}	653 ± 7^{b}
Female	1.05	320 ± 2	979± 10	1565 ± 14	281 ± 2	941 ± 10	1527 ± 14	587 ± 7
	1.20	323 ± 7	995± 20	1585 ± 25	285 ± 6	957 ± 19	1547 ± 24	590 ± 9
	1.35	336 ± 4	1019± 11	1622 ± 19	298 ± 4	981 ± 11	1584 ± 19	603 ± 11
	1.50	341 ± 3	1018± 14	1647 ± 33	302 ± 3	980 ± 14	1609 ± 33	603 ± 14
	1.65	339 ± 4	1025± 12	1616 ± 11	300 ± 4	987 ± 12	1578 ± 11	591 ± 9
	1.80	328 ± 2	1003± 8	1573 ± 11	290 ± 2	965 ± 7	1536 ± 11	571 ± 8
Male	1.05	317 ± 5	1015± 16	1717 ± 33	279 ± 4	976 ± 16	1678 ± 33	697 ± 27
	1.20	313 ± 3	1011± 12	1703 ± 30	274 ± 3	972 ± 12	1664 ± 30	736 ± 3
	1.35	328 ± 5	1067± 21	1761 ± 29	290 ± 5	1029 ± 21	1723 ± 30	688 ± 20
	1.50	326 ± 5	1060± 12	1750 ± 10	287 ± 5	1021 ± 12	1711 ± 10	690 ± 13
	1.65	312 ± 9	1041± 16	1687 ± 16	288 ± 3	1002 ± 16	1648 ± 17	646 ± 18
	1.80	307 ± 7	996± 22	1621 ± 25	269 ± 7	958 ± 22	1583 ± 24	625 ± 11
Straight-run	1.05	319 ± 5	994± 13	1646 ± 15	281 ± 4	955 ± 12	1608 ± 15	652 ± 10
	1.20	343 ± 3	1013± 10	1703 ± 13	304 ± 3	974 ± 10	1665 ± 13	690 ± 13
	1.35	334 ± 6	1037± 11	1658 ± 16	296 ± 6	999 ± 11	1620 ± 16	621 ± 16
	1.50	335 ± 2	1030± 8	1688 ± 8	297 ± 2	992 ± 9	1650 ± 8	658 ± 16
	1.65	340 ± 6	1018± 17	1678 ± 21	301 ± 5	980 ± 17	1640 ± 21	660 ± 13
	1.80	319 ± 4	1021± 15	1655 ± 17	280 ± 4	982 ± 15	1617 ± 17	634 ± 23
Source of variation				------------------------ *P*–values ------------------------				
Rearing System		<0.001	0.005	<0.001	<0.001	0.007	<0.001	<0.001
Lysine level		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rearing system x Lysine level		0.042	0.336	0.039	0.036	0.345	0.040	0.024

[a,b,c] Means in a column not sharing a common superscript are significantly different (*P*≤0.05) by orthogonal contrasts

Table III – 1.3. Effect of rearing system and digestible lysine level on BW and BW gain of male Ross 708 chicks

Rearing system	Lysine level (%)	BW (g)			BW gain (g)			
		13	25	32	0 to 13	0 to 25	0 to 32	25 to 32
Male		317 ± 3^{b}	1035 ± 8	1705 ± 13^{b}	279 ± 3^{b}	997 ± 8	1666 ± 13^{b}	670 ± 9^{b}
Straight-run male		324 ± 3^{a}	1040 ± 7	1738 ± 12^{a}	285 ± 3^{a}	1001 ± 7	1699 ± 12^{a}	699 ± 11^{a}
Male	1.05	317 ± 5	1037± 25	1717 ± 33	279 ± 4	998 ± 25	1678 ± 33	680 ± 27
	1.20	313 ± 3	1011± 12	1703 ± 30	274 ± 3	972 ± 12	1664 ± 30	692 ± 28
	1.35	328 ± 5	1067± 21	1762 ± 30	290 ± 5	1029 ± 21	1723 ± 30	688 ± 20
	1.50	326 ± 5	1060± 12	1750 ± 10	287 ± 5	1021 ± 12	1711 ± 10	690 ± 13
	1.65	312 ± 9	1041± 16	1687 ± 16	273 ± 9	1002 ± 16	1648 ± 17	646 ± 18
	1.80	307 ± 7	996± 22	1621 ± 25	269 ± 7	958 ± 22	1583 ± 24	625 ± 11
Straight-run male	1.05	316 ± 3	1017± 10	1705 ± 23	277 ± 3	978 ± 10	1665 ± 22	688 ± 18
	1.20	337 ± 6	1036± 16	1788 ± 20	299 ± 6	997 ± 16	1749 ± 19	751 ± 13
	1.35	324 ± 8	1056± 19	1698 ± 26	285 ± 8	1018 ± 18	1660 ± 26	642 ± 31
	1.50	325 ± 3	1043± 13	1777 ± 15	287 ± 3	1005 ± 13	1738 ± 15	752 ± 22
	1.65	330 ± 4	1044± 26	1755 ± 42	292 ± 4	1006 ± 26	1716 ± 42	710 ± 24
	1.80	311 ± 5	1040± 23	1705 ± 23	273 ± 5	1002 ± 23	1666 ± 23	664 ± 24
Source of variation				------------------------- *P*–values -------------------------				
Rearing System		0.043	0.678	0.040	0.041	0.679	0.040	0.007
Lysine level		0.031	0.174	0.007	0.026	0.163	0.007	0.001
Rearing system x Lysine level		0.066	0.364	0.042	0.061	0.371	0.042	0.055

[a,b] Means in a column not sharing a common superscript are significantly different (*P*≤0.05) by orthogonal contrasts

Table III – 1.4. Effect of rearing system and digestible lysine level on BW and BW gain of female Ross 708 chicks

Rearing system	Lysine level (%)	BW (g)			BW gain (g)			
		13	25	32	0 to 13	0 to 25	0 to 32	25 to 32
Female		332 ± 2	1009 ± 5^{a}	1601 ± 9	294 ± 2	971 ± 5^{a}	1563 ± 9	595 ± 6
Straight-run female		337 ± 3	997 ± 5^{b}	1606 ± 6	299 ± 3	959 ± 5^{b}	1568 ± 6	607 ± 8
Female	1.05	320 ± 2	979± 10	1565 ± 14	281 ± 2	941 ± 10	1527 ± 14	587 ± 7
	1.20	329 ± 8	1012± 14	1585 ± 25	291 ± 8	973 ± 14	1547 ± 24	590 ± 9
	1.35	336 ± 4	1019± 11	1622 ± 19	298 ± 4	981 ± 11	1584 ± 19	603 ± 11
	1.50	341 ± 3	1018± 14	1647 ± 33	302 ± 3	980 ± 14	1609 ± 33	630 ± 28
	1.65	339 ± 4	1025± 12	1616 ± 11	300 ± 4	987 ± 12	1578 ± 11	591 ± 9
	1.80	328 ± 2	1003± 8	1573 ± 11	290 ± 2	965 ± 7	1536 ± 11	571 ± 8
Straight-run female	1.05	322 ± 10	970± 16	1584 ± 25	284 ± 9	932 ± 16	1546 ± 24	613 ± 17
	1.20	322 ± 23	985± 9	1618 ± 8	284 ± 23	947 ± 9	1580 ± 9	628 ± 14
	1.35	345 ± 7	1019± 11	1623 ± 13	306 ± 7	981 ± 11	1585 ± 13	604 ± 11
	1.50	344 ± 6	998± 6	1600 ± 13	306 ± 5	960 ± 5	1563 ± 13	584 ± 29
	1.65	306 ± 32	1007± 13	1607 ± 14	268 ± 32	969 ± 13	1568 ± 14	613 ± 12
	1.80	326 ± 5	1003± 11	1603 ± 19	288 ± 5	964 ± 11	1565 ± 19	601 ± 27
Source of variation				------------------------- *P*–values -------------------------				
Rearing System		0.198	0.056	0.680	0.197	0.050	0.687	0.223
Lysine level		<0.001	<0.001	0.054	<0.001	<0.001	0.052	0.783
Rearing system x Lysine level		0.724	0.548	0.189	0.688	0.566	0.194	0.218

[a,b] Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table III – 1.5. Regression analysis of effects of digestible lysine on BW of birds raised under sex separate and straight-run regimes

Parameter = BW (g)							
		Quadratic regression					
Rearing system	Age	Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML
Female	13	$Y = 318.885 + 14.374x – 112.780(x–1.425)^2$	0.63	0.007	<0.001	1.489	340
Male		$Y = 296.663 + 24.060x – 135.154(x–1.400)^2$	0.63	0.004	0.002	1.489	331
Straight-run		$Y = 333.385 + 2.222x – 105.273(x–1.425)^2$	0.58	0.743	0.002	1.436	337
Straight-run female		$Y = 332.575 + 8.933x – 129.542(x–1.417)^2$	0.62	0.286	0.002	1.451	345
Straight-run male		$Y = 342.647 – 8.955x – 108.641(x–1.437)^2$	0.36	0.220	0.003	1.396	330
Female	25	$Y = 945.326 + 53.797x – 211.767(x–1.409)^2$	0.65	<0.001	<0.001	1.536	1025
Male		$Y = 1081.612 - 16.284x – 423.378(x–1.438)^2$	0.42	0.541	0.002	1.419	1058
Straight-run		$Y = 998.669 + 24.970x – 202.954(x–1.411)^2$	0.64	0.077	0.003	1.473	1035
Straight-run female		$Y = 945.396 + 44.796x – 168.035(x–1.400)^2$	0.43	0.014	0.038	1.533	1011
Straight-run male		$Y = 1041.334 + 3.246x – 175.936(x–1.394)^2$	0.33	0.863	0.039	1.403	1046
Female	32	$Y = 1617.633 + 2.526x – 334.334(x–1.466)^2$	0.50	0.895	0.001	1.470	1621
Male		$Y = 1989.718 – 167.88x – 576.601(x–1.465)^2$	0.58	<0.001	0.002	1.319	1756
Straight-run		$Y = 1671.793 + 11.959x – 297.167(x–1.434)^2$	0.31	0.586	0.006	1.454	1689
Straight-run female		$Y = 1601.920 + 11.998x – 373.305(x–1.434)^2$	0.34	0.647	0.004	1.450	1619
Straight-run male		$Y = 1823.127 – 36.36x – 376.904(x–1.438)^2$	0.26	0.298	0.024	1.390	1772

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

Table III – 1.6. Regression analysis of effects of digestible lysine on BW gain of birds raised under sex separate and straight-run regimes

Parameter = BW gain (g)								
		Quadratic regression						
Rearing system	Age	Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML	Response at TRML
Female	0 to 13 d	$Y = 280.188 + 14.752x - 111.551(x-1.425)^2$	0.64	<0.001	0.004	1.491	302
Male		$Y = 259.274 + 22.052x - 120.211(x-1.405)^2$	0.53	0.009	0.001	1.497	291
Straight-run		$Y = 295.507 + 2.057x - 109.541(x-1.425)^2$	0.58	0.756	0.001	1.434	298
Straight-run female		$Y = 295.395 + 8.333x - 131.385(x-1.417)^2$	0.63	0.299	0.001	1.449	307
Straight-run male		$Y = 304.404 - 8.886x - 115.551(x-1.437)^2$	0.40	0.215	0.001	1.399	292
Female	0 to 25 d	$Y = 906.917 + 53.991x - 211.312(x-1.409)^2$	0.66	<0.001	<0.001	1.537	986
Male		$Y = 1042.159 - 15.780x - 422.803(x-1.438)^2$	0.42	0.554	0002	1.419	1020
Straight-run		$Y = 960.256 + 25.108x - 206.281(x-1.411)^2$	0.64	0.073	0.002	1.471	996
Straight-run female		$Y = 908.528 + 43.882x - 170.167(x-1.400)^2$	0.43	0.014	0.032	1.529	973
Straight-run male		$Y = 1001.583 + 4.311x - 182.485(x-1.394)^2$	0.34	0.816	0.030	1.406	1008
Female	0 to 32 d	$Y = 1579.008 + 2.833x - 333.941(x-1.466)^2$	0.51	0.881	0.001	1.470	1583
Male		$Y = 1950.451 - 167.517x - 575.196(x-1.465)^2$	0.58	<0.001	0.002	1.319	1717
Straight-run		$Y = 1634.330 + 11.361x - 298.451(x-1.434)^2$	0.32	0.602	0.006	1.453	1651
Straight-run female		$Y = 1564.347 + 11.563x - 372.090(x-1.434)^2$	0.35	0.655	0.003	1.450	1581
Straight-run male		$Y = 1784.013 - 35.785x - 383.350(x-1.438)^2$	0.27	0.303	0.022	1.391	1733
Female	25 to 32 d	$Y = 626.027 - 19.046x - 176.829(x-1.402)^2$	0.47	0.102	0.004	1.348	600
Male		$Y = 832.395 - 97.479x - 280.300(x-1.444)^2$	0.50	0.002	0.032	1.270	700
Straight-run		$Y = 665.254 - 8.113x - 34.031(x-1.431)^2$	0.45	0.630	0.669	1.312	654
Straight-run female		$Y = 664.062 - 28.353x - 244.346(x-1.415)^2$	0.33	0.233	0.037	1.357	625
Straight-run male		$Y = 796.736 - 45.156x - 370.815(x-1.430)^2$	0.21	0.212	0.036	1.369	734

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

Table III – 1.7. Effect of rearing system and digestible lysine level on feed intake and adjFCR of Ross 708 chicks

Rearing system	Lysine level (%)	Feed intake (g)				AdjFCR (g)			
		0 to 13	0 to 25	0 to 32	25 to 32	0 to 13	0 to 25	0 to 32	25 to 32
Female		369 ± 3^{a}	1436 ± 16^{b}	2521 ± 16^{b}	1041 ± 7^{b}	1.253 ± 0.005^{ab}	1.471 ± 0.018	1.581 ± 0.012^{ab}	1.765 ± 0.011^{a}
Male		346 ± 4^{b}	1470 ± 19^{ab}	2654 ± 19^{a}	1148 ± 10^{a}	1.240 ± 0.005^{b}	1.468 ± 0.022	1.570 ± 0.015^{b}	1.713 ± 0.018^{b}
Straight-run		368 ± 4^{a}	1493 ± 24^{a}	2694 ± 24^{a}	1138 ± 10^{a}	1.257 ± 0.005^{a}	1.499 ± 0.024	1.614 ± 0.006^{a}	1.747 ± 0.017^{ab}
Female	1.05	349 ± 8	1449± 58	2487 ± 60	998 ± 10	1.235 ± 0.021	1.521 ± 0.054	1.598 ± 0.030	1.702 ± 0.020
	1.20	364 ± 12	1458± 27	2544 ± 27	1039 ± 13	1.249 ± 0.014	1.511 ± 0.047	1.609 ± 0.029	1.762 ± 0.016
	1.35	373 ± 5	1406± 49	2506 ± 67	1064 ± 19	1.250 ± 0.006	1.422 ± 0.037	1.553 ± 0.028	1.766 ± 0.030
	1.50	380 ± 6	1418± 14	2520 ± 34	1048 ± 17	1.256 ± 0.008	1.438 ± 0.026	1.541 ± 0.035	1.740 ± 0.028
	1.65	379 ± 6	1440± 36	2533 ± 42	1059 ± 12	1.262 ± 0.005	1.449 ± 0.045	1.573 ± 0.025	1.793 ± 0.023
	1.80	367 ± 3	1445± 48	2535 ± 63	1039 ± 18	1.265 ± 0.002	1.483 ± 0.051	1.613 ± 0.031	1.821 ± 0.022
Male	1.05	341 ± 8	1466± 38	2624 ± 55	1143 ± 32	1.220 ± 0.015	1.462 ± 0.027	1.541 ± 0.014	1.635 ± 0.024
	1.20	342 ± 7	1501± 61	2727 ± 82	1173 ± 19	1.245 ± 0.016	1.529 ± 0.056	1.606 ± 0.036	1.637 ± 0.037
	1.35	357 ± 7	1409± 38	2566 ± 47	1131 ± 39	1.232 ± 0.004	1.363 ± 0.040	1.478 ± 0.022	1.695 ± 0.045
	1.50	359 ± 7	1491± 52	2703 ± 69	1166 ± 9	1.248 ± 0.008	1.453 ± 0.066	1.552 ± 0.038	1.691 ± 0.027
	1.65	341 ± 13	1497± 54	2692 ± 73	1164 ± 20	1.248 ± 0.007	1.486 ± 0.048	1.606 ± 0.030	1.806 ± 0.045
	1.80	336 ± 11	1455± 35	2614 ± 38	1113 ± 22	1.249 ± 0.013	1.511 ± 0.069	1.619 ± 0.038	1.781 ± 0.024
Straight-run	1.05	353 ± 5	1688± 28	2689 ± 125	1098 ± 14	1.254 ± 0.006	1.712 ± 0.028	1.737 ± 0.027	1.685 ± 0.031
	1.20	388 ± 4	1410± 70	2710 ± 93	1180 ± 49	1.263 ± 0.015	1.422 ± 0.027	1.593 ± 0.051	1.707 ± 0.053
	1.35	366 ± 10	1441± 25	2609 ± 46	1123 ± 10	1.238 ± 0.011	1.430 ± 0.038	1.577 ± 0.014	1.812 ± 0.051
	1.50	375 ± 4	1511± 35	2716 ± 37	1152 ± 17	1.263 ± 0.009	1.510 ± 0.039	1.612 ± 0.020	1.753 ± 0.030
	1.65	377 ± 7	1431± 62	2729 ± 117	1148 ± 15	1.256 ± 0.019	1.440 ± 0.052	1.569 ± 0.029	1.741 ± 0.031
	1.80	355 ± 7	1527± 62	2712 ± 85	1126 ± 20	1.267 ± 0.008	1.540 ± 0.062	1.636 ± 0.045	1.780 ± 0.043
Source of variation		------------------------- *P*–values -------------------------							
Rearing System		<0.001	0.038	<0.001	<0.001	0.031	0.149	0.008	0.007
Lysine level		0.002	0.070	0.504	0.049	0.062	<0.001	0.004	<0.001
Rearing system x Lysine level		0.210	0.091	0.998	0.700	0.929	0.029	0.042	0.483

^{a,b} Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Figure III – 1.1. Body weight gain in function of digestible lysine intake for broilers raised sex separated or straight-run at 13 d of age

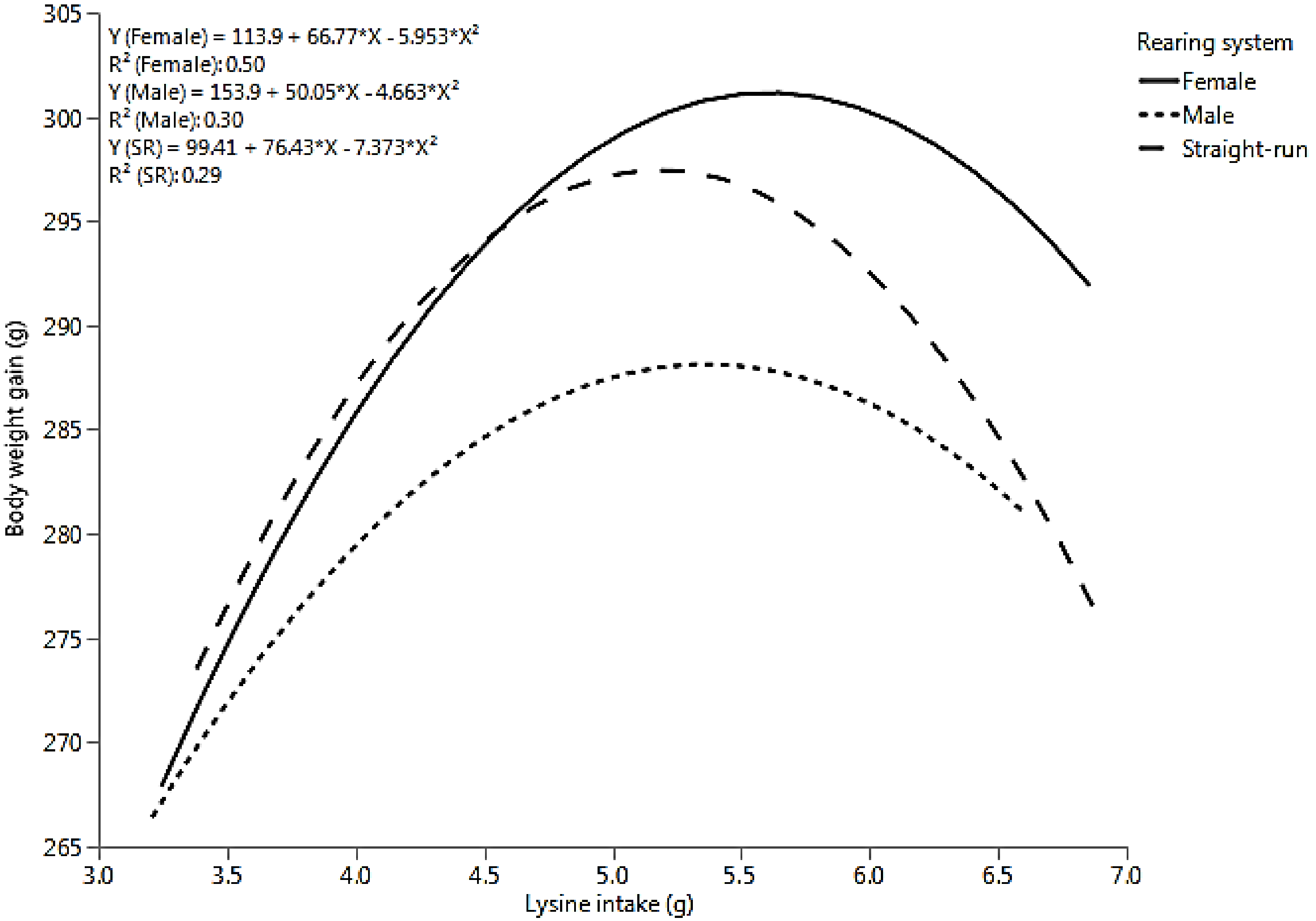

Figure III – 1.2. Body weight gain in function of digestible lysine intake for broilers raised sex separated or straight-run at 25 d of age

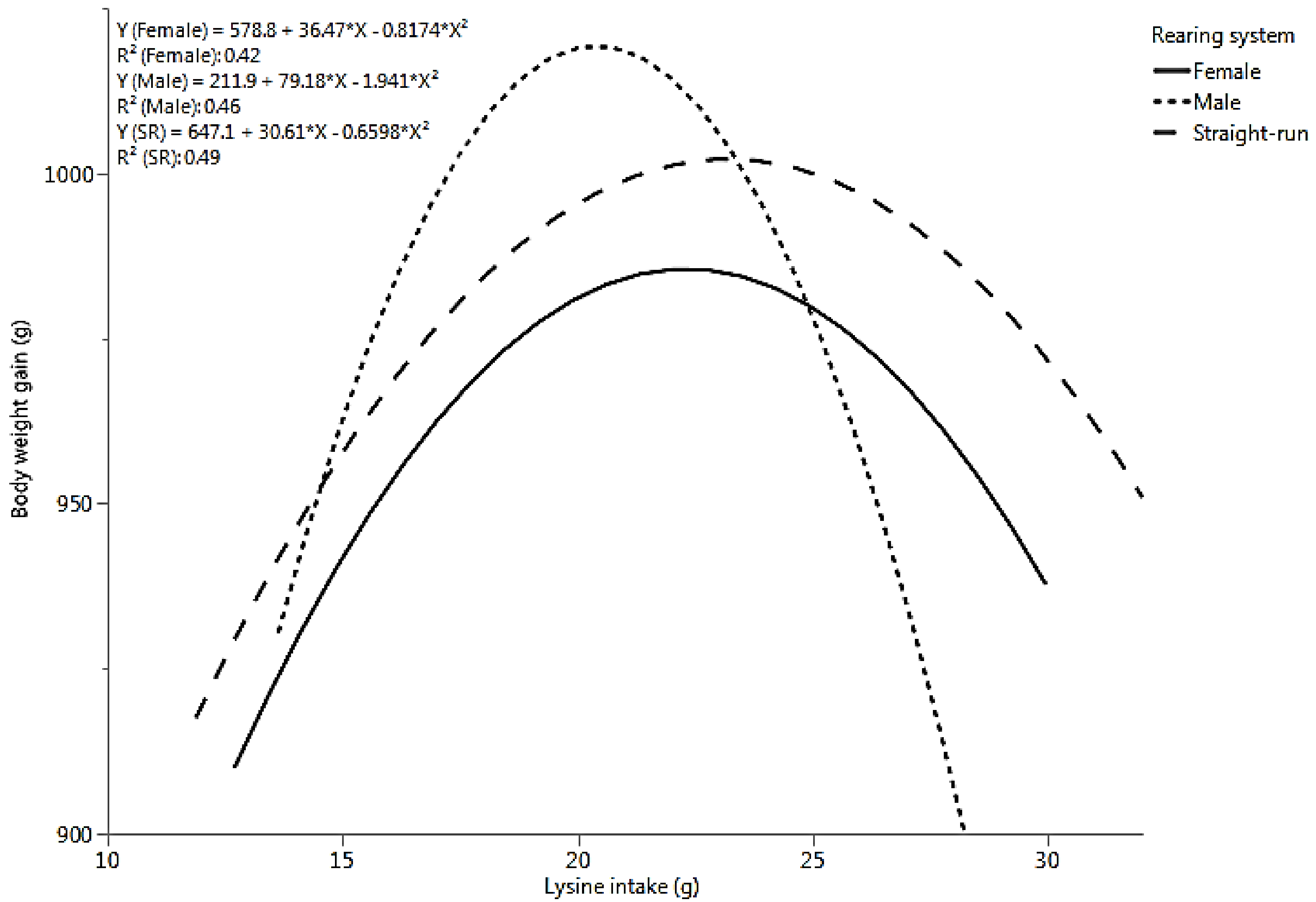

Figure III – 1.3. Body weight gain in function of digestible lysine intake for broilers raised sex separated or straight-run at 32 d of age

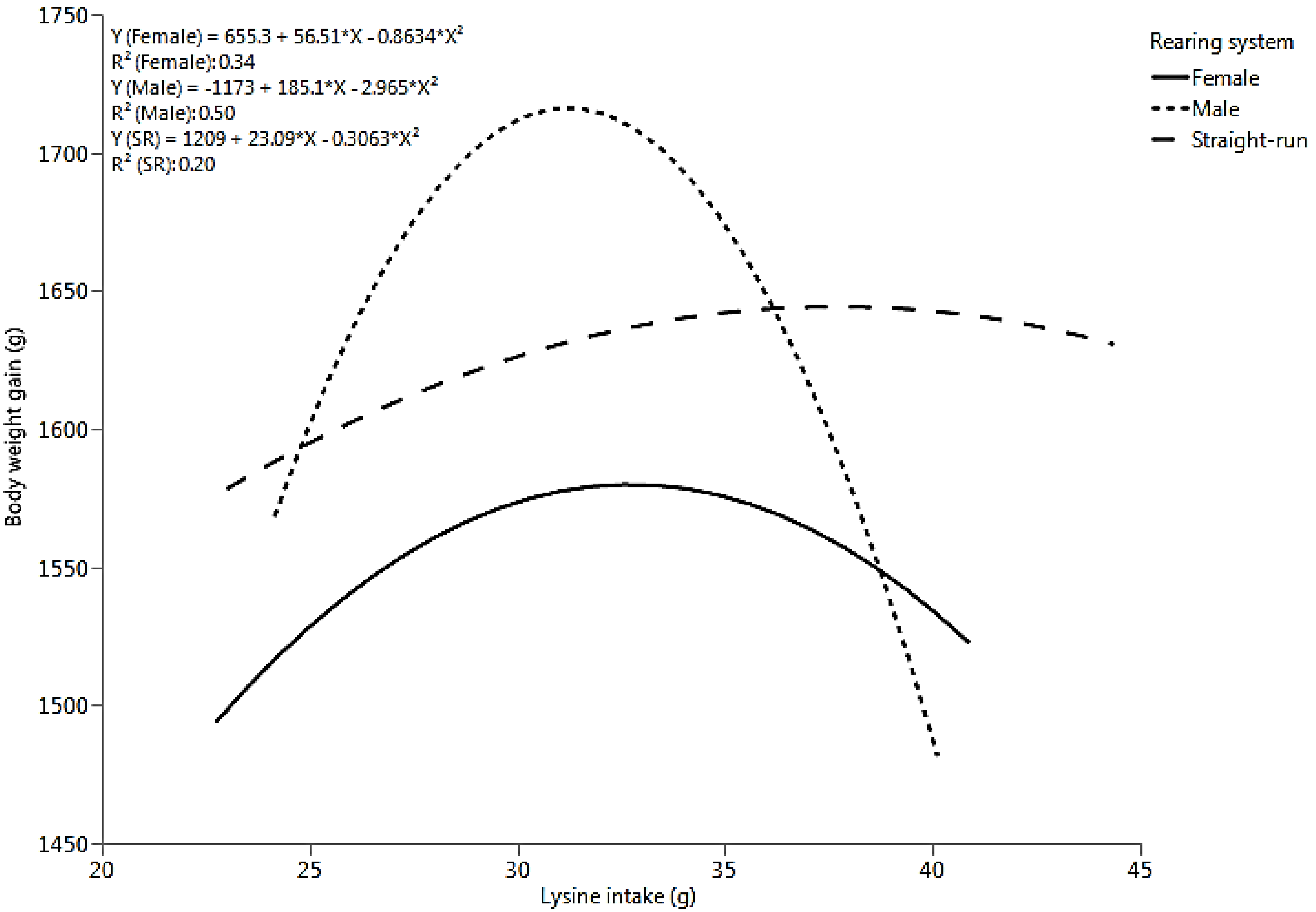

Table III – 1.8. Regression analysis of effects of digestible lysine on BW gain of birds raised under sex separate and straight-run regimes

Parameter	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML	Response at TRML
AdjFCR (g:g)	Female	0 to 13 d	$Y = 1.2467 - 0.00422x + 0.1048(x\text{-}1.460)^2$	0.33	0.667	0.026	1.480	1.241
	Male		$Y = 1.1521 + 0.05947x + 0.0058(x\text{-}1.469)^2$	0.55	<0.001	0.918	↑0.006 g:g/↑ 0.1% Lys	-
	Straight-run		$Y = 1.2434 + 0.00945x + 0.0712(x\text{-}1.448)^2$	0.33	0.467	0.242	NS	-
	Female	0 to 25 d	$Y = 1.6587 - 0.1704x + 0.8556(x\text{-}1.440)^2$	0.56	0.004	0.002	1.540	1.405
	Male		$Y = 1.2270 + 0.1230x + 0.9712(x\text{-}1.402)^2$	0.51	0.071	0.003	1.339	1.396
	Straight-run		$Y = 1.5325 - 0.0683x + 1.1357(x\text{-}1.454)^2$	0.36	0.437	0.006	1.562	1.439
	Female	0 to 32 d	$Y = 1.540 - 0.0032x + 0.6605(x\text{-}1.461)^2$	0.56	0.924	<0.001	1.463	1.535
	Male		$Y = 1.271 + 0.1703x + 0.7320(x\text{-}1.413)^2$	0.63	<0.001	<0.001	1.297	1.502
	Straight-run		$Y = 1.773 - 0.1326x + 0.5420(x\text{-}1.440)^2$	0.36	0.024	0.032	1.562	1.574
	Female	25 to 32 d	$Y = 1.5918 + 0.1207x + 0.0571(x\text{-}1.437)^2$	0.58	<0.001	0.660	↑0.012 g:g/↑ 0.1% Lys	-
	Male		$Y = 1.4358 + 0.1883x + 0.0254(x\text{-}1.463)^2$	0.77	<0.001	0.859	↑0.018 g:g/↑ 0.1% Lys	-
	Straight-run		$Y = 1.5735 + 0.1175x - 0.0307(x\text{-}1.428)^2$	0.44	0.018	0.888	↑0.012 g:g/↑ 0.1% Lys	-
Feed intake (g)	Female	0 to 13 d	$Y = 337.992 + 29.313x – 155.680(x\text{-}1.425)^2$	0.44	0.012	0.004	1.519	381
	Male		$Y = 324.106 + 24.357x – 146.194(x\text{-}1.400)^2$	0.54	0.023	0.003	1.483	359
	Straight-run		$Y = 376.715 – 0.0964x – 137.488(x\text{-}1.437)^2$	0.46	0.993	0.010	1.437	377
	Female	0 to 25 d	$Y = 1590.15 – 131.34x + 545.363(x\text{-}1.438)^2$	0.50	0.004	0.012	1.558	1393
	Male		$Y = 1433.99 + 11.94x + 155.659(x\text{-}1.409)^2$	0.49	0.789	0.432	NS	-
	Straight-run		$Y = 1499.29 – 39.92x + 818.383(x\text{-}1.433)^2$	0.31	0.587	0.022	1.457	1442
	Female	0 to 32 d	$Y = 2635.04 – 93.63x + 247.851(x\text{-}1.450)^2$	0.36	0.054	0.273	↓9.36 g /↑ 0.1% Lys	-
	Male		$Y = 2477.997 + 132.62x – 349.872(x\text{-}1.428)^2$	0.50	0.059	0.235	↑13.26 g /↑ 0.1% Lys	-
	Straight-run		$Y = 2784.575 - 109.38x + 740.499(x\text{-}1.386)^2$	0.32	0.302	0.108	NS	-
	Female	25 to 32 d	$Y = 950.732 + 75.649x - 273.288(x\text{-}1.388)^2$	0.49	0.001	0.010	1.526	1061
	Male		$Y = 1208.158 - 22.443x - 390.75(x\text{-}1.441)^2$	0.24	0.510	0.016	1.412	1176
	Straight-run		$Y = 1081.018 + 48.572x - 286.454(x\text{-}1.408)^2$	0.33	0.054	0.014	1.493	1151

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

NS – not significant (*P*>0.05)

Table III – 1.9. Effect of rearing system and digestible lysine level on BW of processed birds and respective cold carcass weight and yield

Rearing system	Lysine level (%)	Live BW (g)			Cold carcass					
					Weight (g)			Percentage (%)		
		14	26	33	14	26	33	14	26	33
Female		333 ± 3^{ab}	899 ± 7	1437 ± 11^{b}	282 ± 3^{a}	758 ± 7	1210 ± 11^{b}	71.55 ± 0.30^{a}	73.58±0.23	74.37±0.33
Male		324 ± 4^{b}	907 ± 12	1517 ± 19^{a}	267 ± 3^{b}	760 ± 10	1268 ± 16^{a}	69.28 ± 0.33^{b}	72.81±0.23	73.65±0.34
Straight-run		334 ± 4^{a}	891 ± 9	1471 ± 18^{ab}	281 ± 3^{a}	750 ± 7	1236 ± 17^{ab}	70.86 ± 0.28^{a}	73.08±0.21	74.27±0.31
Female	1.05	317 ± 5	871 ± 18	1391 ± 27	264 ± 4	730 ± 15	1163 ± 16	70.07 ± 0.88	73.02±0.77	74.07±0.65
	1.20	332 ± 6	912 ± 14	1449 ± 25	284 ± 7	769 ± 16	1215 ± 22	72.68 ± 0.56	73.33±0.48	74.75±0.46
	1.35	345 ± 8	913 ± 14	1501 ± 29	291 ± 9	774 ± 15	1296 ± 27	71.46 ± 0.69	74.19±0.42	75.03±0.37
	1.50	339 ± 5	900 ± 20	1467 ± 14	289 ± 5	756 ± 18	1223 ± 26	72.44 ± 0.48	73.36±0.57	74.00±1.54
	1.65	346 ± 4	929 ± 12	1413 ± 15	295 ± 1	784 ± 18	1188 ± 19	72.23 ± 0.67	73.88±0.94	74.28±0.48
	1.80	320 ± 7	871 ± 10	1402 ± 12	268 ± 6	733 ± 9	1176 ± 17	70.40 ± 0.49	73.58±0.23	74.10±0.91
Male	1.05	333 ± 13	883 ± 18	1483 ± 42	278 ± 12	736 ± 15	1246 ± 34	69.86 ± 0.61	72.21±0.21	74.06±0.35
	1.20	335 ± 5	862 ± 27	1514 ± 46	275 ± 6	719 ± 19	1254 ± 37	69.25 ± 0.93	72.11±0.67	72.73±1.20
	1.35	327 ± 8	943 ± 19	1545 ± 54	264 ± 6	780 ± 15	1282 ± 50	67.91 ± 1.02	72.50±0.47	72.90±0.82
	1.50	332 ± 14	983 ± 11	1596 ± 30	273 ± 11	831 ± 11	1336 ± 38	69.59 ± 1.02	73.53±0.43	73.55±1.33
	1.65	309 ± 7	924 ± 21	1536 ± 43	255 ± 6	781 ± 19	1295 ± 37	69.94 ± 0.68	73.47±0.73	74.63±0.48
	1.80	308 ± 7	845 ± 24	1428 ± 36	259 ± 8	711 ± 22	1197 ± 32	69.13 ± 0.36	73.14±0.47	74.03±0.46
Straight-run	1.05	320 ± 8	877 ± 22	1363 ± 26	266 ± 6	750 ± 13	1145 ± 22	69.50 ± 0.57	73.30±0.72	74.24±0.25
	1.20	346 ± 11	893 ± 28	1491 ± 48	299 ± 5	754 ± 22	1251 ± 46	72.08 ± 0.44	73.48±0.62	74.33±0.75
	1.35	335 ± 7	902 ± 39	1516 ± 48	278 ± 6	753 ± 32	1263 ± 58	70.48 ± 0.81	72.60±0.52	73.61±1.68
	1.50	326 ± 9	908 ± 21	1501 ± 27	275 ± 8	763 ± 18	1272 ± 23	71.19 ± 0.40	73.33±0.33	75.12±0.26
	1.65	343 ± 8	868 ± 7	1494 ± 56	287 ± 7	732 ± 9	1255 ± 48	70.98 ± 0.65	73.20±0.52	74.10±0.32
	1.80	334 ± 15	896 ± 5	1463 ± 35	281 ± 11	747 ± 7	1233 ± 27	71.18 ± 0.81	72.60±0.47	74.23±0.44
Source of variation					------------------------- *P*–values -------------------------					
Rearing System		0.030	0.376	0.001	<0.001	0.569	0.018	<0.001	0.077	0.255
Lysine level		0.027	0.002	0.001	0.011	0.002	0.004	0.036	0.677	0.982
Rearing system x Lysine level		0.010	0.017	0.644	0.002	0.015	0.516	0.300	0.600	0.797

