Genetic Improvement for Production and Health in Broilers

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Genetic Improvement for Production and Health

in Broilers

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- With summary in Dutch and Farsi

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Chapter 1

General Introduction

Introduction

Poultry production has developed from a side activity on small farms into a specialized global business in only 50 years and now it is the most highly industrialized branch of animal production. There is a growing demand for poultry meat products, because they are relatively cheap, healthy, and convenient. The per capita consumption of poultry products in the United States has grown from 15.3 kg in 1970 to 50.7 kg in 2003. The market share of poultry is increasing compared to total consumption of red meat, which has declined from 59.8 kg per capita in 1970 to 50.7 kg per capita in 2003 (Laux, 2003). Commercial broiler production contributes about 86% to total poultry meat production worldwide, leaving turkey, duck, and other birds such as goose and quail far behind at 7%, 4%, and 3% respectively (Executive Guide to World Poultry Trends, 2002).

Growth rate was the first trait to receive attention in the broiler breeding industry during the emergence of commercial broiler production due to its economic importance. In the 1980s and at the beginning of the 1990s, there was little emphasis on product quality in the market. Consequently, broiler lines with improved production dominated the market, even though they produced carcass with excessive abdominal fat and lower prime cut yields. However, in the mid-1990s, the market changed, demanding higher meat yield and lower abdominal fat deposition in broiler carcasses (Antunes, 2001) as consumers became more interested in healthier foods. In addition, there was a growing emphasis on feed efficiency of broilers as the industry focused increasingly on integrated production operations. In an integrated production system, different and interconnected production processes are managed as a whole. Modern broiler chickens have been intensively selected for production traits, e.g. growth, breast meat yield, and feed efficiency, for more than 50 years. Havenstein et al. (2003a, b) compared broiler performance of a 1957 random-bred control population with that of a 2001 broiler strain cross. They showed that body weight increased from 539 g to 2672 g, breast meat yield increased from 11.6% to 20%, and feed conversion ratio changed from 2.34 to 1.62 at 42 d of age. Over 85% of these changes were due to improvements in the genetic potential of the birds.

The selection of production traits in broilers has been accompanied by negative consequences on different aspects of the birds' physiology (Chambers, 1990; Havenstein et al., 1994; Dunnington and Siegel, 1996; Rauw et al., 1998). These negative consequences are mainly due to the tremendous increase in body mass without parallel improvements in the internal organs, vascular system, and skeleton to support such a rapidly growing and large body mass (Dunnington and Siegel 1996; Katanbaf et al., 1988). The negative characteristics, such as fatness, ascites, leg deformity, and reproduction problems, have a large impact on animal welfare and on the economics of poultry production. Ewart (1993) demonstrated that four major driving forces, i.e., cost/price reduction, quality improvement, product versatility and ethical considerations, have been shaping the poultry breeding industry. The relative importance of quality improvement, product versatility and ethical considerations is growing and depending on the region they are even more important than cost/price reduction. Breeding organizations are increasingly aware of this trend and counteract the basic physiological imbalance by genetic improvement of leg strength and other aspects of general livability such as ascites. However, in order to have sustainable poultry production, greater emphasis on health traits will be required in the future. The science of genetics and physiology provide the basic knowledge required creating efficient genetic change in production and health traits and, therefore, these disciplines are key components in developing improved breeding programs (Emmerson, 2003). The future success of the broiler industry depends on the bird being able to continue to perform at present levels but with minimized negative effects on fitness traits, which reduces the management resources required (Pollock, 1999). Information on phenotypic and genetic parameters for production traits and traits related to health are needed for the design of breeding programs aimed at improving the balance between production and health traits.

Aim and outline of the thesis

This thesis aims to optimize the genetic improvement of production and health traits in broilers. In Chapter 2, the genetic and phenotypic parameters for abdominal, subcutaneous, and intramuscular fat and the genetic correlations between fat deposition and production traits are estimated. In Chapter 3, the consequences of different slaughter ages and different housing systems on genetic parameter estimations in broilers are shown. In Chapter 4, possibilities of using indirect carcass measurements for increasing the genetic response for breast meat yield are studied. In addition, the consequences of differences in accuracy of such methods are investigated. Chapter 5 investigates whether a population under cold stress could be divided into two underlying distributions representing the level of susceptibility to ascites. In addition, the effect of the presence of those underlying distributions on the phenotypic correlations is investigated. Finally, in Chapter 6 the results of this thesis are discussed and placed into a larger context.

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Chapter 2

Estimation of Genetic Parameters for Fat Deposition and Carcass Traits in Broilers

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Abstract

Abdominal and subcutaneous fat are regarded as the main sources of waste in the slaughterhouse. Fat stored intramuscularly is regarded a favorite trait related to meat quality. The objective of current study was to estimate genetic parameters for fat deposition in the three different parts of body and their relationships with other carcass traits. Traits were recorded on 1,752 females and 1,526 male chickens from a meat-type chicken line. Heritability estimates for abdominal fat percentage, skin percentage, as a measure of subcutaneous fat, and intramuscular fat percentage were 0.71, 0.24, and 0.08, respectively. Heritabilities of the other carcass traits were moderate to high (from 0.28 to 0.73).

There was a high genetic correlation between abdominal fat weight and skin weight (0.54), whereas the genetic correlation between abdominal fat weight and intramuscular fat percentage was almost zero (0.02). The BW at 49 d showed a positive genetic correlation with fat production traits, which were high for intramuscular fat percentage (0.87) and moderate for skin percentage (0.17) and abdominal fat percentage (0.13). Therefore, carcass traits could be improved by selection for increased breast muscle and reduced abdominal fat without decreased intramuscular fat.

Key word: broiler, genetic correlation, fat deposition, carcass traits, intramuscular fat

Introduction

The primary goal of broiler breeding is to improve profitability of broiler meat production. Until recently most birds were sold whole, but there has been a dramatic increase in the proportion of birds being grown for portioning and further processing (Ewart, 1993). Poultry production and processing technologies have become rapidly accessible, and are being implemented on a worldwide basis, which will allow continued expansion and competitiveness in this meat sector (Aho, 2001). Therefore, the success of poultry meat production has been strongly related to improvements in growth and carcass yield, mainly by increasing breast proportion and reducing abdominal fat. Intensive selection of meat-type chickens for growth for more than 50 yr has increased growth rate but rapid growth has been accompanied by a number of negative consequences, including an increase in fat deposition (Griffin, 1996).