^{a,b} Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table III – 1.10. Effect of rearing system and digestible lysine level on BW of processed birds and respective cold carcass weight and yield

Rearing system	Lysine level (%)	*Pectoralis major*						*Pectoralis minor*					
		Weight (g)			Percentage (%)			Weight (g)			Percentage (%)		
		14	26	33	14	26	33	14	26	33	14	26	33
Female		41 ± 1^{a}	158 ± 3	278 ± 3	17.05 ± 0.14	23.84 ± 0.23	25.77±0.22	9 ± 0.2^{a}	35 ± 0.6	62 ± 0.6	3.74 ± 0.05	5.32 ± 0.08	5.82 ± 0.07^{a}
Male		38 ± 1^{b}	157 ± 4	287 ± 5	17.04 ± 0.16	23.81 ± 0.29	25.63±0.28	8 ± 0.2^{b}	34 ± 0.9	62 ± 1.0	3.63 ± 0.05	5.18 ± 0.09	5.58 ± 0.06^{b}
Straight-run		41 ± 1^{a}	154 ± 2	284 ± 5	17.30 ± 0.16	23.62 ± 0.20	25.83±0.23	9 ± 0.2^{a}	34 ± 0.5	62 ± 0.9	3.81 ± 0.07	5.25 ± 0.07	5.60 ± 0.06^{b}
Female	1.05	36 ± 1	143 ± 6	262 ± 8	16.07 ± 0.11	22.46 ± 0.49	25.52±0.56	8 ± 0.2	32 ± 1.6	59 ± 1.0	3.40 ± 0.07	5.02 ± 0.15	5.73 ± 0.09
	1.20	41 ± 2	156 ± 6	274 ± 8	17.08 ± 0.32	23.14 ± 0.44	25.29±0.26	9 ± 0.4	35 ± 1.9	61 ± 1.4	3.61 ± 0.11	5.16 ± 0.27	5.62 ± 0.18
	1.35	43 ± 1	164 ± 5	298 ± 6	17.45 ± 0.18	24.10 ± 0.29	25.88±0.44	9 ± 0.3	36 ± 1.3	63 ± 1.1	3.86 ± 0.11	5.33 ± 0.15	5.53 ± 0.10
	1.50	41 ± 1	159 ± 6	297 ± 5	16.81 ± 0.44	23.95 ± 0.56	27.34±0.50	9 ± 0.3	35 ± 0.7	64 ± 1.7	3.67 ± 0.10	5.27 ± 0.16	5.96 ± 0.20
	1.65	45 ± 1	174 ± 4	267 ± 4	17.86 ± 0.22	25.29 ± 0.28	25.36±0.54	10 ± 0.1	37 ± 1.8	63 ± 1.4	3.97 ± 0.05	5.35 ± 0.22	5.95 ± 0.07
	1.80	39 ± 1	155 ± 5	271 ± 8	17.04 ± 0.14	24.11 ± 0.55	25.20±0.54	9 ± 0.2	37 ± 0.4	64 ± 1.1	3.90 ± 0.07	5.77 ± 0.07	6.13 ± 0.19
Male	1.05	38 ± 2	139 ± 5	277 ± 7	16.13 ± 0.18	21.80 ± 0.39	25.16±0.26	8 ± 0.5	30 ± 1.4	58 ± 1.7	3.55 ± 0.08	4.66 ± 0.15	5.28 ± 0.14
	1.20	40 ± 1	141 ± 5	272 ± 10	17.18 ± 0.25	22.57 ± 0.27	24.57±0.72	9 ± 0.2	32 ± 1.4	61 ± 1.9	3.76 ± 0.13	5.01 ± 0.22	5.58 ± 0.09
	1.35	39 ± 1	164 ± 4	293 ± 14	17.44 ± 0.28	24.37 ± 0.61	26.06±0.54	8 ± 0.4	35 ± 1.5	61 ± 2.3	3.63 ± 0.16	5.23 ± 0.17	5.45 ± 0.22
	1.50	39 ± 2	182 ± 6	309 ± 10	17.03 ± 0.23	25.20 ± 0.68	26.25±0.95	8 ± 0.5	39 ± 2.0	68 ± 1.0	3.48 ± 0.08	5.56 ± 0.17	5.78 ± 0.15
	1.65	38 ± 2	169 ± 6	302 ± 10	17.36 ± 0.35	24.84 ± 0.40	26.42±0.50	8 ± 0.2	34 ± 2.8	65 ± 2.7	3.48 ± 0.04	5.06 ± 0.28	5.63 ± 0.12
	1.80	37 ± 2	149 ± 6	268 ± 14	17.09 ± 0.67	24.07 ± 0.24	25.31±0.75	9 ± 0.2	35 ± 1.0	61 ± 2.1	3.86 ± 0.16	5.55 ± 0.08	5.75 ± 0.04
Straight-run	1.05	38 ± 1	146 ± 4	253 ± 8	16.80 ± 0.25	22.41 ± 0.36	24.87±0.25	8 ± 0.5	31 ± 0.9	57 ± 1.5	3.76 ± 0.17	4.78 ± 0.20	5.61 ± 0.06
	1.20	42 ± 1	155 ± 7	287 ± 15	16.66 ± 0.32	23.46 ± 0.55	25.83±0.62	9 ± 0.6	35 ± 1.4	61 ± 1.9	3.63 ± 0.18	5.28 ± 0.13	5.52 ± 0.16
	1.35	42 ± 2	154 ± 9	307 ± 16	17.63 ± 0.49	23.39 ± 0.38	26.17±0.78	9 ± 0.6	34 ± 1.5	67 ± 2.0	3.70 ± 0.19	5.15 ± 0.19	5.76 ± 0.11
	1.50	40 ± 2	162 ± 5	292 ± 9	17.24 ± 0.44	24.33 ± 0.48	25.96±0.62	9 ± 0.3	36 ± 0.9	60 ± 1.8	3.80 ± 0.13	5.47 ± 0.09	5.25 ± 0.16
	1.65	44 ± 1	152 ± 3	288 ± 9	17.93 ± 0.29	23.95 ± 0.38	25.84±0.36	10 ± 0.6	34 ± 1.2	62 ± 2.0	4.10 ± 0.19	5.33 ± 0.15	5.57 ± 0.03
	1.80	41 ± 2	157 ± 4	280 ± 4	17.61 ± 0.37	24.18 ± 0.35	26.34±0.81	9 ± 0.5	36 ± 0.9	64 ± 1.1	3.87 ± 0.17	5.51 ± 0.11	5.87 ± 0.22
Source of variation							------------------------- *P*–values -------------------------						
Rearing System		0.001	0.406	0.244	0.295	0.649	0.797	<0.001	0.414	0.858	0.194	0.400	0.006
Lysine level		<0.001	<0.001	<0.001	<0.001	<0.001	0.036	0.017	<0.001	<0.001	0.191	<0.001	0.016
RS x LL		0.121	0.007	0.229	0.778	0.189	0.404	0.004	0.335	0.030	0.196	0.763	0.075

[a,b] Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table III – 1.11. Effect of rearing system and digestible lysine level on BW of processed birds and respective cold carcass weight and yield

Rearing system	Lysine level (%)	Legs						Wings				Paws		
		Weight (g)			Percentage (%)			Weight (g)		Percentage (%)		Weight (g)		
		14	26	33	14	26	33	26	33	26	33	14	26	33
Female		61±1^{ab}	192±2	292±3^{c}	25.44±0.16^{b}	29.04±0.22	27.23±0.19^{b}	78^{a}±1	112±1^{b}	11.80±0.09	10.48±0.06	14±0.2	35±0.3^{c}	51±0.6^{c}
Male		60±1^{b}	193±3	320±4^{a}	26.66±0.17^{a}	29.58±0.24	28.58±0.18^{a}	76^{ab}±1	118±1^{a}	11.66±0.10	10.63±0.08	14±0.2	39±0.6^{a}	61±0.8^{a}
Straight-run		62±1^{a}	189±2	302±4^{b}	26.22±0.15^{a}	29.01±0.25	27.46±0.17^{b}	75^{b}±1	114±1^{b}	11.53±0.11	10.51±0.09	14±0.2	37±0.4^{b}	56±0.8^{b}
Female	1.05	57±1	192±6	280±5	25.59±0.66	30.25±0.56	27.25±0.25	76±2	108±2	11.96±0.34	10.51±0.10	13±0.3	35±0.8	48±0.8
	1.20	59±2	196±4	294±5	24.42±0.18	29.35±0.33	27.22±0.43	79±1	111±2	11.88±0.29	10.24±0.11	14±0.4	36±0.8	51±0.8
	1.35	64±2	194±5	306±8	25.91±0.22	28.63±0.51	26.63±0.58	78±1	118±3	11.63±0.25	10.29±0.20	14±0.6	35±0.7	53±1.4
	1.50	62±2	194±5	294±5	25.41±0.38	29.37±0.46	27.06±0.61	79±2	115±1	12.01±0.17	10.67±0.17	15±0.3	35±0.8	52±1.9
	1.65	63±1	194±3	288±5	25.29±0.16	28.31±0.52	27.48±0.44	80±3	110±1	11.65±0.23	10.54±0.08	15±0.1	36±0.6	51±1.2
	1.80	59±1	183±2	288±6	25.98±0.21	28.63±0.52	27.75±0.48	75±1	110±2	11.72±0.18	10.63±0.15	14±0.2	35±0.4	53±1.5
Male	1.05	62±3	193±3	311±8	26.59±0.18	30.33±0.34	28.32±0.45	74±2	116±3	11.70±0.28	10.59±0.14	15±0.7	38±0.8	58±1.8
	1.20	62±2	185±5	318±7	26.98±0.50	29.81±0.50	28.97±0.38	74±1	120±4	11.92±0.14	10.98±0.22	15±0.4	37±1.3	61±1.3
	1.35	59±2	198±6	318±11	26.76±0.62	29.49±0.98	28.36±0.46	78±2	120±3	11.63±0.41	10.72±0.26	14±0.5	41±0.6	62±2.0
	1.50	61±2	204±8	338±7	26.61±0.56	29.08±0.49	28.89±0.65	80±3	123±2	11.36±0.22	10.54±0.24	14±0.6	42±1.3	65±1.3
	1.65	57±1	199±3	333±4	26.64±0.23	29.23±0.58	28.33±0.40	78±1	117±3	11.60±0.23	10.26±0.14	13±0.3	41±1.5	64±1.3
	1.80	57±2	177±5	302±8	26.40±0.30	29.58±0.61	28.61±0.42	73±3	112±2	11.77±0.16	10.68±0.17	13±0.4	35±1.1	58±1.1
Straight-run	1.05	59±2	185±6	280±7	26.47±0.51	28.24±0.74	27.70±0.48	74±3	106±2	11.37±0.25	10.53±0.17	14±0.6	36±0.7	51±0.8
	1.20	66±1	190±9	301±12	25.83±0.14	29.02±0.80	27.09±0.40	73±1	115±4	11.19±0.27	10.39±0.14	15±0.5	37±1.3	55±2.3
	1.35	60±1	193±8	316±9	25.61±0.34	29.54±0.54	27.04±0.26	79±3	119±3	12.12±0.35	10.70±0.37	14±0.5	37±1.3	58±0.9
	1.50	62±2	193±6	311±6	26.60±0.21	28.90±0.62	27.60±0.35	75±2	117±3	11.33±0.17	10.35±0.15	14±0.5	38±0.7	56±0.5
	1.65	64±2	185±2	301±14	26.18±0.48	29.33±0.39	27.13±0.26	74±1	114±5	11.73±0.21	10.32±0.14	15±0.4	37±0.6	56±2.6
	1.80	63±3	189±3	306±6	26.65±0.30	29.00±0.58	28.17±0.54	74±1	116±2	11.44±0.12	10.76±0.28	14±0.6	37±0.6	58±1.1
Source of variation		------------------------- *P*–values -------------------------												
Rearing System		0.028	0.397	<.0001	<0.001	0.179	<0.001	0.049	0.001	0.156	0.362	0.410	<0.001	<0.001
Lysine level		0.100	0.027	0.002	0.492	0.781	0.353	0.035	0.001	0.941	0.515	0.384	0.008	<0.001
RS[1] x LL[2]		0.002	0.238	0.213	0.201	0.376	0.845	0.615	0.441	0.238	0.252	0.003	0.017	0.089

[a,b] Means in a column not sharing a common superscript are significantly different (*P*≤0.05) by orthogonal contrasts

[1] RS – Rearing system

[2] LL – Lysine level

Table III – 1.12. Regression analysis of effects of digestible lysine on cold carcass weight and yield of birds raised under sex separate and straight-run regimes

Parameter	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML
Cold carcass weight (g)	Female	14	$Y = 264.569 + 19.105x - 166.454(x - 1.428)^2$	0.61	0.025	<0.001	1.485	292
	Male		$Y = 294.735 - 20.870x + 16.149(x - 1.452)^2$	0.51	0.037	0.709	↓2.09g /↑ 0.1% Lys	-
	Straight-run		$Y = 282.660 + 0.0218x - 7.178(x - 1.438)^2$	0.52	0.998	0.879	NS	-
	Female	26	$Y = 848.458 - 54.170x - 254.059(x - 1.431)^2$	0.56	0.015	0.008	1.324	774
	Male		$Y = 797.163 + 9.533x - 679.807(x - 1.416)^2$	0.60	0.730	<0.001	1.423	811
	Straight-run		$Y = 798.244 - 25.367x - 109.411(x - 1.436)^2$	0.25	0.294	0.329	NS	-
	Female	33	$Y = 1261.693 - 5.337x - 148.875(x - 1.425)^2$	0.46	0.865	<0.001	1.407	1254
	Male		$Y = 1388.827 - 22.799x - 962.742(x - 1.425)^2$	0.51	0.613	<0.001	1.413	1356
	Straight-run		$Y = 1196.742 + 76.967x - 778.169(x - 1.428)^2$	0.45	0.121	0.002	1.477	1309
Cold carcass percentage (%)	Female	14	$Y = 72.501 + 0.176x - 19.637(x - 1.433)^2$	0.53	0.843	<0.001	1.437	72.75
	Male		$Y = 71.394 - 0.852x - 4.288(x - 1.431)^2$	0.07	0.406	0.370	NS	-
	Straight-run		$Y = 69.084 + 1.454x - 4.785(x - 1.444)^2$	0.29	0.161	0.295	NS	-
	Female	26	$Y = 72.146 + 1.192x - 2.970(x - 1.431)^2$	0.28	0.131	0.415	NS	-
	Male		$Y = 72.23 + 0.611x - 4.209(x - 1.419)^2$	0.33	0.300	0.120	NS	-
	Straight-run		$Y = 74.65 - 0.916x - 2.601(x - 1.441)^2$	0.06	0.271	0.495	NS	-
	Female	33	$Y = 74.97 + 0.244x - 4.494(x - 1.425)^2$	0.22	0.606	0.050	1.452	75.32
	Male		$Y = 74.59 - 0.209x - 1.447(x - 1.434)^2$	0.25	0.719	0.607	NS	-
	Straight-run		$Y = 75.66 - 0.486x - 5.020(x - 1.434)^2$	0.14	0.444	0.093	NS	-

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

NS – not significant ($P > 0.05$)

Table III – 1.13. Regression analysis of effects of digestible lysine on *pectoralis major* and *minor* weight and yield of birds raised under sex separate and straight-run regimes

Parameter	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML
Pectoralis major weight (g)	Female	14	$Y = 39.676 + 3.035x - 41.872(x-1.430)^2$	0.50	0.142	<0.001	1.466	44
	Male		$Y = 40.414 - 0.577x - 13.121(x-1.417)^2$	0.31	0.786	0.174	NS	-
	Straight-run		$Y = 37.895 + 2.753x - 13.121(x-1.425)^2$	0.53	0.189	0.477	NS	-
	Female	26	$Y = 141.094 + 16.110x - 99.702(x-1.430)^2$	0.31	0.076	0.018	1.511	165
	Male		$Y = 137.546 + 23.870x - 202.890(x-1.430)^2$	0.57	0.017	<0.001	1.489	172
	Straight-run		$Y = 146.339 + 9.035x - 59.255(x-1.428)^2$	0.23	0.258	0.121	NS	-
	Female	33	$Y = 288.554 + 2.093x - 221.918(x-1.412)^2$	0.42	0.857	<0.001	1.417	292
	Male		$Y = 284.304 + 17.426x - 233.484(x-1.419)^2$	0.43	0.226	0.002	1.456	309
	Straight-run		$Y = 247.652 + 32.026x - 192.646(x-1.425)^2$	0.48	0.034	0.009	1.508	295
Pectoralis major percentage (%)	Female	14	$Y = 15.581 + 1.408x - 6.687(x-1.420)^2$	0.48	0.002	0.003	1.525	17.65
	Male		$Y = 15.038 + 1.641x - 3.122(x-1.404)^2$	0.39	0.003	0.174	↑0.1641 % /↑ 0.1% Lys	-
	Straight-run		$Y = 15.443 + 1.431x - 1.711(x-1.419)^2$	0.31	0.008	0.467	↑0.1431 % /↑ 0.1% Lys	-
	Female	26	$Y = 19.600 + 3.244x - 4.609(x-1.425)^2$	0.49	<0.001	0.173	↑0.3244 % /↑ 0.1% Lys	-
	Male		$Y = 19.489 + 3.561x - 12.177(x-1.425)^2$	0.62	<0.001	<0.001	1.571	24.82
	Straight-run		$Y = 21.400 + 1.827x - 4.880(x-1.433)^2$	0.32	0.009	0.107	↑0.1827 % /↑ 0.1% Lys	-
	Female	33	$Y = 25.722 + 0.345x - 6.791(x-1.398)^2$	0.23	0.621	0.046	1.423	26.21
	Male		$Y = 25.193 + 0.731x - 7.340(x-1.428)^2$	0.41	0.361	0.057	1.478	26.26
	Straight-run		$Y = 24.667 + 1.219x - 9.647(x-1.404)^2$	0.46	0.043	0.002	1.467	26.42
Pectoralis minor weight (g)	Female	14	$Y = 7.340 + 1.508x - 7.776(x-1.433)^2$	0.53	<0.001	0.001	1.530	10
	Male		$Y = 8.694 - 0.568x + 3.808(x-1.414)^2$	0.33	0.325	0.152	NS	-
	Straight-run		$Y = 8.260 + 0.488x + 2.249(x-1.430)^2$	0.48	0.382	0.381	NS	-
	Female	26	$Y = 28.139 + 4.868x - 3.185(x-1.452)^2$	0.31	0.012	0.685	↑0.4868 g /↑ 0.1% Lys	-
	Male		$Y = 25.571 + 8.046x - 36.232(x-1.425)^2$	0.45	0.005	0.004	1.536	37
	Straight-run		$Y = 27.628 + 5.486x - 15.170(x-1.428)^2$	0.48	<0.001	0.034	1.609	36
	Female	33	$Y = 54.909 + 5.558x - 13.208(x-1.422)^2$	0.35	0.005	0.128	↑0.6121 g /↑ 0.1% Lys	-
	Male		$Y = 55.841 + 6.121x - 36.058(x-1.425)^2$	0.30	0.076	0.023	1.510	63
	Straight-run		$Y = 55.763 + 6.140x - 33.334(x-1.425)^2$	0.28	0.061	0.035	1.517	65
Pectoralis minor percentage (%)	Female	14	$Y = 2.828 + 0.650x - 0.509(x-1.428)^2$	0.46	<0.001	0.454	↑0.0650 % /↑ 0.1% Lys	-
	Male		$Y = 3.126 + 0.219x - 1.739(x-1.431)^2$	0.53	0.122	0.009	1.494	3.45
	Straight-run		$Y = 3.200 + 0.405x + 0.485(x-1.425)^2$	0.15	0.138	0.695	NS	-
	Female	26	$Y = 4.074 + 0.859x + 0.726(x-1.448)^2$	0.34	0.004	0.535	↑0.0859 % /↑ 0.1% Lys	-
	Male		$Y = 3.710 + 1.234x - 2.656(x-1.419)^2$	0.68	<0.001	0.007	1.651	5.60
	Straight-run		$Y = 4.217 + 0.863x - 2.057(x-1.420)^2$	0.55	<0.001	0.023	1.630	5.53
	Female	33	$Y = 5.088 + 0.404x + 1.526(x-1.409)^2$	0.23	0.059	0.119	↑0.0404 % /↑ 0.1% Lys	-
	Male		$Y = 5.092 + 0.408x - 0.612(x-1.430)^2$	0.47	0.005	0.313	↑0.0408 % /↑ 0.1% Lys	-
	Straight-run		$Y = 5.196 + 0.190x + 1.793(x-1.42)^2$	0.12	0.423	0.119	NS	-

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

NS – not significant ($P>0.05$)

Table III – 1.14. Regression analysis of effects of digestible lysine on wings, and legs weight and yield, and paw weights of birds raised under sex separate and straight-run regimes

Parameter	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML
Wings weight (g)	Female	26	$Y = 82.925 - 2.913x - 23.204(x-1.467)^2$	0.33	0.120	0.013	1.404	78.74
	Male		$Y = 78.300 + 0.563x - 42.687(x-1.428)^2$	0.26	0.864	0.009	1.435	79.11
	Straight-run		$Y = 71.687 + 2.468x - 14.832(x-1.441)^2$	0.34	0.243	0.138	NS	-
	Female	33	$Y = 113.688 + 0.719x - 51.463(x-1.429)^2$	0.40	0.794	<0.001	1.436	115
	Male		$Y = 130.854 - 5.190x - 66.057(x-1.437)^2$	0.60	0.100	<0.001	1.398	123
	Straight-run		$Y = 97.178 + 14.351x - 42.691(x-1.417)^2$	0.54	0.001	0.023	1.585	119
Wings percentage (%)	Female	26	$Y = 12.377 - 0.332x - 2.266(x-1.463)^2$	0.12	0.346	0.140	NS	-
	Male		$Y = 12.016 - 0.336x + 2.593(x-1.438)^2$	0.12	0.395	0.153	NS	-
	Straight-run		$Y = 11.267 + 0.165x - 0.569(x-1.428)^2$	0.14	0.519	0.643	NS	-
	Female	33	$Y = 10.027 + 0.268x + 1.094(x-1.425)^2$	0.15	0.133	0.207	NS	-
	Male		$Y = 11.433 - 0.525x - 1.106(x-1.404)^2$	0.33	0.082	0.392	NS	-
	Straight-run		$Y = 10.038 + 0.190x + 2.264(x-1.428)^2$	0.16	0.505	0.097	NS	-
Legs weight (g)	Female	14	$Y = 57.194 + 3.875x - 38.339(x-1.444)^2$	0.54	0.061	<0.001	1.495	63
	Male		$Y = 72.067 - 7.735x - 19.219(x-1.450)^2$	0.49	0.010	0.124	↓0.7735 g /↑ 0.1% Lys	-
	Straight-run		$Y = 57.444 + 3.654x - 3.654(x-1.425)^2$	0.40	0.215	0.782	NS	-
	Female	26	$Y = 223.981 - 19.579x - 35.659(x-1.454)^2$	0.55	0.001	0.125	↓1.9579 g /↑ 0.1% Lys	-
	Male		$Y = 192.425 + 4.148x - 53.580(x-1.402)^2$	0.29	0.644	0.204	NS	-
	Straight-run		$Y = 180.066 + 5.943x - 15.577(x-1.428)^2$	0.28	0.409	0.635	NS	-
	Female	33	$Y = 284.373 + 7.268x - 95.215(x-1.409)^2$	0.56	0.295	0.008	1.447	295
	Male		$Y = 336.659 + 2.765x - 292.049(x-1.441)^2$	0.69	0.786	<0.001	1.446	341
	Straight-run		$Y = 268.808 + 34.588x - 167.451(x-1.413)^2$	0.54	0.004	0.003	1.516	319
Legs percentage (%)	Female	14	$Y = 24.227 + 0.653x - 4.184(x-1.436)^2$	0.18	0.270	0.133	NS	-
	Male		$Y = 27.594 - 0.349x - 4.445(x-1.411)^2$	0.21	0.515	0.087	NS	-
	Straight-run		$Y = 24.496 + 1.058x - 2.179(x-1.438)^2$	0.18	0.064	0.389	NS	-
	Female	26	$Y = 31.792 - 2.047x + 3.306(x-1.439)^2$	0.42	0.006	0.311	↓0.2047 % /↑ 0.1% Lys	-
	Male		$Y = 30.110 - 0.765x + 7.388(x-1.433)^2$	0.23	0.321	0.051	NS	28.99
	Straight-run		$Y = 28.180 + 0.791x - 4.577(x-1.425)^2$	0.11	0.417	0.311	NS	-
	Female	33	$Y = 26.550 + 0.291x + 3.711(x-1.417)^2$	0.33	0.597	0.170	NS	-
	Male		$Y = 29.890 - 0.649x - 3.591(x-1.416)^2$	0.15	0.312	0.214	NS	-
	Straight-run		$Y = 26.441 + 0.516x - 5.290(x-1.436)^2$	0.36	0.353	0.045	1.485	27.19
Paws weight (g)	Female	14	$Y = 12.942 + 1.080x - 8.164(x-1.441)^2$	0.55	0.024	<0.001	1.507	14.53
	Male		$Y = 17.335 - 2.243x - 2.882(x-1.438)^2$	0.48	0.020	0.336	↓0.2243 g /↑ 0.1% Lys	-
	Straight-run		$Y = 13.908 + 0.355x - 1.116(x-1.452)^2$	0.58	0.555	0.686	NS	-
	Female	26	$Y = 36.664 - 0.457x - 8.395(x-1.448)^2$	0.17	0.632	0.066	NS	-
	Male		$Y = 39.792 + 0.826x - 24.223(x-1.411)^2$	0.33	0.630	0.004	1.428	41
	Straight-run		$Y = 33.735 + 2.186x - 3.226(x-1.436)^2$	0.21	0.071	0.550	NS	-
	Female	33	$Y = 45.988 + 4.594x - 17.007(x-1.402)^2$	0.33	0.013	0.043	1.537	53
	Male		$Y = 61.853 + 1.980x - 46.862(x-1.420)^2$	0.47	0.400	<0.001	1.441	65
	Straight-run		$Y = 44.323 + 9.408x - 20.740(x-1.417)^2$	0.63	<0.001	0.011	1.644	59

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

NS – not significant ($P > 0.05$)

Evaluation of Starter Dietary Digestible Lysine Level on Broilers Raised under a Sex Separated or Straight-run Housing Regime

Part 2: Economics of Sex separation and Digestible Lysine Level for Maximum Returns[1]

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[1] M.J. Da Costa[1], G. Colson[1], T.J. Frost[2], J. Halley[3], G.M. Pesti[1]
[1]University of Georgia, Athens, GA 30606
[2]Wayne Farms LLC, 4110 Continental Drive, Oakwood, Georgia 30566
[3]Aviagen Inc., 5015 Bradford Drive, Huntsville, AL 35805
To be submitted to Poultry Science

ABSTRACT

The objective of this experiment was to determine the net returns maximum digestible lysine (dLys) levels (NRML) when maintaining the ideal amino acid ratio for starter diets of broilers raised sex separate or comingled (straight-run). 3,240 Ross 708 chicks were separated by sex and placed in 90 pens by two rearing types: sex separate (36 males or 36 females) or straight-run (18 males + 18 females). Each rearing type was fed six starter diets (25d) formulated to have dLys levels between 1.05 and 1.80%. A common grower diet with 1.02% of dLys was fed from 25 to 32d. Body weight gain (BWG) and feed intake were assessed at 25 and 32d for performance evaluation. Additionally at 26 and 33d, four birds per pen were sampled for carcass yield evaluation. Data were modeled using response surface methodology in order to estimate feed intake and whole carcass weight at 1,600g live BW. Returns over feed cost were estimated for a 1.8 million broiler complex of each rearing system that were under nine feed/meat price scenarios. Results indicated that females needed more feed to reach market weight, followed by straight-run birds, and then males. At medium meat and feed prices, female birds had NRML at 1.07% of dlys, whereas straight-run and males had NRML at 1.05%. As feed prices increased and meat prices increased, females had NRML increased up to 1.15% of dLys. Sex separation resulted in increased revenue under certain feed and meat prices, and before sex cost was deducted. When the sexing cost was added to the returns, sex separation was not shown to be economically viable when targeting birds for light market BW.

Keywords: sex separate, straight run, lysine, protein, economics

INTRODUCTION

The poultry industry worldwide is constantly seeking the most economically favorable strategies in order to achieve maximum returns. Strategies that can affect bird performance and reduce feeding costs can also greatly impact production costs and result in either savings or loss. Throughout the years, the economic advantages of raising birds sex separate or sex commingled has been one of the main strategies that have been evaluated, however, the results reported in the literature are inconsistent. Some studies revealed benefits of sex separation related with improved performance and flock uniformity at market weight (Becker and Berg, 1959; Deaton, et al., 1973; Gehle, et al., 1974; Laseinde and Oluyemi, 1994; de Albuquerque, et al., 2006; Api, 2014), while other studies did not observe any benefit on sex separation (Smith, et al., 1954; Hess, et al., 1960; Lang, et al., 1960; Lamoreux and Proudfoot, 1969). Nevertheless, most of the studies present in the literature were conducted using less selected bird strains. Considering the yearly changes observed on the broiler genetics (Zuidhof, et al., 2014), there is a need to re-assess the advantages of raising broilers sex separate using modern broiler breeds.

Sex separation also allows for the feeding of different diets to each gender and gives the ability to explore potential differences that genders might have on specific nutrient requirements. Protein level (or digestible lysine level when maintaining the amino acid ratios) can significantly affect bird performance and carcass yield (Bartov and Plavnik, 1998; Corzo, et al., 2004; Kidd, et al., 2004; Kidd, et al., 2005; Pesti, 2009; Corzo, et al., 2010), and therefore can greatly impact company profit margins. Specifically, dietary protein level provided over the first wk post-hatch of broilers can majorly impact bird performance, due to having effects that carry over until processing age (Kidd, et al., 1998; Kidd and Fancher, 2001; Labadan, et al., 2001; Sterling, et al., 2003; Garcia and Batal, 2005; Sterling, et al., 2005; Garcia, et al., 2006; Plumstead, et al., 2007;

Dozier and Payne, 2012). Furthermore, it has been shown that the dietary amino acid level needed to maximize performance is not necessarily the same that will yield higher net returns (Dozier, et al., 2006a; Dozier, et al., 2006b; Pesti and Vedenov, 2011; Aftab, 2012; Trevisan, et al., 2014; Basurco, et al., 2015).

Taking into account all the factors described previously, the objectives of the present experiment were to evaluate the economic returns of rearing broilers sex separate or straight-run, and determine the net return maximum level (NRML) of digestible lysine for the starter phase, when using a modern broiler strain under both rearing systems.

MATERIAL AND METHODS

There were 18 experimental treatments that consisted of a factorial combination of three broiler rearing types with six dietary protein levels.

Sex separate vs. Straight-run treatments

A total of 3,240 d-old sexed Ross 708 chicks were placed and raised in 90 pens, according to one of the three following treatments: male, female, and straight-run. At placing, for the male and female treatments, 36 chicks of the respective sex treatment were randomly selected, weighed, and identified with a neck tag; for the straight-run treatment, 18 males and 18 females were used instead. From this point forward, the treatments will be called a rearing system.

Dietary treatments

The diets fed in the present experiment were corn-soybean meal-based with two dietary phases used: starter – 0 to 25 d (experimental phase), and grower – 15 to 32 d (common diet).

The starter diets were fed as a crumble-based diet and the grower diets were fed as pellets. There were six dietary starter treatments based on digestible lysine inclusion level with the ideal amino acid ratios maintained (Table 1). The dietary digestible lysine levels were obtained by formulating a base (1.05% dLys) and summit (1.80% dLys) diets, which were posteriorly blended in different proportions, resulting in six digestible lysine treatments (1.05, 1.20, 1.35, 1.50, 1.65, and 1.85 % of dLys). The calculated digestible amino acid values used were based on Ajinomoto Heartland LLC. (2004).

Birds and Husbandry

All practices regarding animal management were approved by the Institutional Animal Care and Use Committee of the University of Georgia. The experiment was performed in a window-less room with 48 pens that were 1.22 x 1.52 m in dimension. Each pen had one hanging tubular feeder with 170 cm of feeder space (4.7 cm/bird), 10 nipple drinkers, and the floor was covered with 0.05 m of used pine shavings as litter. For the first three days of brooding, one cardboard tray with feed was placed in each pen to ease the access to feed by the chickens. Both water and feed were consumed *ad libitum*. Temperature, ventilation, and lighting programs were checked twice a day and followed commercial practices. Chicks where housed at 34°C and then the temperature was gradually reduced 3°C every wk until the temperature reached 20°C. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing 24 h of light at 30 lux for the first 7 d, 16 h of light at 3.5 lux with 8 h of dark from 7 to 28 d of age, and 20 h of light at 3.5 lux with 6 h of dark from 28 d until the end of the trial.

Performance data

Group BW per pen were evaluated at hatch, 13, 25, and 32 d of age. Additionally, feed consumption was recorded to calculate feed intake and FCR. Mortality was checked twice a d and BW was recorded to calculate adjFCR.

Processing data

At 14, 26, and 33 d, the four birds that had the lowest numbered neck tags were selected for processing. In the straight-run pens, two birds of each sex were selected also based on the lowest neck tag number. Birds were withdrawn from feed for eight hours over night. Birds were individually weighed prior to processing, immediately following evisceration (pre-chill/hot carcass weight) and after chilling (cold carcass weight without giblets (WOG)). Paws were taken and weighed prior to hot carcass weighing. Carcasses were chilled in water and ice at 1°C for 240 min. Subsequently, carcasses were deboned and the *pectoralis major, pectoralis minor*, wings, and legs were weighed for carcass yield. For the 14 d cut-ups, wings were not deboned and were considered part of the shell weight.

Data Analysis

The economic feasibility of the rearing system and NRML determination was based on an input (feed) output (meat) base under different scenarios of feed and meat prices. The economic simulations were performed for a market BW of 1,600 g to be sold as a whole carcass, while considering a broiler complex producing 1,800,000 birds with an allocation of 900,000 birds of each gender for the sex separate rearing (Table III. 2.2). An estimate of feed intake for the target market BW for each rearing system was determined using response surface analysis.

Feed intake data for each gender across the experiment were fitted considering bird BW and digestible lysine level as the predictor variables:

$$Feed\ intake = intercept + \beta 1 \times BW + \beta 2 \times dLys + \beta 3 \times BW^2 + \beta 4 \times dLys^2 + \beta 5 \times BW \ \times dLys$$

Subsequently, using the same methodology, whole carcass weight was expressed in a function of BW and digestible lysine to estimate carcass WOG weight for each market BW:

$$Carcass\ WOG = intercept + \beta 1 \times BW + \beta 2 \times dLys + \beta 3 \times BW^2 + \beta 4 \times dLys^2 + \beta 5 \times BW \ \times dLys$$

Isoquants for the market BW were set for each rearing system using the response surface equations; combinations of feed intake with digestible lysine and BW with digestible lysine were obtained to determine feed intake and whole carcass weight.

There were nine price scenarios formulated, considering a combination of three feed prices (low – 80% of medium, medium, and high 120% of medium) with three meat prices (low – 80% of medium, medium, and high 120% of medium). The cut-up parts were based on the Urner Barry weekly insider's poultry report from May 26th 2016. Net returns were calculated based on the return from meat selling over feed cost with an associated fixed cost of \$0.009/bird when chicks were sex separated. All the previous data were analyzed and modeled using JMP Pro 12 (SAS Inst. Inc., Cary, NC) software.

RESULTS AND DISCUSSION

Bird performance data regarding the responses of each rearing system to the graded levels of digestible lysine were not evaluated herein and were presented elsewhere. The estimates and respective predictive models for bird individual feed intake needed to reach the 1,600 g market BW according to the graded levels of digestible lysine and are presented on the Table III – 2.3. Overall, males needed less feed to reach 1,600 g, followed by straight-run, and then female birds. This is consistent with the Groen, et al. (1998) findings where the cost of producing 1 kg carcass was compared, and it was observed that males had a lower cost on feed ($1.269) than females ($1.370). Digestible lysine quadratically affected females (*P*=0.002) and males (*P*=0.032) and tended (*P*=0.108) to quadratically affect straight-run birds. The lack of significant (*P*>0.05) effect for the straight-run broilers is clearly a result of increased intra and inter-pen variation when both sexes are present. The isoquants set to 1,600 g of live BW (Figure III – 2.1) revealed that feed intake was minimized at 1.465, 1.230, and 1.386 % of digestible lysine for female, male, and straight-run birds respectively.