Abdominal and subcutaneous fat are being regarded as the main sources of waste in the slaughterhouse. Because abdominal fat is highly correlated (0.6 to 0.9) with total carcass lipids, it is used as the main criterion reflecting excessive fat deposition in broilers (Chambers, 1990). Havenstein et al. (2003) described that fat in broiler (at 43 d of age) accounts for as much as 10 to 15 % of the total carcass weight. Therefore there is substantial potential to improve feed efficiency and carcass quality by further reducing fatness. Beside abdominal and subcutaneous fat that are unfavorable traits, intramuscular fat could be a favorable trait. In beef cattle, intramuscular fat makes some contribution to sensory palatability. Measures of sensory palatability incorporate attributes such as tenderness, juiciness and flavor (Oddy et al., 2001). Nishimura et al. (1999) reported that intramuscular fat, in Longissimus muscle may physically alter connective tissue structure and thereby reduce toughness of the meat. Although intramuscular fat plays a major role in broiler meat quality (flavor and juiciness) (Chizzolini et al., 1999), very few estimates of its heritability and genetic correlation with other important traits have been published.

The speed of feathering in birds can also influence carcass composition. Fotsa et al. (2001) mentioned, owing to the considerable power of thermal insulation of the plumage, this phenomenon may favor heat dissipation into the environment and thus has an influence on traits of economic importance (*i.e.,* feed intake, growth rate, and fatness).

The possibility of genetically improving carcass quality by selection depends on the genetic variability of BW and body composition. Body composition can be significantly improved by selection, as shown by the level of breast muscle heritability ranging from 0.53 and 0.65 in the studies of Vereijken (1992), Le Bihan-Duval et al. (1998, 1999), and Rance et al. (2002). For abdominal fat, heritability ranges between 0.50 and 0.80 (Chambers, 1990; Griffin et al., 1991; Le Bihan-Duval et al., 1998; Rance et al., 2002). The objective of current study was to estimate heritabilities and genetic and phenotypic correlation for fat deposition in 3 different parts of the carcass with other carcass traits.

Materials and Methods

Population

Two genetically different outcross broiler dam lines originating from the White Plymouth Rock breed were chosen as the foundation of the experimental population. The maternal line had a rather high reproductive performance and was fast feathering, and the paternal line had a rather high growth performance and was slow feathering. After nine generations of intercrossing (F_9), carcass-related traits were recorded for 3,278 birds (i.e., 1,752 females and 1,526 males). These birds were produced by 31 sires and 57 dams. The total pedigree file consisted of 13,491 birds. The experimental birds were hatched during 13 different wk in 1999 and 2000. Birds were housed in a litter system for broilers until the age of 49 d. The birds were in the same pen starting from d 0, where they received feed and water for *ad libitum*. Animal density was around 20 birds / m^2 and illumination was 23 h / d. A commercial broiler feed, consisting of crumbled concentrates containing 2,980 kcal / kg and 21% protein, was used.

Traits

Body weight at 35 and 49 d of age (BW_{35} and BW_{49}) were measured on live birds, BW_{49} was measured after 4 h with no access to feed and prior to transporting the birds for processing. After slaughter at the same day of age, the weights of carcass (CW), abdominal fat (AFW), breast muscle (BMW), and skin (SW) were measured. The CW was measured on the chilled carcass after removal of feathers, head, lungs, liver, kidneys, gastrointestinal tract, and abdominal fat. The ratio of these traits to BW_{49} was calculated as carcass percentage (CP), abdominal fat percentage (AFP), breast muscle percentage (BMP), and skin percentage (SP). Subcutaneous fat mainly determines the weight of skin. Therefore, in the present study, SW and SP were considered as indicators of subcutaneous fat weight and percentage. Intramuscular fat content of part of the breast muscle, pectoralis minor, was measured by means of extraction in a Soxhlet apparatus with petroleum ether (AOAC, 1990), and intramuscular fat percentage (IFP) was calculated. Because of experimental limitations, IFP was measured on 1,467 birds.

Genetic Analyses

Descriptive statistics, including the test of the normality of the distribution of traits, were obtained from the UNIVARIATE procedure of SAS® (SAS institute, 1999). An animal model was used to estimate the genetic parameters of carcass-related traits. In order to find the best model, a likelihood ratio test was used. Based on likelihood ratio test, no difference was found between models with and without maternal and common environmental effects, and interactions among the main effects appeared non significant; therefore, maternal, common environmental effects and interactions were ignored in the final model:

$$Y_{ijkm} = \mu + s_i + f_j + h_k + a_m + e_{ijkm}$$

where Y_{ijkm} = the performance of the chicken m, s_i = fixed effect of sex i (i = 1, female and 2, male), f_j = fixed effect of feathering j (j = 1, fast and 2, slow feathering), h_k = fixed effect of week of hatch k (k= 1,2,…13), a_m = random direct genetic effect of chicken m, and e_{ijkm} = random residual effect.

The same model was used for all the traits under study. Univariate analyses were used to estimate heritabilities. Multivariate analyses were used to estimate genetic and phenotypic correlations between all combinations of traits. Parameter estimates were obtained using the ASREML software (Gilmour et al., 2000).

Results

Description of Traits

The statistical description of carcass-related traits is summarized in Table 1. Due to missing observations, the number of observations differed among traits. The average of CP, AFP, BMP, SP, and IFP were 66.09, 3.38, 13.03, 1.97 and 1.4% respectively.

The effect of sex was significant for all traits (Table 1). The mean values for all traits were higher in males than in females except for AFW, AFP, and SP. Results showed that males were leaner than females. Feathering had a significant effect only on BW_{35}, BW_{49}, AFW, and AFP. Averages of BW_{35} and BW_{49} for slow-feathering birds (1,270 and 1,989g, respectively) were higher than for fast-feathering birds (1,202, and 1,883g, respectively). On the other hand, averages of AFW and AFP for slow-feathering birds were lower (64.1 g and 3.2%, respectively) than for fast-feathering birds (68.3 g and 3.7%, respectively). These results showed that slow-feathering birds were leaner than fast feathering birds. The effect of week of hatch was significant for all traits. The mean values for carcass traits were higher in birds with older mothers than those with younger mothers.

Genetic parameters

The genetic parameters for carcass-related traits are presented in Table 2. Heritability estimates for AFP, SP, and IFP were 0.71, 0.24, and 0.08 respectively. Heritabilities of other carcass traits were from 0.28 to 0.73. The highest heritabilities (up to 0.73) were obtained for AFW, AFP, and BMP.

In the current study, BW_{49} showed large genetic correlations with CW and BMW (0.97 and 0.64, respectively), whereas the genetic correlations of BW_{49} with CP and BMP were smaller (0.22 and 0.12, respectively) (Table 2). Also BW_{49} showed positive genetic correlations with fat production traits which were 0.87 for IFP, 0.17 for SP, and 0.13 for AFP. A large genetic correlation between CP and BMP (0.74) was found and the estimate for CW and BMW was very similar (0.77).