The estimated whole carcass WOG weights for the 1,600 g market BW are presented in Table III – 2.4. Digestible lysine only quadratically affected females (*P*=0.025), whereas males and straight-run birds that were sampled did not have carcass weight that was significantly affected by the amino acid inclusion. Nevertheless, the isoquants for the 1,600 g BW revealed that carcass WOG weight was maximized at 1.498, and 1.416 % of digestible lysine for female and straight-run birds respectively. On the contrary, males had carcass minimized at 1.235 % of digestible lysine with carcass weight increasing as digestible lysine increased after this point. The gross returns per bird raised on the different rearing system clearly portrayed the effects of digestible lysine on carcass yield (Table III – 2.5). However, even though bird gain was maximized at relatively high digestible lysine levels, the NRMLs showed that low levels of digestible lysine might be more economically feasible when targeting light market weight. At medium feed and meat prices, the economic simulations determined that males and straight-run birds had NRML at the lowest level of digestible lysine (net returns = $2.2402, and $2.2140 for male and straight-run birds respectively), whereas females had NRML at 1.07 % of digestible lysine (net returns = $2.1913). The discrepancy between the optimum levels of digestible lysine for gross or net returns is mainly related with the effects of digestible lysine on feed intake and feed price. The lowest feeding costs for the three rearing systems were observed at the lowest levels of digestible lysine. All these findings indicate, that even though feeding higher levels of digestible lysine might yield more carcass weight, the feeding costs are the driving force to maximize the net returns. Consequently, feeding low levels of digestible lysine, which correspond to the lower feeding costs, show to be a more economically beneficial scenario. This driving force of feeding cost is especially relevant for males and straight-run birds, where regardless of feed and meat prices the net-returns are always higher at the lowest digestible lysine level (Table III – 2.6). Similar conclusions were drawn by Eits, et al. (2005), where as the price of protein-rich raw material increased, the dietary balanced protein of the diet decreased for maximum gross margin. On the contrary, as meat prices increased or feed prices decreased, the NRMLs increased. At the most unfavorable markets (low meat with high feed prices), the NRML was estimated at 1.05% of digestible lysine, whereas when the markets were favorable (high meat and low feed prices) the NRML increased to 1.15% of digestible lysine. The economic effects of feeding various amino acid densities (low, moderate, and high) and energy levels (low, moderate, and high) for a light market weight has been evaluated by Basurco, et al. (2015). For Cobb 500 females targeted to small whole carcass markets (1.0 kg eviscerated carcass) under high and low feed/meat price scenarios, these authors concluded that for low market BW, the fixed costs (farm and processing) play a major role in the returns because the differences on performance induced by changing dietary factors (variable cost) are so diminished and have little to no impact on the economic returns. Nevertheless, high energy density combined with either moderate or high amino acid density resulted in higher gross margins (Basurco, et al., 2015), which was not coherent with the results presented herein.

When evaluating the economic feasibility of sex separation after sexing cost and when feeding the same levels of digestible lysine to all the rearing systems (Table III – 2.5), it was observed that up to 1.30 % of digestible lysine, sex separation resulted in economic losses that ranged from -$13,177 to -$422. The economic advantages of sex separation were the highest ($7,609) when 1.64 % of digestible lysine was fed. Nevertheless, the objective of this experiment was to evaluate the economic feasibility of sex separation when feeding dietary digestible lysine at NRML for each rearing system. Under the nine feed and meat price scenarios, it was observed that sex separation only resulted in a marginal returns advantage when meat prices were low and/or feed prices were high (Table III – 2.6). Nevertheless, when the fixed cost of sexing ($0.009/bird) was subtracted from the returns, it showed that sex separation could result in economic losses. Sex separation only revealed an insignificant advantage ($396) to the straight-run birds, when low meat prices and high feed prices were present. Overall, straight-run birds resulted in extra returns that ranged from $6,089 to $24,502.

Overall, it was concluded that for light market BW (1,600 g) sex separation rearing is not economically favorable. However, it should be considered that economic savings at the processing plant related with increase bird uniformity when broilers are raised sex separated, was not considered here. In addition, NRML of digestible lysine were significantly lower than the levels that maximized BW gain. Therefore, feeding low levels of digestible lysine should be considered when marketing broilers to be sold as a whole carcass at light weights.

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Table III – 2.1 Ingredient composition (%) and formulated nutrient contents of the starter diets with differing levels of digestible lysine and grower diet

Diet blend	Low	80%Low 20%High	60%Low 40%High	40%Low 60%High	20%Low 80%High	High	Grower
% dLys	1.05	1.20	1.35	1.50	1.65	1.80	1.02
Price ($)	274.39	295.23	316.06	336.90	357.73	378.57	268.02
Corn	62.39	57.55	52.70	47.85	43.02	38.18	62.97
Soybean Meal, 48%	25.97	29.91	33.85	37.78	41.72	45.66	20.63
Distillers dried grains/solubles	4.00	4.00	4.00	4.00	4.00	4.00	6.00
Poultry by-product meal	3.00	3.00	3.00	3.00	3.00	3.00	6.34
DL-Methionine	0.22	0.30	0.39	0.47	0.55	0.63	0.24
L-Lysine-HCl, 78%	0.18	0.25	0.33	0.40	0.48	0.55	0.20
L-Threonine, 98.5%	0.07	0.12	0.17	0.23	0.28	0.33	0.06
Poultry Fat	1.52	2.25	2.97	3.70	4.42	5.15	2.00
Limestone	0.54	0.53	0.53	0.53	0.52	0.52	0.34
Defluorinated phosphate, 18%	1.28	1.26	1.23	1.21	1.18	1.15	0.39
Salt (NaCl)	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin Premix[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix[2]	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Nicarbazin[3]	0.04	0.04	0.04	0.04	0.04	0.04	0.04
BMD[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated nutrient composition							
ME, kcal/g	3,050	3,050	3,050	3,050	3,050	3,050	3,120
CP, %	20.09	21.72	23.35	24.97	26.60	28.22	20.01
Calcium, %	0.96	0.96	0.96	0.96	0.96	0.96	0.87
Total phosphorus, %	0.72	0.73	0.74	0.74	0.75	0.75	0.69
Available phosphorus, %	0.48	0.48	0.48	0.48	0.48	0.48	0.44
Potassium, %	0.75	0.81	0.88	0.94	1.01	1.07	0.66
Chloride, %	0.34	0.35	0.37	0.38	0.39	0.41	0.36
Sodium, %	0.27	0.27	0.27	0.27	0.27	0.27	0.25
dArg, %	1.17	1.27	1.38	1.49	1.60	1.70	1.12
dIle, %	0.73	0.79	0.85	0.91	0.97	1.04	0.70
dLeu, %	1.57	1.65	1.74	1.82	1.90	1.98	1.57
dLys, %	1.05	1.20	1.35	1.50	1.65	1.80	1.02
dMet, %	0.51	0.60	0.70	0.80	0.90	0.99	0.53
dTSAA, %	0.78	0.89	1.00	1.11	1.22	1.34	0.80
dThr, %	0.71	0.81	0.91	1.01	1.11	1.21	0.68
dTrp, %	0.20	0.21	0.23	0.25	0.27	0.29	0.18
dVal, %	0.82	0.88	0.94	1.00	1.06	1.12	0.82

[1] Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B12 (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[2] Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO4.H2O), 101 mg; iron (FeSO4.7H2O), 20 mg; zinc (Zn)), 80 mg; copper (CuSO4.5H2O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

[3] Nicarb® 25% (Nicarbazine – Type A) – 100 ppm of nicarbazin provided in the final feed

[4] BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin

Table III – 2.2 Simulation of a production scenario in a 1,800,000 broiler complex when using a sex separate *vs.* straight-run regime

Production strategy 1,800,000 birds complex			
Rearing system		Market BW	Cost of sexing ($/bird)
		1,600	
Sex separated	Female	900,000	0.009
	Male	900,000	
Sex comingled	Straight-run	1,800,000	0

Table III – 2.3 Predictive models and estimated feed intake (FI) based on dietary digestible lysine (dLys) and BW of Ross 708 raised straight-run or sex separate at 1,600 g live BW market weight

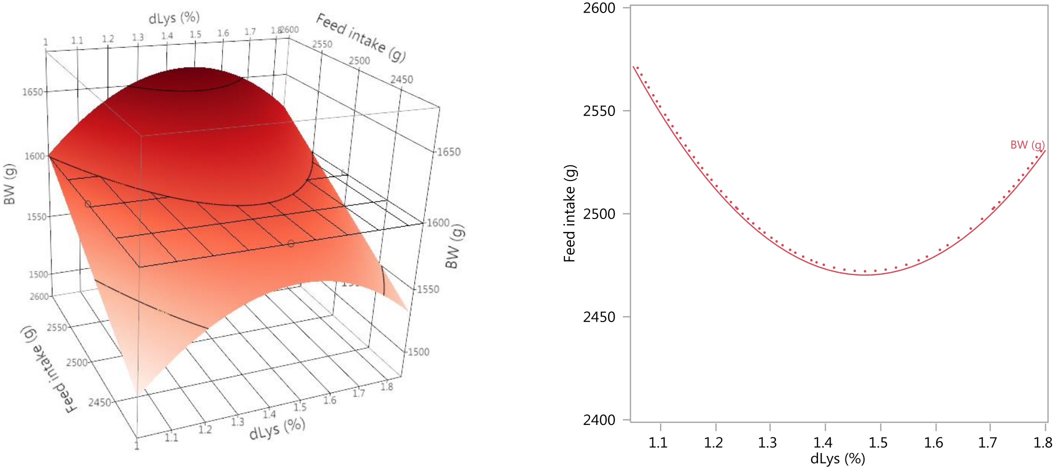
Rearing system	R^2	Equation
Female	0.99	$FI = -259.7706-33.64899\times dLys+1.7029511\times BW+498.4923\times(dLys-1.42416)^2-0.011858\times(dLys-1.42416)\times(BW-971.005)+0.0001907\times(BW-971.005)^2$
Male	0.99	$FI = -409.1536+99.865683\times dLys+1.6596829\times BW+431.80511\times(dLys-1.42584)^2+0.1182909\times(dLys-1.42584)\times(BW-1011.32)+0.0001183\times(BW-1011.32)^2$
Straight-run	0.98	$FI = -315.8605+15.488426\times dLys+1.733304\times BW+432.21854\times(dLys-1.425)^2+0.0310015\times(dLys-1.425)\times(BW-1005.44)+0.0001356\times(BW-1005.44)^2$

Source of variation	*P*-value		
	Female	Male	Straight-run
dLys	0.312	0.024	0.789
BW	<0.001	<0.001	<0.001
dLys*dLys	0.002	0.032	0.108
dLys*BW	0.855	0.129	0.768
BW*BW	<0.001	0.015	0.050

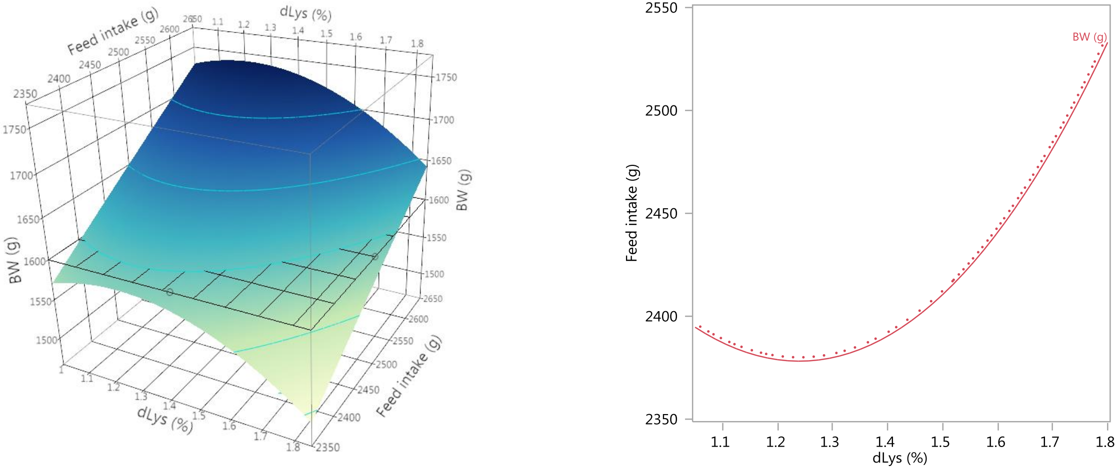
Digestible Lysine (%)	Market BW (1,600 g)		
	Female	Male	Straight-run
	Estimated feed intake (g)		
1.05	2,578	2,427	2,575
1.08	2,566	2,423	2,567
1.11	2,555	2,419	2,560
1.14	2,544	2,417	2,553
1.17	2,535	2,415	2,547
1.20	2,527	2,413	2,542
1.23	2,519	2,413	2,537
1.26	2,513	2,413	2,534
1.29	2,507	2,415	2,531
1.32	2,502	2,417	2,529
1.35	2,498	2,419	2,527
1.38	2,495	2,423	2,527
1.41	2,493	2,427	2,527
1.44	2,492	2,432	2,528
1.47	2,492	2,438	2,530
1.50	2,492	2,445	2,532
1.53	2,494	2,452	2,536
1.56	2,496	2,460	2,540
1.59	2,499	2,469	2,545
1.62	2,504	2,479	2,550
1.65	2,509	2,489	2,557
1.68	2,515	2,501	2,564
1.71	2,521	2,513	2,572
1.74	2,529	2,526	2,581
1.77	2,538	2,539	2,591
1.80	2,547	2,554	2,601

Figure III – 2.1 Response surface graph and respective response contour plot to evaluate feed intake needed when varying levels of digestible lysine for an isoquant set to the target market BW of 1,600 g for Ross 708 female, male, and straight-run birds

Female



Male



Straight-run

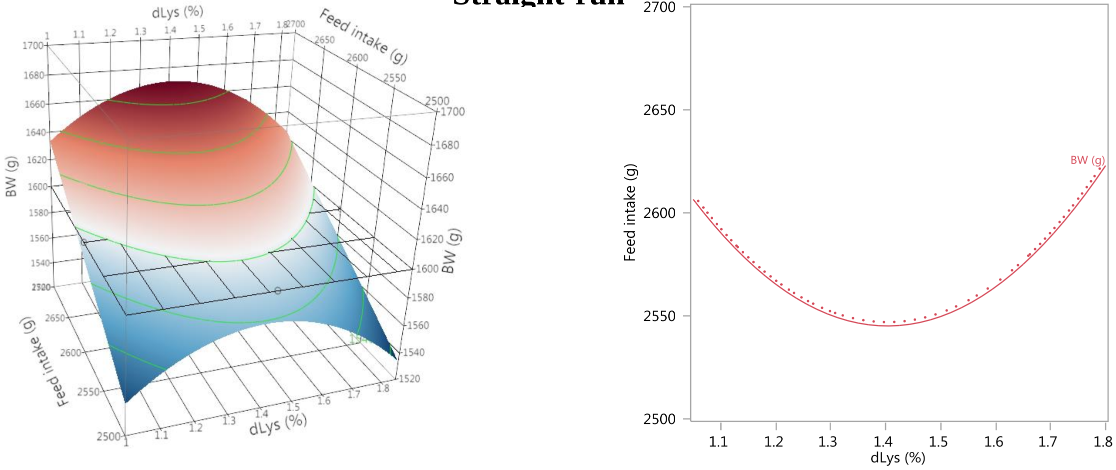


Table III – 2.4 Predictive models and estimated whole carcass (WOG – without giblets), outputs based on dietary digestible lysine (dLys) and BW of Ross 708 broilers raised straight-run or sex separate at 1,600 g BW market

		Whole carcass WOG
Rearing system	R^2	Equation
Female	0.99	$Y = 1.3191068+2.8284612\times dLys+0.8397822\times BW-51.27238\times(dLys-1.42931)^2+0.0059127\times(dLys-1.42931)\times(BW-877.502)-0.0000008507\times(BW-877.502)^2$
Male	0.99	$Y = -19.00262+7.6824546\times dLys+0.8436927\times BW+26.600616\times(dLys-1.4267)^2+0.0035818\times(dLys-1.4267)\times(BW-900.18)+0.0000015427\times(BW-900.18)^2$
Straight-run	0.99	$Y = 4.6863421-4.246648\times dLys+0.8426955\times BW-3.622556\times(dLys-1.42584)^2+0.0059124\times(dLys-1.42584)\times(BW-893.431)+0.0000048259\times(BW-893.431)^2$

Source of variation	*P*-value		
	Female	Male	Straight-run
dLys	0.558	0.184	0.372
BW	<0.001	<0.001	<0.001
dLys*dLys	0.025	0.310	0.870
dLys*BW	0.582	0.766	0.572
BW*BW	0.919	0.849	0.510

Digestible Lysine (%)	Market BW (g) 1,600		
	Female	Male	Straight-run
	Estimated carcass weight (g)		
1.05	1,338.50	1,342.56	1,348.87
1.08	1,339.83	1,342.29	1,348.94
1.11	1,341.07	1,342.06	1,349.01
1.14	1,342.22	1,341.89	1,349.08
1.17	1,343.28	1,341.76	1,349.13
1.20	1,344.25	1,341.68	1,349.18
1.23	1,345.12	1,341.65	1,349.23
1.26	1,345.90	1,341.66	1,349.27
1.29	1,346.59	1,341.73	1,349.30
1.32	1,347.18	1,341.84	1,349.32
1.35	1,347.68	1,342.00	1,349.34
1.38	1,348.09	1,342.20	1,349.35
1.41	1,348.41	1,342.46	1,349.35
1.44	1,348.64	1,342.76	1,349.35
1.47	1,348.77	1,343.11	1,349.34
1.50	1,348.82	1,343.51	1,349.33
1.53	1,348.76	1,343.96	1,349.31
1.56	1,348.62	1,344.45	1,349.28
1.59	1,348.39	1,345.00	1,349.24
1.62	1,348.06	1,345.59	1,349.20
1.65	1,347.64	1,346.22	1,349.16
1.68	1,347.13	1,346.91	1,349.10
1.71	1,346.52	1,347.64	1,349.04
1.74	1,345.83	1,348.43	1,348.97
1.77	1,345.04	1,349.25	1,348.90
1.80	1,344.16	1,350.13	1,348.82

Table III – 2.5 Estimate of dietary digestible lysine (dLys) NRML[1] from selling whole chicken carcasses (WOG) at 1,600 g market at medium feed and meat prices

dLys	Feeding cost ($/bird)			Gross return ($/bird)			Net return ($/bird)			Returns Complex ($)		Returns from
(%)	Female	Male	Straight-run	Female	Male	Straight-run	Female	Male	Straight-run	Sex separate	Straight-run	sex separation
1.05	0.7000	0.6597	0.6996	2.8912	2.8999	2.9136	2.1912	2.2402	2.2140	3,972,021	3,985,199	-13,177
1.06	0.7009	0.6614	0.7008	2.8921	2.8997	2.9136	2.1913	2.2383	2.2128	3,970,455	3,983,020	-12,565
1.07	0.7018	0.6630	0.7021	2.8931	2.8995	2.9137	2.1913	2.2365	2.2115	3,968,831	3,980,790	-11,959
1.08	0.7027	0.6647	0.7034	2.8940	2.8993	2.9137	2.1913	2.2346	2.2103	3,967,150	3,978,508	-11,358
1.09	0.7037	0.6664	0.7048	2.8950	2.8992	2.9138	2.1912	2.2328	2.2090	3,965,412	3,976,176	-10,764
1.10	0.7047	0.6681	0.7062	2.8958	2.8990	2.9138	2.1911	2.2309	2.2077	3,963,618	3,973,793	-10,176
1.11	0.7057	0.6699	0.7076	2.8967	2.8989	2.9139	2.1910	2.2290	2.2063	3,961,766	3,971,360	-9,594
1.12	0.7068	0.6717	0.7090	2.8976	2.8987	2.9139	2.1908	2.2271	2.2049	3,959,858	3,968,877	-9,019
1.13	0.7079	0.6735	0.7104	2.8984	2.8986	2.9140	2.1905	2.2251	2.2035	3,957,892	3,966,343	-8,451
1.14	0.7090	0.6753	0.7119	2.8992	2.8985	2.9140	2.1902	2.2232	2.2021	3,955,871	3,963,761	-7,890
1.15	0.7101	0.6772	0.7134	2.9000	2.8984	2.9140	2.1899	2.2212	2.2006	3,953,792	3,961,128	-7,336
1.16	0.7113	0.6790	0.7150	2.9007	2.8983	2.9141	2.1895	2.2192	2.1991	3,951,658	3,958,447	-6,789
1.17	0.7124	0.6809	0.7165	2.9015	2.8982	2.9141	2.1890	2.2173	2.1976	3,949,467	3,955,717	-6,250
1.18	0.7137	0.6829	0.7181	2.9022	2.8981	2.9142	2.1885	2.2153	2.1961	3,947,219	3,952,938	-5,718
1.19	0.7149	0.6848	0.7197	2.9029	2.8981	2.9142	2.1880	2.2132	2.1945	3,944,916	3,950,110	-5,194
1.20	0.7162	0.6868	0.7213	2.9036	2.8980	2.9142	2.1874	2.2112	2.1929	3,942,556	3,947,235	-4,679
1.21	0.7175	0.6888	0.7230	2.9042	2.8980	2.9143	2.1868	2.2092	2.1913	3,940,141	3,944,312	-4,171
1.22	0.7188	0.6909	0.7247	2.9048	2.8980	2.9143	2.1861	2.2071	2.1896	3,937,669	3,941,341	-3,671
1.23	0.7201	0.6929	0.7264	2.9055	2.8980	2.9143	2.1853	2.2051	2.1880	3,935,142	3,938,323	-3,181
1.24	0.7215	0.6950	0.7281	2.9060	2.8980	2.9144	2.1845	2.2030	2.1863	3,932,559	3,935,257	-2,698
1.25	0.7229	0.6971	0.7299	2.9066	2.8980	2.9144	2.1837	2.2009	2.1845	3,929,920	3,932,145	-2,225
1.26	0.7243	0.6992	0.7316	2.9071	2.8980	2.9144	2.1828	2.1988	2.1828	3,927,226	3,928,986	-1,760
1.27	0.7258	0.7014	0.7334	2.9077	2.8980	2.9144	2.1819	2.1967	2.1810	3,924,476	3,925,781	-1,305
1.28	0.7273	0.7035	0.7353	2.9082	2.8981	2.9145	2.1809	2.1945	2.1792	3,921,671	3,922,530	-859
1.29	0.7288	0.7057	0.7371	2.9086	2.8981	2.9145	2.1798	2.1924	2.1774	3,918,811	3,919,233	-422
1.30	0.7303	0.7080	0.7390	2.9091	2.8982	2.9145	2.1788	2.1902	2.1755	3,915,895	3,915,890	5
1.31	0.7319	0.7102	0.7409	2.9095	2.8983	2.9145	2.1776	2.1881	2.1736	3,912,924	3,912,502	422
1.32	0.7335	0.7125	0.7428	2.9099	2.8984	2.9145	2.1764	2.1859	2.1717	3,909,898	3,909,069	829
1.33	0.7351	0.7148	0.7448	2.9103	2.8985	2.9145	2.1752	2.1837	2.1698	3,906,817	3,905,591	1,226
1.34	0.7367	0.7171	0.7467	2.9107	2.8986	2.9146	2.1739	2.1815	2.1678	3,903,681	3,902,068	1,613
1.35	0.7384	0.7194	0.7487	2.9110	2.8987	2.9146	2.1726	2.1793	2.1658	3,900,491	3,898,501	1,990
1.36	0.7401	0.7218	0.7508	2.9113	2.8989	2.9146	2.1712	2.1771	2.1638	3,897,245	3,894,890	2,355
1.37	0.7418	0.7242	0.7528	2.9116	2.8990	2.9146	2.1698	2.1748	2.1618	3,893,945	3,891,235	2,710
1.38	0.7436	0.7266	0.7549	2.9119	2.8992	2.9146	2.1683	2.1726	2.1597	3,890,591	3,887,537	3,054
1.39	0.7454	0.7290	0.7569	2.9121	2.8993	2.9146	2.1667	2.1703	2.1577	3,887,182	3,883,795	3,387
1.40	0.7472	0.7314	0.7590	2.9124	2.8995	2.9146	2.1652	2.1681	2.1556	3,883,719	3,880,010	3,709
1.41	0.7490	0.7339	0.7612	2.9126	2.8997	2.9146	2.1635	2.1658	2.1534	3,880,201	3,876,182	4,019
1.42	0.7509	0.7364	0.7633	2.9128	2.8999	2.9146	2.1619	2.1635	2.1513	3,876,629	3,872,312	4,318
1.43	0.7528	0.7389	0.7655	2.9129	2.9001	2.9146	2.1601	2.1612	2.1491	3,873,003	3,868,399	4,604
1.44	0.7547	0.7415	0.7677	2.9131	2.9004	2.9146	2.1583	2.1589	2.1469	3,869,324	3,864,444	4,879
1.45	0.7567	0.7440	0.7699	2.9132	2.9006	2.9146	2.1565	2.1566	2.1447	3,865,590	3,860,448	5,142
1.46	0.7586	0.7466	0.7721	2.9133	2.9009	2.9146	2.1546	2.1543	2.1424	3,861,802	3,856,410	5,392
1.47	0.7607	0.7492	0.7744	2.9134	2.9011	2.9146	2.1527	2.1519	2.1402	3,857,960	3,852,330	5,630
1.48	0.7627	0.7518	0.7767	2.9134	2.9014	2.9146	2.1507	2.1496	2.1379	3,854,065	3,848,210	5,855
1.49	0.7647	0.7545	0.7790	2.9134	2.9017	2.9146	2.1487	2.1472	2.1356	3,850,116	3,844,049	6,068
1.50	0.7668	0.7571	0.7813	2.9134	2.9020	2.9145	2.1466	2.1449	2.1332	3,846,114	3,839,847	6,267
1.51	0.7689	0.7598	0.7836	2.9134	2.9023	2.9145	2.1445	2.1425	2.1309	3,842,058	3,835,605	6,454
1.52	0.7711	0.7625	0.7860	2.9134	2.9026	2.9145	2.1423	2.1401	2.1285	3,837,949	3,831,322	6,627
1.53	0.7733	0.7653	0.7884	2.9133	2.9029	2.9145	2.1401	2.1377	2.1261	3,833,787	3,827,000	6,787
1.54	0.7755	0.7680	0.7908	2.9133	2.9033	2.9145	2.1378	2.1353	2.1237	3,829,572	3,822,639	6,933
1.55	0.7777	0.7708	0.7932	2.9131	2.9037	2.9145	2.1355	2.1329	2.1212	3,825,303	3,818,238	7,065
1.56	0.7799	0.7736	0.7957	2.9130	2.9040	2.9144	2.1331	2.1305	2.1188	3,820,981	3,813,798	7,184
1.57	0.7822	0.7764	0.7981	2.9129	2.9044	2.9144	2.1306	2.1280	2.1163	3,816,607	3,809,319	7,288
1.58	0.7845	0.7792	0.8006	2.9127	2.9048	2.9144	2.1282	2.1256	2.1138	3,812,180	3,804,802	7,378
1.59	0.7869	0.7820	0.8031	2.9125	2.9052	2.9144	2.1256	2.1231	2.1112	3,807,700	3,800,246	7,454
1.60	0.7892	0.7849	0.8056	2.9123	2.9056	2.9143	2.1231	2.1207	2.1087	3,803,167	3,795,652	7,515
1.61	0.7916	0.7878	0.8082	2.9121	2.9060	2.9143	2.1204	2.1182	2.1061	3,798,582	3,791,021	7,561
1.62	0.7941	0.7907	0.8108	2.9118	2.9065	2.9143	2.1177	2.1158	2.1035	3,793,944	3,786,352	7,592
1.63	0.7965	0.7936	0.8133	2.9115	2.9069	2.9142	2.1150	2.1133	2.1009	3,789,254	3,781,645	7,609
1.64	0.7990	0.7966	0.8159	2.9112	2.9074	2.9142	2.1122	2.1108	2.0983	3,784,512	3,776,902	7,609
1.65	0.8015	0.7995	0.8186	2.9109	2.9078	2.9142	2.1094	2.1083	2.0956	3,779,717	3,772,122	7,595
1.66	0.8040	0.8025	0.8212	2.9106	2.9083	2.9141	2.1065	2.1058	2.0929	3,774,870	3,767,305	7,565
1.67	0.8066	0.8055	0.8238	2.9102	2.9088	2.9141	2.1036	2.1033	2.0903	3,769,971	3,762,452	7,519
1.68	0.8092	0.8086	0.8265	2.9098	2.9093	2.9141	2.1006	2.1008	2.0875	3,765,021	3,757,563	7,457
1.69	0.8118	0.8116	0.8292	2.9094	2.9098	2.9140	2.0976	2.0982	2.0848	3,760,018	3,752,639	7,379
1.70	0.8145	0.8147	0.8319	2.9089	2.9104	2.9140	2.0945	2.0957	2.0820	3,754,963	3,747,678	7,285
1.71	0.8172	0.8177	0.8347	2.9085	2.9109	2.9139	2.0913	2.0932	2.0793	3,749,857	3,742,683	7,174
1.72	0.8199	0.8208	0.8374	2.9080	2.9115	2.9139	2.0881	2.0906	2.0765	3,744,699	3,737,652	7,047
1.73	0.8226	0.8239	0.8402	2.9075	2.9120	2.9138	2.0849	2.0881	2.0737	3,739,490	3,732,587	6,903
1.74	0.8254	0.8271	0.8430	2.9070	2.9126	2.9138	2.0816	2.0855	2.0708	3,734,229	3,727,487	6,742
1.75	0.8282	0.8302	0.8458	2.9064	2.9132	2.9137	2.0783	2.0830	2.0680	3,728,917	3,722,353	6,564
1.76	0.8310	0.8334	0.8486	2.9059	2.9138	2.9137	2.0749	2.0804	2.0651	3,723,554	3,717,185	6,369
1.77	0.8338	0.8366	0.8514	2.9053	2.9144	2.9136	2.0715	2.0778	2.0622	3,718,139	3,711,983	6,156
1.78	0.8367	0.8398	0.8543	2.9047	2.9150	2.9136	2.0680	2.0752	2.0593	3,712,674	3,706,747	5,926
1.79	0.8396	0.8430	0.8571	2.9040	2.9156	2.9135	2.0644	2.0726	2.0564	3,707,157	3,701,479	5,678
1.80	0.8425	0.8462	0.8600	2.9034	2.9163	2.9135	2.0608	2.0700	2.0534	3,701,589	3,696,177	5,412

Table III – 2.6 Estimates of dietary digestible lysine (dLys) NRML^1 from selling chicken as whole carcass (1,600 market BW) on a production scenario of a 1,800,000 Ross 708 broiler complex when using a sex separate *vs.* straight-run under combinations of various feed and meat prices^2

Final net returns for a complex (1,800,000 birds) producing birds at two target live BW raised sex separate or sex comingled

Meat Price	Feed Price	NRML			Final net returns for the 1,800,000 broiler complex		Returns from sex separation ($) at NRML for the complex	
		Female	Male	Straight-run	Sex separate	Sex comingled	Before sexing cost	After sexing cost
Low	Low	1.07	1.05	1.05	3,174,472	3,188,159	2,513	-13,687
	Medium	1.05	1.05	1.05	2,929,626	2,936,319	9,507	-6,693
	High	1.05	1.05	1.05	2,684,875	2,684,479	16,596	396
Medium	Low	1.12	1.05	1.05	4,217,645	4,237,038	-3,193	-19,393
	Medium	1.07	1.05	1.05	3,972,140	3,985,199	3,142	-13,058
	High	1.05	1.05	1.05	3,727,270	3,733,359	10,111	-6,089
High	Low	1.15	1.05	1.05	5,261,416	5,285,918	-8,302	-24,502
	Medium	1.11	1.05	1.05	5,015,248	5,034,078	-2,630	-18,830
	High	1.07	1.05	1.05	4,769,808	4,782,238	3,770	-12,430

CHAPTER 4

Evaluation of Grower Dietary Digestible Lysine Level on Broilers Raised Under a Sex Separated or Straight-Run Housing Regime

Part 1: Live Production and Carcass Yield Parameters[1]

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[1] M.J. Da Costa[1], T.J. Frost[2], J. Halley[3], G.M. Pesti[1]
[1]University of Georgia, Athens, GA 30606
[2]Wayne Farms LLC, 4110 Continental Drive, Oakwood, Georgia 30566
[3]Aviagen Inc., 5015 Bradford Drive, Huntsville, AL 35805
To be submitted to Poultry Science

ABSTRACT

The objective of this experiment was to model the responses to dietary digestible lysine (dLys) levels (maintaining the ideal amino acid ratio) in grower diets when raising broilers sex separate or straight-run. 2,160 Ross 708 chicks were separated by sex and placed in 90 pens by two rearing types: sex separate (24 males or 24 females) or straight-run (12 males and 12 females). All birds were fed a common starter diet with 1.32% of dLys for up to 14d. Afterwards, each rearing type was fed six grower diets formulated to have dLys levels between 0.90 to 1.30% in 0.08% increments until 32d of age. A common finisher with 0.88% of dLys was fed from 32 to 42d. Body weight gain (BWG), feed intake (FI), and adjusted feed conversion (adjFCR) were assessed at 14, 32, and 42d. Additionally at 33d and 43d, four birds per pen were sampled for carcass yield evaluation. Data were analyzed using a factorial arrangement of treatments and non-linear regression, where linear and quadratic effects of dLys were fitted. At 32d, males were the heaviest followed by straight-run and then females. There was a quadratic effect of dLys with BWG being maximized at 1.147, 1.205, and 1.147% for males, straight-run, and females respectively. For the grower phase, males, straight-run, and females adjFCR were minimized at dLys levels of 1.222, 1.159, and 1.109% respectively. At 42d, males were the heaviest, followed by the straight-run group and then females. At this age, BWG was maximized at 1.122, 1.233, and 1.180% dLys for males, straight-run, and females respectively. Straight-run birds tend to have higher FI and adjFCR than sex separate birds throughout the experiment. *Pectoralis major* weight and yield increased linearly as dLys increased at both processing times. There was also evidence that straight-run birds result in lower total breast meat when compared to sex separate birds. In conclusion, straight-run birds needed higher levels of dLys and FI for gain than sex separate birds.

Keywords: sex separate, straight-run, lysine, protein, grower

INTRODUCTION

Rearing broilers sex separate is a common practice worldwide. Notwithstanding, in the U.S.A. straight-run flocks are still the most prevalent. The disadvantages of changing to sex separate rearing is one of the main dilemmas throughout the years of the American poultry industry. Broiler sex separation can bring several benefits, such as improved growth rate, better feed efficiency (due to a more appropriate allocation of the diet that each gender needs), and reduced bird size variability in the final product facilitating processing. Previous research is rather ambiguous, with reports providing evidences for both the advantages and disadvantages of sex separation. On one hand, there are multiple studies that show no benefits of sex separation (Smith, et al., 1954; Hess, et al., 1960; Lang, et al., 1960; Lamoreux and Proudfoot, 1969). However, none of these analysis were done using modern broiler strains and for a heavier market BW. Nonetheless, it is also described in the literature that sex separation can result in improvement of performance and flock uniformity (Becker and Berg, 1959; Deaton, et al., 1973; Gehle, et al., 1974; Laseinde and Oluyemi, 1994; de Albuquerque, et al., 2006; Api, 2014). The sexual dimorphism in broilers starts during egg incubation while chicks are still embryos (Burke and Sharp, 1989; Henry and Burke, 1998). The differences between genders subsist throughout the birds' life, resulting in different growth rates, feed intake, and feed efficiency (Gous, et al., 1999; May and Lott, 2001). In addition, differences in social behavior (fighting, pecking, threatening, and submissive responses) between chicks of different sex can result in increased social stress and changes in feeding behavior (Guhl, 1958).

The differences in growth rate when broilers are raised sex-separated creates the possibility to explore different nutritional plans, and to consider gender specific dietary protein levels since this nutrient has a great role on broiler performance and carcass yield (Bartov and Plavnik, 1998; Corzo, et al., 2004; Kidd, et al., 2004; Kidd, et al., 2005; Pesti, 2009; Corzo, et al., 2010). Therefore there is a need to study optimum levels of amino acid nutrition for each gender. Nowadays, diets are formulated on a digestible amino acid level base, having lysine as a reference with the other amino acids expressed in a ratio to lysine. It is well known that lysine impacts the bird's performance and carcass characteristics, with genders revealing different dietary optimum levels (Sterling, et al., 2003; Kidd, et al., 2004; Corzo, et al., 2005; Sterling, et al., 2005; Plumstead, et al., 2007). However, a great part of these studies were done by increasing only lysine levels and not keeping the amino acid ratio. This approach can result in a limited response since there is a chance that other dispensable or indispensable amino acid became limited, and consequently protein synthesis stopped. The increase in crude protein, by keeping the amino acid ratio to lysine, will generally guarantee the presence of enough dispensable amino acids, while consequently reducing the needs of synthesizing them by usage of indispensable amino acids (Almquist, 1957).

Taking into consideration the limited information on potential advantages of raising broilers sex separate when using modern genetic strains in addition to the possible differences that genders might have on lysine when keeping the amino acid ratio, the objective of this experiment was to evaluate the effects on performance and carcass characteristics of graded lysine levels while maintaining the ideal amino acid ratio during the grower phase for broilers raised sex separate *vs.* straight-run.