The CP and BMP traits had negative genetic correlations with AFP (–0.55 and –0.39, respectively). Genetic correlations among abdominal fat, subcutaneous fat, and intramuscular fat were greater between AFW and SW (0.54) whereas the genetic correlation between AFW and IFP was almost zero (0.02).

TABLE 1. Means, standard deviations, minimum and maximum values, and results of the analysis of variance of different carcass traits[1]

Trait [2,3]	N	Mean	SD	Min	Max	Sex effect[4]	Feather effect[5]	Hatch [6]
BW_{35} (g)	2,995	1,251	179.7	615	1,877	161.54***	10.27**	***
BW_{49} (g)	3,254	1,960	271.6	1,072	2,905	360.21***	27.72*	***
CW (g)	3,254	1,296	187.1	649	1,945	225.92***	NS	***
CP (%)	3,254	66.1	2.3	53.3	74.2	0.43***	NS	***
BMW (g)	3,243	255.9	44.8	99.0	442	43.07***	NS	***
BMP (%)	3,243	13	1.2	8.0	17.3	0.13*	NS	***
AFW (g)	3,246	65.9	18.1	11.5	138	–3.71**	–3.49***	***
AFP (%)	3,246	3.4	0.9	0.6	7.1	–0.71***	–0.10***	***
SW (g)	3,119	38.5	8.6	13.6	75.1	3.05***	NS	***
SP (%)	3,119	1.8	0.39	0.9	3.7	–0.24***	NS	***
IFP (%)	1,467	1.4	0.36	0.1	2.7	0.06***	NS	***

[1] Except BW_{35}, other traits were measured at 49 d.

[2] BW_{35} = BW at 35 d; BW_{49} = BW at 49 d; CW = carcass weight; CP = carcass percentage; AFW = abdominal fat weight; AFP = abdominal fat percentage; BMW = breast muscle weight; BMP = breast muscle percentage; SW = skin weight; SP = skin percentage; and IFP = intramuscular fat percentage.

[3] Percentage (%) indicates that traits were expressed as percentage of BW at 49 d of age, except IFP, which was intramuscular fat content expressed as percentage of the weight of a sample from the pectoralis minor muscle.

[4] In the analysis the effect of female sex was fixed at zero.

[5] In the analysis the effect of fast feathering was fixed at zero.

[6] Because of large effects of week of hatch, only the significance of this trait was shown.

*$P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

Discussion

The mean values for all traits were higher in males than in females except for AFW, AFP, and SP. Males were leaner than females. Le Bihan-Duval et al. (1998) found the same results and noted that there is no clear explanation for the difference between sexes, but phenomena such as greater competition between males, different nutritional needs, and greater impact of hormones for fatness in females could be involved. The mean values of carcass-related traits showed that slow-feathering birds were leaner than fast-feathering birds. Slow-feathering birds probably use more energy for stabilizing the body temperature, because of low feather density; therefore their fat deposition is less than fast-feathering birds. In current study, the mean values of all traits were higher in birds with older mothers than those had younger mothers. Peebles et al. described that older hens lay larger eggs that hatch into larger chickens, and egg weight and hatching weight of chickens are correlated with market age weight.

In current experiment, the variance in BW_{35} and BW_{49} was greater than in commercial situations, which was probably due to the population being a cross between two extreme lines with no subsequent selection. According to the review of Chambers (1990), the existence of maternal or dominance effects for BW could be expected, and Chapuis et al. (1996) estimated the size of maternal effects between 2 and 8% of total variability. Clement et al. (2001) demonstrated that if maternal genetic effects exist but are neglected in the model, the direct heritability is overestimated. In the present study, the number of dams per sire and the total number of observations were limited. This could explain why the maternal effect was not significant.

The current estimates of the heritability of BW, carcass weight, and carcass percentage were close to previous published estimates for broiler chickens (Chambers, 1990; Le Bihan- Duval et al., 1998, 2001). High heritabilities were found in present study for abdominal fat weight and percentage. These estimates were in agreement with estimates reported by Leenstra and Pit (1988), Griffin (1996), Le Bihan-Duval et al. (1998), and Rance et al. (2002), which ranged from 0.45 to 0.85.

TABLE 2. Estimates of heritabilities (diagonal), genetic (above the diagonal) and phenotypic (below the diagonal) correlations with their approximate standard errors (in parenthesis) of different carcass traits[1]

Trait [2,3]	BW_{35} (g)	BW_{49} (g)	CW (g)	CP (%)	BMW (g)	BMP (%)	AFW (g)	AFP (%)	SW (g)	SP (%)	IFP (%)
BW_{35} (g)	0.44 (0.07)	0.94 (0.02)	0.89 (0.03)	0.10 (0.15)	0.58 (0.10)	0.06 (015)	0.44 (0.12)	0.20 (0.15)	0.68 (0.09)	0.31 (0.15)	0.91 (0.15)
BW_{49} (g)	0.88 (0.01)	0.33 (0.07)	0.97 (0.01)	0.22 (0.15)	0.64 (0.09)	0.12 (0.15)	0.38 (0.13)	0.13 (0.15)	0.60 (0.10)	0.17 (0.16)	0.87 (0.10)
CW (g)	0.85 (0.00)	0.97 (0.00)	0.33 (0.06)	0.46 (0.10)	0.77 (0.07)	0.31 (0.14)	0.23 (0.15)	-0.03 (0.15)	0.55 (0.11)	0.11 (0.16)	0.80 (0.14)
CP (%)	0.23 (0.02)	0.22 (0.03)	0.44 (0.38)	0.41 (0.07)	0.68 (0.08)	0.74 (0.07)	-0.44 (0.13)	-0.55 (0.11)	-0.04 (0.16)	-0.19(0.16)	0.52 (0.23)
BMW (g)	0.68 (0.03)	0.78 (0.02)	0.84 (0.01)	0.50 (0.03)	0.47 (0.08)	0.84 (0.05)	0.18 (0.03)	-0.09 (0.05)	0.16 (0.15)	-0.19 (0.15)	0.7 (0.17)
BMP (%)	0.16 (0.05)	0.18 (0.04)	0.31 (0.04)	0.58 (0.03)	0.75 (0.02)	0.73 (0.09)	-0.20 (0.05)	-0.28 (0.05)	-0.27 (0.14)	NC	0.55 (0.22)
AFW (g)	0.45 (0.04)	0.46 (0.03)	0.38 (0.04)	-0.14 (0.04)	-0.06 (0.15)	-0.36 (0.13)	0.62 (0.09)	0.96 (0.01)	0.54 (0.11)	0.44 (0.13)	0.02 (0.33)
AFP (%)	0.16 (0.05)	0.12 (0.04)	0.05 (0.04)	-0.25 (0.04)	-0.22 (0.14)	-0.39 (0.13)	0.93 (0.02)	0.71 (0.09)	0.49 (0.10)	0.41 (0.14)	-0.32 (0.29)
SW (g)	0.46 (0.02)	0.51 (0.02)	0.52 (0.02)	0.23 (0.03)	0.34 (0.03)	-0.02 (0.04)	0.42 (0.03)	0.29 (0.03)	0.28 (0.06)	NC	0.37 (0.27)
SP (%)	0.11 (0.03)	0.10 (0.03)	0.12 (0.03)	0.16 (0.03)	0.00 (0.03)	NC	0.41 (0.03)	0.25 (0.04)	NC	0.24 (0.05)	-0.05 (0.32)
IFP (%)	0.16 (0.03)	0.14 (0.03)	0.14 (0.03)	0.10 (0.03)	0.12 (0.03)	0.10 (0.04)	0.05 (0.04)	-0.01 (0.04)	0.09 (0.03)	-0.03 (0.03)	0.08 (0.04)