MATERIAL AND METHODS

There were 18 experimental treatments that consisted of a factorial combination of three broiler rearing types with six dietary protein (digestible lysine) levels.

Sex Separate vs. Straight-Run Treatments

A total of 2,160 day old sexed Ross 708 chicks were placed and raised in 90 pens according to one of the three following treatments: male, female, and straight-run. At placing for the male and female treatments, 24 chicks of the respective sex treatment were randomly selected, weighed, and identified with a neck tag; for the straight-run treatment, 12 males and 12 females were used. From this point forward, this treatment will be called as a rearing system.

Dietary Treatments

The diets fed in the current experiment were corn-soybean meal-based with three dietary phases used: starter – 0 to 14 d (common diet phase), grower – 14 to 32 d (experimental diet), and finisher – 32 to 42 d (common diet phase). The starter diets were fed as crumble, and the grower and finisher diets were fed as pellets. There were six dietary grower treatments based on digestible lysine inclusion level with the ideal amino acid ratios maintained (Table IV – 1.1). The dietary digestible lysine levels were obtained by formulating a base (0.90% dLys) and summit (1.30% dLys) diets, which were posteriorly blended in different proportions, resulting in six digestible lysine treatments (0.90, 0.98, 1.06, 1.14, 1.22, and 1.30 % of dLys). The calculated digestible amino acid values used were based on Ajinomoto Heartland LLC. (2004) values.

Birds and Husbandry

All practices regarding animal management were approved by the Institutional Animal Care and Use Committee of the University of Georgia. The experiment was performed in a window-less room with 48 pens of 1.22 x 1.52 m dimensions. Each pen had one hanging tubular feeder with 170 cm of feeder space (7.1 cm/bird), 10 nipple drinkers, and the floor was covered with 0.05 m of used pine shavings litter. For the first three days of brooding, one cardboard tray with feed was placed in each pen to ease the access of feed to the chickens. Both water and feed were consumed *ad libitum*. Temperature, ventilation, and lighting programs were checked twice a day and followed commercial practices. Chicks were housed at 34°C and then the temperature was gradually reduced 3°C every wk until it reached 20°C. Lighting came from 27 Paragon EC40005 incandescent light fixtures providing 24 h of light at 30 lux for the first 7 d, 16 h of light at 3.5 lux with 8 h of dark from 7 to 28 d of age, and 20 h of light at 3.5 lux with 6 h of dark from 28 d until the end of the trial.

Performance Data

Group BW were evaluated at hatch, 14, 32, and 42d of age for each pen. Additionally, feed consumption was recorded to calculate feed intake and FCR. Mortality was checked twice a d, and BW was recorded to calculate adjFCR.

Processing Data

At 33 and 43d, the four birds that had the lowest numbered neck tag were selected for processing. In the straight-run pens, two birds of each sex were also selected based on the lowest neck tag number. Birds were withdrawn from feed for eight hours over-night. Birds were individually weighed prior to processing, immediately following evisceration (pre-chill/hot carcass weight) and after chilling (cold carcass weight). Paws were taken and weighed prior to hot carcass weighing. Carcasses were chilled in water and iced at 1°C for 240 min. Subsequently, carcasses were deboned and the *pectoralis major, pectoralis minor*, wings, and legs were weighed for carcass yield.

Data Analysis

Data were analyzed as a completely randomized design in a 3x6 factorial arrangement of treatments. Before analysis, percentage data had to be transformed to arcsine in order to obtain normality. For these data, the true means are presented with the *P*-values coming from the analysis of the transformed data. The factorial analysis was first run considering the arrangement of the three rearing treatments with the six digestible lysine levels. Then, an analysis of gender within each rearing treatment, male and female reared sex separate *vs.* straight-run, was considered as the first factor, which was then crossed with the digestible lysine levels. Interactions and main effects were evaluated, and when the rearing system was significant at $P \leq 0.05$, means were separated using orthogonal contrasts. Afterwards, all the response data for each gender were fitted using six models (quadratic, logistic 3 parameters, logistic 4 parameters, Gompertz, mechanistic growth, and Michaelis Menten), using the digestible lysine levels as the independent variable. The models were ranked using the Akaike information criterion, and the model with the lowest value was chosen as the one that better described the data (data not shown). This analysis revealed that the model that fit the data set the best was the second order polynomial. Therefore, regression reports with linear and quadratic effects, maximum/minimum responses, and digestible lysine levels at which maximum/minimum response was observed

(TRML – technical response maximum level) for each rearing system are presented. All the previous data were analyzed and modeled using JMP Pro 11 (SAS Inst. Inc., Cary, NC) software.

RESULTS

Performance

No significant ($P>0.05$) effects of treatments were observed on any performance parameter at 14d. The BW and BW gain (BWG) results are presented in Table IV – 1.2. A main effect ($P<0.001$) for rearing was present for both BW and BWG at 32 and 42d of age. At both ages, males were the heaviest, followed by straight-run birds, and then females. When evaluating the growth of each gender within each rearing system (Table IV – 1.3 and 1.4), it was evident ($P<0.005$) that each gender benefited differently from sex separation at 32d. At this age, straight-run males were heavier than sex separated males (1870 g *vs*. 1825 g), whereas straight-run females were lighter than sex-separated females (1712 *vs.* 1667). No significant ($P>0.05$) differences were observed at 42d when comparing the gain of genders within the rearing system. A main effect ($P<0.001$) of digestible lysine level was apparent at 32 and 42d, with no interactions within the rearing system observed ($P>0.05$). The effects of digestible lysine levels on each rearing system are depicted through the second order polynomial models present on the Table IV – 1.5 and 1.6. At 32d, male and female had BWG maximized (1820 g and 1707 g respectively) at similar digestible lysine levels (males = 1.147 % dLys; females = 1.145 % % dLys). On the contrary, straight-run rearing system birds revealed higher TRML (1.205 % dLys) for a BWG of 1797 g. Looking at each gender within the straight-run pens, both males and females revealed higher TRML than the sex separated birds (males = 1.186 % dLys; females = 1.183 % of dLys). The TRMLs for the grower phase (14 to 32d) were similar to the ones observed at 32d, with the exception of females revealing slightly higher TRMLs than males (1.147 % dLys *vs.* 1.139 % dLys). TRMLs at 42d revealed the same trends as in the grower period, with females having a scarcely higher TRML than males (1.180 % dLys *vs.* 1.122 % dLys). At this age, it was also evident that each gender within straight-run pens needed extra lysine for maximum gain. This was especially evident for females, where a linear response to digestible lysine was attained against a quadratic response observed in sex separate females.

Feed intake and adjFCR results are presented on Table IV – 1.7. As in the growth data, a main effect of the rearing system was observed on feed intake at 32 and 42d. At 32d and for the grower phase (14 to 32 d), male and straight-run rearing systems had higher feed intake in comparison with females. At 42d, straight-run birds had an intermediate and statistically similar feed intake (5003 g) when compared with females (4865 g) and males (5080 g). The adjFCR was also significantly different at 32 and 42d of age. At 32d and for the grower phase, both females and straight-run rearing systems resulted in the higher adjFCRs. However, at 42d the female rearing system had the highest adjFCR statistically different, with males having the lower adjFCR. No effects (*P*>0.05) of digestible lysine or treatment interactions were observed on FI throughout the experiment. On the contrary, digestible lysine levels did have a significant effect on adjFCR throughout the experiment. The regression reports for the grower phase, showed that males needed higher TRML (1.222 % dLys) for adjFCR when compared with females (1.109 % dLys) and straight-run (1.159 % dLys) birds. It was interesting to observe that for the 32 and 42d period, females did not benefit from graded levels of lysine for adjFCR, whereas males decreased linearly for adjFCR as digestible lysine levels increased. For feed intake, the grower phase regression reports show that male and female feed intake is affected distinctly by digestible lysine accretion. As digestible lysine increased, females had an increased feed intake, whereas males had a feed intake reduction with digestible lysine increments. The straight-run rearing system also showed an increase of feed intake with the increase of lysine.

Figures IV – 1.1, 1.2, and 1.3 represent the BWG quadratic response ($P<0.001$) according to digestible lysine intake for each rearing system for the periods of 0 to 32, 14 to 32, and 0 to 42d respectively. Overall, straight-run birds need higher lysine intake for a maximum response when compared to males and females that were sex separated. From 0 to 32d, straight-run birds presented the highest (34.24 g) digestible lysine intake needed to maximize gain (1784 g). For the same period, males needed a digestible lysine intake of 33.10 g to attain maximum BW gain of 1818 g, and females needed 33.87 g for a maximum gain of 1715 g. For the grower phase, females, males, and straight-run birds showed a necessary digestible lysine intake of 27.25, 27.3, and 30.70 g, respectively, for BW maximization (BW gain max: females = 1347 g; males = 1470 g; straight-run = 1448 g). At 42d, the digestible lysine intake for maximum gain was 53.61, 52.43, and 54.86 for females, males, and straight-run birds respectively (BW gain max: females = 1347 g; males = 1470 g; straight-run = 1448 g).

Processing

The bird BW and cold carcass yield for the birds sampled during processing are presented in Table IV – 1.9. The live BW and cold carcass weight results shown, are affected by the main concerns of the rearing system and digestible lysine levels for the two different processing ages. For both ages, males were the heaviest, followed by straight-run birds, and then female birds. Cold carcass percentages were also shown to be affected by the rearing system. At 33d, females (77.95 %) and straight-run birds (77.49 %) had the higher carcass yield in contrast with males (76.34 %). However, at a later processing age (43d), females (79.30) resulted in the highest carcass yields when compared to both males (78.75 %) and straight-run (78.82 %) birds. For the cut-up weights, the *pectoralis major* weight was statistically different between the three rearing system for both processing ages (Table IV – 1.10). At 33d, males (338 g) resulted in heavier *pectoralis major*, followed by straight-run birds (325 g), and then by females (317 g). At 43d, both female (564 g) and straight-run (581 g) birds had the lowest weights of *pectoralis major*, and males had the highest (625 g). The *Pectoralis major* percentage was not affected (P>0.05) by the rearing system. Digestible lysine impacted both *pectoralis major* weight and percentage at 33 and 43d, with no treatment interactions present. Contrarily to *pectoralis major* results, both *pectoralis minor* weight and percentage were affected by the rearing system at 33 and 43d respectively (Table IV – 1.10). At 33d, females and straight-run birds resulted in the lowest *pectoralis minor* weight (69 g) in comparison to males (72 g). However at this age, females presented the higher yields (5.48 %), followed by males (5.33 %), and then straight-run (5.31 %) birds. At 43d, males (123 g) had the heaviest *pectoralis minor* weight, followed by straight-run (120 g) birds, and finally the females (117 g). The percentage for *pectoralis minor* was the highest in females (5.71 %), followed by straight-run birds (5.66 %), and then the males (5.36 %). Regarding the effects of digestible lysine on the *pectoralis minor*, it was shown that this factor only affected muscle weight both at 33 and at 43d of age. The rearing system also affected leg weight and percentage at both processing ages. Males had the higher leg weights and percentages, followed by straight-run birds, and then female birds for both ages (Table IV – 1.11). Wing weight was affected by the rearing system at both ages. At 33d, males (138 g) and straight-run birds (135 g) had the heaviest wings in contrast to the females (129 g). At 43d, similar results were observed, with males presenting higher weights (222 g), followed by straight-run birds (207 g), and then females (196 g). Wing percentage was not affected by the rearing system. Digestible lysine level affected leg and wing weight at both of the processing ages. Paw weights were also affected by a main effect of rearing system and digestible lysine levels at 33 and 43d (Table IV – 1.11). Overall, males had higher paws weights, followed by straight-run birds, and then females.

The regression equations for cold carcass parameters are presented in Table IV – 1.12. At 33d, male and female carcass weights were affected quadratically by digestible lysine, with TRMLS of 1.147 and 1.105 dLys respectively. Birds coming from straight-run pens responded linearly to digestible lysine level increments. The regression analysis at 43d revealed that the female cold carcass weights were not affected by digestible lysine after the finisher phase, whereas males had a TRML of 1.147 % of digestible lysine, and the straight-run birds increased carcass weight linearly as digestible lysine increased. *Pectoralis major* regression reports showed that overall *pectoralis major* weight and percentage increased linearly as digestible lysine increased. At 33d, per 0.1% increase in digestible lysine, males had the higher *pectoralis major* weight gain (8.802 g), followed by females (7.287 g), and lastly by straight-run birds (7.069 g). Similar effects were observed at 43d, with male, female, and straight-run birds increasing 14.173, 13.056, and 11.640 g of *pectoralis major* gain per 0.1% of digestible lysine increase. As every increase of 0.1 % of digestible lysine , *pectoralis major* percentage was increased the most in males (0.489 %), followed by females (0.400 %), and then by straight-run birds (0.335 %) at 33d of age. It was interesting to observe that the digestible lysine levels did not affect the straight- run birds *pectoralis major* percentages after the finisher phase (43d). Both the female and male rearing systems responded linearly to digestible lysine at this age. The *pectoralis minor* results at 33d revealed a quadratic response by the females to digestible lysine with a TRML of 1.150 % dLys. On the other hand, both male and straight-run birds increased muscle weight linearly by 1.252 g and 1.952 g respectively, as digestible lysine increased by 0.1 %. At 43d, both females and males *pectoralis minor* responded quadratically to digestible lysine, with TRMLs of 1.127 and 1.125 % of dLys respectively. Conversely, straight-run birds' *pectoralis minor* weight increased linearly by 4.130 g to each 0.1 % digestible lysine increase. No effects of digestible lysine were observed on *pectoralis minor* percentage. At the end of the grower phase (33d), wing weights were affected quadratically by digestible lysine for the three rearing systems. Females (1.060 % dLys) had the lowest TMRL, followed by males (1.145 % dLys), and then straight-run birds (1.180 % dLys). However, after the finisher phase (43d), neither female nor male were affected by digestible lysine levels, whereas the straight-run birds' wing weight increased linearly as digestible lysine increased. Wing percentages were decreased linearly as digestible lysine increased at 33d in females, and 33 and 43d in straight-run birds. Leg weight showed to be affected quadratically at 33 and 43d for both male and females. Females had higher TRML at 33d (1.134 *vs.* 1.115 % dLys), per contrast this rearing system showed lower TRML than males at 43d (1.119 *vs.* 1.166 % dLys). Regression equations revealed no effects of digestible lysine on paw weights.

DISCUSSION

The absence of significant treatment effects at 14d showed that broilers raised sex separate or straight-run, do not differ in performance during the early stages. On the other hand, the growth data at 32 and 42d clearly reflected the differences between genders and rearing systems. It was evident and consistent with the literature reports that males had the highest production rate, followed by straight-run birds, and then females (Smith, et al., 1954; Hess, et al., 1960; Brake, et al., 1993; Gous, et al., 1999; May and Lott, 2001; Aggrey, 2002; de

Albuquerque, et al., 2006; Aggrey, 2009; Shim, et al., 2012; Api, 2014; Zuidhof, et al., 2014). It was interesting to observe that sex separation impacted growth of each gender differently at 32d. Comparing straight-run and sex separate females showed that comingle females with males can result in impaired growth for the females. Conversely, males benefited by being reared with females, resulting in heavier birds at 32d. It has been shown that when establishing social order, males tend to express a higher percentage of aggressive behavior, resulting in females being exposed to increased social stress, with little opportunity to feed in comparison with the males (Guhl, 1958). Therefore, it is possible that the differences in gain observed herein are related with males out-competing females when it comes to access to the feeder, due to a significant difference in body size. Nevertheless, it was curious to observe that this effect was not detected at 42d. One possible explanation for the loss of effect at later stages, is that the plateau on the daily gain of each gender allowed the birds that were initially growing slower to eventually meet similar weight gains.

The results of feed intake and adjFCR followed the same trend as the gain data; however, there were some indications of birds that were raised in a straight-run rearing system to be less efficient than sex separate birds at 32d. When comparing feed intake results with the BWG data, it is apparent that even though BWG of straight-run birds was statistically intermediate between males and females, the same pattern was not indicated for the feed intake. Straight-run birds had the highest feed intake (statistically the same as males), which was not followed with a higher BWG. The adjFCR results at 32d also have the same pattern as feed intake, where rather than having intermediate adjFCR values in comparison with males and females, the straight-run birds presented the highest values. Still, the results at 42d suggest that the lower feed efficiency presented by the straight-run birds might have been recovered at later stages. It should be pointed out that bird density was determined on a projection of 38 kg/m^2 (approximately 0.09 m^2/bird) of live weight for males at 42d (Estevez, 2007) with a feeder space above the genetic line recommendations (70 birds per a 38.5 cm diameter feeder). Considering that male and females grow at different rates, each rearing system pen ended up with different bird stocking density, which might have impacted the final results. Notwithstanding, both feed intake and adjFCR values are highly correlated with body size, so an interpretation of these parameters *per se* might be misleading. An approach where the output (BW gain) is expressed in function of input (feed intake) for a determine bird size, would allow a more fair comparison and answer the final question: what is the real net gain to feed intake of birds raised sex separate *vs.* straight-run?

The response of growth to digestible lysine was proven to be better described by a second order polynomial model, rather than models that describe a plateau in the response. This revealed that the higher levels of digestible lysine impaired bird performance. To the authors' knowledge, effects on performance of levels as high as 1.30 % of digestible lysine when maintaining the amino acid ratio for a phase similar to the one evaluated herein (14 to 32d of age) has not been reported. When diets are formulated using a constant amino acid ratio to lysine, as digestible lysine levels increase the crude protein content will also increase. The effects of increasing crude protein levels of iso-caloric diets usually lead to improved feed efficiency, increased carcass yield, and decreased fat content (Bartov and Plavnik, 1998; Corzo, et al., 2004; Kidd, et al., 2004; Kidd, et al., 2005; Pesti, 2009; Corzo, et al., 2010). However, the increase in dietary lysine or crude protein levels does not yield a linear response. This is because an excess of amino acids means the birds will have to metabolize the excess, resulting in decreased utilization and efficiency (D'Mello, 1994). Evaluation of optimal digestible lysine levels can be done through two experimental approaches by maintaining or not maintaining the amino acid ratio to lysine, with both approaches having pros and cons. When the amino acid ratio is not maintained, digestible lysine is increased by adding extra lysine in the synthetic form to a basal diet. This approach allows isolation of the specific amino acid role on bird performance. However, the response might be limited since there is a chance that lysine reaches the TRML due to another amino acid turning into the limiting amino acid, which has been shown in several experiments (Morris, et al., 1987; Abebe and Morris, 1990; Hurwitz, et al., 1998; Sklan and Noy, 2003; Sterling, et al., 2003; Sterling, et al., 2005; Plumstead, et al., 2007). Therefore, increasing digestible lysine *per se* does not guarantee the presence of enough indispensable and dispensable amino acids, which might lead to a usage of indispensable amino acids for synthesis of the dispensable ones (Almquist, 1957). The second approach, where the amino acid ratio is maintained, has the limitation of the response observed being related with the increase of crude protein rather than the isolated amino acid. This methodology was the one used in the present experiment; therefore, the responses to digestible lysine should be interpreted as a response to crude protein instead.

The regression reports at 32d estimated a similar TRML of digestible lysine needed for BWG for both males (1.147 % dLys) and females (1.145 % dLys), whereas straight-run birds had a slightly higher estimate (1.205 % dLys). However, when determining TRML for adjFCR during the grower phase, it was evident that males (1.222 % dLys) needed higher levels than straight-run birds (1.159 % dLys), and females (1.109 % dLys). Garcia, et al. (2006) evaluated the effect of digestible lysine level from 0.73 to 1.13 % for the period between 21 and 38d of age for both males and females Cobb 500. Contrarily to what was observed herein, males were shown to have a higher requirement of digestible lysine than females for maximum growth (0.97% vs. 0.93% dLys), whereas no differences on TRML were detected for FCR (0.96 %

dLys). Han and Baker (1994) also determined that from 22 to 43d of age, Ross x Ross males had a higher requirement of lysine in comparison with females. The authors reported that BW was maximized when males and females were fed 0.85% and 0.78% of digestible lysine respectively. In addition, digestible lysine levels that optimized feed efficiency were 0.89% and 0.85% for males and females. When evaluating levels of digestible lysine for males that were Ross x Ross TP16 and Cobb x Cobb 700, Dozier, et al. (2010) determined higher requirements for the Ross birds in comparison with Cobb from 28 to 42d. BW gain, and feed conversion ratio were optimized at 0.988, and 1.053 % of digestible lysine respectively for the Ross birds, whereas the Cobb 700 broilers had the parameters optimized at 0.965 and 1.012 of digestible lysine. Overall, it is evident that TRMLs reported in the literature for the same growing period were lower than the ones estimated herein. This is probably related with the fact that most of the literature reported above had estimated lysine requirements not maintaining the amino acid ratio. Therefore, it is possible for the TRML value to be under-estimated due to a shortage on other amino acids, not allowing a maximum response. In addition, different genetics can result in the differences of the TRML determined. Regarding birds reared straight-run, Dimova (2012) estimated an optimum digestible lysine level for BWG and FCR of 0.96, and 0.99 % respectively for the period between 35 to 48d when using Cobb 500 FF female x Hubbard M99 male cross chicks. In another experiment, the same author reported digestible lysine TRML for BWG and FCR of 0.86 and 0.91 % for males of Cobb 500 x Cobb FF. Even though the genetics were different between experiments, these results suggest that birds raised straight-run have a higher TRML in comparison with sex separate birds. Looking at TRMLs estimated for the 42d data for BWG, it was observed that females and straight-run birds had slightly higher values when compared with the values at 32d. On the other hand, males showed that slightly lower levels than the one estimated at 32d improved gain at 42 d. The interaction of early lysine on nutrition and performance during posterior phases was studied previously (Kidd, et al., 1998; Kidd and Fancher, 2001), and overall results showed that lower lysine levels early on in life can result in impaired performance at market age. Therefore it is possible that for the female and straight-run birds, the lower TRMLs determined at 32d could have been enough to sustain performance at 32d, however, not high enough to result in improved performance at 42d. In the present experiment, digestible lysine did not impact consistent feed intake, which is in agreement with the literature. In the same paper, Plumstead, et al. (2007) observed that CP could or could not affect the feed intake of the birds. In one experiment where effects of metabolizable energy, digestible lysine, and amino acid balance (CP from 21.9, 23.5, 25.2, and 26.9%) were evaluated on bird performance up to 21d of age, the authors reported no effect of CP on feed intake. Conversely, in a second experiment where diets with two levels of protein (22.0 vs. 27.0 % CP), combined with increased levels of digestible lysine while maintaining or not maintaining the ratio to other essential amino acids were evaluated, Plumstead, et al. (2007) observed that feeding low CP diets with low digestible lysine can significantly reduce BWG and feed intake of the chicks. Similarly, when evaluating the effects of feeding diets with 16.2 to 28.0 % of CP during the first 7d of life, Sklan and Noy (2003) observed that feed intake increased linearly at 7d, with carryover effects on feed intake at 40d of age. Sterling, et al. (2005), also observed increased feed intake as CP of the diet increased (17, 20, 23, and 26 % of CP). However, in a previous study, the same authors (Sterling, et al., 2003) did not observe any difference on feed intake when feeding three levels of CP (17, 20, and 23 %). Also, Bartov and Plavnik (1998), reporting that CP levels slightly below the requirement can result in increased feed intake. As it is perceived, the effects of CP and digestible lysine on feed intake are not consistent among the literature. It has to be considered, though, that BW gain, feed intake, and feed efficiency are in relation with each other, which might make some results difficult to interpret. The TRMLs for BWG are generally described in the literature to be lower than the TRMLs for adjFCR (Garcia and Batal, 2005; Abudabos and Aljumaah, 2010; Mehri, et al., 2010; Dozier and Payne, 2012). The same was observed herein for the pens that had the sex separated males and females, however, straight-run birds were shown to have higher TRMLs for maximum BWG than for optimum adjFCR.

For the processing data, the breast meat results revealed that straight-run birds might have lower total meat output than sex separate birds. At 43d, males produced the most weight of *pectoralis major*, whereas females and straight-run birds produced the same amount statistically. The same effect was detected on *pectoralis minor* at 33d of age. Considering that straight-run pens are comprised of half males and half females, it would be logical for the output to be intermediate to both genders, rather than be the same as the one observed in females. In opposite to most of the responses obtained on performance, *pectoralis major* weight and yield have shown to be affected linearly rather than quadratically. Overall, increasing digestible lysine levels resulted in more muscle accretion. Males were the rearing system that benefitted the most from increasing digestible lysine, followed by females. Considering that straight-run pens should be an average of female and male pens, it was interesting to observe that birds in this rearing system were the ones that benefitted the less from increasing digestible lysine. *Pectoralis minor* also showed to be affected by digestible lysine and tended to increase linearly with digestible lysine. Despite this tendency, females seemed to have *pectoralis minor* maximized at levels between 1.150 and 1.27 of digestible lysine. Looking to the literature, it is apparent that the levels described to maximize breast meat yield to be close to the values that maximize weight gain or lay in between the values that optimize gain and feed efficiency, which is not consistent to what was observed here. In one hand, Dozier, et al. (2010) estimated 0.962 % of digestible lysine to be the value that maximizes breast weight which was lower than the TRML for weight gain (0.988 % dLys). On the other hand, the same author reported a TRML of 0.981 % of digestible lysine for breast meat weight maximization for Cobb 700; this TRML was higher than the TRML for maximum weight gain (0.965 % dLys). Similarly, Dimova (2012) observed that, for straight-run birds, the TRML of digestible lysine for white meat weight to be lower than the TRML for BWG (0.95 % *vs.* 0.96 % dLys), whereas for male birds the opposite happened (0.90 *vs.* 0.86 % dLys). Regarding the optimum level for each gender, Garcia, et al. (2006) observed that males had higher TRML for breast meat yield than females (0.98 *vs.* 0.90 % dLys).

In conclusion, the results revealed that sex separate rearing can result in birds to be more feed efficient with a higher output of breast meat yield when compared with straight-run birds. In addition, it was patented that straight-run birds might benefit from higher TRMLs of digestible lysine when compared with birds raised sex separate.

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Table IV – 1.1. Ingredient composition (%) and formulated nutrient contents of the starter, grower with differing levels of digestible lysine and finisher diets

Diet blend	Starter	Low	80%Low 20%High	60%Low 40%High	40%Low 60%High	20%Low 80%High	High	Finisher
% dLys	1.32	0.90	0.98	1.06	1.14	1.22	1.30	1.05
Corn	47.90	61.58	58.68	55.78	52.88	49.98	47.08	64.72
Soybean Meal, 48%	36.14	24.22	26.63	29.04	31.46	33.87	36.28	19.15
Distillers dried grains/solubles	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Poultry by-product meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	5.00
DL-Methionine	0.34	0.15	0.16	0.18	0.19	0.20	0.22	0.16
L-Lysine-HCl, 78%	0.21	0.03	0.06	0.09	0.12	0.16	0.19	0.11
L-Threonine, 98.5%	0.09	0.00	0.02	0.04	0.06	0.07	0.09	0.01
Poultry Fat	3.77	2.64	3.08	3.53	3.97	4.42	4.86	3.25
Limestone	0.55	0.53	0.53	0.53	0.52	0.52	0.52	0.38
Defluorinated phosphate, 18%	1.18	1.01	1.00	0.98	0.97	0.95	0.93	0.42
Salt (NaCl)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin Premix[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix[2]	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Nicarbazin[3]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	-
Salinomycin[4]	-	-	-	-	-	-	-	0.04
BMD[5]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Virginiamycin[6]	-	-	-	-	-	-	-	0.03
Calculated nutrient composition								
ME, kcal/g	3,050	3,110	3,110	3,110	3,110	3,110	3,110	3,200
CP, %	24.37	19.50	20.45	21.41	22.37	23.32	24.28	18.54
Calcium, %	0.96	0.87	0.87	0.87	0.87	0.87	0.87	0.78
Total phosphorus, %	0.74	0.68	0.68	0.68	0.69	0.69	0.70	0.63
Available phosphorus, %	0.48	0.44	0.44	0.44	0.44	0.44	0.44	0.39
Potassium, %	0.92	0.72	0.76	0.80	0.84	0.88	0.92	0.64
Chloride, %	0.35	0.31	0.32	0.32	0.33	0.33	0.34	0.33
Sodium, %	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.25
Choline, mg/kg	1.84	1.60	1.65	1.70	1.74	1.79	1.84	1.60
dArg, %	1.45	1.13	1.19	1.26	1.32	1.39	1.46	1.04
dIle, %	0.90	0.71	0.75	0.78	0.82	0.86	0.90	0.65
dLeu, %	1.82	1.56	1.61	1.66	1.72	1.77	1.82	1.50
dLys, %	1.32	0.90	0.98	1.06	1.14	1.22	1.30	0.88
dMet, %	0.67	0.43	0.45	0.48	0.50	0.52	0.55	0.43
dTSAA, %	0.98	0.70	0.73	0.76	0.80	0.83	0.86	0.69
dThr, %	0.86	0.62	0.67	0.72	0.77	0.82	0.87	0.59
dTrp, %	0.25	0.19	0.20	0.21	0.22	0.24	0.25	0.17
dVal, %	0.99	0.80	0.84	0.88	0.92	0.95	0.99	0.76

[1] Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B12 (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[2] Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO4.H2O), 101 mg; iron (FeSO4.7H2O), 20 mg; zinc (Zn)), 80 mg; copper (CuSO4.5H2O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

[3] Nicarb® 25% (Nicarbazine – Type A) – 100 ppm of nicarbazin provided in the final feed

[4] Bio-Cox® 60 (Salynomycin – Type A) – provided 50 g of salinomycin per ton of the final diet

[5] BMD (Bacitracin Methylene Disalicylate – Type A) – provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

[6] Stafac® 50 (Virginiamycin – Type A) – provided 50 g of virginiamycin per ton of the final diet

Table IV – 1.2. Effect of rearing system and grower phase digestible lysine level on BW and BW gain of Ross 708 chicks

Rearing system	Lysine level (%)	BW (g)			BW gain (g)			
		14	32	42	0 to 14	0 to 32	0 to 42	14 to 32
Female		391 ± 2	1706 ± 17^{c}	2663 ± 16^{c}	350 ± 2	1665 ± 17^{c}	2622 ± 16^{c}	1315 ± 16^{c}
Male		392 ± 4	1835 ± 17^{a}	3020 ± 20^{a}	350 ± 4	1793 ± 17^{a}	2978 ± 20^{a}	1443 ± 15^{a}
Straight-run		393 ± 2	1771 ± 20^{b}	2869 ± 17^{b}	352 ± 2	1730 ± 20^{b}	2828 ± 17^{b}	1379 ± 19^{b}
Female	0.90	397 ± 6	1654± 37	2636 ± 37	355 ± 5	1612 ± 36	2594 ± 37	1257 ± 32
	0.98	386 ± 3	1647± 18	2635 ± 33	345 ± 4	1606 ± 19	2594 ± 33	1261 ± 17
	1.06	385 ± 5	1725± 37	2630 ± 54	344 ± 5	1684 ± 37	2590 ± 53	1340 ± 33
	1.14	393 ± 8	1764± 45	2711 ± 43	352 ± 8	1723 ± 45	2670 ± 43	1371 ± 41
	1.22	391 ± 7	1741± 61	2680 ± 37	349 ± 7	1700 ± 61	2638 ± 37	1351 ± 59
	1.30	394 ± 7	1706± 15	2685 ± 20	354 ± 8	1665 ± 15	2645 ± 20	1311 ± 10
Male	0.90	380 ± 8	1746± 27	2915 ± 44	339 ± 8	1705 ± 27	2874 ± 44	1366 ± 22
	0.98	402 ± 8	1829± 50	3099 ± 46	360 ± 8	1788 ± 49	3057 ± 46	1427 ± 47
	1.06	389 ± 7	1848± 17	3025 ± 44	347 ± 7	1806 ± 17	2983 ± 44	1459 ± 16
	1.14	404 ± 10	1867± 43	3075 ± 54	363 ± 10	1826 ± 43	3034 ± 54	1463 ± 40
	1.22	389 ± 14	1883± 63	3014 ± 43	348 ± 13	1842 ± 63	2973 ± 43	1495 ± 49
	1.30	387 ± 8	1834± 17	2991 ± 33	346 ± 8	1793 ± 17	2950 ± 33	1447 ± 17
Straight-run	0.90	386 ± 3	1614± 63	2747 ± 24	345 ± 2	1573 ± 63	2706 ± 24	1228 ± 62
	0.98	397 ± 6	1764± 29	2832 ± 29	356 ± 6	1723 ± 29	2791 ± 29	1368 ± 23
	1.06	392 ± 2	1789± 36	2859 ± 22	350 ± 2	1748 ± 36	2818 ± 22	1398 ± 34
	1.14	398 ± 6	1841± 38	2958 ± 50	358 ± 5	1800 ± 38	2918 ± 50	1442 ± 35
	1.22	390 ± 11	1800± 32	2911 ± 34	349 ± 11	1759 ± 31	2870 ± 35	1409 ± 38
	1.30	393 ± 5	1820± 25	2905 ± 28	353 ± 6	1779 ± 25	2864 ± 28	1427 ± 22
Source of variation				------------------------- *P*–values -------------------------				
Rearing System		0.843	<0.001	<0.001	0.827	<0.001	<0.001	<0.001
Lysine level		0.155	<0.001	<0.001	0.129	<0.001	<0.001	<0.001
Rearing system x Lysine level		0.304	0.712	0.229	0.324	0.708	0.231	0.7328

[a,b,c] Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table IV – 1.3. Effect of rearing system and grower phase digestible lysine level on BW and BW gain of male Ross 708 chicks

Rearing system	Lysine level (%)	BW (g)			BW gain (g)			
		14	32	42	0 to 14	0 to 32	0 to 42	14 to 32
Male		392 ± 4	1825 ± 14^{b}	3020 ± 20	350 ± 4	1784 ± 14^{b}	2978 ± 20	1435 ± 13
Straight-run male		396 ± 4	1870 ± 20^{a}	3032 ± 24	354 ± 4	1829 ± 20^{a}	2991 ± 24	1474 ± 19
Male	0.90	380 ± 8	1746 ± 27	2909 ± 44	339 ± 8	1705 ± 27	2868 ± 53	1366 ± 22
	0.98	401 ± 8	1829 ± 50	3093 ± 46	360 ± 8	1788 ± 49	3051 ± 46	1428 ± 47
	1.06	389 ± 7	1848 ± 17	3030 ± 44	347 ± 7	1806 ± 17	2989 ± 44	1459 ± 16
	1.14	403 ± 10	1867 ± 43	3069 ± 54	362 ± 10	1826 ± 43	3028 ± 54	1463 ± 40
	1.22	389 ± 14	1828 ± 11	3020 ± 43	348 ± 13	1787 ± 11	2979 ± 43	1449 ± 7
	1.30	388 ± 8	1834 ± 17	2997 ± 33	346 ± 8	1793 ± 17	2955 ± 33	1447 ± 17
Straight-run male	0.90	387 ± 7	1731 ± 20	2855 ± 56	346 ± 7	1690 ± 19	2813 ± 56	1341 ± 21
	0.98	401 ± 8	1869 ± 62	3053 ± 45	360 ± 8	1828 ± 62	3012 ± 45	1468 ± 57
	1.06	406 ± 9	1882 ± 38	3023 ± 43	364 ± 9	1840 ± 38	2981 ± 43	1477 ± 31
	1.14	397 ± 7	1926 ± 60	3097 ± 67	356 ± 7	1885 ± 60	3056 ± 67	1529 ± 55
	1.22	388 ± 16	1879 ± 38	3081 ± 49	346 ± 16	1837 ± 37	3040 ± 50	1491 ± 36
	1.30	395 ± 6	1934 ± 35	3086 ± 30	354 ± 7	1893 ± 35	3045 ± 30	1539 ± 34
Source of variation				------------------------- *P*–values -------------------------				
Rearing System		0.370	0.049	0.571	0.361	0.048	0.575	0.071
Lysine level		0.128	0.004	<0.001	0.137	0.004	<0.001	0.005
Rearing system x Lysine level		0.721	0.800	0.375	0.703	0.791	0.410	0.695

^{a,b} Means in a column not sharing a common superscript are significantly different (*P*≤0.05) by orthogonal contrasts

Table IV – 1.4. Effect of rearing system and grower phase digestible lysine level on BW and BW gain of female Ross 708 chicks

Rearing system	Lysine level (%)	BW (g)			BW gain (g)			
		14	32	42	0 to 14	0 to 32	0 to 42	14 to 32
Female		391 ± 2	1712 ± 17^{a}	2663 ± 16	350 ± 2	1671 ± 17^{a}	2622 ± 16	1320 ± 16^{a}
Straight-run female		390 ± 3	1667 ± 20^{b}	2677 ± 17	349 ± 3	1626 ± 20^{b}	2636 ± 17	1277 ± 19^{b}
Female	0.90	396 ± 6	1651 ± 37	2630 ± 37	354 ± 5	1610 ± 36	2588 ± 37	1255 ± 32
	0.98	386 ± 3	1645 ± 18	2621 ± 33	345 ± 4	1603 ± 19	2580 ± 33	1259 ± 17
	1.06	385 ± 5	1727 ± 37	2636 ± 54	345 ± 5	1686 ± 37	2595 ± 53	1342 ± 33
	1.14	393 ± 8	1801 ± 40	2717 ± 43	353 ± 8	1760 ± 40	2676 ± 43	1405 ± 35
	1.22	391 ± 7	1744 ± 61	2694 ± 37	350 ± 7	1703 ± 61	2652 ± 37	1353 ± 59
	1.30	394 ± 7	1703 ± 15	2680 ± 20	353 ± 8	1662 ± 15	2639 ± 20	1309 ± 10
Straight-run female	0.90	385 ± 7	1496 ± 41	2649 ± 42	344 ± 7	1455 ± 41	2608 ± 42	1112 ± 49
	0.98	392 ± 5	1663 ± 35	2597 ± 16	351 ± 5	1623 ± 35	2556 ± 16	1272 ± 34
	1.06	377 ± 7	1653 ± 8	2636 ± 42	336 ± 7	1612 ± 8	2595 ± 42	1277 ± 16
	1.14	399 ± 4	1753 ± 28	2717 ± 35	359 ± 4	1712 ± 28	2676 ± 34	1354 ± 27
	1.22	394 ± 7	1723 ± 45	2736 ± 52	353 ± 8	1682 ± 45	2695 ± 52	1329 ± 50
	1.30	393 ± 7	1712 ± 26	2726 ± 36	351 ± 6	1671 ± 25	2685 ± 36	1319 ± 20
Source of variation				------------------------- *P*–values -------------------------				
Rearing System		0.772	0.035	0.548	0.831	0.035	0.541	0.039
Lysine level		0.130	<0.001	0.030	0.119	<.0001	0.029	<0.001
Rearing system x Lysine level		0.533	0.189	0.947	0.499	0.187	0.947	0.270

^{a,b} Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table IV – 1.5. Regression analysis of effects of grower phase digestible lysine on BW of birds raised under sex separate and straight-run regimes

Parameter = BW (g)								
		Quadratic regression						
Rearing system	Age	Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML[1]
Female	32	$Y = 1557.036 + 169.318x - 2174.403(x-1.106)^2$	0.52	0.050	0.005	1.145	1748
Male		$Y = 1706.156 + 137.805x - 1686.090(x-1.102)^2$	0.41	0.043	0.006	1.143	1861
Straight-run		$Y = 1422.446 + 360.260x - 1780.126(x-1.103)^2$	0.45	<0.001	0.037	1.204	1838
Straight-run female		$Y = 1237.806 + 445.757x - 2919.074(x-1.107)^2$	0.55	<0.001	0.004	1.183	1748
Straight-run male		$Y = 1384.515 + 480.939x - 2825.333(x-1.100)^2$	0.45	0.002	0.031	1.185	1453
Female	42	$Y = 2445.560 + 227.999x - 1524.864 (x-1.105)^2$	0.39	0.012	0.047	1.180	2706
Male		$Y = 2981.239 + 84.777x - 3274.703 (x-1.109)^2$	0.61	0.412	<0.001	1.121	3076
Straight-run		$Y = 2450.627 + 399.132x -1490.245(x-1.099)^2$	0.51	<0.001	0.057	1.233	2916
Straight-run female		$Y = 2289.406 + 328.451x - 274.558(x-1.103)^2$	0.43	<0.001	0.713	1.701	2750
Straight-run male		$Y = 2530.266 + 492.575x - 2433.330(x-1.104)^2$	0.56	<0.001	0.036	1.205	3099

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

Table IV – 1.6. Regression analysis of effects of digestible lysine on BW gain of birds raised under sex separate and straight-run regimes

Parameter = BW gain (g)							
		Quadratic regression					
Rearing system	Age	Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML[1]
Female	0 to 32 d	$Y = 1515.172 + 170.155x - 2175.739(x-1.106)^2$	0.52	0.049	0.005	1.145	1707
Male		$Y = 1665.359 + 137.445x - 1683.484(x-1.106)^2$	0.41	0.043	0.006	1.147	1820
Straight-run		$Y = 1380.379 + 361.111x - 1778.652(x-1.103)^2$	0.45	<0.001	0.036	1.205	1797
Straight-run female		$Y = 1196.982 + 445.987x - 2935.234(x-1.107)^2$	0.55	<0.001	0.004	1.183	1708
Straight-run male		$Y = 1341.298 + 482.413x - 2805.661(x-1.100)^2$	0.45	0.002	0.031	1.186	1893
Female	0 to 42 d	$Y = 2403.638 + 228.895x - 1526.546(x-1.105)^2$	0.40	0.011	0.047	1.180	2665
Male		$Y = 2939.802 + 84.844x - 3266.634(x-1.109)^2$	0.62	0.411	<0.001	1.122	3034
Straight-run		$Y = 2408.611 + 399.945x - 1486.834(x-1.099)^2$	0.51	<0.001	0.058	1.233	2875
Straight-run female		$Y = 2248.560 + 328.733x + 258.100(x-1.003)^2$	0.43	<0.001	0.729	↑ 32.8g /↑ 0.1% Lys	-
Straight-run male		$Y = 2487.112 + 493.999x - 2412.997(x-1.104)^2$	0.56	<0.001	0.037	1.206	3058
Female	14 to 32 d	$Y = 1116.133 + 211.874x - 2292.700(x-1.101)^2$	0.46	0.014	0.003	1.147	1354
Male		$Y = 1321.692 + 146.219x - 1869.266(x-1.100)^2$	0.43	0.031	0.002	1.139	1485
Straight-run		$Y = 1038.984 + 350.232x - 1666.340(x-1.103)^2$	0.46	<0.001	0.039	1.208	1444
Straight-run female		$Y = 877.793 + 418.725x - 2918.31(x-1.107)^2$	0.53	<0.001	0.045	1.179	1356
Straight-run male		$Y = 981.063 + 484.215x - 2597.771(x-1.100)^2$	0.45	0.001	0.033	1.193	1536

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

Table IV – 1.7. Effect of rearing system and digestible lysine level on feed intake and adjFCR of Ross 708 chicks

Rearing system	Lysine level (%)	Feed intake (g)				AdjFCR (g)			
		0 to 14	0 to 32	0 to 42	14 to 32	0 to 14	0 to 32	0 to 42	14 to 32
Female		505 ± 11	2755 ± 26^{b}	4865 ± 46^{b}	2254 ± 23^{b}	1.444 ± 0.026	1.668 ± 0.016^{a}	1.829 ± 0.021^{a}	1.742 ± 0.016^{a}
Male		513 ± 12	2925 ± 28^{a}	5080 ± 56^{a}	2412 ± 19^{a}	1.430 ± 0.023	1.620 ± 0.014^{b}	1.682 ± 0.017^{b}	1.662 ± 0.014^{b}
Straight-run		526 ± 10	2879 ± 21^{a}	5003 ± 50^{ab}	2352 ± 20^{a}	1.496 ± 0.026	1.669 ± 0.020^{a}	1.728 ± 0.017^{b}	1.700 ± 0.016^{ab}
Female	0.90	512 ± 34	2647± 19	4890 ± 162	2162 ± 14	1.437 ± 0.073	1.711 ± 0.037	1.835 ± 0.051	1.790 ± 0.027
	0.98	497 ± 17	2698± 47	4815 ± 60	2202 ± 40	1.440 ± 0.061	1.680 ± 0.020	1.831 ± 0.011	1.749 ± 0.018
	1.06	475 ± 19	2746± 64	4683 ± 66	2271 ± 47	1.381 ± 0.037	1.631 ± 0.018	1.766 ± 0.035	1.693 ± 0.023
	1.14	536 ± 46	2813± 61	4889 ± 83	2276 ± 64	1.518 ± 0.107	1.633 ± 0.019	1.787 ± 0.050	1.659 ± 0.024
	1.22	508 ± 17	2840± 86	5041 ± 155	2331 ± 79	1.455 ± 0.033	1.678 ± 0.076	1.960 ± 0.070	1.816 ± 0.067
	1.30	504 ± 11	2787± 56	4871 ± 92	2283 ± 48	1.430 ± 0.057	1.676 ± 0.046	1.792 ± 0.045	1.745 ± 0.043
Male	0.90	511 ± 33	2916± 43	5076 ± 100	2405 ± 19	1.504 ± 0.072	1.711 ± 0.025	1.727 ± 0.019	1.760 ± 0.032
	0.98	526 ± 33	2990± 77	5245 ± 211	2464 ± 47	1.457 ± 0.075	1.601 ± 0.012	1.672 ± 0.044	1.653 ± 0.015
	1.06	540 ± 40	2962± 66	5124 ± 192	2423 ± 35	1.460 ± 0.039	1.639 ± 0.025	1.750 ± 0.068	1.662 ± 0.023
	1.14	513 ± 24	2914± 64	5075 ± 101	2401 ± 42	1.412 ± 0.037	1.598 ± 0.039	1.632 ± 0.013	1.643 ± 0.047
	1.22	507 ± 24	2975± 95	5136 ± 55	2468 ± 72	1.456 ± 0.028	1.616 ± 0.021	1.692 ± 0.022	1.655 ± 0.024
	1.30	481 ± 30	2792± 57	4826 ± 109	2311 ± 34	1.293 ± 0.026	1.558 ± 0.034	1.617 ± 0.036	1.600 ± 0.021
Straight-run	0.90	533 ± 33	2822± 38	4867 ± 83	2289 ± 36	1.549 ± 0.103	1.804 ± 0.070	1.751 ± 0.017	1.790 ± 0.023
	0.98	544 ± 16	2879± 12	5223 ± 198	2336 ± 23	1.529 ± 0.043	1.673 ± 0.029	1.812 ± 0.065	1.712 ± 0.033
	1.06	500 ± 12	2778± 16	4869 ± 68	2278 ± 28	1.428 ± 0.036	1.592 ± 0.035	1.682 ± 0.019	1.636 ± 0.046
	1.14	536 ± 30	2908± 57	4942 ± 99	2372 ± 55	1.498 ± 0.085	1.617 ± 0.032	1.664 ± 0.030	1.647 ± 0.027
	1.22	510 ± 29	2926± 74	5047 ± 135	2416 ± 69	1.457 ± 0.054	1.665 ± 0.046	1.728 ± 0.040	1.715 ± 0.049
	1.30	534 ± 28	2958± 53	5072 ± 52	2423 ± 51	1.513 ± 0.059	1.662 ± 0.024	1.731 ± 0.029	1.696 ± 0.029
Source of variation					------------------------- *P*–values -------------------------				
Rearing System		0.369	<0.001	0.008	<0.001	0.167	0.050	<0.001	0.001
Lysine level		0.838	0.232	0.201	0.109	0.541	0.001	0.035	<0.001
Rearing system x Lysine level		0.806	0.180	0.377	0.250	0.688	0.558	0.098	0.427

^{a,b} Means in a column not sharing a common superscript are significantly different (*P*≤0.05) by orthogonal contrasts

Figure IV – 1.1. Body weight gain in function of digestible lysine intake for broilers raised sex separated or straight-run at 32 d of age

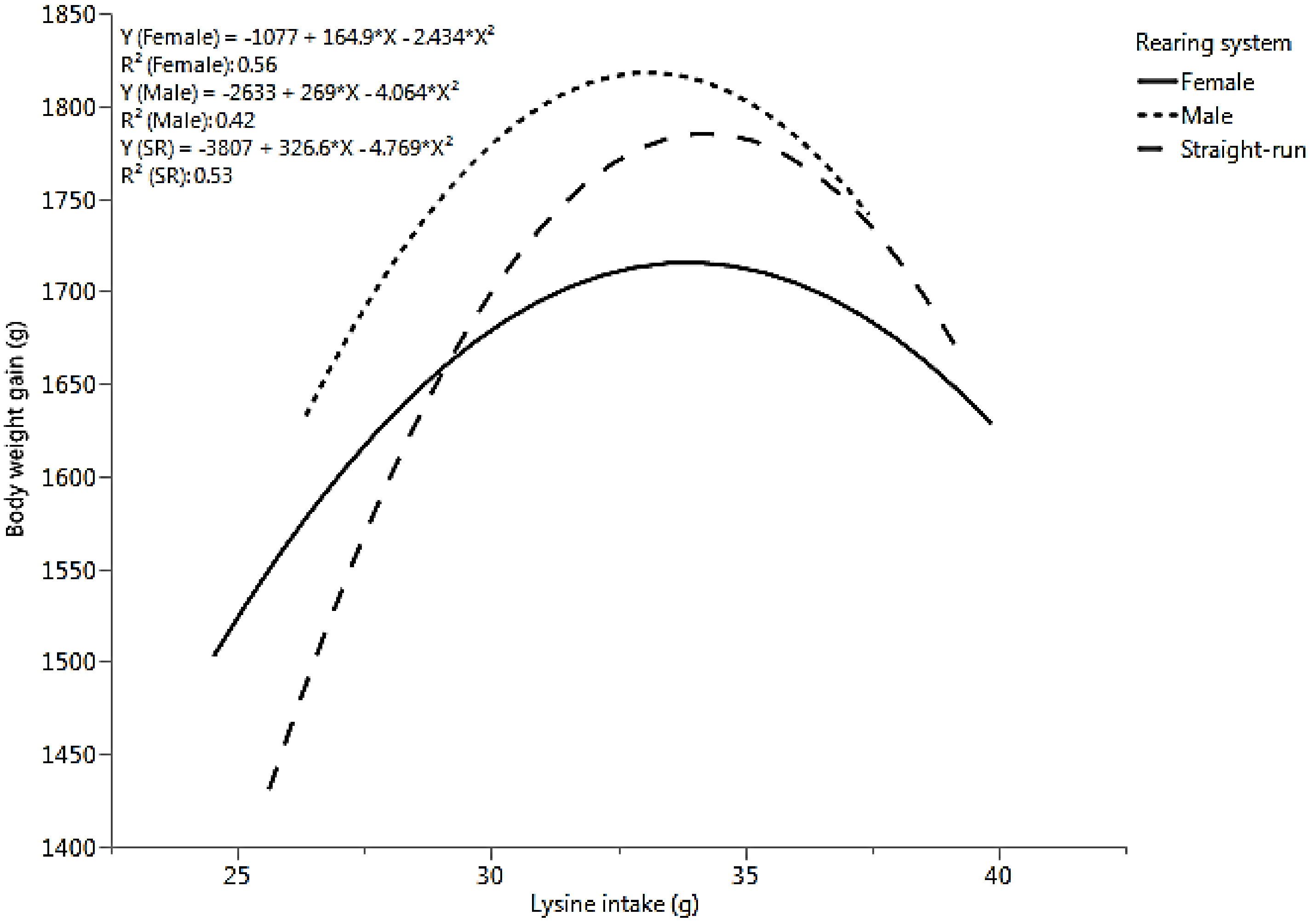

Figure IV – 1.2. Body weight gain in function of digestible lysine intake for broilers raised sex separated or straight-run from 14 to 32 d of age

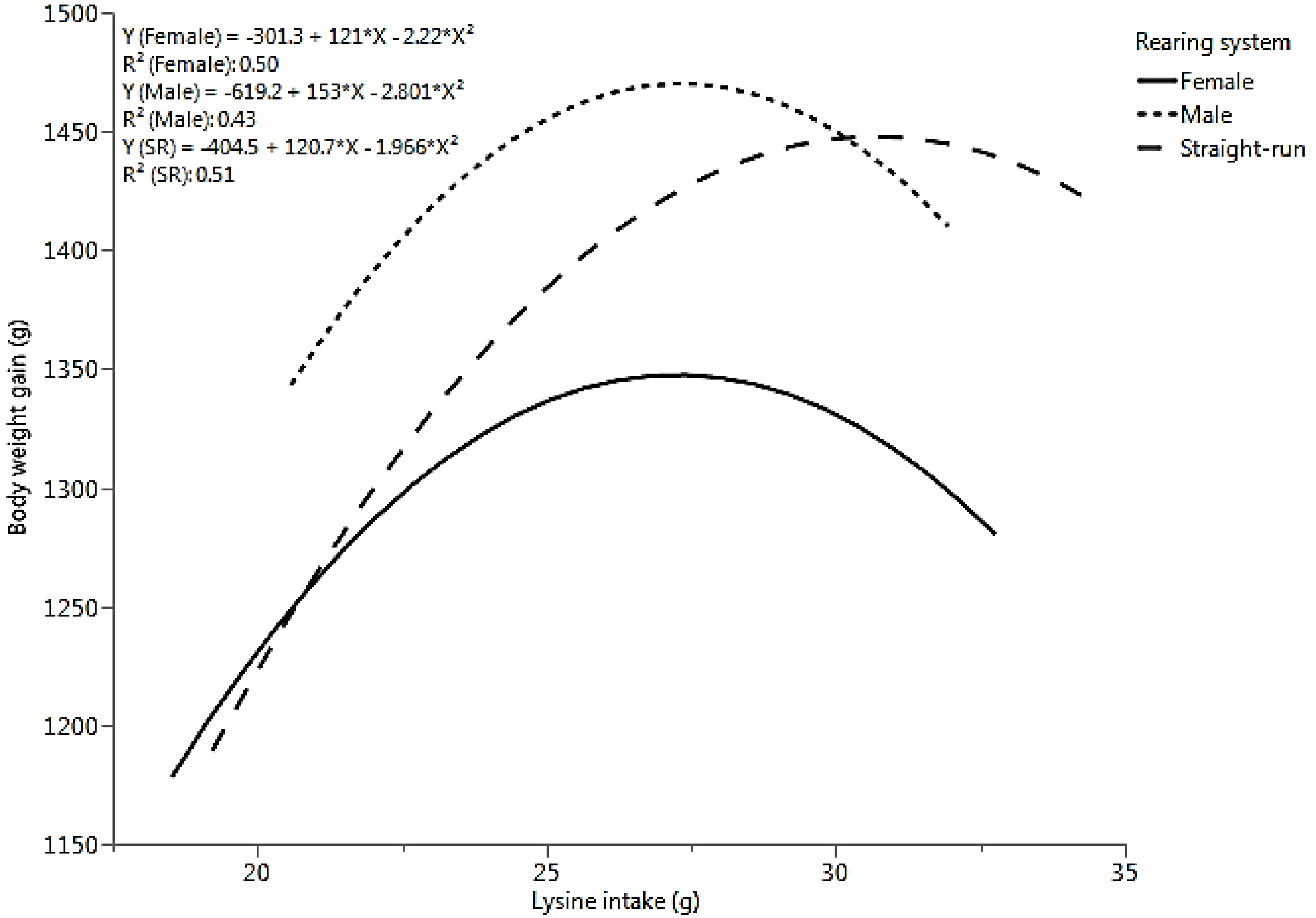

Figure IV – 1.3. Body weight gain in function of digestible lysine intake for broilers raised sex separated or straight-run at 42 d of age

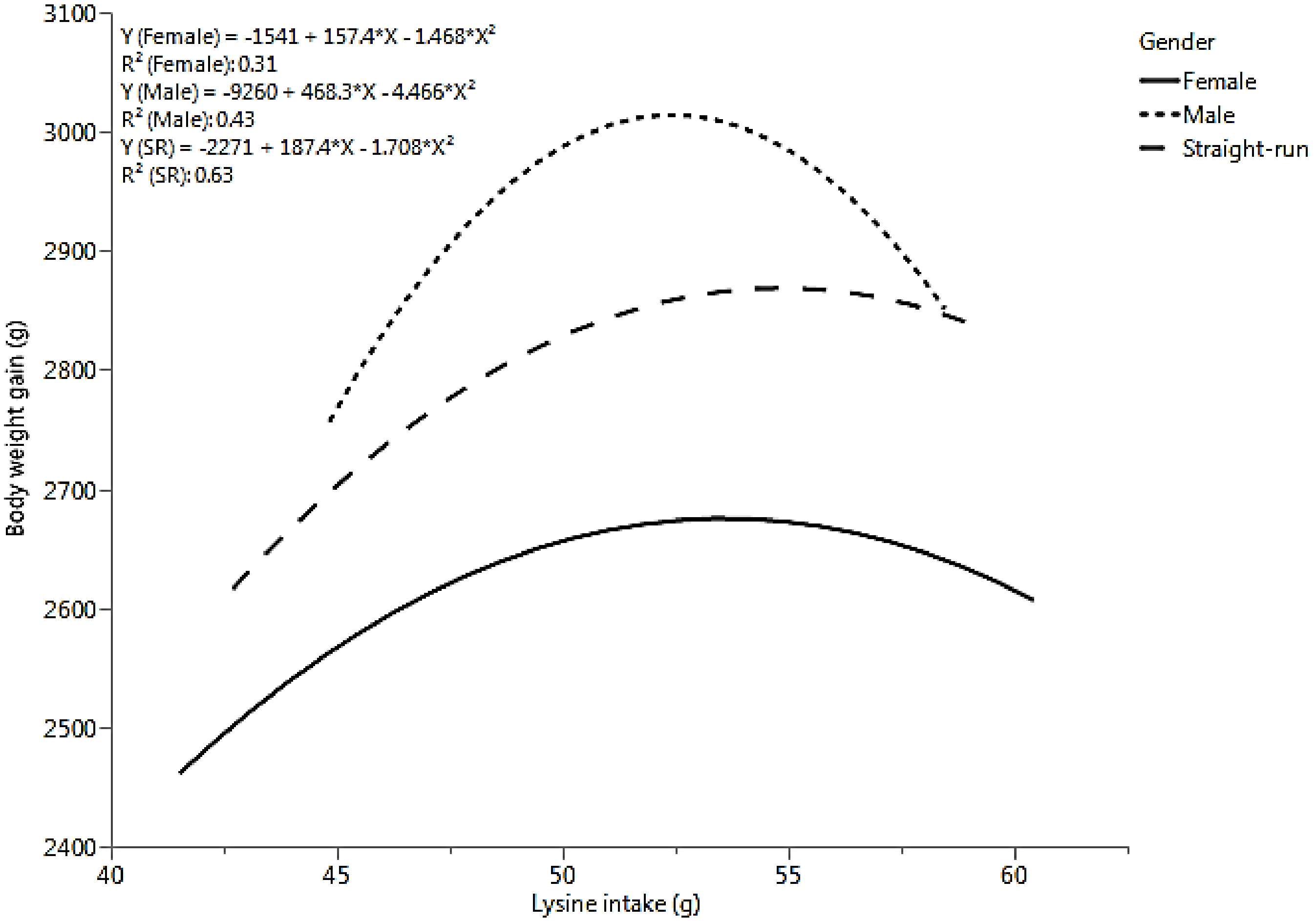

Table IV – 1.8. Regression analysis of effects of digestible lysine on BW gain of birds raised under sex separate and straight-run regimes

Parameter	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML[1]
AdjFCR (g:g)	Female	0 to 32 d	$Y = 1.685 + 0.03666x + 0.8270(x – 1.082)^2$	0.21	0.576	0.129	NS	-
	Male		$Y = 1.970 – 0.33137x + 0.4087(x – 1.096)^2$	0.45	<0.001	0.557	↓0.033 g:g /↑ 0.1% Lys	-
	Straight-run		$Y = 1.823 – 0.19552x + 2.4927(x – 1.103)^2$	0.41	0.030	0.003	1.142	1.604
	Female	0 to 42 d	$Y = 1.854 – 0.05401x + 0.6380(x – 1.100)^2$	0.02	0.698	0.586	NS	-
	Male		$Y = 1.905 – 0.23969x + 0.5436(x – 1.087)^2$	0.39	0.002	0.386	↓0.023 g:g /↑ 0.1% Lys	-
	Straight-run		$Y = 1.810 – 0.12741x + 1.6239(x – 1.090)^2$	0.35	0.078	0.010	1.129	1.669
	Female	14 to 32 d	$Y = 1.824 – 0.12397x + 2.4822(x – 1.084)^2$	0.46	0.138	0.001	1.109	1.688
	Male		$Y = 1.928 – 0.28342x + 1.1830(x – 1.103)^2$	0.70	<0.001	0.007	1.222	1.598
	Straight-run		$Y = 1.924 – 0.24461x + 2.0744(x – 1.100)^2$	0.44	0.006	0.007	1.159	1.669
Feed intake (g)	Female	0 to 32 d	$Y = 2364.437 + 354.914x – 1919.396(x – 1.093)^2$	0.40	0.004	0.053	1.185	2769
	Male		$Y = 3334.548 – 337.859x – 3276.118(x – 1.089)^2$	0.53	0.030	0.012	1.037	2975
	Straight-run		$Y = 2526.678 + 303.409x – 850.149(x – 1.091)^2$	0.45	0.012	0.368	↑30.34 g /↑ 0.1% Lys	-
	Female	0 to 42 d	$Y = 4415.323 + 373.236x – 28.822(x – 1.103)^2$	0.06	0.236	0.991	NS	-
	Male		$Y = 5513.505 – 344.178x – 4255.870(x – 1.099)^2$	0.36	0.227	0.088	NS	-
	Straight-run		$Y = 4369.737 – 461.080x – 2800.646(x – 1.098)^2$	0.23	0.059	0.169	NS	-
	Female	14 to 32 d	$Y = 1875.656 + 332.219x – 811.327(x – 1.103)^2$	0.41	0.004	0.386	↑33.22 g /↑ 0.1% Lys	-
	Male		$Y = 2669.500 – 222.117x – 1536.401(x – 1.091)^2$	0.38	0.043	0.082	↓22.21 g /↑ 0.1% Lys	-
	Straight-run		$Y = 2066.378 + 250.802x – 83.477(x – 1.084)^2$	0.27	0.036	0.928	↑25.08 g /↑ 0.1% Lys	-

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

Table IV – 1.9. Effect of rearing system and grower phase digestible lysine level on BW of processed birds and respective cold carcass weight and yield

Rearing system	Lysine level (%)	Live BW (g)		Cold carcass			
				Weight (g)		Percentage (%)	
		33	43	33	43	33	43
Female		1615 ± 18^{c}	2603 ± 28^{c}	1259 ± 14^{c}	2065 ± 23^{c}	77.95±0.29^{a}	79.30±0.14^{a}
Male		1769 ± 17^{a}	2914 ± 25^{a}	1351 ± 14^{a}	2295 ± 21^{a}	76.34±0.22^{b}	78.75±0.17^{b}
Straight-run		1688 ± 13^{b}	2717 ± 26^{b}	1308 ± 13^{b}	2146 ± 21^{b}	77.49±0.25^{a}	78.82±0.14^{b}
Female	0.90	1527 ± 22	2578 ± 112	1199 ± 13	2041 ± 88	78.57±0.77	79.20±0.15
	0.98	1583 ± 47	2624 ± 68	1238 ± 38	2064 ± 63	78.18±0.67	78.60±0.58
	1.06	1634 ± 35	2524 ± 56	1272 ± 26	2011 ± 45	77.33±0.70	79.66±0.30
	1.14	1668 ± 43	2690 ± 52	1290 ± 27	2144 ± 43	77.42±0.80	79.73±0.15
	1.22	1699 ± 48	2602 ± 71	1326 ± 45	2065 ± 63	77.98±0.64	79.33±0.33
	1.30	1579 ± 27	2602 ± 45	1233 ± 29	2062 ± 33	78.22±0.88	79.31±0.32
Male	0.90	1669 ± 31	2822 ± 88	1277 ± 27	2207 ± 75	76.49±0.44	78.14±0.41
	0.98	1802 ± 34	2943 ± 49	1383 ± 30	2303 ± 33	76.67±0.34	78.20±0.27
	1.06	1798 ± 30	2879 ± 41	1368 ± 25	2277 ± 32	76.05±0.41	79.13±0.46
	1.14	1778 ± 53	3041 ± 43	1343 ± 42	2421 ± 31	75.56±0.72	79.60±0.16
	1.22	1772 ± 30	2884 ± 73	1368 ± 28	2261 ± 58	77.03±0.37	78.43±0.37
	1.30	1797 ± 43	2916 ± 13	1370 ± 32	2302 ± 20	76.24±0.72	78.99±0.42
Straight-run	0.90	1621 ± 34	2556 ± 46	1251 ± 27	1999 ± 35	77.28±0.67	78.20±0.24
	0.98	1648 ± 13	2716 ± 29	1278 ± 9	2150 ± 22	77.19±0.35	79.19±0.12
	1.06	1679 ± 37	2780 ± 79	1290 ± 33	2135 ± 33	76.89±0.30	78.26±0.26
	1.14	1709 ± 37	2767 ± 75	1313 ± 32	2237 ± 50	76.87±0.35	79.42±0.20
	1.22	1705 ± 8	2710 ± 60	1331 ± 17	2132 ± 39	78.13±0.75	78.70±0.43
	1.30	1764 ± 23	2773 ± 47	1386 ± 30	2227 ± 34	78.60±0.80	79.15±0.33
Source of variation		------------------------ *P*–values ------------------------					
Rearing System		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lysine level		0.001	0.020	0.003	0.001	0.177	0.036
Rearing system x Lysine level		0.269	0.709	0.299	0.782	0.931	0.300

[a,b,c] Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table IV – 1.10. Effect of rearing system and grower phase digestible lysine level on BW of processed birds and respective cold carcass weight and yield

Rearing system	Lysine level (%)	*Pectoralis major*				*Pectoralis minor*			
		Weight (g)		Percentage (%)		Weight (g)		Percentage (%)	
		33	43	33	43	33	43	33	43
Female		317±5^{b}	564 ± 8^{b}	25.13 ± 0.16	27.29±0.19	69 ± 0.9^{b}	117 ± 1.2^{b}	5.48 ± 0.05^{a}	5.71 ± 0.06^{a}
Male		338±5^{a}	625 ± 8^{a}	24.87 ± 0.22	27.20±0.19	72 ± 0.9^{a}	123 ± 1.7^{a}	5.33 ± 0.05^{ab}	5.36 ± 0.06^{b}
Straight-run		325±4^{ab}	581 ± 7^{b}	24.81 ± 0.21	27.17±0.18	69 ± 0.8^{b}	120 ± 1.4^{ab}	5.31 ± 0.05^{b}	5.66 ± 0.06^{ab}
Female	0.90	295±3	546 ± 26	24.62 ± 0.37	26.72±0.22	64 ± 2.2	114 ± 2.9	5.31 ± 0.15	5.83 ± 0.18
	0.98	305±11	559 ± 22	24.67 ± 0.23	27.01±0.48	68 ± 1.8	117 ± 4.0	5.51 ± 0.13	5.71 ± 0.08
	1.06	324±5	545 ± 14	25.23 ± 0.11	27.05±0.27	70 ± 1.3	115 ± 2.9	5.49 ± 0.05	5.73 ± 0.19
	1.14	322±9	589 ± 11	24.92 ± 0.17	27.49±0.68	70 ± 1.0	125 ± 1.2	5.46 ± 0.07	5.87 ± 0.15
	1.22	333±18	572 ± 19	25.05 ± 0.64	27.66±0.47	73 ± 2.0	112 ± 1.3	5.48 ± 0.12	5.44 ± 0.15
	1.30	324±9	574 ± 18	26.29 ± 0.26	27.82±0.52	70 ± 2.4	117 ± 1.3	5.65 ± 0.13	5.69 ± 0.07
Male	0.90	308±9	581 ± 30	24.06 ± 0.34	26.22±0.67	67 ± 1.5	114 ± 3.9	5.26 ± 0.10	5.19 ± 0.15
	0.98	352±12	626 ± 16	25.36 ± 0.61	27.16±0.37	75 ± 2.2	124 ± 1.2	5.41 ± 0.09	5.39 ± 0.11
	1.06	326±8	619 ± 14	23.82 ± 0.55	27.11±0.41	73 ± 2.2	124 ± 1.7	5.32 ± 0.22	5.46 ± 0.10
	1.14	333±13	659 ± 11	24.74 ± 0.38	27.18±0.28	72 ± 2.8	135 ± 3.7	5.34 ± 0.11	5.59 ± 0.15
	1.22	353±7	618 ± 11	25.51 ± 0.42	27.40±0.35	73 ± 1.6	119 ± 2.5	5.28 ± 0.12	5.27 ± 0.08
	1.30	354±15	648 ± 11	25.75 ± 0.44	28.14±0.31	74 ± 1.7	121 ± 4.2	5.37 ± 0.07	5.26 ± 0.19
Straight-run	0.90	296±8	535 ± 17	23.65 ± 0.52	26.64±0.50	65 ± 1.7	113 ± 3.1	5.24 ± 0.06	5.66 ± 0.20
	0.98	325±5	589 ± 12	25.36 ± 0.32	27.57±0.44	67 ± 1.1	117 ± 2.1	5.21 ± 0.09	5.49 ± 0.05
	1.06	325±9	583 ± 16	25.19 ± 0.34	27.01±0.47	70 ± 1.7	120 ± 3.1	5.50 ± 0.12	5.58 ± 0.06
	1.14	327±11	606 ± 8	24.89 ± 0.34	27.36±0.32	67 ± 1.4	125 ± 2.1	5.22 ± 0.13	5.70 ± 0.14
	1.22	330±5	589 ± 12	24.83 ± 0.44	27.63±0.60	71 ± 1.3	124 ± 2.7	5.36 ± 0.12	5.82 ± 0.15
	1.30	346±4	581 ± 15	24.93 ± 0.77	26.83±0.11	74 ± 1.3	123 ± 4.8	5.35 ± 0.16	5.70 ± 0.20
Source of variation		------------------------- *P*–values -------------------------							
Rearing System		0.002	<0.001	0.403	0.885	0.005	0.003	0.021	<0.001
Lysine level		<0.001	0.001	0.002	0.043	<0.001	<0.001	0.396	0.520
Rearing System x Lysine level		0.598	0.908	0.171	0.772	0.376	0.256	0.858	0.432

[a,b] Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table IV – 1.11. Effect of rearing system and grower phase digestible lysine level on BW of processed birds and respective cold carcass weight and yield

Rearing system	Lysine level (%)	Legs				Wings				Paws	
		Weight (g)		Percentage (%)		Weight (g)		Percentage (%)		Weight (g)	
		33	43	33	43	33	43	33	43	33	43
Female		347±5^{c}	559±7^{c}	27.51±0.20^{b}	27.24±0.17^{b}	129±1^{b}	196±2^{c}	10.22±0.06	9.53±0.06	60±0.8^{c}	82±1.2^{c}
Male		380±3^{a}	639±6^{a}	28.08±0.12^{a}	27.84±0.16^{a}	138±1^{a}	222±2^{a}	10.23±0.06	9.69±0.06	71±0.6^{a}	108±1.0^{a}
Straight-run		362±4^{b}	588±7^{b}	27.63±0.19^{ab}	27.52±0.17^{ab}	135±1^{a}	207±2^{b}	10.33±0.06	9.72±0.07	65±0.6^{b}	93±1.0^{b}
Female	0.90	323±6	537±12	26.99±0.35	27.33±0.15	125±2	194±6	10.48±0.11	9.56±0.16	57±1.0	78±2.0
	0.98	346±17	560±16	27.97±0.63	27.25±0.48	125±3	199±4	10.13±0.15	9.70±0.16	60±2.7	84±3.4
	1.06	348±10	559±19	27.03±0.30	27.80±0.44	131±2	192±6	10.23±0.11	9.54±0.20	61±1.5	81±2.7
	1.14	360±7	583±24	27.84±0.21	27.13±0.59	131±3	203±4	10.17±0.13	9.49±0.04	60±2.2	86±2.4
	1.22	369±12	565±21	27.74±0.22	27.32±0.40	135±2	195±6	10.21±0.23	9.42±0.09	65±1.6	84±4.0
	1.30	338±9	549±8	27.47±0.86	26.61±0.20	124±3	195±3	10.10±0.12	9.48±0.22	57±0.9	80±3.0
Male	0.90	362±7	622±22	28.35±0.22	28.22±0.50	130±3	216±5	10.18±0.20	9.84±0.16	68±1.5	105±3.4
	0.98	381±7	648±6	27.60±0.19	28.11±0.32	139±3	221±3	10.03±0.08	9.59±0.08	72±1.1	107±1.6
	1.06	395±7	618±13	28.83±0.07	27.16±0.49	143±4	224±3	10.48±0.25	9.89±0.10	73±1.7	106±2.2
	1.14	380±8	671±8	28.32±0.37	27.70±0.26	139±3	230±5	10.38±0.10	9.49±0.12	71±1.4	112±1.5
	1.22	385±7	634±17	27.86±0.17	28.01±0.21	138±3	216±4	9.99±0.08	9.55±0.17	71±1.4	105±1.5
	1.30	376±7	641±11	27.53±0.22	27.84±0.45	141±4	225±4	10.33±0.09	9.79±0.21	70±1.2	111±2.6
Straight-run	0.90	352±11	552±15	28.17±0.37	27.67±0.59	129±2	195±3	10.38±0.13	9.79±0.20	64±0.8	88±0.6
	0.98	352±8	587±13	27.33±0.68	27.23±0.35	135±1	209±6	10.48±0.18	9.72±0.23	63±1.4	92±2.1
	1.06	359±10	592±7	27.90±0.55	27.57±0.26	134±2	207±5	10.41±0.14	9.62±0.23	65±1.5	92±2.2
	1.14	369±10	600±16	28.12±0.47	27.09±0.26	136±3	216±5	10.42±0.11	9.77±0.10	64±1.0	97±2.8
	1.22	360±2	589±20	27.07±0.33	27.53±0.51	136±1	207±4	10.23±0.09	9.70±0.15	66±1.1	93±3.3
	1.30	377±10	610±19	27.21±0.21	28.02±0.48	139±2	210±7	10.03±0.11	9.72±0.21	68±1.8	96±2.1
Source of variation		------------------------ *P*–values ------------------------									
Rearing System		<0.001	<0.001	0.045	0.047	<0.001	<0.001	0.359	0.116	<0.001	<0.001
Lysine level		0.014	0.026	0.341	0.873	0.003	0.008	0.184	0.837	0.012	0.010
Rearing System x Lysine level		0.320	0.844	0.211	0.454	0.172	0.830	0.225	0.882	0.070	0.737

^{a,b,c} Means in a column not sharing a common superscript are significantly different ($P \leq 0.05$) by orthogonal contrasts