[1] Except BW_{35}, other traits were measured at 49 d.

[2] BW_{35} = BW at 35 d; BW_{49} = BW at 49 d; CW = carcass weight; CP = carcass percentage; AFW = abdominal fat weight; AFP = abdominal fat percentage; BMW = breast muscle weight; BMP = breast muscle percentage; SW = skin weight; SP = skin percentage; IFP = intramuscular fat percentage; and NC= not converged.

[3] Percentage (%) indicates that traits were expressed as percentage of BW at 49 d of age, except IFP that was intramuscular fat content expressed as percentage the weight of a sample from the pectoralis minor muscle.

In the current study, positive genetic correlations were observed between BW and fat production traits (AFW, SW, and IFP). Almost all estimates of the genetic correlations of BW with AFW and AFP that have been published are unfavorably positive (Chambers, 1990; Le Bihan-Duval et al., 1998; Deeb and Lamont, 2002). Sinsigalli et al. (1987) noted that abdominal and subcutaneous fat deposition in chickens selected for rapid growth is associated with changing concentrations of hormones and neural control mechanisms (hunger-satiety control mechanisms) which regulate feed intake. Therefore, most modern meat-type chickens eat more than they require for muscle growth and maintenance. This excessive energy intake leads to increasing fat deposition in the body.

The large differences between genetic and phenotypic correlations for carcass traits may imply a relatively large influence of environmental conditions for these traits. In present study, AFW and SW were highly correlated, but the genetic correlation between AFW and IFP was almost zero. Evans (1977) estimated that abdomen and skin store the major part of body fat in poultry and that they are highly correlated. On the other hand, Cahaner et al. (1986) found that considerable changes in the size of adipose tissue are not accompanied by substantial changes in inter- or intramuscular fat in the chicken. Hrdinka et al. (1996) described that the abdominal and subcutaneous fat had very similar fatty acid patterns and differed significantly from the composition of the fat extracted from breast. These results, together with the results of current study, indicated that selection for reducing AFW does not automatically result in a change in IFP and probably meat quality. The IFP trait showed positive genetic correlations with BW, CW, CP, BMW, and BMP. Selection for increased BMW or BW therefore, will result in an increased IFP. Marshall (1994) reviewed the literature and suggested that selection for beef tenderness would be compatible with selection for improvement in most other carcass traits. This conclusion was supported by Wulf et al. (1996), who reported positive genetic relationships among production, carcass traits, and beef palatability traits.

The results of the present study showed that the genetic correlation between BW and BMP was 0.12. This finding was in agreement with Le Bihan-Duval et al. (1998) who reported low genetic correlations between BW and BMP (0.15 to 0.2). Therefore, including BMP in the selection index could be justified, especially for lines that are used for further processing. However selection for BMP not only increases breast muscle production but also decreases AFW and AFP, because there is a negative genetic correlation between this trait and fat production traits. Ricard and Tourille (1988) reported the negative genetic correlations between these traits. Therefore, BMP could be an economically important trait in these lines.

In conclusion carcass composition could be improved by selection for increasing CP and BMP and decreased AFW and AFP without decreased IFP. But these kinds of selections in practice have been accompanied by a number of negative consequences, including increased incidence of leg problems and ascites (Julian, 1998). These effects are likely related to disruption of physiological homeostasis. However, more investigations are needed for clarification of physiological relationship between fat storage in different parts of carcass (e.g., abdominal fat) and animal health.

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Chapter 3

Effect of Age and Housing System on Genetic Parameters for Broiler Carcass Traits

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Abstract

The effect of age and housing system on genetic parameters for BW and carcass traits was investigated. Traits were measured on broilers of different ages (48, 63, and 70 d). Birds in groups the 48 and 70 d groups were raised in group housing, whereas birds in the 63 d group were raised in the same housing up to 22 d and in individual cages between 22 and 63 d. Each group consisted of ~2,000 individuals from a single group of parents. Carcass, breast meat, abdominal fat, and back half were expressed as percentage of BW. The heritabilities of BW at 48, 63, and 70 d were 0.31, 0.26, and 0.19, respectively, and the Heritabilities of back half percentage at 48, 63, and 70 d were 0.42, 0.38, and 0.21, respectively. For other carcass traits, heritabilities were in the same range in different age groups. A positive genetic correlation was found between BW and valuable parts of carcass (breast meat and back half) at 48 d; these relationships were negative at 70 d. The genetic correlation between BW and abdominal fat percentage at 70 d was higher than at 48 d. The increase in growth at 48 d was accompanied by increase in valuable parts; at 70 d it was accompanied by an increase in abdominal fat percentage. The genetic correlation of BW at 48 d between individual cage and group housing demonstrated a genotype by environment interaction for performance of birds, which has consequences for design of breeding schemes.

Key words: broiler, genetic correlation, carcass traits, genotype by environment interaction

Introduction

The marketing of poultry has been greatly diversified with a significant increase in cut-up (parts) and processed products (Le Bihan-Duval et al., 2001). Demand for high quality parts and further-processed convenience foods have driven the poultry industry to change its marketing practices (Roenigk and Pedersen, 1987; Watts and Kennett, 1995). In 1970, 73% of poultry in the United States was sold primarily in supermarkets as ready-to-cook whole carcasses, and 23% of the products were sold as cut-up parts (Watts and Kennett, 1995). By 1995, less than 10% of the poultry products sold in the United States were whole carcasses, and the balance was sold as parts or further processed convenience foods in supermarkets and restaurants (National Agricultural Statistics Service, 2000). Today, with the vast majority of poultry being marketed in this manner, yield of high value items such as breasts and boneless filets has become critical to processors (Young et al., 2001). Traditionally, broilers have been bred to grow quickly so they reach their market weight by the age of 42 to 45 d. However, there is a growing trend in the poultry broiler industry to produce heavier birds for further processing (Leeson et al., 2000; Young et al., 2001).

The most common age for marketing broiler chickens is increasing, and, in the United States it is approaching 56 to 60 d for male birds. Furthermore, a market age of up to 80 d is suggested when future directions of the industry are discussed. The same trend is occurring in Canada (Leeson et al., 2000). Although increasing the market weight of birds generally increases live cost of production, the fixed costs of processing are reduced. In addition, only a finite number of birds may be processed in a plant within a given time period. Therefore, increasing the market weight of birds allows for increased plant meat yield without increasing the bird capacity of a processing plant (Saleh et al., 2004). Raising birds to a live weight of 6 to 7 kg could also benefit poultry producers. Although a great deal is known about genetic parameters for BW and carcass traits of broilers, many of these parameter estimations are based on studies conducted using birds grown to 6 or 7 wk of age. There is limited published research dealing with birds grown to the weights now demanded for further processing.

On breeding farms, birds are evaluated based on their efficiency of production. For such evaluation, birds need to be put into individual cages to measure individual feed intake. On commercial farms, however, broilers are kept in group housing systems. In practice, it is assumed that the performance of birds in a cage is an indicator for performance in group housing, and genotype by environment interaction (G×E) is ignored. However, there is evidence that BW of birds raised in individual cages and in group housing are not the same trait (Tolon and Yalcin, 1997; Van Kaam et al., 1999). There are very few studies on genetic parameter estimation for BW and carcass traits between these environments. The objective of the present study was to estimate genetic parameters for BW and carcass traits at different ages and different housing systems to investigate the effect of age and housing system on genetic parameters of these traits.

Materials and Methods

Population

The experimental population was resulted from a cross between 2 genetically different outcross broiler dam lines originating from the White Plymouth Rock breed. The maternal line had a relatively high reproductive performance, and the paternal line had a relatively high growth performance. In one line, 14 males and, in the other line 14 females, were crossed to produce the F_1 generation. From the F_1 generation, 10 male and 10 female birds were parents of the F_2 generation. From the F_2 generation, 172 males and 279 females were used to produce the F_3 generation. Each female was mated to one male only and each male was mated to 1 up to 5 females. The offspring of F_2 females were randomly distributed over the 3 experimental groups. An experiment was conducted on the F_3 generation, in which measurements were taken from 3 groups of birds at different ages: 48, 63, and 70 d. There were approximately 2,000 individuals in each group of birds. Birds in groups 48 and 70 d were raised in group housing, whereas birds in the 63 d group were raised in the same group housing up to 22 d of age and subsequently housed individually until 63 d. Individual cages were used to enable measurements of individual feed intake. All 3 groups of birds originated from the same parents, which provided the possibility to estimate genetic correlations between traits measured in different experiments. During the lifetime of the broilers, feed and water were supplied ad libitum, and illumination was available for 23 h/d. A commercial broiler feed, consisting of crumbled concentrates containing 2,980 kcal of ME / kg and 21% protein was used.

Trait

The BW and carcass traits were measured on 3 groups of related birds (Table 1). In the first group, BW was measured at 48 d (BW_g48); in the second group BW was measured at 48 (BW_i48) and 63 d (BW_i63); and in the third group BW was measured at 70 d (BW_g70). Birds were slaughtered at 48, 63, and 70 d in the first, second, and third groups, respectively. After slaughter, carcass weight was measured on the chilled carcass after removal of feathers, head, lungs, liver, kidneys, gastrointestinal tract, and abdominal fat. Carcass (CP), breast meat (BMP), abdominal fat (AFP), and back half (leg and half of the back; BHP) percentage were calculated in relation to live BW. Carcass traits were measured in the 3 d after slaughter. To remove this effect, data were corrected for day of carcass measurement.

Genetic Analyses

Descriptive statistics, including the test of the normality of the distribution of traits, were obtained from the UNIVARIATE procedure of SAS® (SAS Institute, 1999). An animal model was used to estimate the genetic parameters of carcass-related traits:

$$Y_{jklm} = \mu + Class_j + Sex_k + Day_l + a_m + e_{jklm}$$

where Y_{jklm} was the performance of chicken m in class j of sex k on day l; $Class_j$ was the fixed effect of class (j = 1,2,…,47 for birds in the 48 d group, j = 1,2,…,40 for birds in the 63 d group and j = 1,2,…,42 for birds in the 70 d group); classes were formed based on the age of the dam and the hatching day of the bird; Sex_k was the fixed effect of sex k (k = 1,2; female or male); Day_l was the fixed effect of the day l (l = 1,2,3) on which carcass traits were measured after slaughter; a_m was the random direct genetic effect of individual m ; and e_{jklm} was the random residual effect.

The fixed and random effects were identical for all the traits under study. Univariate analyses were used to estimate heritabilities. Bivariate analyses were used to estimate genetic correlations between traits using ASREML software (Gilmour et al., 2000).

TABLE 1. The list of traits[1] measured

Group housing	Individual cage	Group housing
BW_g48	BW_i48	BW_g70
CP_g48	BW_i63	CP_g70
BMP_g48	CP_i63	BMP_g70
BHP_g48	BMP_i63	BHP_g70
AFP_g48	BHP_i63	AFP_g70
	AFP_i63	

[1]CP = carcass percentage; BMP = breast meat percentage; BHP = back half percentage; AFP = abdominal fat percentage; g = group housing; i = individual cage; 48, 63, and 70 = age (in days) at which that trait was measured.

Results and Discussion

Description of Traits

Descriptive statistics of the traits are summarized in Table 2. Distributions of the traits were investigated for deviations of normality. All traits were found to be normally distributed. The average BW and abdominal fat percentages were higher in older birds. Birds weighed around 2,210 g at 48 d, 2,890 g at 63 d, and 3,450 g at 70 d. The average abdominal fat percentage was 2.95% for 48 d birds, 3.26% for 63 d birds, and 4.11% for 70 d birds. The average of other carcass traits hardly changed in the different age groups.

The effect of class, which was a combination of the age of dam and hatching day of the bird, had a significant effect for all traits (Table 2).