Table IV – 1.12. Regression analysis of effects of grower phase digestible lysine on cold carcass weight and yield of birds raised under sex separate and straight-run regimes

Parameter	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML[1]
Cold carcass weight (g)	Female	33	$Y = 1207.367 + 82.053x - 2415.293(x-1.088)^2$	0.41	0.288	<0.001	1.105	1297
	Male		$Y = 1200.578 + 164.105x - 1654.347(x-1.097)^2$	0.35	0.063	0.034	1.147	1385
	Straight-run		$Y = 989.063 + 29.847x + 269.553(x-1.101)^2$	0.39	<0.001	0.677	↑29.85 g /↑ 0.1% Lys	-
	Female	43	$Y = 1896.416 + 168.983x - 2254.596(x-1.103)^2$	0.27	0.206	0.066	NS	-
	Male		$Y = 2101.384 + 214.844x - 2266.741(x-1.100)^2$	0.44	0.089	0.037	1.147	2343
	Straight-run		$Y = 1662.504 + 460.776x - 1401.861(x-1.087)^2$	0.55	<0.001	0.092	↑46.08 g /↑ 0.1% Lys	-
Cold carcass percentage (%)	Female	33	$Y = 80.1971 - 2.09851x + 2.97115(x-1.093)^2$	0.05	0.270	0.862	NS	-
	Male		$Y = 75.660 + 0.53196x + 13.33188(x-1.082)^2$	0.20	0.656	0.184	NS	-
	Straight-run		$Y = 75.293 + 1.59279x + 0.86347(x-1.092)^2$	0.13	0.183	0.929	NS	-
	Female	43	$Y = 78.9171 + 0.65071x - 10.43851(x-1.100)^2$	0.13	0.394	0.112	NS	-
	Male		$Y = 76.8161 + 1.97732x - 15.82722(x-1.113)^2$	0.31	0.073	0.086	NS	-
	Straight-run		$Y = 77.0254 + 2.11154x - 16.77715(x-1.089)^2$	0.36	0.013	0.025	1.152	79.39

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

NS – not significant ($P>0.05$)

Table IV – 1.13. Regression analysis of effects of digestible lysine on *pectoralis major* and *minor* weight and yield of birds raised under sex separate and straight-run regimes

Parameter	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML[1]
Pectoralis major weight (g)	Female	33	$Y = 244.835 + 72.86938x - 347.66540(x-1.096)^2$	0.37	0.006	0.095	↑7.287 g /↑ 0.1% Lys	-
	Male		$Y = 245.592 + 88.02264x - 369.58090(x-1.097)^2$	0.35	0.010	0.183	↑8.802 g /↑ 0.1% Lys	-
	Straight-run		$Y = 245.334 + 70.69164x - 159.49480(x-1.113)^2$	0.37	0.002	0.365	↑7.069g /↑ 0.1% Lys	-
	Female	43	$Y = 424.664 + 130.56208x - 588.56190(x-1.111)^2$	0.29	0.014	0.175	↑13.056 g /↑ 0.1% Lys	-
	Male		$Y = 481.061 + 141.17333x - 590.26230(x-1.100)^2$	0.48	0.003	0.124	↑14.173 g /↑ 0.1% Lys	-
	Straight-run		$Y = 461.493 + 116.40499x - 456.83640(x-1.104)^2$	0.34	0.006	0.172	↑11.640 g /↑ 0.1% Lys	-
Pectoralis major percentage (%)	Female	33	$Y = 20.6049 + 3.99973x + 10.07581(x-1.093)^2$	0.69	<0.001	0.087	↑0.400 % /↑ 0.1% Lys	-
	Male		$Y = 19.5214 + 4.89236x + 6.23702(x-1.098)^2$	0.46	<0.001	0.544	↑0.489 % /↑ 0.1% Lys	-
	Straight-run		$Y = 21.3839 + 3.35247x + 1.16447(x-1.092)^2$	0.30	0.007	0.901	↑0.335 % /↑ 0.1% Lys	-
	Female	43	$Y = 23.6410 + 2.93981x + 11.95484(x-1.091)^2$	0.39	0.004	0.139	↑0.294 % /↑ 0.1% Lys	-
	Male		$Y = 23.3256 + 3.55700x + 6.82547(x-1.103)^2$	0.49	<0.001	0.395	↑0.356 % /↑ 0.1% Lys	-
	Straight-run		$Y = 28.1815 - 0.61816x - 10.30219(x-1.113)^2$	0.07	0.603	0.314	NS	-
Pectoralis minor weight (g)	Female	33	$Y = 55.1258 + 14.50651x - 126.33870(x-1.093)^2$	0.38	0.010	0.008	1.150	79
	Male		$Y = 59.4941 + 12.51695x - 75.99680(x-1.109)^2$	0.34	0.025	0.099	↑1.252 g /↑ 0.1% Lys	-
	Straight-run		$Y = 46.4673 + 19.52355x + 48.39131(x-1.100)^2$	0.56	<0.001	0.174	↑1.952 g /↑ 0.1% Lys	-
	Female	43	$Y = 110.3213 + 9.10030x - 175.1290(x-1.101)^2$	0.42	0.192	0.007	1.127	120
	Male		$Y = 112.4110 + 13.24217x - 254.14770(x-1.099)^2$	0.36	0.164	0.004	1.125	127
	Straight-run		$Y = 77.6899 + 41.30183x - 102.28600(x-1.086)^2$	0.57	<0.001	0.162	↑4.130 g /↑ 0.1% Lys	-
Pectoralis minor percentage (%)	Female	33	$Y = 5.1073 + 0.32651x + 2.17625(x-1.107)^2$	0.16	0.294	0.413	NS	-
	Male		$Y = 5.5203 - 0.16789x + 0.92913(x-1.108)^2$	0.22	0.603	0.733	NS	-
	Straight-run		$Y = 4.7204 + 0.52952x + 0.90517(x-1.093)^2$	0.13	0.082	0.730	NS	-
	Female	43	$Y = 6.0072 - 0.36070x + 4.30912(x-1.103)^2$	0.13	0.272	0.158	NS	-
	Male		$Y = 5.0605 + 0.34410x - 3.81519(x-1.091)^2$	0.16	0.336	0.218	NS	-
	Straight-run		$Y = 4.9745 + 0.57428x + 5.52904(x-1.091)^2$	0.18	0.142	0.103	NS	-

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

NS – not significant ($P>0.05$)

Table IV – 1.14. Regression analysis of effects of grower phase digestible lysine level on wings, and legs weight and yield, and paw weights of birds raised under sex separate and straight-run regimes

	Rearing system	Age	Quadratic regression					
			Equation	R^2	Linear *P*-value	Quadratic *P*-value	TRML[1]	Response at TRML[1]
Wings weight (g)	Female	33	$Y = 120.669 - 10.3760x - 139.847(x-1.097)^2$	0.30	0.159	0.032	1.060	109
	Male		$Y = 123.151 + 15.2244x - 155.623(x-1.096)^2$	0.31	0.086	0.049	1.145	140
	Straight-run		$Y = 116.850 + 18.6688x - 105.237(x-1.091)^2$	0.42	0.002	0.039	1.180	138
	Female	43	$Y = 193.635 + 6.0822x - 217.514(x-1.109)^2$	0.15	0.645	0.074	NS	-
	Male		$Y = 201.535 + 21.5443x - 134.757(x-1.096)^2$	0.33	0.075	0.174	NS	-
	Straight-run		$Y = 172.501 + 33.9612x - 181.853(x-1.104)^2$	0.27	0.025	0.145	↑3.396 g /↑ 0.1% Lys	-
Wings percentage (%)	Female	33	$Y = 11.1935 - 0.9313x + 2.411(x-1.100)^2$	0.25	0.019	0.450	↓0.093 % /↑ 0.1% Lys	-
	Male		$Y = 10.2858 - 0.0770x + 2.399(x-1.110)^2$	0.12	0.809	0.391	NS	-
	Straight-run		$Y = 11.6694 - 1.0941x - 6.316(x-1.104)^2$	0.37	0.003	0.036	↓0.109 % /↑ 0.1% Lys	-
	Female	43	$Y = 10.884 - 1.2010x - 1.403(x-1.102)^2$	0.53	<0.001	0.603	↓0.120 % /↑ 0.1% Lys	-
	Male		$Y = 9.796 - 0.1780x + 6.610(x-1.093)^2$	0.31	0.656	0.060	NS	-
	Straight-run		$Y = 9.097 + 0.5625x + 0.942(x-1.103)^2$	0.13	0.219	0.815	NS	-
Legs weight (g)	Female	33	$Y = 313.469 + 40.381x - 663.901(x-1.104)^2$	0.37	0.124	0.005	1.134	359
	Male		$Y = 362.438 + 24.014x - 560.558(x-1.094)^2$	0.36	0.257	0.005	1.115	389
	Straight-run		$Y = 316.896 + 35.840x - 284.804(x-1.106)^2$	0.23	0.113	0.144	NS	-
	Female	43	$Y = 537.389 + 32.114x - 976.191(x-1.103)^2$	0.62	0.267	0.002	1.119	573
	Male		$Y = 557.113 + 85.908x - 892.808(x-1.118)^2$	0.31	0.079	0.041	1.166	655
	Straight-run		$Y = 512.779 + 78.723x - 458.522(x-1.096)^2$	0.23	0.064	0.187	NS	-
Legs percentage (%)	Female	33	$Y = 27.298 + 0.304x - 17.646(x-1.097)^2$	0.24	0.752	0.038	1.106	27.63
	Male		$Y = 30.252 - 1.836x - 9.258(x-1.104)^2$	0.30	0.017	0.143	↓0.184 % /↑ 0.1% Lys	-
	Straight-run		$Y = 29.080 - 1.598x + 7.012(x-1.109)^2$	0.20	0.130	0.433	1.066 (minimum)	27.39
	Female	43	$Y = 29.962 - 1.959x - 22.398(x-1.110)^2$	0.33	0.065	0.020	NS	-
	Male		$Y = 27.866 - 0.109x + 3.629(x-1.109)^2$	0.28	0.912	0.670	NS	-
	Straight-run		$Y = 26.537 + 0.688x + 12.001(x-1.100)^2$	0.07	0.585	0.277	NS	-
Paws weight (g)	Female	33	$Y = 3.7753 - 0.02542x - 2.61256(x-1.107)^2$	0.29	0.897	0.149	NS	-
	Male		$Y = 4.4791 - 0.39167x - 1.65920(x-1.101)^2$	0.17	0.087	0.390	NS	-
	Straight-run		$Y = 4.0994 - 0.27352x + 1.70900(x-1.091)^2$	0.25	0.075	0.176	NS	-
	Female	43	$Y = 3.4550 - 0.24828x + 0.23268(x-1.097)^2$	0.18	0.086	0.842	NS	-
	Male		$Y = 3.6800 - 0.01517x + 1.61393(x-1.093)^2$	0.42	0.920	0.213	NS	-
	Straight-run		$Y = 3.1582 + 0.20848x + 1.17963(x-1.100)^2$	0.24	0.267	0.465	NS	-

[1] TRML – technical response maximum level; corresponds to the maximum level of digestible lysine need to obtain maximum response

NS – not significant ($P>0.05$)

Evaluation of Grower Dietary Digestible Lysine Level on Broilers Raised under a Sex Separated or Straight-run Housing Regime

Part 2: Economics of Sex separation and Digestible Lysine Level for Maximum Returns[1]

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[1] M.J. Da Costa[1], G. Colson[1], T.J. Frost[2], J. Halley[3], G.M. Pesti[1]
[1]University of Georgia, Athens, GA 30606
[2]Wayne Farms LLC, 4110 Continental Drive, Oakwood, Georgia 30566
[3]Aviagen Inc., 5015 Bradford Drive, Huntsville, AL 35805
To be submitted to Poultry Science

ABSTRACT

The objective of this experiment was to determine the net return maximum digestible lysine (dLys) level (NRML), while maintaining the ideal amino acid ratio for grower diets, of broilers raised sex separate or straight-run. 2,160 Ross 708 chicks were separated by sex and placed in 90 pens by two rearing types; sex separate (24 males or 24 females) or straight-run (12 males + 12 females). All birds were fed a common starter diet with 1.32% of dLys up to 14d. Afterwards, each rearing type was fed six grower diets formulated to have dLys levels between 0.90 and 1.30% in 0.08% increments until 32d of age. A common finisher with 0.88% of dLys was fed from 32 to 42d. Body weight gain (BWG, and feed intake (FI) were assessed at 14, 32, and 42d. Additionally at 33 and 43d, four birds per pen were sampled for carcass yield evaluation. Data were modeled using response surface methodology in order to estimate feed intake and carcass cut-up weights at two market ages (1,700, and 2,900g live BW). Returns over feed cost were estimated for a 1.8 million broiler complex of each rearing system under nine feed/meat price scenarios. For whole carcass markets, (1,700g) females and straight-run birds had NRML at 0.90 and 1.01% of dLys respectively. This showed an economic advantage of $25,507 for the sex separate complex. For the cut-up market, (2,900g) males and straight-run birds had NRML at 1.30 and 1.14 % dLys respectively. Feeding at NRML levels showed an economic advantage of $86,834 for sex separate birds. Sex separation resulted in increased returns, regardless of the feed and meat price scenarios, with an extra income that ranged from $85,013 to $139,669 when dLys was at NRML. Rearing sex separate was shown to be economically important, especially at high feed prices, resulting in increased company profitability.

Keywords: sex separate, straight-run, lysine, protein, economics

INTRODUCTION

Profit maximization is one of the main pillars of the poultry industry across the world. Still, there are several practices regarding management and nutrition strategies that are based on anecdotal evidence that which lack of solid scientific proof. The advantages of rearing broilers sex separated *vs.* sex comingled is one of the topics that is the most doubted, with existing pros and cons of sex separation described in the literature. The benefits of sex separation have been related with improved performance and flock uniformity at market weight (Becker and Berg, 1959; Deaton, et al., 1973; Gehle, et al., 1974; Laseinde and Oluyemi, 1994; de Albuquerque, et al., 2006; Api, 2014). Nevertheless, there is also some evidence that sex separation can result in having no advantages or detrimental effects on bird performance (Smith, et al., 1954; Hess, et al., 1960; Lang, et al., 1960; Lamoreux and Proudfoot, 1969). Despite the conflicting evidence, most of the studies performed in this regard were done using less selected bird genetics. With the evolution of the broiler strains observed over the past years (Zuidhof, et al., 2014), it is necessary to re-assess the two rearing systems using modern broiler breeds.

Raising broilers sex separate also opens up the opportunity to formulate diets specifically designed for each gender in order to attain maximum return. Dietary protein level (or digestible lysine level when maintaining the amino acid ratios) is one of the nutrients that is the most expensive in the diet and can significantly impact bird performance and carcass yield (Bartov and Plavnik, 1998; Corzo, et al., 2004; Kidd, et al., 2004; Kidd, et al., 2005; Pesti, 2009; Corzo, et al., 2010). In addition, there are some studies that have shown that the dietary amino acid level that will maximize performance is not necessarily the same that will result in maximum profit (Dozier, et al., 2006a; Dozier, et al., 2006b; Pesti and Vedenov, 2011; Aftab, 2012; Trevisan, et al., 2014; Basurco, et al., 2015).

Considering all the factors described previously, the objectives of the present experiment were to evaluate the economic returns of rearing broilers sex separate or straight-run and determine the net return maximum level (NRML) of digestible lysine when using a modern broiler strain under both rearing systems.

MATERIAL AND METHODS

There were 18 experimental treatments consisting of a factorial combination of three broiler rearing types with six dietary protein (digestible lysine) levels.

Sex separate vs. Straight-run treatments

A total of 2,160 d old sexed Ross 708 chicks were placed and raised in 90 pens according to one of the three following treatments: male, female, and straight-run. At placing for the male and female treatments, 24 chicks of the respective sex treatment were randomly selected, weighed, and identified with a neck tag; for the straight-run treatment, 12 males and 12 females were used instead. From this point forward, this treatment will be called as rearing system.

Dietary treatments

The diets fed in the present experiment were corn-soybean meal-based with three dietary phases used: starter – 0 to 14 d (common diet phase), grower – 14 to 32 d (experimental diet), and finisher – 32 to 42 d (common diet phase). The starter diets were fed as a crumbled feed, and the grower and finisher diets were fed as pellets. There were six dietary grower treatments based on digestible lysine inclusion level with the ideal amino acid ratios maintained (Table 1). The dietary digestible lysine levels were obtained by formulating a base (0.90% dLys) and summit

(1.30% dLys) diets that were posteriorly blended in different proportions, resulting in six digestible lysine treatments (0.90, 0.98, 1.06, 1.14, 1.22, and 1.30 % of dLys). The calculated digestible amino acid values used were based on Ajinomoto Heartland LLC. (2004).

Birds and Husbandry

All practices regarding animal management were approved by the Institutional Animal Care and Use Committee of the University of Georgia. The experiment was performed in a window-less room with 48 pens that were 1.22 x 1.52 m in dimension. Each pen had one hanging tubular feeder with 170 cm of feeder space (7.1 cm/bird), 10 nipple drinkers, and the floor was covered with 0.05 m of used pine shavings as litter. For the first three d of brooding, one cardboard tray with feed was placed in each pen to ease the access to feed by the chickens. Both water and feed were consumed *ad libitum*. Temperature, ventilation, and lighting programs were checked twice a day and followed commercial practices. Chicks were housed at 34°C and then the temperature was gradually reduced 3°C every wk until the temperature reached 20°C. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing 24 h of light at 30 lux for the first 7 d, 16 h of light at 3.5 lux with 8 h of dark from 7 to 28 d of age, and 20 h of light at 3.5 lux with 6 h of dark from 28 d until the end of the trial.

Performance data

Group BW per pen were evaluated at hatch, 14, 32, and 42 d of age. Additionally, feed consumption was recorded to calculate feed intake and FCR. Mortality was checked twice a d and BW was recorded to calculate adjFCR.

Processing data

At 33 and 43 d, the four birds that had the lowest numbered neck tag were selected for processing. In the straight-run pens, two birds of each sex were selected that were also based on the lowest neck tag number. Birds were withdrawn off from feed for eight hours over night. Birds were individually weighed prior to processing, immediately following evisceration (pre-chill/hot carcass weight) and after chilling (cold carcass weight without giblets – WOG). Paws were taken and weighed prior to hot carcass weighing. Carcasses were chilled in water and ice at 1°C for 240 min. Subsequently, carcasses were deboned and the *pectoralis major, pectoralis minor*, wings, and legs were weighed for carcass yield

Data Analysis

The economic feasibility of the rearing system and NRML determination was based on an input (feed) output (meat) base under different scenarios of feed and meat prices. The economic simulations were performed for two market BW, 1,700 g birds to be sold as whole birds and the 3,900 g to be sold as cut-ups, considering a broiler complex producing 1,800,000 birds (a wk of production roughly) with an allocation of 900,000 birds for each market weight (Table IV. 2.2). For the sex separate rearing, females and males were used for the lighter and heavier market weights respectively, whereas for the comingled sex straight-run birds were used for both market weights. An estimate of feed intake for each market BW of each rearing system was determined using response surface analysis. Feed intake data for each gender across the experiment were fitted considering bird BW and digestible lysine level as the predictor variables:

$$Feed\ intake = intercept + \beta 1 \times BW + \beta 2 \times dLys + \beta 3 \times BW^2 + \beta 4 \times dLys^2 + \beta 5 \times BW\ \times dLys$$

Subsequently, using the same methodology, cut-up parts' (whole carcass, *pectoralis major*, *pectoralis minor*, whole wings, whole legs, and paws) weights were expressed in function of BW and digestible lysine to estimate each parts' weight for each market BW:

$$Cut - up\ weight = intercept + \beta 1 \times BW + \beta 2 \times dLys + \beta 3 \times BW^2 + \beta 4 \times dLys^2 + \beta 5 \times BW\ \times dLys$$

Isoquants for each market BW were set using the response surface equations, and combinations of feed intake with digestible lysine, and BW with digestible lysine obtained to determine feed intake and cut-up weights respectively.

There were nine price scenarios formulated, considering a combination of three feed prices (low – 80% of medium, medium, and high 120% of medium) with three meat prices (low – 80% of medium, medium, and high 120% of medium). The cut-up parts were based on the Urner Barry weekly insider's poultry report from May 26th 2016. Net returns were calculated based on the return from meat selling over feed costs with an associated fixed cost of \$0.009/bird when chicks were sex separated. All the previous data were analyzed and modeled using JMP Pro 12 (SAS Inst. Inc., Cary, NC) software.

RESULTS AND DISCUSSION

Bird performance data regarding the responses of each rearing system to the graded levels of digestible lysine were not evaluated herein and were presented elsewhere. The estimates and respective predictive models for bird individual feed intake needed to reach each of the two market BW according to the graded levels of digestible lysine, are presented on the Table IV – 2.3. Overall, estimates revealed males needing less feed to reach market weight, followed by straight-run, and then female birds. This is consistent with Groen, et al. (1998) findings, that when comparing the cost of producing 1 kg carcass, observed that males had a lower cost for feed (\$1.269) than females (\$1.370). It was also observed that digestible lysine levels did not affect females feed intake, but did affect males linearly, and straight-run quadratically. The different effects of digestible lysine present herein are also evident in the literature, where there is an incongruity of results (Bartov and Plavnik, 1998; Sklan and Noy, 2003; Sterling, et al., 2003; Sterling, et al., 2005; Plumstead, et al., 2007). Nevertheless, the effects of digestible lysine on feed intake at each market BW are depicted on Figures IV – 2.1, 2.2, 2.3, and 2.4. Even though digestible lysine did not significantly affect the feed intake of females, the isoquant set at 1,700 g of BW revealed that feed intake decreased as digestible lysine increased up to 1.165 % (minimum) starting to increase after (Figure IV – 2.1). Straight-run birds' feed intake behaved in a similar fashion, with a minimum at 1.165 % of dLys. For the heavier market weight, males had feed intake decreased linearly as digestible lysine increased (Figure IV – 2.3), whereas straight-run birds had feed intake affected quadratically presenting a minimum at 1.206 % of digestible lysine.

The estimated whole carcass WOG weights for the 1,700 g market BW are presented in Table IV – 2.4. No effects of digestible lysine were observed on carcass WOG weight for the female and straight-run birds sampled. The economic simulation showed that females had NRML at the lowest level of digestible lysine (0.90 % dLys = $2.0774/bird), whereas straight-run birds had NRML at 1.01 % of digestible lysine ($2.0490/bird). For the females, the highest gross returns corresponded to the highest net returns since 0.90 % of digestible lysine yielded a higher BW (Figure IV – 2.5) and lowest feed cost were estimated. Conversely for the straight-run birds, the gross returns were maximized at the highest level of digestible lysine not corresponding to the NRML. This indicates that birds had higher yields at the higher levels of digestible lysine (Figure IV – 2.5), but the costs of feed to attain these gains in yield did not compensate financially. Comparing the females and straight-run birds at each digestible lysine level, it was observed that sex separation resulted in increased revenue up to 1.00 % of digestible lysine. At the lowest levels of digestible lysine, the sex separation resulted in an extra $30,374 for the complex. In opposite, at the higher digestible lysine levels, sex separation resulted in $38,388 estimated losses for the complex. The economic effects of amino acid density (low, moderate, and high) and energy levels (low, moderate, and high) on Cobb 500 females targeted small whole carcass markets (1.0 kg eviscerated carcass) under high and low feed/meat price scenarios that were studied by Basurco, et al. (2015) previously. The authors state that for low market BW, the fixed costs (farm and processing) play a major role in the returns, being that the differences on performance induced by changing dietary factors (variable cost) are so diminished that they have little to no impact on the economic returns. Still, the authors observed that high energy density combined with either moderate or high amino acid density resulted in higher gross margins.

For the 2,900 g market BW, the estimated cut-up weights are presented on the Tables IV – 2.4 and 2.6. *Pectoralis major* increased linearly with a digestible lysine increase on males, whereas straight-run birds tended to be affected quadratically. The *pectoralis minor* was only affected significantly by a quadratic effect on males. Neither males nor straight-run birds had wings, legs, or paws affected significantly by digestible lysine. Still, the economic analysis revealed NRML at 1.30 % of digestible lysine for males ($2.8633/bird) and 1.14 % for straight-run birds ($2.7668/bird). Again for the sex separated birds, the level that maximized gross returns ($4.2477/bird) was the same that maximized net returns. Conversely, straight-run birds had the gross returns maximized ($4.1837/bird) at higher levels of digestible lysine (1.23 % dLys) than NRML. These differences are mainly related with the effects of digestible lysine on *pectoralis major* weight (Figure IV – 2.6), since this cut is the major contributor on the total gross returns for each bird (Table IV – 2.7). The isoquants presented on Figure IV – 2.6 show that for males the *pectoralis major* increased as digestible lysine increased, and for straight-run birds this muscle weight was maximized at 1.14% of digestible lysine. For both cases, the digestible lysine levels for *pectoralis major* cut weight maximization matched the NRML. It was interesting to observe that different cut-up parts had gross returns maximized at different digestible lysine levels. Therefore, variation on price for specific cuts throughout time should be considered when deciding dietary digestible lysine levels, since the NRML will vary with the price changes. For the advantages of sex separation over sex comingled, it was observed that regardless of digestible lysine level, sex separate birds always resulted in higher return. The economic advantage of sex separation for the complex varied from $59,256 to $141,852 in extra profit, when compared with the straight-run flocks. These differences in NRML observed between the two market weights have been described previously by Eits, et al. (2005), who evaluated the differences between dietary protein when formulating for profit or performance, and concluded that dietary balanced protein level of the diet should be based on how broilers are marketed.

The effects on NRML of the combination of low, medium, and high prices of feed and meat are described on the Table IV – 2.8. At first, the NRML were estimated for each meat price combination, subsequently the NRML for each rearing system was used to estimate the net returns for each complex, and then the economic advantages of sex separation were determined. For both market weights, as meat price increased the economic advantage of raising birds sex separate also increased. For the whole carcass market, the economic advantage of sex separation was present at any price scenario, and ranged from $17,752 to $32,689 of extra income per wk. It was evident that as feed prices increased the economic advantage of sex separation decreased, a fact that was probably related to males being economically more feed efficient than females (Groen, et al., 1998). The NRML for females were stable at 0.90 % of digestible lysine for females regardless of price scenario, whereas in the straight-run birds NRML slightly decreased as feed prices increased. The heavy bird market results also showed sex separation to have more of an economic advantage than sex comingled. Contrarily to the low market weight, the heavy bird market net returns showed that the economic advantage of sex separation increased as price of feed increased. This economic advantage ranged from $66,227 at low meat and feed prices, to $107,441 at high feed and meat price per wk. As expected, digestible lysine levels determined for gross returns did not vary, but the NRML did vary with changes in price of feed and meat for the straight-run birds. As meat prices increased the NRML for straight-run birds increased, and in opposite direction, as feed prices increased NRML decreased. Male birds NRML (1.30 % dLys) did not change with the various price scenarios. The usage of increased dietary amino acid density when meat prices are higher has been suggested previously by Dozier, et al. (2006b). In a set of two studies, these authors evaluated the effects of amino acid density (low, moderate, or high) for the withdrawal period (36 to 56 d) on the economic feasibility under twenty-four scenarios for straight-run Ross 708 birds. The authors concluded that the most economic advantages of feeding high amino acid densities come when meat prices were considered the highest. Decreasing meat prices reduced the economic differences between the treatments. Considering a complex of 1 million broilers per wk, the authors estimated that feeding high amino acid density diets under a base price of meat and feed, could result in an additional income of $7,000 and $11,000/wk when comparing with medium and low amino acid densities.

The differences in the economical responses can be better understood when evaluating the partial contribution of each cut-up part on the gross returns against the cost of feed (Figure

IV – 2.6). For the 1,700 g females as digestible lysine increased, cost of feeding increased, and the gross and net returns decreased. On the other hand for the straight-run 1,700 g birds, as digestible lysine increased, gross returns increased, but cost of feed showed a minimum at 0.97 % of digestible lysine, which resulted in a NRML of 1.01 % of digestible lysine. The returns at heavier market weights were mainly determined by the *pectoralis major* and leg contributions. In the case of males, the cost of feeding increased with digestible lysine, but so did the increase in gross returns on *pectoralis major*, legs (maximum gross return at 1.25 % dLys), and wings. Therefore, the NRML for this gender were set at the highest level of digestible lysine tested (1.30 % dLys). For the heavy market straight-run birds, the cost of feeding also increased as digestible lysine increased, but *pectoralis major*, legs, and wings' gross returns were maximized at 1.14, 1.30, and 1.21 % of digestible lysine respectively. Consequently, considering the cost of feed over the gross returns from the several cut-up parts, the NRML was determined at 1.14 of digestible lysine.

When combining the results of each market BW to compare sex separate *vs.* straight-run rearing system when using NRML of digestible lysine, it was observed that sex separation resulted in increased returns regardless of the feed and meat price scenarios ($85,013 to $13,669 of extra return from sex separation). Overall, as meat prices increased the benefits of raising sex separate also increased. It is noteworthy to point out that returns of sex separation also increased as feed prices increased, revealing that sex separation might be especially beneficial at the times that feed is expensive and companies might have shorter profit margins. Besides the evident advantage of sex separation on the economics of a company, one could debate that if the sexing cost increased it might turn sex separation to not be feasible. Consequently, it was determined how much sexing cost would be allowed to increase, for a low meat and feed price scenario

(scenario with the lowest returns from sex separation), in order to make the returns from both systems equal. Results revealed that under the worst case scenario, sex separation would start to be economically unfavorable if sexing cost increased to values higher than $0.056/bird, which is roughly six times the cost used here ($0.009). Consequently, it is evident that there is a large margin for sexing cost to vary and still be economically favorable. At last, it should be considered all the economic simulation were performed for a production period of a wk. If the net returns for the year are considered at NRML of digestible lysine, it is observed that the extra returns from sex separation could range from $4,420,676 to $7,262,788 yearly, which can impact greatly companies' revenue.

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Table IV – 2.1 Ingredient composition (%) and formulated nutrient contents of the starter, grower with differing levels of digestible lysine and finisher diets

Diet blend	Starter	Low	80%Low 20%High	60%Low 40%High	40%Low 60%High	20%Low 80%High	High	Finisher
% dLys	1.32	0.90	0.98	1.06	1.14	1.22	1.30	1.05
Price ($)	317.35	263.88	274.23	284.58	294.94	305.29	315.64	253.35
Corn	47.90	61.58	58.68	55.78	52.88	49.98	47.08	64.72
Soybean Meal, 48%	36.14	24.22	26.63	29.04	31.46	33.87	36.28	19.15
Distillers dried grains/solubles	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Poultry by-product meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	5.00
DL-Methionine	0.34	0.15	0.16	0.18	0.19	0.20	0.22	0.16
L-Lysine-HCl, 78%	0.21	0.03	0.06	0.09	0.12	0.16	0.19	0.11
L-Threonine, 98.5%	0.09	0.00	0.02	0.04	0.06	0.07	0.09	0.01
Poultry Fat	3.77	2.64	3.08	3.53	3.97	4.42	4.86	3.25
Limestone	0.55	0.53	0.53	0.53	0.52	0.52	0.52	0.38
Defluorinated phosphate, 18%	1.18	1.01	1.00	0.98	0.97	0.95	0.93	0.42
Salt (NaCl)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin Premix[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix[2]	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Nicarbazin[3]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	-
Salinomycin[4]	-	-	-	-	-	-	-	0.04
BMD[5]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Virginiamycin[6]	-	-	-	-	-	-	-	0.03
Calculated nutrient composition								
ME, kcal/g	3,050	3,110	3,110	3,110	3,110	3,110	3,110	3,200
CP, %	24.37	19.50	20.45	21.41	22.37	23.32	24.28	18.54
Calcium, %	0.96	0.87	0.87	0.87	0.87	0.87	0.87	0.78
Total phosphorus, %	0.74	0.68	0.68	0.68	0.69	0.69	0.70	0.63
Available phosphorus, %	0.48	0.44	0.44	0.44	0.44	0.44	0.44	0.39
Potassium, %	0.92	0.72	0.76	0.80	0.84	0.88	0.92	0.64
Chloride, %	0.35	0.31	0.32	0.32	0.33	0.33	0.34	0.33
Sodium, %	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.25
dArg, %	1.45	1.13	1.19	1.26	1.32	1.39	1.46	1.04
dIle, %	0.90	0.71	0.75	0.78	0.82	0.86	0.90	0.65
dLeu, %	1.82	1.56	1.61	1.66	1.72	1.77	1.82	1.50
dLys, %	1.32	0.90	0.98	1.06	1.14	1.22	1.30	0.88
dMet, %	0.67	0.43	0.45	0.48	0.50	0.52	0.55	0.43
dTSAA, %	0.98	0.70	0.73	0.76	0.80	0.83	0.86	0.69
dThr, %	0.86	0.62	0.67	0.72	0.77	0.82	0.87	0.59
dTrp, %	0.25	0.19	0.20	0.21	0.22	0.24	0.25	0.17
dVal, %	0.99	0.80	0.84	0.88	0.92	0.95	0.99	0.76

[1] Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B12 (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[2] Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO4.H2O), 101 mg; iron (FeSO4.7H2O), 20 mg; zinc (Zn)), 80 mg; copper (CuSO4.5H2O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

[3] Nicarb® 25% (Nicarbazine – Type A) – 100 ppm of nicarbazin provided in the final feed

[4] Bio-Cox® 60 (Salynomycin – Type A) – provided 50 g of salinomycin per ton of the final diet

[5] BMD (Bacitracin Methylene Disalicylate – Type A) – provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

[6] Stafac® 50 (Virginiamycin – Type A) – provided 50 g of virginiamycin per ton of the final diet

Table IV – 2.2 Simulation of a production scenario in a 1,800,000 broiler complex when using a sex separate *vs.* straight-run regime

Production strategy for 2 market BW (1,800,000 birds complex)				
Rearing system		Number of birds allocated per market BW		Cost of sexing ($/bird)
		1,700	2,900	
Sex separated	Female	900,000	0	0.009
	Male	0	900,000	
Sex comingled	Straight-run	900,000	900,000	0

Table IV – 2.3 Predictive models and estimated feed intake (FI) based on BW of Ross 708 raised straight-run or sex separate at two market ages

Rearing system	R^2	Equations
Female	0.98	$FI = -332.3149-145.9255\times dLys+1.9390223\times BW+1222.1304\times(dLys-1.1)^2-0.114236\times(dLys-1.1)\times(BW-1576.28)+0.0001505\times(BW-1576.28)^2$
Male	0.99	$FI = 197.46565-450.7847\times dLys+1.7580987\times BW-154.9007\times(dLys-1.09775)^2-0.239724\times(dLys-1.09775)\times(BW-1733.72)+0.000070987\times BW-1733.72)^2$
Straight-run	0.99	$FI = -19.39127-352.2642\times dLys+1.8270244\times BW+2716.5646\times(dLys-1.09865)^2-0.184636\times(dLys-1.09865)\times(BW-1663)+0.0001046\times(BW-1663)^2$

Source of variation	*P*-value		
	Female	Male	Straight-run
dLys	0.4557	0.002	0.025
BW	<0.001	<0.001	<0.001
dLys*dLys	0.4699	0.900	0.044
dLys*BW	0.5892	0.080	0.232
BW*BW	0.0011	0.004	0.001

Digestible Lysine (%)	Market BW (g)					
	1,700	2,900	1,700	2,900	1,700	2,900
	Female		Male		Straight-run	
	Estimated feed intake (g)					
0.90	2,887	5,502	2,773	5,036	2,878	5,275
0.92	2,874	5,487	2,765	5,023	2,851	5,242
0.94	2,863	5,473	2,757	5,009	2,825	5,213
0.96	2,852	5,460	2,750	4,995	2,802	5,185
0.98	2,843	5,447	2,741	4,982	2,781	5,159
1.00	2,834	5,436	2,733	4,968	2,762	5,136
1.02	2,826	5,426	2,725	4,954	2,745	5,114
1.04	2,820	5,416	2,717	4,939	2,730	5,095
1.06	2,814	5,408	2,708	4,925	2,718	5,079
1.08	2,809	5,400	2,699	4,911	2,707	5,064
1.10	2,806	5,394	2,690	4,896	2,699	5,051
1.12	2,803	5,389	2,682	4,881	2,693	5,041
1.14	2,801	5,384	2,672	4,867	2,689	5,033
1.16	2,801	5,381	2,663	4,852	2,688	5,027
1.18	2,801	5,378	2,654	4,837	2,688	5,023
1.20	2,802	5,377	2,645	4,821	2,691	5,021
1.22	2,804	5,376	2,635	4,806	2,696	5,022
1.24	2,807	5,376	2,625	4,791	2,703	5,024
1.26	2,811	5,378	2,616	4,775	2,712	5,029
1.28	2,817	5,380	2,606	4,759	2,724	5,036
1.30	2,823	5,383	2,596	4,744	2,738	5,045

Figure IV – 2.1 Response surface graph and respective response contour plot to evaluate feed intake needed when varying levels of digestible lysine for an isoquant set to the target market BW of 1,700 g for Ross 708 females