TABLE 2. Means, standard deviations, minimum, and maximum and the result of the analysis of variance of carcass traits measured at 48, 63, and 70 d

Trait[1]	Number	Mean	SD	Min	Max	Class[2]	Sex[3]	Day[4]
BW_g48 (g)	1,964	2,210	335	1,220	3,023	***	361.8***	NS
CP_g48 (%)	1,963	67.42	1.83	53.87	74.76	***	0.43***	NS
BMP_g48 (%)	1,957	13.36	1.28	5.57	17.68	***	0.14**	**
BHP_g48 (%)	1,958	28.50	1.09	20.76	32.67	***	0.59***	**
AFP_g48 (%)	1,931	2.95	0.90	0.17	6.38	***	–0.86***	*
BW_i48 (g)	2,080	2,190	327	1,088	3,132	***	328.4***	NS
BW_i63 (g)	2,007	2,890	423	1,630	4,090	***	501.9***	NS
CP_i63 (%)	1,786	67.33	1.96	54.85	75.25	***	1.01***	NS
BMP_i63 (%)	1,784	13.31	1.33	8.32	21.47	***	0.2**	NS
BHP_i63 (%)	1,777	28.71	1.49	20.54	42.52	***	1.13**	**
AFP_i63 (%)	1,759	3.26	1.12	0.22	6.82	***	–1.26***	NS
BW_g70 (g)	1,913	3,450	546	2,030	4,880	*	702***	NS
CP_g70 (%)	1,801	69.52	1.95	61.20	75.31	***	1.38***	*
BMP_g70 (%)	1,799	14.76	1.31	10.24	23.30	*	0.56***	NS
BHP_g70 (%)	1,799	29.08	1.33	24.49	40.13	*	1.04***	NS
AFP_g70 (%)	1,761	4.11	1.27	0.10	9.22	*	–1.48***	NS

[1]CP = carcass percentage; BMP = breast meat percentage; BHP = back half percentage; AFP = abdominal fat percentage; g = group housing; i = individual cage; and 48, 63, and 70 = age (in days) at which that trait was measured.

[2]Class = combination of the age of dam and the hatching day of the bird; because of large effects of class, only the significance of this effect is shown.

[3]In the analysis, the effect of female sex was fixed at zero.

[4]Day = the day of carcass traits measurements after slaughter; because of more than 2 effects of day, only the significance of this effect is shown.

*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.

Current results show that the mean values for BW and carcass traits in offspring from classes with older dams were higher than classes with younger dams. Older hens lay larger eggs that hatch into larger chickens and egg weight and hatching weight of chickens are correlated with market weight (Peebles et al., 1999). The effect of sex was significant for all traits at different ages. The mean values for BW and carcass traits were higher in males than in females except for AFP, which was higher in females. The increase in percentage of total body fat and abdominal fat is much higher in females than in males (Edwards et al., 1973; Fisher, 1984; Leenstra, 1986; Le Bihan-Duval et al., 1998). Phenomena such as greater competition between males, different nutritional needs, and greater impact of indigenous hormones in females could be involved. The effect of day of measurement was significant for some traits (i.e., BMP_g48, BHP_g48, AFP_g48, BHP_i63, and CP_g70). The mean value for these traits was higher on the first day than on the second and third days after slaughter. Extra bleeding and loss of water would influence the weight of carcass parts on d 2 or 3 after slaughter.

Genetic Parameters

The genetic parameters for BW and carcass traits in the different age groups are presented in Tables 3, 4, and 5. Heritabilities of BW and BHP were lower in older birds. The heritabilities of BW at 48, 63, and 70 d were 0.31, 0.26, and 0.19 and the heritabilities of BHP at 48, 63, and 70 d were 0.42, 0.38, and 0.21, respectively. Prado-González et al. (2003) found lower direct heritability for BW at older ages, whereas Kinney (1969), using data from the literature and estimates based on ANOVA procedures, reported mean heritability values of 0.43 (range = 0.19 to 0.66) for BW of 4-wk-old chickens, 0.38 (range = 0.01 to 0.88) for BW of 8-wk-old chickens, and 0.40 (range = 0.38 to 0.73) for BW of 12-wk-old chickens. However, differences in heritability estimates could be attributed to method of estimation, breed, environmental effects, and sampling error due to small data set or sample size. For other carcass traits, heritabilities in the different age groups were in the same range. The current estimates of the heritability of BW (0.31), CP (0.44), and BMP (0.58) at 48 d were close to previously published estimates in broiler chickens (Kuhlers and McDaniel, 1996; Le Bihan-Duval et al., 1998, 2001; Zerehdaran et al., 2004). The heritability of AFP (0.50) was in agreement with estimates reported by Griffin (1996), Le

Bihan-Duval et al. (1998), Rance et al. (2002), and Zerehdaran et al. (2004), which ranged from 0.50 to 0.71.

In the 48 d group, BW_g48 showed positive genetic correlations with CP_g48 (0.24), BMP_g48 (0.30), and BHP_g48 (0.26) (Table 3). These positive genetic correlations indicate that growth at 48 d is related to development of valuable parts, i.e., carcass, breast, and back half. In addition, the genetic correlation between BW_g48 and AFP_g48 was unfavorably positive (0.18), which is evidence that modern broilers selected for more rapid growth exhibit excessive body fat deposition particularly in the abdominal cavity (Mallard and Douaire, 1988; Chambers, 1990; Griffin, 1996; Le Bihan-Duval et al., 1998; Deeb and Lamont, 2002; Zerehdaran et al., 2004). In broilers, the main selection criterion is BW at a fixed age after feeding ad libitum. This method increases feed intake and, indirectly, the fat content of the bird (McCarthy and Siegel, 1983). However, negative genetic correlations between AFP and CP (–0.63), BMP (–0.51), and BHP (–0.14) were found. Current results show that selection for improving prime parts of carcass at 48 d will be accompanied by reduced fat deposition in the abdomen.

TABLE 3. Estimation of heritabilities (diagonal), genetic (above the diagonal) and phenotypic (below the diagonal) correlations with their approximate standard errors (in parentheses) of carcass traits measured at 48 d

Traits[1]	BW_g48	CP_g48	BMP_g48	BHP_g48	AFP_g48
BW_g48 (g)	0.31 (0.06)	0.24 (0.16)	0.30 (0.13)	0.26 (0.15)	0.18 (0.16)
CP_g48 (%)	0.21 (0.03)	0.44 (0.07)	0.72 (0.07)	0.51 (0.09)	–0.63 (0.10)
BMP_g48 (%)	0.24 (0.03)	0.54 (0.02)	0.58 (0.07)	–0.25 (0.12)	–0.51 (0.09)
BHP_g48 (%)	0.16 (0.03)	0.43 (0.02)	–0.12 (0.03)	0.42 (0.07)	–0.14 (0.07)
AFP_g48 (%)	0.15 (0.03)	–0.28 (0.02)	–0.28 (0.03)	–0.08 (0.03)	0.50 (0.07)

[1]CP = carcass percentage; BMP = breast meat percentage; BHP = back half percentage; AFP = abdominal fat percentage; g = traits were measured on 48-d-old birds reared in group housing.

This is in agreement with Ricard and Tourille (1988), Le Bihan-Duval et al. (1998), and Zerehdaran et al. (2004) who reported negative genetic correlations between valuable parts and abdominal fat deposition.

In the 63 d group, BW_i63 showed positive genetic correlations with CP_i63 (0.19), BMP_i63 (0.11), and BHP_i63 (0.09) (Table 4). Although genetic relationships at 63 d were lower than at 48 d, they indicated growth at 63 d of age was still related to developing valuable parts. In addition, the genetic correlation between BW_i63 and AFP_i63 was greater (0.26) than those relationships at 48 d (0.18), which was evidence that the body shifts from muscle production to fat deposition at this age. In the 70 d group, BW_g70 showed almost no genetic correlation with CP_g70 (0.08) and even negative genetic correlations with BMP_g70 (–0.18) and BHP_g70 (–0.31; Table 5). These genetic relationships indicate that growth at 70 d of age is less or even antagonistically related to developing valuable parts. In addition, the genetic correlation between BW_g70 and AFP_g70 was even greater (0.35) than those relationships at 63 d (0.26) and 48 d (0.18). Age of the broiler has a distinct effect on fat deposition; older birds have a higher fat content than younger birds (Brake et al., 1993). Changes in percentage of fat with age are larger than changes in percentage of protein and ash (Perreault and Lesson, 1992; Leenstra, 1982).

TABLE 4. Estimation of heritabilities (diagonal), genetic (above the diagonal) and phenotypic (below the diagonal) correlations with their approximate standard errors (in parentheses) of carcass traits measured at 63 d

Traits[1]	BW_i63	CP_i63	BMP_i63	BHP_i63	AFP_i63
BW_i63 (g)	0.26 (0.06)	0.19 (0.15)	0.11 (0.14)	0.09 (0.15)	0.26 (0.16)
CP_i63 (%)	0.02 (0.03)	0.48 (0.07)	0.75 (0.06)	0.47 (0.10)	–0.51 (0.10)
BMP_i63 (%)	0.18 (0.03)	0.52 (0.02)	0.57 (0.06)	–0.26 (0.13)	–0.42 (0.10)
BHP_i63 (%)	0.02 (0.03)	0.53 (0.02)	–0.05 (0.03)	0.38 (0.07)	–0.27 (0.15)
AFP_i63 (%)	0.23 (0.03)	–0.32 (0.03)	–0.28 (0.03)	–0.16 (0.03)	0.53 (0.07)

[1]CP = carcass percentage; BMP = breast meat percentage; BHP = back half percentage; AFP = abdominal fat percentage; i = traits were measured on 63-d-old birds reared in individual cages.

Selection for BW at a fixed age in chickens has consistently resulted in an increase in percentage of carcass fat beyond the age of selection (Pym and Solvyns, 1979; Barbato et al., 1983; Siegel and Dunnington, 1987; Sizemore and Barbato, 2002).

The present results show that prolonging the production period of current broilers with the same management until 70 d in order to produce heavy birds for processing is not efficient. In producing heavy birds, emphasis should be on maximizing monetary return instead of maximizing growth rate. Older birds have a bigger risk of developing metabolic disorders and carcass fatness. Therefore, heavy broilers should not simply be considered conventional birds grown to older age. Nutrition and general management strategies from first day need to be different for birds grown for 48 d and those grown for 70 d (Leeson et al., 2000).

TABLE 5. Estimation of heritabilities (diagonal), genetic (above the diagonal) and phenotypic (below the diagonal) correlations with their approximate standard errors (in parentheses) of carcass traits measured at 70 d

Traits[1]	BW_g70	CP_g70	BMP_g70	BHP_g70	AFP_g70
BW_g70 (g)	0.19 (0.04)	0.08 (0.12)	–0.18 (0.16)	–0.31 (0.19)	0.35 (0.12)
CP_g70 (%)	–0.02 (0.02)	0.41 (0.07)	0.69 (0.08)	0.41 (0.12)	–0.58 (0.09)
BMP_g70 (%)	0.15 (0.03)	0.52 (0.02)	0.54 (0.07)	–0.24(0.14)	–0.56 (0.09)
BHP_g70 (%)	0.04 (0.03)	0.48 (0.03)	–0.07 (0.03)	0.21 (0.06)	–0.12 (0.17)
AFP_g70 (%)	0.20 (0.03)	–0.44 (0.03)	–0.38 (0.03)	–0.15 (0.03)	0.51 (0.07)

[1]CP = carcass percentage; BMP = breast meat percentage; BHP = back half percentage; AFP = abdominal fat percentage; g = traits were measured on 70-d-old birds reared in group housing.

Effect of Housing System

Genetic correlations in different housing systems ranged from 0.74 (CP_g48-CP_i63) to 0.98 (BW_i48-BW_i63; Table 6). The genetic correlation between BW_g48 and BW_i63 (0.79) was lower than genetic correlation between BW_g48 and BW_g70 (0.92). In addition, genetic correlation between BW_i48 and BW_g48 (0.80) was lower than the genetic correlation between BW_i48 and BW_i63 (0.98).

TABLE 6. Estimation of genetic correlations (r_g) with their approximate standard errors (in parentheses) of BW and carcass traits measured in different environments

Trait[1]	r_g	Trait[1]	r_g	Trait[1]	r_g
BW_g48-BW_i48	0.80 (0.07)	CP_g48-CP_i63	0.74 (0.10)	BHP_g48-BHP_i63	0.78 (0.10)
BW_g48-BW_i63	0.78 (0.08)	CP_g48-CP_g70	0.92 (0.07)	BHP_g48-BHP_g70	0.91 (0.05)
BW_g48-BW_g70	0.92 (0.08)	CP_i63-CP_g70	0.83 (0.06)	BHP_i63-BHP_g70	0.86 (0.08)
BW_i48-BW_i63	0.98 (0.02)	BMP_g48-BMP_i63	0.89 (0.06)	AFP_g48-AFP_i63	0.84 (0.06)
BW_i48-BW_g70	0.82 (0.10)	BMP_g48-BMP_g70	0.98 (0.05)	AFP_g48-AFP_g70	0.97 (0.02)
BW_i63-BW_g70	0.89 (0.07)	BMP_i63-BMP_g70	0.93 (0.05)	AFP_i63-AFP_g70	0.96 (0.02)

[1]CP = carcass percentage; BMP = breast meat percentage; BHP = back half percentage; AFP = abdominal fat percentage; g = group housing; i = individual cage; 48, 63, and 70 = age (in days) at which that trait was measured.