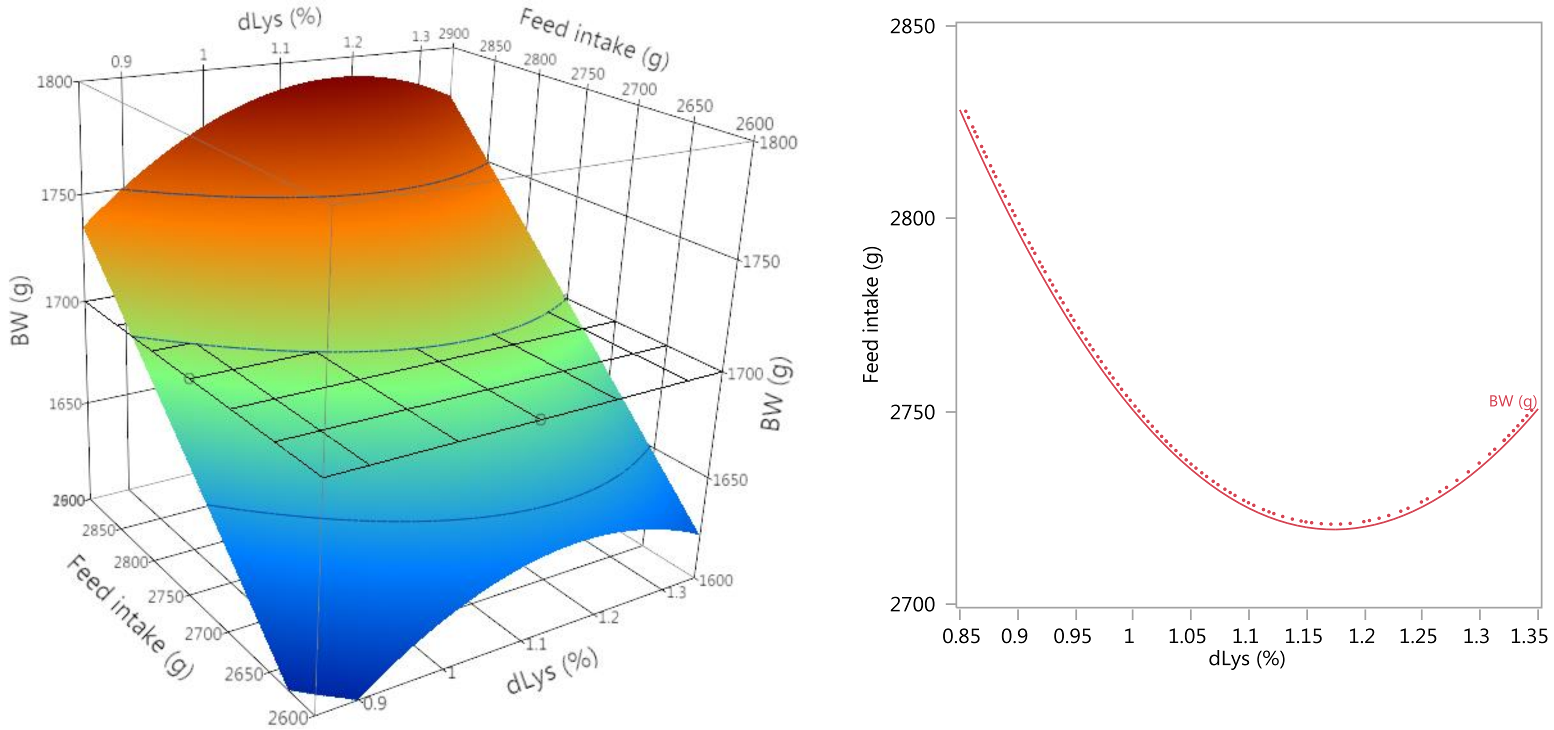


Figure IV – 2.2 Response surface graph and respective response contour plot to evaluate feed intake needed when varying levels of digestible lysine for an isoquant set to the target market BW of 1,700 g for Ross 708 straight-run birds

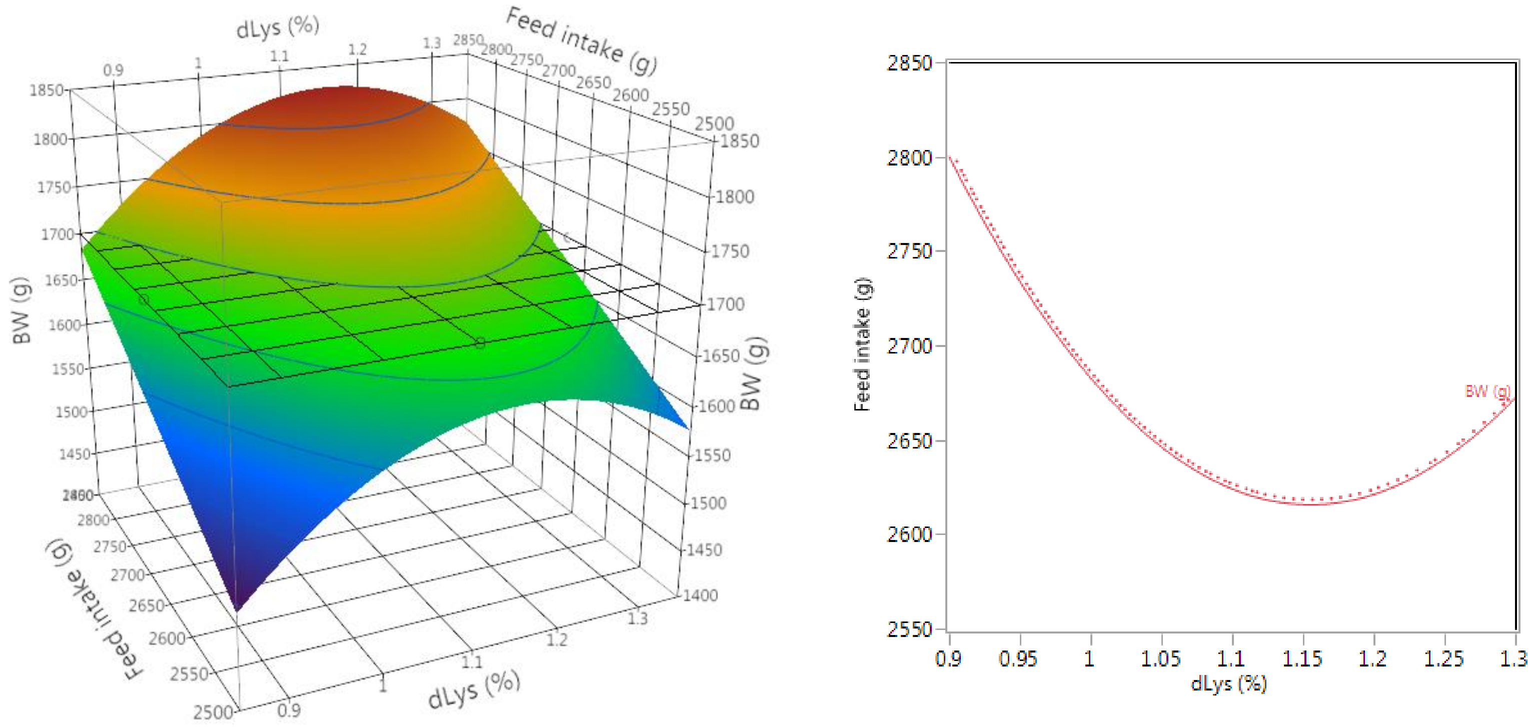


Figure IV – 2.3 Response surface graph and respective response contour plot to evaluate feed intake needed when varying levels of digestible lysine for an isoquant set to the target market BW of 2,900 g for Ross 708 males

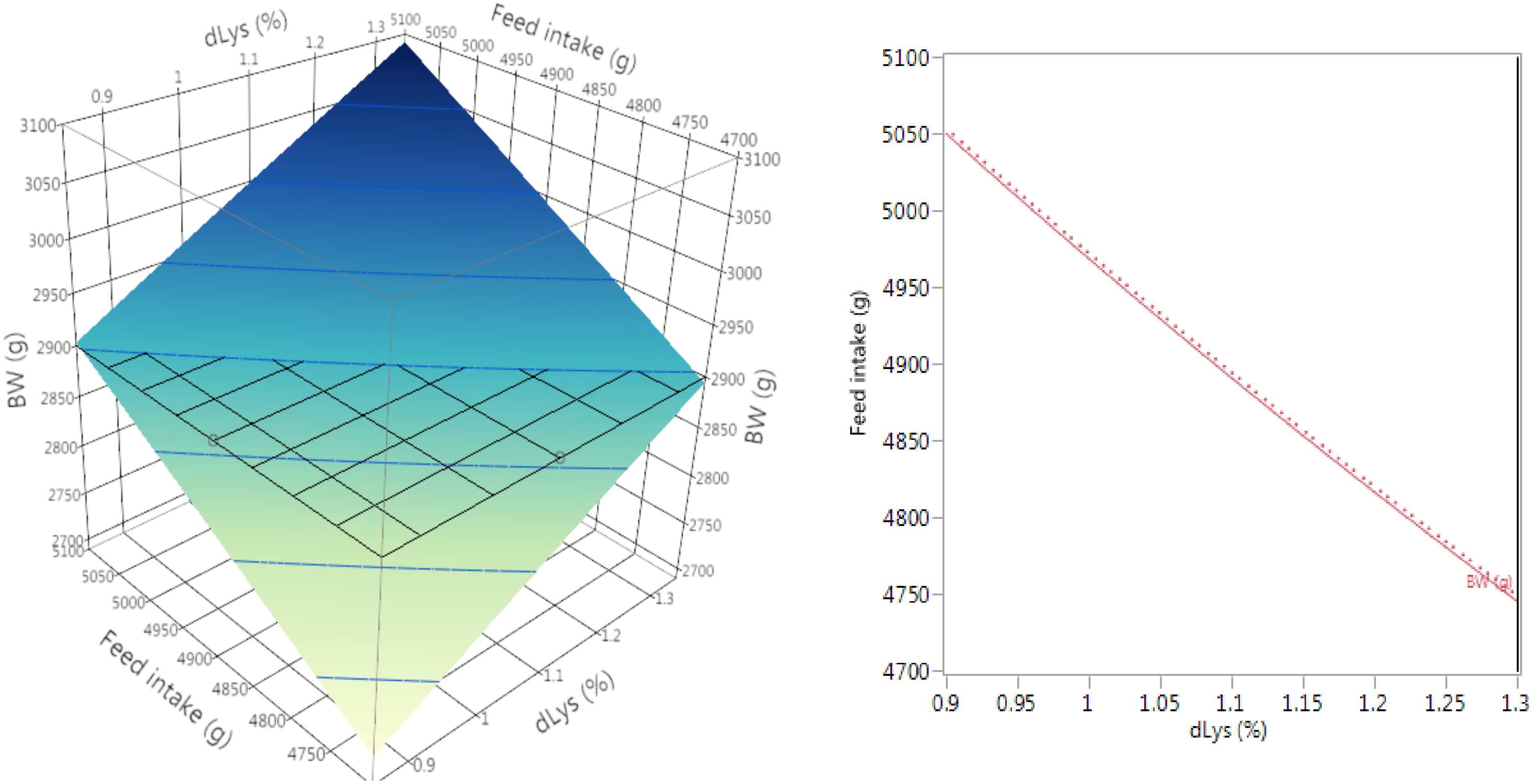


Figure IV – 2.4 Response surface graph and respective response contour plot to evaluate feed intake needed when varying levels of digestible lysine for an isoquant set to the target market BW of 2,900 g for Ross 708 straight-run birds

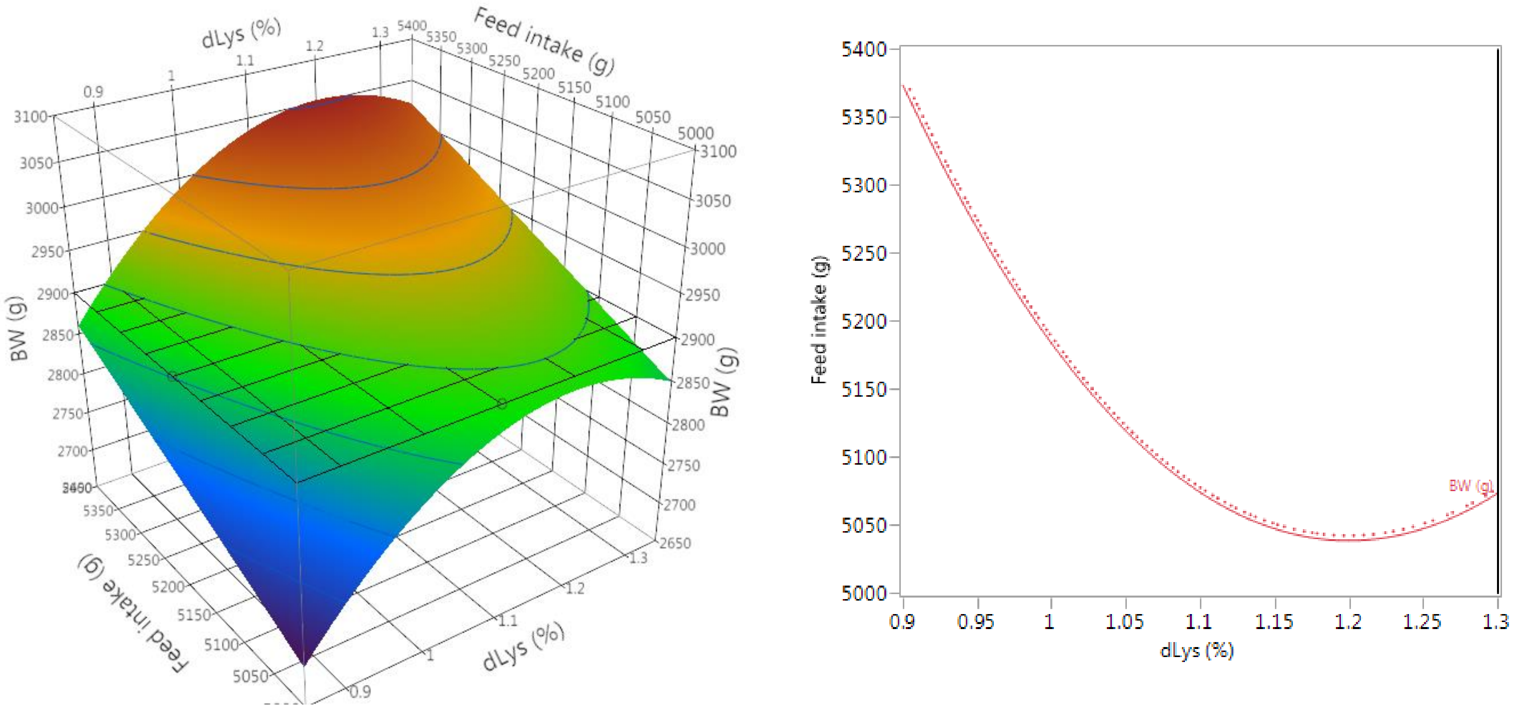


Table IV – 2.4 Predictive models and estimated whole carcass (WOG – without giblets), *pectoralis major*, *pectoralis minor*, weight outputs based on BW of Ross 708 broilers raised straight-run or sex separate at two market ages

Parameter	Rearing system	R^2	Equation
Whole carcass (WOG[1])	Female	0.99	$Y = -68.3831+4.4095326\times dLys+0.8145763\times BW+62.507963\times(dLys-1.10068)^2+0.0514559\times(dLys-1.10068)\times(BW-2118.12)+0.0000222\times(BW-2118.12)^2$
	Male	0.99	$Y = -130.427+16.193739\times dLys+0.8246125\times BW-71.89149\times(dLys-1.09862)^2+0.0537611\times(dLys-1.09862)\times(BW-2361.7)+0.000016947\times(BW-2361.7)^2$
	Straight-run	0.99	$Y = -104.1682+37.880891\times dLys+0.8141891\times BW+84.508894\times(dLys-1.09857)^2-0.0069\times(dLys-1.09857)\times(BW-2183.45)-0.00002543\times(BW-2183.45)^2$
Pectoralis major	Female	0.99	$Y = -127.8675+39.123545\times dLys+0.2465021\times BW+210.97778\times(dLys-1.09932)^2+0.0339889\times(dLys-1.09932)\times(BW-2101.61)+0.0000013434\times(BW-2101.61)^2$
	Male	0.99	$Y = -174.8031+55.001943\times dLys+0.2526633\times BW+205.84421\times(dLys-1.10414)^2+0.0089593\times(dLys-1.10414)\times(BW-2342.08)+0.0000041182\times(BW-2342.08)^2$
	Straight-run	0.98	$Y = -79.26125+6.6212453\times dLys+0.2485065\times BW-312.9099\times(dLys-1.10203)^2+0.0210687\times(dLys-1.10203)\times(BW-2192.27)-0.00006134\times(BW-2192.27)^2$
Pectoralis minor	Female	0.95	$Y = -1.868365+0.7765098\times dLys+0.0472922\times BW-12.00887\times(dLys-1.1)^2+0.0033955\times(dLys-1.1)\times(BW-2109.13)-0.000022\times(BW-2109.13)^2$
	Male	0.96	$Y = -7.534428+2.9286489\times dLys+0.0440347\times BW-98.22289\times(dLys-1.10068)^2+0.0045832\times(dLys-1.10068)\times(BW-2351.16)+0.000001542\times(BW-2351.16)^2$
	Straight-run	0.96	$Y = -12.93772+5.9165231\times dLys+0.0490894\times BW-41.42525\times(dLys-1.1)^2+0.0194045\times(dLys-1.1)\times(BW-2202.24)-0.00002157\times(BW-2202.24)^2$

Source of variation	*P*-value								
	Whole carcass			*Pectoralis major*			*Pectoralis minor*		
	Female	Male	Straight-run	Female	Male	Straight-run	Female	Male	Straight-run
dLys	0.842	0.498	0.071	0.010	0.002	0.746	0.887	0.590	0.263
BW	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
dLys*dLys	0.748	0.723	0.646	0.106	0.167	0.088	0.799	0.039	0.379
dLys*BW	0.221	0.197	0.889	0.226	0.763	0.640	0.742	0.626	0.095
BW*BW	0.342	0.531	0.460	0.931	0.830	0.023	<0.001	0.802	0.002

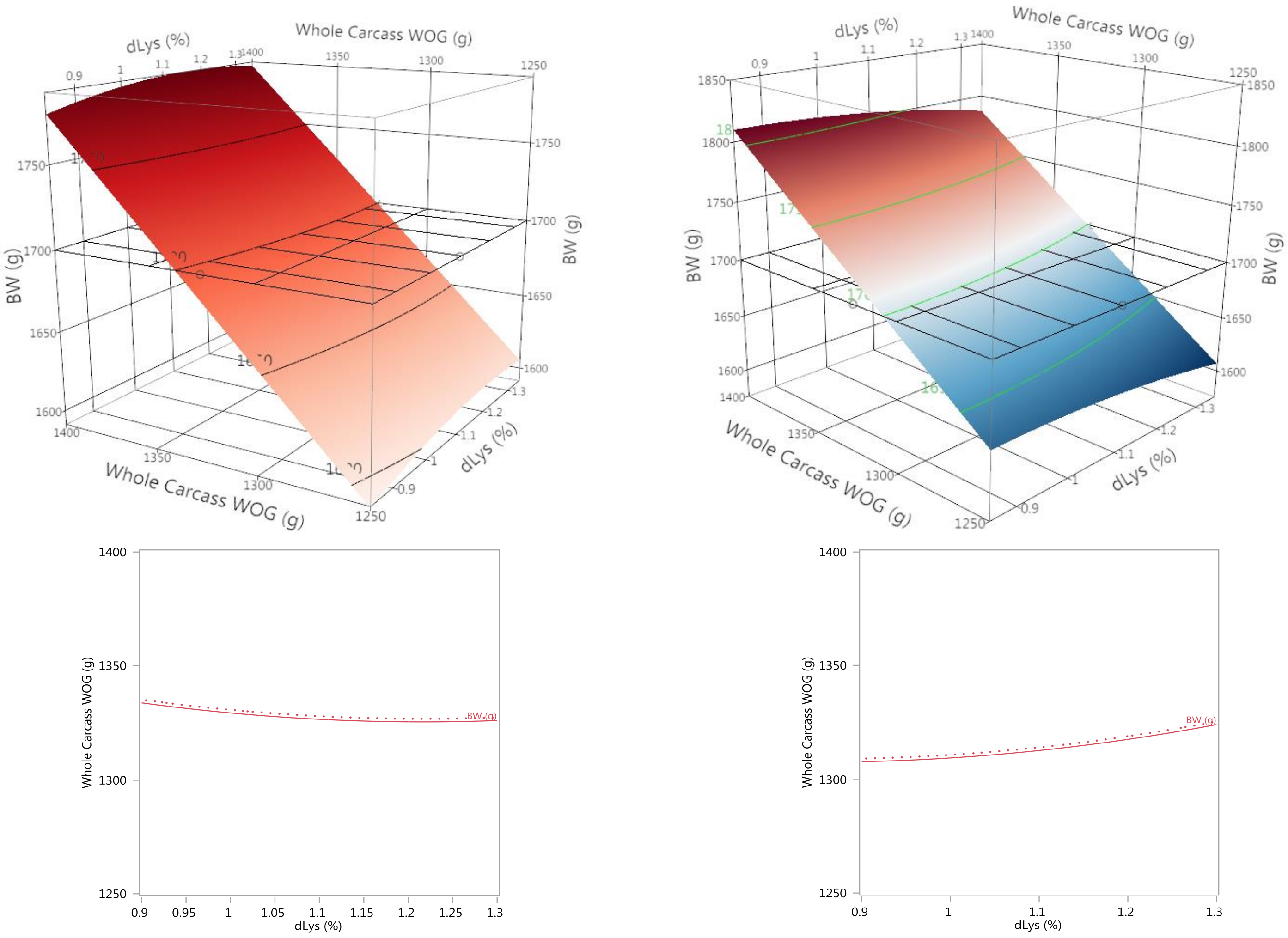
Digestible Lysine (%)	Market BW (g)											
	1,700	2,900	1,700	2,900	1,700	2,900	1,700	2,900	1,700	2,900	1,700	2,900
	Female	Male	Straight-Run		Female	Male	Straight-Run		Female	Male	Straight-Run	
	Whole carcass weight				*Pectoralis major*				*Pectoralis minor*			
	Estimated part weight (g)											
0.90	1,331	2,272	1,311	2,282	337.7	616.3	323.6	600.9	75.3	118.8	70.7	119.9
0.92	1,330	2,273	1,311	2,282	336.6	615.9	325.9	603.7	75.4	119.7	70.9	120.6
0.94	1,329	2,275	1,311	2,282	335.7	615.6	328.0	606.3	75.5	120.4	71.1	121.3
0.96	1,329	2,276	1,312	2,283	335.0	615.6	329.9	608.6	75.6	121.1	71.3	121.9
0.98	1,328	2,277	1,312	2,283	334.4	615.7	331.4	610.7	75.6	121.8	71.4	122.5
1.00	1,327	2,279	1,312	2,283	334.0	615.9	332.8	612.5	75.6	122.3	71.6	123.1
1.02	1,327	2,280	1,313	2,283	333.7	616.3	333.8	614.1	75.7	122.8	71.6	123.6
1.04	1,326	2,281	1,314	2,284	333.6	616.9	334.7	615.4	75.7	123.2	71.7	124.1
1.06	1,326	2,282	1,314	2,284	333.7	617.7	335.2	616.5	75.7	123.5	71.7	124.6
1.08	1,326	2,283	1,315	2,285	334.0	618.6	335.6	617.4	75.7	123.7	71.6	125.0
1.10	1,325	2,284	1,316	2,286	334.4	619.7	335.6	617.9	75.7	123.9	71.6	125.4
1.12	1,325	2,285	1,317	2,286	335.0	620.9	335.5	618.3	75.7	123.9	71.5	125.8
1.14	1,325	2,285	1,317	2,287	335.8	622.3	335.0	618.3	75.7	123.9	71.4	126.1
1.16	1,324	2,286	1,318	2,288	336.7	623.9	334.4	618.2	75.6	123.8	71.2	126.4
1.18	1,324	2,287	1,320	2,289	337.8	625.7	333.4	617.8	75.6	123.7	71.0	126.7
1.20	1,324	2,287	1,321	2,290	339.1	627.6	332.3	617.1	75.5	123.4	70.8	127.0
1.22	1,324	2,288	1,322	2,291	340.6	629.6	330.8	616.2	75.5	123.1	70.5	127.2
1.24	1,324	2,289	1,323	2,292	342.2	631.9	329.2	615.0	75.4	122.7	70.2	127.3
1.26	1,324	2,289	1,324	2,293	344.0	634.3	327.2	613.6	75.3	122.2	69.9	127.5
1.28	1,324	2,289	1,326	2,294	345.9	636.8	325.1	611.9	75.2	121.7	69.6	127.6
1.30	1,324	2,290	1,327	2,296	348.0	639.6	322.6	610.0	75.1	121.0	69.2	127.7

Table IV – 2.5 Estimate of dietary digestible lysine (dLys) NRML[1] from selling whole chicken carcasses (WOG) at 1,700 g market weight on a production scenario of a 900,000 Ross 708 broiler complex when using a sex separate (females) *vs.* straight-run under medium feed and meat prices

Estimate of dLys NRML at medium feed and meat prices for a 1,700 g whole WOG carcass market									
dLys	Feed cost ($/bird)		Gross return ($/bird)		Net return ($/bird)		Net return complex ($)		Returns from sex
(%)	Female	Straight-run	Female	Straight-run	Female	Straight-run	Female	Straight-run	separation ($)
0.90	0.7887	0.7876	2.8751	2.8313	2.0774	2.0436	1,869,650	1,839,276	30,374
0.91	0.7901	0.7869	2.8742	2.8315	2.0751	2.0445	1,867,588	1,840,070	27,518
0.92	0.7916	0.7863	2.8734	2.8317	2.0728	2.0453	1,865,506	1,840,799	24,707
0.93	0.7931	0.7859	2.8725	2.8319	2.0704	2.0461	1,863,404	1,841,462	21,942
0.94	0.7946	0.7855	2.8717	2.8322	2.0681	2.0467	1,861,281	1,842,056	19,224
0.95	0.7962	0.7852	2.8709	2.8326	2.0657	2.0473	1,859,135	1,842,580	16,555
0.96	0.7979	0.7851	2.8702	2.8329	2.0633	2.0478	1,856,967	1,843,032	13,935
0.97	0.7996	0.7851	2.8694	2.8333	2.0609	2.0482	1,854,775	1,843,410	11,365
0.98	0.8013	0.7852	2.8687	2.8338	2.0584	2.0486	1,852,558	1,843,712	8,846
0.99	0.8031	0.7854	2.8680	2.8342	2.0559	2.0488	1,850,316	1,843,936	6,380
1.00	0.8050	0.7858	2.8674	2.8347	2.0534	2.0490	1,848,048	1,844,081	3,967
1.01	0.8069	0.7862	2.8667	2.8353	2.0508	2.0490	1,845,752	1,844,143	1,609
1.02	0.8089	0.7869	2.8661	2.8359	2.0483	2.0490	1,843,429	1,844,123	-694
1.03	0.8109	0.7876	2.8656	2.8365	2.0456	2.0489	1,841,076	1,844,016	-2,940
1.04	0.8130	0.7885	2.8650	2.8372	2.0430	2.0487	1,838,694	1,843,823	-5,129
1.05	0.8152	0.7895	2.8645	2.8379	2.0403	2.0484	1,836,281	1,843,540	-7,259
1.06	0.8174	0.7906	2.8640	2.8386	2.0376	2.0480	1,833,837	1,843,166	-9,329
1.07	0.8197	0.7919	2.8635	2.8394	2.0348	2.0474	1,831,360	1,842,699	-11,338
1.08	0.8220	0.7933	2.8631	2.8402	2.0321	2.0468	1,828,850	1,842,137	-13,286
1.09	0.8245	0.7949	2.8627	2.8410	2.0292	2.0461	1,826,307	1,841,478	-15,171
1.10	0.8269	0.7966	2.8623	2.8419	2.0264	2.0452	1,823,728	1,840,720	-16,992
1.11	0.8295	0.7985	2.8620	2.8428	2.0235	2.0443	1,821,114	1,839,862	-18,748
1.12	0.8321	0.8005	2.8616	2.8437	2.0205	2.0432	1,818,463	1,838,901	-20,438
1.13	0.8348	0.8027	2.8613	2.8447	2.0175	2.0420	1,815,775	1,837,836	-22,061
1.14	0.8375	0.8050	2.8610	2.8458	2.0145	2.0407	1,813,048	1,836,664	-23,616
1.15	0.8404	0.8075	2.8608	2.8468	2.0114	2.0393	1,810,282	1,835,384	-25,102
1.16	0.8433	0.8101	2.8606	2.8479	2.0083	2.0378	1,807,477	1,833,994	-26,518
1.17	0.8462	0.8129	2.8604	2.8490	2.0051	2.0361	1,804,630	1,832,493	-27,862
1.18	0.8493	0.8159	2.8602	2.8502	2.0019	2.0343	1,801,742	1,830,877	-29,135
1.19	0.8524	0.8190	2.8601	2.8514	1.9987	2.0324	1,798,811	1,829,145	-30,334
1.20	0.8556	0.8223	2.8599	2.8527	1.9954	2.0303	1,795,837	1,827,296	-31,458
1.21	0.8588	0.8258	2.8599	2.8539	1.9920	2.0281	1,792,819	1,825,327	-32,508
1.22	0.8622	0.8294	2.8598	2.8553	1.9886	2.0258	1,789,755	1,823,236	-33,481
1.23	0.8656	0.8332	2.8598	2.8566	1.9852	2.0234	1,786,646	1,821,022	-34,376
1.24	0.8691	0.8372	2.8598	2.8580	1.9817	2.0208	1,783,490	1,818,683	-35,193
1.25	0.8727	0.8414	2.8598	2.8594	1.9781	2.0180	1,780,286	1,816,216	-35,930
1.26	0.8763	0.8457	2.8598	2.8609	1.9745	2.0151	1,777,033	1,813,621	-36,587
1.27	0.8801	0.8503	2.8599	2.8624	1.9708	2.0121	1,773,732	1,810,894	-37,163
1.28	0.8839	0.8550	2.8600	2.8639	1.9671	2.0089	1,770,380	1,808,035	-37,655
1.29	0.8878	0.8599	2.8601	2.8655	1.9633	2.0056	1,766,976	1,805,040	-38,064
1.30	0.8918	0.8650	2.8603	2.8671	1.9595	2.0021	1,763,521	1,801,909	-38,388

[1] NRML – Net returns maximization level (pink and green cells represent maximums for female and straight-run birds respectively)

Figure IV – 2.5 Response surface graph and respective response contour plot to estimate whole carcass weight based on 1,700g market BW (isoquant) when varying levels of digestible lysine for Ross 708 female and straight-run birds



Female

Straight-run

Table IV – 2.6 Predictive models and estimated legs, wings, and paws weight outputs based on BW of Ross 708 broilers raised straight-run or sex separate at two market ages

Parameter	Rearing system	R^2	Equation
Wings	Female	0.99	Y = 30.037901-8.940106×dLys+0.0676403×BW-25.31223×(dLys-1.09661)^2-0.000762×(dLys-1.09661)×(BW-2102.53)-0.0000008045×(BW-2102.53)^2
	Male	0.98	Y = 9.7541018+1.7888861×dLys+0.0728576×BW+6.4334815×(dLys-1.10068)^2+0.0006765×(dLys-1.10068)×(BW-2351.16)-0.000006847×(BW-2351.16)^2
	Straight-run	0.97	Y = 22.316953-0.038247×dLys+0.070303×BW-65.91098×(dLys-1.1)^2+0.020504×(dLys-1.1)×(BW-2202.24)-0.00001761×(BW-2202.24)^2
Legs	Female	0.98	Y = 1.81798-12.94186×dLys+0.2193233×BW-179.0289×(dLys-1.1)^2-0.048872×(dLys-1.1)×(BW-2109.13)+0.000034376×(BW-2109.13)^2
	Male	0.99	Y = -19.92046+1.5080849×dLys+0.2236642×BW-65.90827×(dLys-1.10414)^2+0.0316779×(dLys-1.10414)×(BW-2342.08)+0.000011643×(BW-2342.08)^2
	Straight-run	0.98	Y = -6.483433+5.4334933×dLys+0.2208033×BW+6.9111949×(dLys-1.1)^2+0.0785686×(dLys-1.1)×(BW-2202.24)-0.00004151×(BW-2202.24)^2
Paws	Female	0.93	Y = 21.347332-2.226394×dLys+0.0239739×BW-53.64075×(dLys-1.1)^2-0.006344×(dLys-1.1)×(BW-2109.13)+0.000011588×(BW-2109.13)^2
	Male	0.98	Y = 17.428277-1.683969×dLys+0.0317074×BW-11.82981×(dLys-1.09724)^2+0.0057751×(dLys-1.09724)×(BW-2342.05)-0.000001473×(BW-2342.05)^2
	Straight-run	0.96	Y = 13.87864+4.6322182×dLys+0.0272169×BW+13.465912×(dLys-1.1)^2+0.0095197×(dLys-1.1)×(BW-2202.24)-0.0000009519×(BW-2202.24)^2

Source of variation	*P*-value								
	Wings			Legs			Paws		
	Female	Male	Straight-run	Female	Male	Straight-run	Female	Male	Straight-run
dLys	0.041	0.741	0.996	0.450	0.924	0.768	0.525	0.574	0.124
BW	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
dLys*dLys	0.497	0.890	0.281	0.230	0.628	0.967	0.082	0.644	0.613
dLys*BW	0.925	0.942	0.172	0.135	0.251	0.055	0.340	0.268	0.148
BW*BW	0.858	0.268	0.049	0.060	0.511	0.085	0.003	0.660	0.804

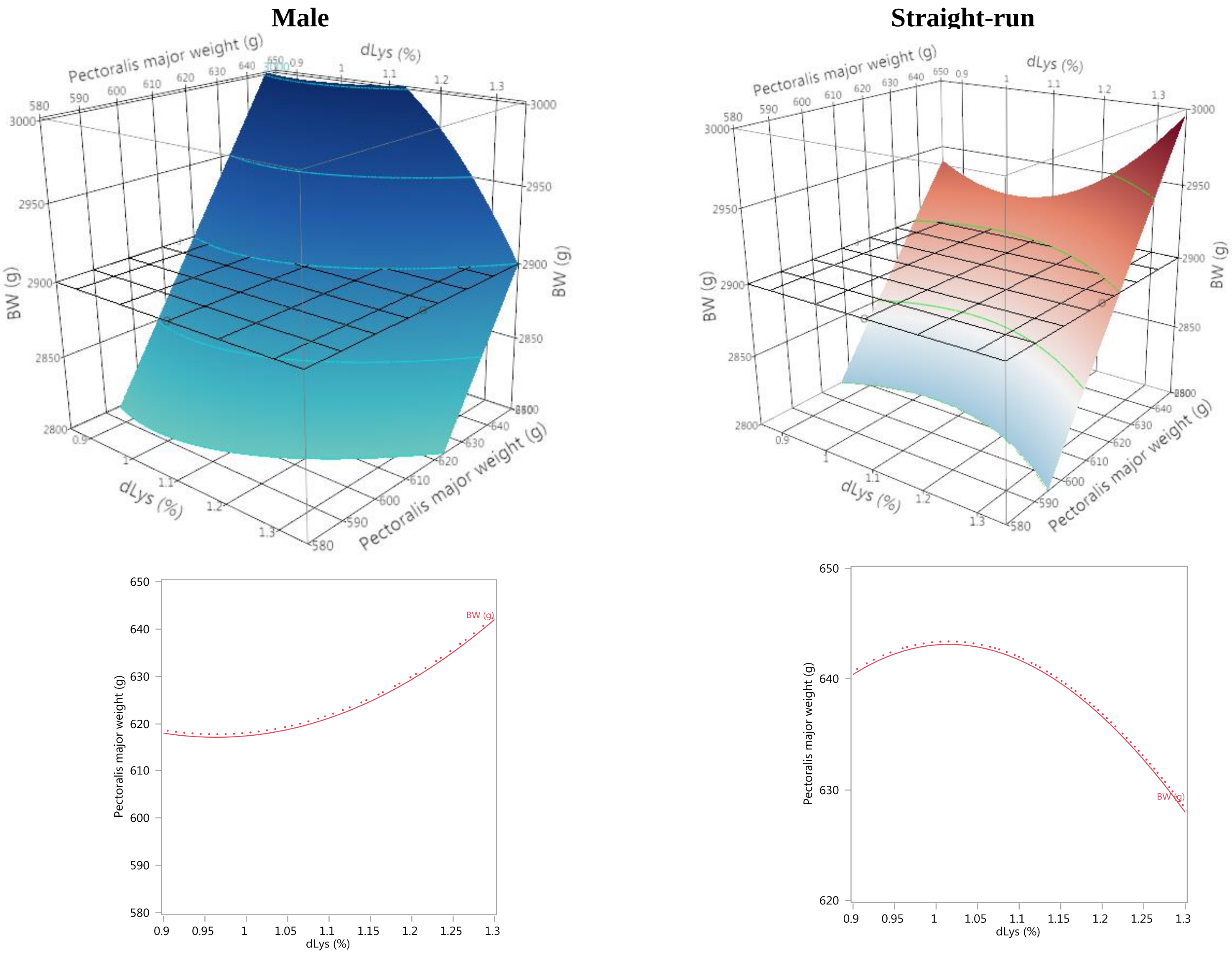
Digestible Lysine (%)	Market BW (g)											
	1,700	2,900	1,700	2,900	1,700	2,900	1,700	2,900	1,700	2,900	1,700	2,900
	Female	Male	Straight-Run		Female	Male	Straight-Run		Female	Male	Straight-Run	
	Whole carcass weight				*Pectoralis major*				*Pectoralis minor*			
	Estimated part weight (g)											
0.90	135.8	220.8	136.8	212.1	357.6	627.3	371.5	607.8	59.4	106.3	65.6	95.7
0.92	135.8	220.8	137.1	212.9	359.1	628.2	370.7	609.0	59.8	106.4	65.5	95.8
0.94	135.8	220.8	137.3	213.6	360.5	629.1	370.0	610.1	60.2	106.5	65.4	96.0
0.96	135.8	220.8	137.5	214.3	361.7	629.9	369.3	611.3	60.5	106.6	65.3	96.1
0.98	135.8	220.8	137.6	214.9	362.8	630.6	368.6	612.5	60.8	106.7	65.2	96.3
1.00	135.7	220.8	137.7	215.5	363.7	631.3	367.9	613.7	61.0	106.8	65.2	96.4
1.02	135.6	220.8	137.8	216.0	364.5	631.9	367.2	614.8	61.2	106.9	65.1	96.6
1.04	135.5	220.8	137.7	216.5	365.1	632.5	366.5	616.0	61.4	106.9	65.1	96.8
1.06	135.4	220.9	137.7	216.9	365.6	633.0	365.8	617.2	61.5	107.0	65.0	97.0
1.08	135.2	220.9	137.5	217.3	366.0	633.5	365.1	618.4	61.6	107.0	65.0	97.2
1.10	135.1	220.9	137.3	217.6	366.2	633.9	364.4	619.6	61.6	107.1	65.0	97.4
1.12	134.9	221.0	137.1	217.8	366.3	634.3	363.7	620.8	61.6	107.1	65.0	97.7
1.14	134.7	221.0	136.8	218.0	366.2	634.6	363.0	622.0	61.5	107.1	65.0	97.9
1.16	134.4	221.1	136.5	218.2	366.0	634.9	362.4	623.3	61.4	107.1	65.0	98.2
1.18	134.2	221.2	136.1	218.3	365.6	635.1	361.7	624.5	61.3	107.1	65.1	98.4
1.20	133.9	221.2	135.7	218.3	365.1	635.2	361.1	625.7	61.1	107.1	65.1	98.7
1.22	133.6	221.3	135.2	218.3	364.5	635.3	360.4	626.9	60.9	107.1	65.2	99.0
1.24	133.3	221.4	134.6	218.3	363.7	635.4	359.8	628.2	60.6	107.1	65.2	99.3
1.26	133.0	221.5	134.0	218.2	362.7	635.4	359.1	629.4	60.3	107.0	65.3	99.6
1.28	132.7	221.5	133.4	218.0	361.7	635.3	358.5	630.7	59.9	107.0	65.4	99.9
1.30	132.3	221.6	132.6	217.8	360.4	635.2	357.9	631.9	59.5	106.9	65.5	100.2

Table IV – 2.7 Estimate of dietary digestible lysine (dLys) NRML[1] from selling chicken as cut-ups at 2,900 g market BW on a production scenario of a 900,000 Ross 708 broiler complex when using a sex separate (males) *vs.* straight-run under medium feed and meat prices

Estimate of dLys NRML at medium feed and meat prices for a 2,900 g market BW sold as cut-up parts															
dLys (%)	Gross returns per cut-up part ($)										Net returns ($/bird)		Net return complex ($)		Returns from sex separation ($)
	Male					Straight-run									
	Pectoralis major	*Pectoralis minor*	Wings	Legs	Paws	*Pectoralis major*	*Pectoralis minor*	Wings	Legs	Paws	Male	Straight-run	Male	Straight-run	
0.90	1.61793	0.49542	0.75063	1.15429	0.14033	1.58627	0.49990	0.72110	1.11842	0.12635	2.8154	2.6578	2,533,859	2,392,007	141,852
0.91	1.61735	0.49725	0.75062	1.15513	0.14041	1.59009	0.50138	0.72246	1.11948	0.12643	2.8160	2.6667	2,534,411	2,400,053	134,358
0.92	1.61688	0.49900	0.75061	1.15594	0.14049	1.59375	0.50283	0.72378	1.12054	0.12652	2.8166	2.6753	2,534,960	2,407,757	127,204
0.93	1.61652	0.50067	0.75061	1.15673	0.14056	1.59724	0.50425	0.72505	1.12161	0.12660	2.8172	2.6835	2,535,509	2,415,117	120,392
0.94	1.61626	0.50225	0.75061	1.15749	0.14063	1.60057	0.50563	0.72627	1.12267	0.12669	2.8178	2.6913	2,536,060	2,422,134	113,926
0.95	1.61612	0.50375	0.75061	1.15823	0.14070	1.60373	0.50698	0.72745	1.12374	0.12679	2.8185	2.6987	2,536,616	2,428,808	107,808
0.96	1.61608	0.50517	0.75062	1.15894	0.14076	1.60673	0.50829	0.72859	1.12482	0.12689	2.8191	2.7057	2,537,178	2,435,138	102,040
0.97	1.61615	0.50651	0.75064	1.15963	0.14083	1.60956	0.50957	0.72968	1.12589	0.12699	2.8197	2.7124	2,537,749	2,441,125	96,624
0.98	1.61633	0.50777	0.75065	1.16030	0.14088	1.61223	0.51081	0.73072	1.12697	0.12709	2.8204	2.7186	2,538,332	2,446,768	91,564
0.99	1.61662	0.50894	0.75068	1.16094	0.14094	1.61473	0.51202	0.73172	1.12805	0.12720	2.8210	2.7245	2,538,928	2,452,066	86,862
1.00	1.61702	0.51003	0.75070	1.16156	0.14099	1.61707	0.51319	0.73268	1.12913	0.12731	2.8217	2.7300	2,539,541	2,457,021	82,520
1.01	1.61753	0.51105	0.75074	1.16215	0.14104	1.61924	0.51433	0.73359	1.13021	0.12742	2.8224	2.7351	2,540,171	2,461,631	78,541
1.02	1.61814	0.51197	0.75077	1.16272	0.14109	1.62125	0.51544	0.73446	1.13130	0.12754	2.8231	2.7399	2,540,823	2,465,896	74,927
1.03	1.61886	0.51282	0.75081	1.16327	0.14113	1.62309	0.51651	0.73528	1.13239	0.12767	2.8239	2.7442	2,541,497	2,469,817	71,680
1.04	1.61970	0.51359	0.75086	1.16379	0.14117	1.62476	0.51754	0.73605	1.13348	0.12779	2.8247	2.7482	2,542,197	2,473,392	68,805
1.05	1.62064	0.51427	0.75091	1.16428	0.14121	1.62627	0.51855	0.73679	1.13458	0.12792	2.8255	2.7518	2,542,925	2,476,623	66,302
1.06	1.62169	0.51487	0.75096	1.16476	0.14124	1.62762	0.51951	0.73747	1.13567	0.12805	2.8263	2.7550	2,543,682	2,479,508	64,174
1.07	1.62285	0.51539	0.75102	1.16520	0.14127	1.62880	0.52045	0.73811	1.13677	0.12819	2.8272	2.7578	2,544,473	2,482,048	62,425
1.08	1.62411	0.51583	0.75108	1.16563	0.14130	1.62981	0.52134	0.73871	1.13788	0.12833	2.8281	2.7603	2,545,297	2,484,242	61,056
1.09	1.62549	0.51618	0.75115	1.16603	0.14132	1.63066	0.52221	0.73926	1.13898	0.12847	2.8291	2.7623	2,546,159	2,486,090	60,070
1.10	1.62697	0.51646	0.75122	1.16640	0.14134	1.63135	0.52303	0.73977	1.14009	0.12862	2.8301	2.7640	2,547,061	2,487,592	59,469
1.11	1.62857	0.51665	0.75129	1.16675	0.14136	1.63187	0.52383	0.74023	1.14120	0.12877	2.8311	2.7653	2,548,004	2,488,748	59,256
1.12	1.63027	0.51676	0.75137	1.16708	0.14138	1.63222	0.52459	0.74065	1.14231	0.12893	2.8322	2.7662	2,548,991	2,489,557	59,434
1.13	1.63208	0.51679	0.75146	1.16738	0.14139	1.63241	0.52531	0.74103	1.14343	0.12908	2.8334	2.7667	2,550,025	2,490,020	60,005
1.14	1.63400	0.51673	0.75154	1.16766	0.14140	1.63244	0.52600	0.74135	1.14454	0.12924	2.8346	2.7668	2,551,107	2,490,136	60,971
1.15	1.63603	0.51660	0.75164	1.16791	0.14140	1.63229	0.52666	0.74164	1.14566	0.12941	2.8358	2.7666	2,552,241	2,489,905	62,336
1.16	1.63817	0.51638	0.75173	1.16814	0.14140	1.63199	0.52728	0.74188	1.14679	0.12958	2.8371	2.7659	2,553,428	2,489,327	64,101
1.17	1.64041	0.51608	0.75184	1.16835	0.14140	1.63152	0.52787	0.74207	1.14791	0.12975	2.8385	2.7649	2,554,671	2,488,402	66,269
1.18	1.64276	0.51570	0.75194	1.16853	0.14140	1.63088	0.52842	0.74222	1.14904	0.12992	2.8400	2.7635	2,555,972	2,487,129	68,843
1.19	1.64523	0.51523	0.75205	1.16869	0.14139	1.63008	0.52894	0.74232	1.15017	0.13010	2.8415	2.7617	2,557,334	2,485,509	71,825
1.20	1.64780	0.51469	0.75217	1.16882	0.14138	1.62911	0.52942	0.74238	1.15130	0.13029	2.8431	2.7595	2,558,758	2,483,541	75,217
1.21	1.65048	0.51406	0.75229	1.16893	0.14137	1.62798	0.52987	0.74240	1.15244	0.13047	2.8447	2.7569	2,560,247	2,481,225	79,023
1.22	1.65327	0.51335	0.75241	1.16901	0.14135	1.62668	0.53028	0.74237	1.15358	0.13066	2.8464	2.7540	2,561,804	2,478,560	83,244
1.23	1.65617	0.51256	0.75254	1.16907	0.14133	1.62521	0.53066	0.74229	1.15472	0.13086	2.8483	2.7506	2,563,431	2,475,547	87,884
1.24	1.65917	0.51168	0.75267	1.16911	0.14131	1.62359	0.53101	0.74217	1.15586	0.13105	2.8501	2.7469	2,565,130	2,472,186	92,944
1.25	1.66229	0.51073	0.75281	1.16912	0.14128	1.62179	0.53132	0.74201	1.15700	0.13125	2.8521	2.7428	2,566,904	2,468,476	98,428
1.26	1.66551	0.50969	0.75295	1.16911	0.14125	1.61983	0.53159	0.74180	1.15815	0.13146	2.8542	2.7382	2,568,754	2,464,416	104,337
1.27	1.66884	0.50857	0.75309	1.16907	0.14122	1.61771	0.53183	0.74154	1.15930	0.13166	2.8563	2.7333	2,570,683	2,460,008	110,675
1.28	1.67228	0.50737	0.75324	1.16901	0.14119	1.61542	0.53204	0.74124	1.16046	0.13188	2.8585	2.7281	2,572,694	2,455,251	117,444
1.29	1.67583	0.50609	0.75340	1.16892	0.14115	1.61297	0.53221	0.74090	1.16161	0.13209	2.8609	2.7224	2,574,789	2,450,144	124,646
1.30	1.67949	0.50472	0.75355	1.16881	0.14111	1.61035	0.53235	0.74051	1.16277	0.13231	2.8633	2.7163	2,576,970	2,444,687	132,283

[1] NRML – Net returns maximization level (blue and green cells represent NRML for each cut-up for male and straight-run birds respectively)

Figure IV – 2.6 Response surface graph and respective response contour plot to estimate *pectoralis major* weight based on 2,900 g market BW (isoquant) when varying levels of digestible lysine for Ross 708 male and straight-run bird



Male

Straight-run

Table IV – 2.8 Estimates of dietary digestible lysine (dLys) NRML[1] from selling chicken as whole carcass (1,700 market BW) or as cut-ups (2,900 g market BW) on a production scenario of a 1,800,000 Ross 708 broiler complex when using a sex separate *vs.* straight-run under combinations of various feed and meat prices[2]

Whole carcass market (1,700 g live BW) for 900,000 birds produced sex separated (females) or sex comingled						
Meat Price	Feed Price	NRML (dLys %)		Net return complex ($) at NRML (9,000,000 birds)		Returns from sex separation ($) at NRML for the complex
		Female	Straight-run	Female	Straight-run	
Low	Low	0.90	1.01	1,494,100	1,475,315	18,785
	Medium	0.90	1.00	1,352,126	1,333,826	18,300
	High	0.90	0.99	1,210,152	1,192,399	17,752
Medium	Low	0.90	1.03	2,011,625	1,985,783	25,841
	Medium	0.90	1.01	1,869,650	1,844,143	25,507
	High	0.90	1.00	1,727,676	1,702,642	25,034
High	Low	0.90	1.05	2,529,149	2,496,460	32,689
	Medium	0.90	1.03	2,387,175	2,354,587	32,588
	High	0.90	1.01	2,245,200	2,212,972	32,228

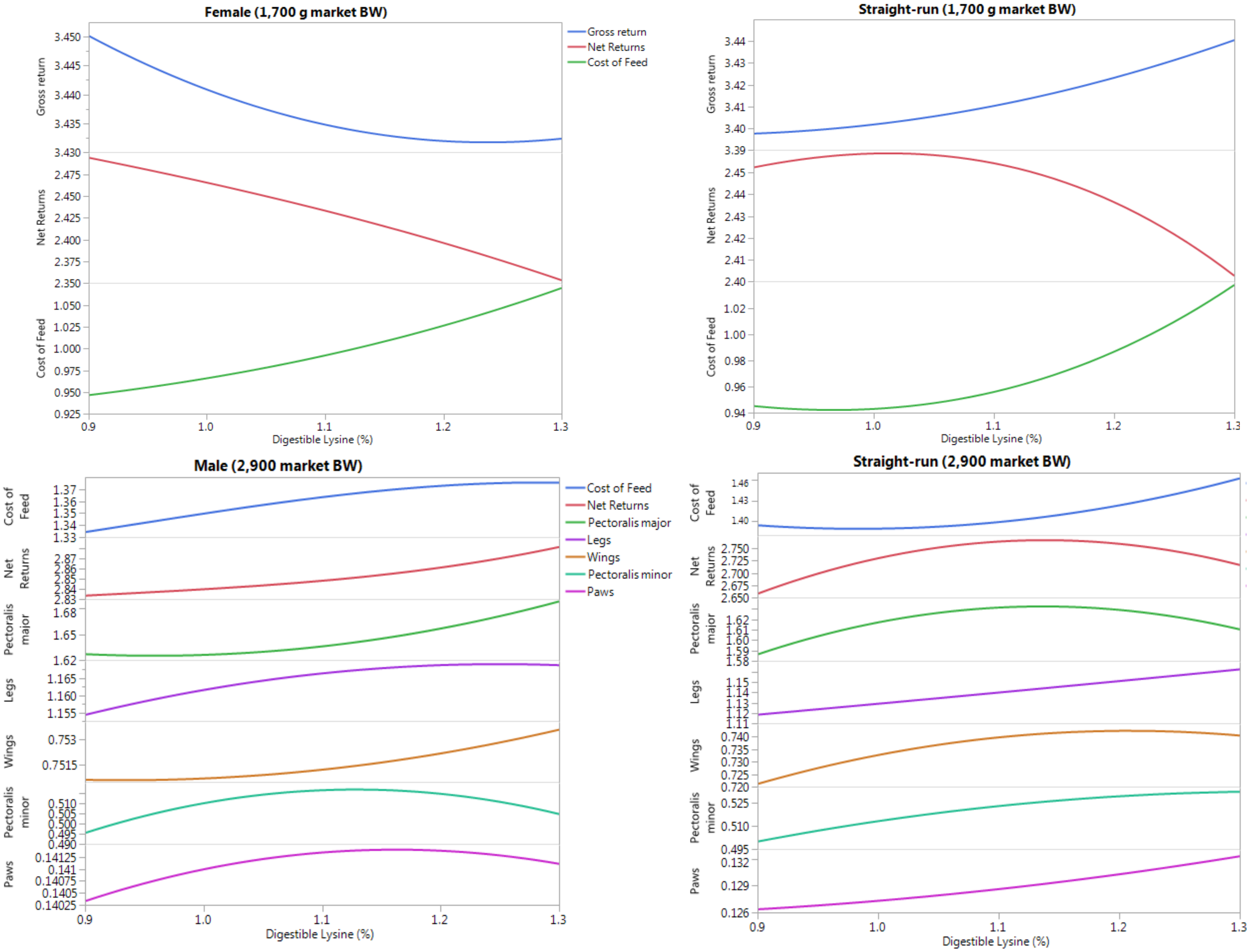
Carcass cut-up market (2,900 g live BW) for 900,000 birds produced sex separated (males) or sex comingled																
Meat Price	Feed Price	Gross return maximum level per cut-up part										NRML		Net return complex ($) at NRML (9,000,000 birds)		Returns from sex separation ($) at NRML for the complex
		Male					Straight-run									
		Pectoralis major	*Pectoralis minor*	Wings	Legs	Paws	*Pectoralis major*	*Pectoralis minor*	Wings	Legs	Paws	Male	Straight-run	Male	Straight-run	
Low	Low	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.14	2,058,336	1,992,109	66,227
	Medium	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.13	1,810,766	1,739,194	71,573
	High	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.11	1,563,196	1,486,773	76,423
Medium	Low	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.15	2,824,541	2,743,544	80,997
	Medium	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.14	2,576,970	2,490,136	86,834
	High	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.13	2,329,400	2,237,198	92,203
High	Low	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.16	3,590,745	3,495,364	95,380
	Medium	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.15	3,343,175	3,241,525	101,650
	High	1.30	1.13	1.30	1.25	1.16	1.14	1.30	1.21	1.30	1.30	1.30	1.14	3,095,605	2,988,164	107,441

Final net returns for a complex (1,800,000 birds) producing birds at two target live BW raised sex separate or sex comingled				
Meat Price	Feed Price	Sex separate	Sex comingled	Returns from sex separation ($)
Low	Low	3,552,437	3,467,424	85,013
	Medium	3,162,892	3,073,020	89,872
	High	2,773,348	2,679,172	94,175
Medium	Low	4,836,165	4,729,327	106,838
	Medium	4,446,621	4,334,280	112,341
	High	4,057,076	3,939,840	117,236
High	Low	6,119,894	5,991,824	128,070
	Medium	5,730,349	5,596,111	134,238
	High	5,340,805	5,201,136	139,669

[1] NRML – Net returns maximization level (blue and green cells represent NRML for each cut-up for male and straight-run birds respectively)

[2] Meat medium prices – Whole carcass WOG = $2.16; *Pectoralis major* = $2.64; *Pectoralis minor* = $ 4.17; Wings = $3.40; Legs = $1.84; Paws = $1.32; Feed medium prices – Starter = $317.35/ton; Grower = Table IV – 2.1; Finisher = $253.35/ton; Feed and meat low and high prices were calculated as 80% and 120% of the medium prices respectively

Figure IV – 2.6 Cost of feeding and returns (net and gross) as digestible lysine increases for two market BW (1,700 and 2,900 g) of broilers Ross 708 raised straight-run or sex separate under medium prices of feed and meat



CHAPTER 5

Conclusions

CONCLUSION

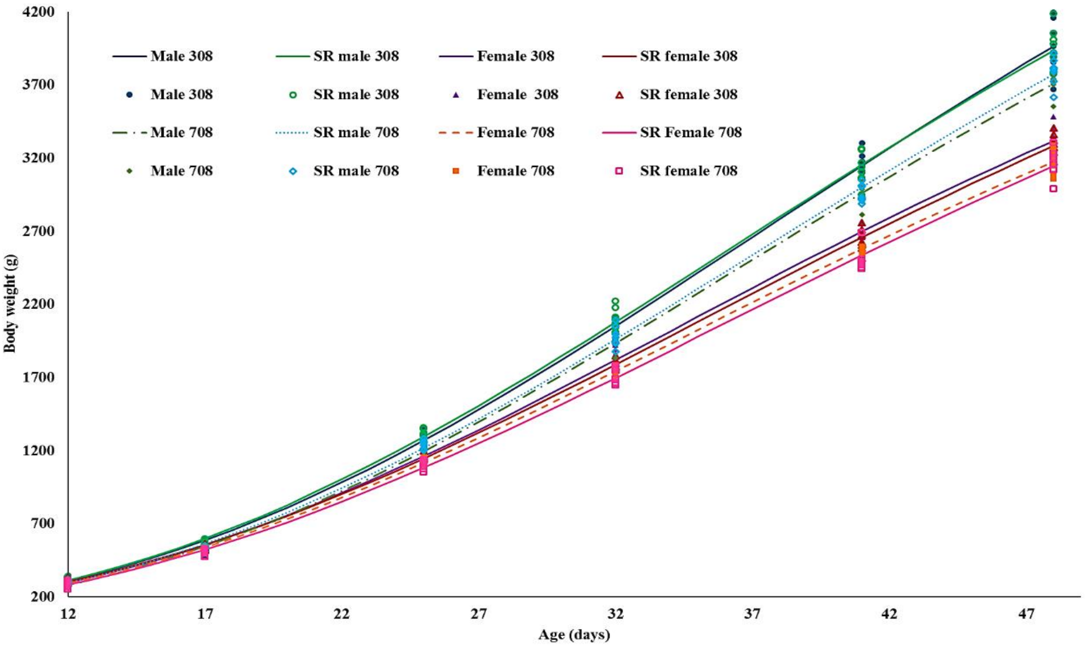
The United States of America is the country that produces the most poultry meat worldwide. The poultry industry has a major impact on the country's economy because it has a positive impact on jobs, wages, and federal and state revenue. Success of the poultry business relies on the constant seeking of strategies that maximize returns for the companies, while at the same time fulfills consumer demands. Therefore, factors that affect bird performance, health, and final product quality have to be taken into consideration when strategically planning a company business. There are several factors that can affect bird performance and health, but management (housing) and nutrition factors are probably the most significant since they have a greater impact on the production cost. Regarding the consumer, poultry companies try to target consumer preferences by selling chickens in cut-up parts, and at the same time the company aggregates extra value to the final product, which increases revenues.

There are not a lot of alternatives to contour the fixed costs of housing, and management costs, however there are still some strategies that need to be evaluated in order to obtain maximum profit. In the USA, broiler flocks are raised as straight-run (males and females together), however, in other parts of the world raising broilers sex separated is a common practice. The advantages of raising birds sex separate is related with the opportunity to explore different growth curves and specific nutritional needs expressed by each gender. Feeding of the birds represents roughly 70% of the cost of production. Consequently, formulating diets that maximize profit is a key step to achieving business success. The dietary protein level strongly influences bird performance and meat output, but conversely it is also one of the most costly nutrients of the diet. Therefore, a balance on the gains of meat by feeding cost should be considered when formulating diets.

In view of the importance of management and feeding costs on company profitability, it is essential to clarify if raising broilers sex separate *vs.* straight-run is economically beneficial, and it is also essential to determine levels of protein that maximize financial returns for each gender. Additionally, evaluation of bird size uniformity at market age for broilers raised under the two rearing systems should be evaluated, since this parameter can greatly impact the broiler slaughtering process. Consequently, three experiments were conducted to evaluate effect of the rearing system and dietary protein level on the production net returns and bird variability at market weight. For all the experiments, an economic simulation was performed for various market weights, considering a 1,800,000 broiler complex under nine price scenarios coming from a combination of three feed and meat prices (low, medium, and high). A sexing cost of $0.009/bird was considered.

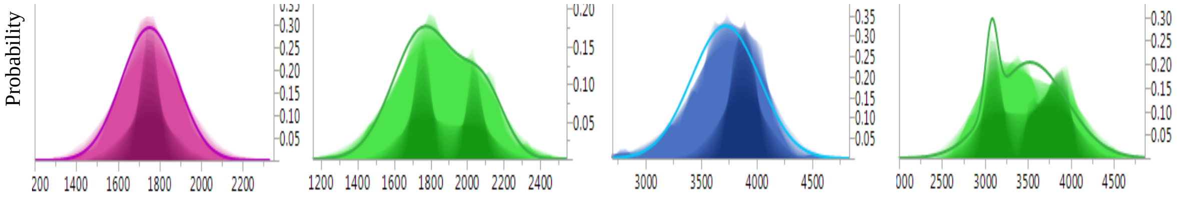
As a first approach (Chapter II), two genetic lines (Ross 308 and Ross 708) were either raised sex separated or sex commingled, to evaluate if performance, carcass yield, bird variability, and economics would be different just by the effect of social factors. Results revealed that females could benefit from sex separation in terms of gain and uniformity, whereas males had BW gained impaired when raised with other males (Figure V – 1). It is possible that the differences in growth are related with feed space competition and stressful social factors. In addition, the economic simulations for the complex (a week of production) showed extra returns from sex separation for both strains when broilers were marked at 1,700 g (females and straight-run – sold as whole carcass) and 3,700 g (males and straight-run – sold as cut-ups) of live weight. The extra net returns from sex separation for Ross 308 ranged from $66,600 to

Figure V-1. Growth curve (Gompertz model) of male and female Ross 308 and 708 broilers raised sex separated or straight-run



$133,200, whereas for Ross 708 the extra returns ranged from $179,100 to $330,300 depending on market meat and feed prices. Even though the economic advantage of sex separation was clear, it was also evident that different genetics will benefit from it in a different magnitude. Bird variability was evaluated by targeting various market weights and estimating the percentage of birds present within 100 g of the range of the target weight for birds reared either sex separate or straight-run. It was observed that depending on market weight, straight-run flocks resulted in 9.1

Figure V - 2. Ross 708 BW distribution of flocks of female, male, and straight-run birds at 32 and 48 days of age

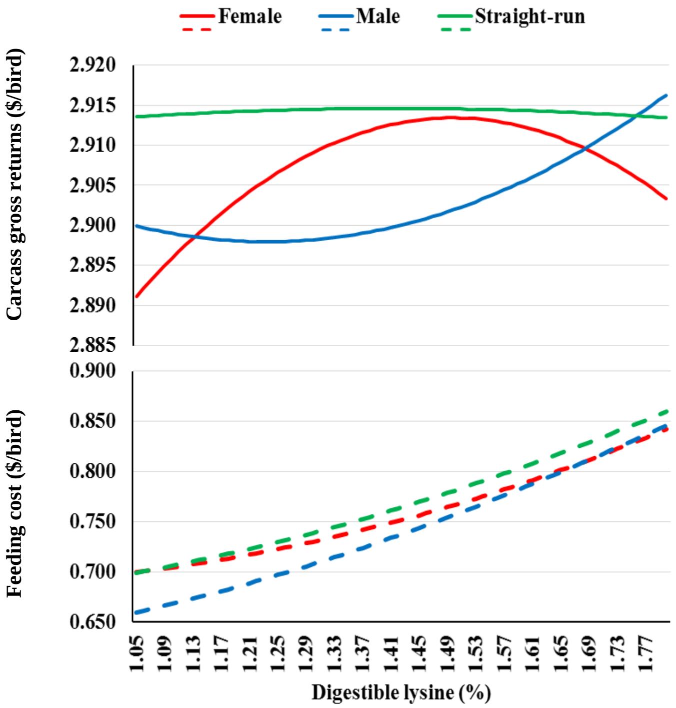


Female			Straight-run			Male			Straight-run		
32 days						48 days					
μ: 1752g	CI 95%		μ: 1848g	CI 95%		μ: 3718g	CI 95%		μ: 3468g	CI 95%	
SD: 136	1734g	1770g	SD: 215	1819g	1877g	SD: 306	3669g	3767g	SD: 437	3398g	3539g

to 16.6 % less birds within the range than sex separate flocks. This is a clear result of increased BW variability when both sexes are present in a flock (Figure V – 2).

Following these results, starter (experiment 2) and grower (experiment 3) phase digestible lysine levels for maximum technical (TRML) and net returns (NRML) were determined for birds raised sex separate or straight-run. The economic simulations performed followed the same lines as in the first experiment, with the exception that the dietary costs were set at the NRML of digestible lysine for each rearing system. The starter phase experiment (Chapter III) evaluated levels of digestible lysine between 1.05 to 1.80 % of the diet (amino acid ratio was maintained) from 25 days of age, followed by a common grower diet (1.02 % of digestible lysine) fed up to 32 days. Bird BW at 32 days was affected quadratically by digestible lysine with TRMLs obtained at 1.47, 1.32, and 1.45 %, for female, male, and straight-run birds respectively. However, for a target market weight of 1,600 g live BW to be sold as whole carcass WOG, the NRMLs were significantly lower than the TRMLs. When meat and feed price were set at medium levels, net returns were maximized at 1.07, 1.05, and 1.05 % of digestible lysine for female, male, and straight-run birds. Figure V – 3 reveals why the NRML were determined to be at the lowest level of digestible lysine evaluated.

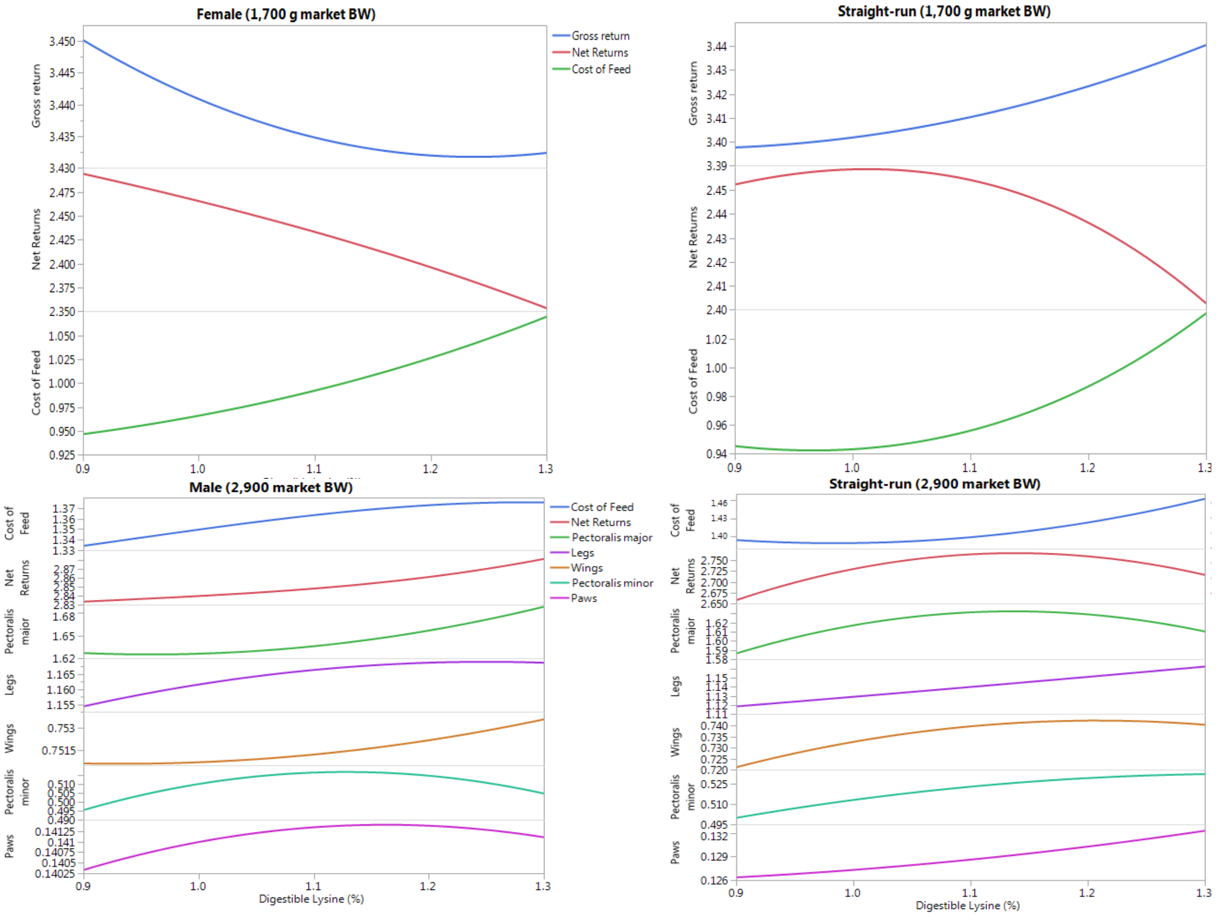
Figure V - 3. Carcass returns and feeding cost per bird for the 3 rearing systems for a live BW of 1,600 g when feeding increased levels of digestible lysine maintaining the amino acid ratios



Overall, the feeding costs increased as digestible lysine increased with the carcass gross returns not following the same pattern and increase. Therefore, it was at low digestible lysine levels that the difference between gross returns and feeding costs was maximized, corresponding to the higher net returns. Varying the feed and meat prices did not affect NRML for males and straight-run birds, whereas females had NRML increasing up to 1.15 % of digestible lysine when high meat/low feed prices were set. The whole complex (1,800, 000 birds) was marketed at 1,600 g of live weight for both sex separated genders (900,000 males + 900,000 females) and straight-run birds. The sex separation was only shown to be economically beneficial at low meat or high feed prices (extra \$2,513 to \$16,596 from sex separation), before sexing cost was subtracted from returns. When the cost of sexing (\$0.009/bird) was considered, it was observed that for light market BW, sex separation resulted in economic losses (up to -\$24,502). It should be taken into account though, that processing advantages and economic savings of increased bird uniformity at market age, were not taken into consideration on the economic simulation.

The grower phase (14 to 32 days; finisher diet fed up to 42 days) experiment (Chapter IV) intended to evaluate the effects on performance and economics of digestible lysine (0.90 to 1.30% – amino acid ratio was maintained) when raising birds to the market weights of 1,600 (sold as whole carcass WOG) and 2,900 g (sold as cut-ups). For the sex separate rearing, females and males were targeted for the light heavy market weight respectively, whereas straight-run rearing had birds of both genders present at the two market weights. At 32 days (light market weight), females and straight-run birds had BW maximized at 1.15 and 1.20 % of digestible lysine respectively. Closer to the heavy market weight (42 days) the TRMLs for BW of male and straight-run birds were 1.21 and 1.23 % respectively. At this age, *pectoralis major* and *minor* were shown to increase linearly as digestible lysine increased. The NRMLs for both market weights were determined by using response surface methodology in order to estimate feed intake and carcass/cut-up part weights at the set BW (1,700 and 2,900 g live BW). For the whole carcass WOG market, at medium feed and meat prices, NRMLs were set at 0.90 and 1.01 for females and straight-run birds respectively. Female NRML were unchanged by feed and meat price variation, whereas straight-run NRML increased as meat price increased or feed price decreased. The whole carcass market had returns maximized at 1.30 and 1.14 % of digestible lysine for males and straight-run birds respectively. Similarly to the whole carcass results, NRML remained the same regardless of meat and feed prices scenarios for males, whereas straight-run NRML increased as meat prices increased or feed price decreased. It is clear that digestible lysine levels set for maximum performance or for maximum net returns are different.

Figure V - 4. Cost of feeding and returns (net and gross) as digestible lysine increases for two market BW (1,700 and 2,900 g) of broilers Ross 708 raised straight-run or sex separate under medium prices of feed and meat



This is related with the meat gross returns obtained by feeding various levels of digestible lysine over the feeding costs needed to attain the meat sales (Figure V – 4). In addition, NRMLs will vary according to market objectives and also with feed and meat prices observed. Therefore it is essential for companies' nutritionists to know ahead what kind of market is being targeted, and also to get accurate feed and meat price projections in order to formulate diets that are economically efficient. Also, it is advised that a company determines the NRMLs for their own environmental conditions conducting their own experimentation before committing with any decision that can affect majorly the returns. There are multiple factors such as temperature, genetics, coccidiosis program, etc., that can affect NRML determination. Along with these examples, the different NRMLs for birds raised sex separate or straight-run observed herein are good proof of how management can affect optimum dietary levels.

The economic simulation for the 1,800,000 bird complex for the grower experiment, revealed that when birds were fed at NRML for the two market BW, the returns from sex separation ranged from $85,013 when the meat and feed prices were low to $139,669 when the meat and feed prices were high. It should be considered that this complex represents roughly a week of production, and when transposing the returns for a yearly basis, a company could potentially be making an extra income ranging from $4,420,676 to $7,262,788 per complex. Moreover, the results of the first experiment revealed that as birds age, the returns from sex separation increase. At 48 days in the first experiment, in the worst and best case scenario, the yearly extra returns from sex separation were $3,463,200 and $17,175,600 respectively. Also, it should be considered that these economic advantages are possibly being underestimated, since birds were fed a common diet, and no value was given to bird uniformity at market weight. One of the limitations of the present experiments was to consider the same pay per whole carcass or cut-up part for the economic simulations. In reality, the pay to the companies varies according to the products falling within a weight range stipulated by the buyer. For example, for *pectoralis major*, it can be stipulated that the company will be payed $2.640/kg for every cut that falls within the range of 500 to 580 g. Anything that will fall outside of this range (lower or higher) will get a paid lower than the one set for the range. The results of the bird BW distribution within a population from the first experiment reveal that straight-run flocks will have higher probability of birds falling outside of the desired range resulting in economic losses.

In conclusion, it is clear that regardless of meat and feed price scenarios, sex separation can result in increased revenue for poultry companies when targeting various market weights. In addition, with the current market trends in the US of raising birds to older stages to attain heavy weights, the returns from sex separation are even more significant to the companies. Besides the contribution to the financial health of the companies, these extra savings allow companies to budget some of these returns for research in order to become more efficient, and at last more sustainable.