For carcass traits, genetic correlations followed the same pattern; for example, the genetic correlation between CP_g48 and CP_i63 (0.74) was lower than genetic correlation between CP_g48 and CP_g70 (0.92). The present results revealed that genetic correlations for traits, measured in the same environment, were higher than those measured in different environments. In addition, genetic correlation of BW48 between 2 different environments (0.8) demonstrated a G×E for performance of birds in individual cages and in the group housing system. The methods for estimating the magnitude of G×E as genetic correlations, have been described by Prabhakaran and Jain (1994) and Mathur and Horst (1994). The genetic correlation of the same traits in different environments is expected to be one if there are no interactions. As the deviations from one increase, the interactions become higher.

Muir et al (1992) showed that G×E could originate from differences in scale or change in rank. Interactions that arise mainly from heterogeneity of scaling among environments are generally considered unimportant. However, the best linear unbiased prediction (BLUP) method accounts automatically for heterogeneous variance provided that the covariance structure is known (Gianola, 1986). In present study, G×E was analyzed using a multivariate BLUP model treating the same trait in different environments as separate traits, which are correlated. Consequently, the genetic correlation obtained was a clean measure of G×E due to reranking. The present results confirmed earlier findings by

Van Kaam et al. (1999) who found a QTL for BW at 48 d of age on birds that were reared in the cage. They found a genetic correlation of 0.60 between BW48 in a cage system and group housing. They concluded that the performance of chickens under different housing conditions is different. Tolon and Yalcin (1997) showed that the husbandry system significantly affected BW at 48 d in broilers. In group housing, there could be more competition between chickens. Additionally, chickens housed individually could be stressed due to their limited freedom and also due to changes in housing at 3 wk, when they were switched over to individual housing. One of the important problems in the presence of interaction is that of selection. There are reasons to believe that genetic superiority in one environment may not hold for other environmental conditions, leading to a change in the ranking order of the genotypes in different environments. The interaction effect with respect to BW would influence the feed efficiency of broilers in breeding farms and commercial farms.

In conclusion, clear evidence was found for a genotype by environment interaction for BW48 in group housing and individual cages. This has consequences for the design of broiler breeding schemes. In addition, genetic relationships between carcass traits at different ages revealed that an increase in growth at 48 d is accompanied by an increase in valuable parts, whereas at 70 d it is accompanied by an increase in abdominal fat weight.

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Chapter 4

Broiler Breeding Strategies Using Indirect Carcass Measurements

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Abstract

The objective of the current study was to determine the consequences of using indirect carcass measurements on the genetic response and rate of inbreeding in broiler breeding programs. In the base breeding scheme, selection candidates were evaluated based on direct carcass measurements on relatives. The possibilities of using indirect carcass measurements were investigated in alternative breeding schemes. Three alternative schemes, including indirect and own performance information for carcass traits on selection candidates, were evaluated by deterministic simulation. In the first scheme, indirect carcass traits were measured on male selection candidates. In the second scheme, indirect carcass traits were measured on male selection candidates and direct carcass traits were measured on relatives. In the third scheme, indirect carcass traits were measured on male and female selection candidates, and direct carcass traits were measured on relatives. In the base scheme, the genetic response for breast meat percentage (BMP) was 0.3%, and the rate of inbreeding was 0.96% per generation. In the third alternative scheme, the response for BMP increased by 66.2% compared with the base scheme, and the rate of inbreeding decreased to 0.79% per generation. The improved genetic gain resulted from increased accuracy of selection. The use of own performance information for selection candidates reduced the rate of inbreeding in alternative schemes, which is desirable for long-term selection. The accuracy of the indirect carcass measurements had consequences on the response for BMP and the rate of inbreeding. In most cases, an accuracy of 30% was sufficient to result in a higher gain for BMP and a lower rate of inbreeding compared with the base scheme.

Key words: broiler, carcass, deterministic simulation, indirect measurement, own performance

Introduction

The major aim of broiler breeding over the past 50 yr has been to improve growth rate, feed conversion, and meat yield. The poultry industry has traditionally evaluated broiler performance based on feed conversion and BW gain. However, strong consumer demand for breast meat has increased its value to the industry and led poultry producers to look for ways to optimize breast muscle growth (Ewart, 1993; Watts and Kennett, 1995). For many producers, breast yield is considered as important as growth rate and feed conversion (Baeza and Leclercq, 1998). Although growth rate and feed conversion can be recorded on live birds, birds have to be slaughtered to measure carcass traits. Consequently, selection of sires and dams for carcass traits is based only on information recorded on relatives and not based on their own performance. Selection based on information of relatives, e.g., best linear unbiased prediction (BLUP) selection, would increase the correlation between estimated breeding values (EBV) of relatives, resulting in a higher rate of inbreeding (Burrows, 1984; Bijma et al., 2001).

Indirect carcass measurements provide the opportunity to collect information on live birds and as a result the own performance information for carcass traits would be available on selection candidates. A range of indirect measurement methods is available. Some of these techniques use simple, inexpensive equipment, and others require sophisticated, expensive equipment (Latshaw and Bishop, 2001). Body conformation traits, i.e., breast width, length, and thickness are good indicators for predicting breast muscle weight. The keel length shows a strong phenotypic correlation with the weight of breast muscle (0.8 in ducks and 0.7 in chicken and geese; Rymkiewicz and Bochno, 1999; Bochno et al., 2000). Moreover, Komender and Grashorn (1990) observed a high genetic correlation (0.62) between the thickness, and weight of breast muscles in ducks. Those results were confirmed by other studies on chickens and geese (Rymkiewicz and Bochno, 1999). Originally, the thickness of breast muscle was measured using needle catheters, but recently ultrasonic apparatus has been employed. The results with both techniques show a similar correlation with the weight of breast muscle (Canope et al., 1997). More expensive, but accurate techniques to assess body composition of live birds are: computed tomography scan (CT scan) (Bentsen and Sehested, 1989; Remignon et al., 1997; Glasbey and Robinson, 2002), magnetic resonance imaging (MRI), and echography (Grashorn, 1996). Tang et al.

(2002) found high phenotypic correlations for BW ($r = 0.98$), total adipose tissue ($r = 0.99$), and abdominal adipose tissue ($r = 0.98$) between MRI and dissection methods in rats.

Information is lacking on the minimum level of accuracy of indirect measurements of own performance that is required to justify incorporation in broiler breeding schemes. The objective of the present study was to determine the consequences of using indirect carcass measurements for the genetic response and rate of inbreeding in a broiler breeding program.

Materials and Methods

Selection response and the rate of inbreeding were predicted by deterministic simulation of single-stage selection schemes with discrete generations, using the program SelAction (Rutten et al., 2002). The program accounts for reduction in variance due to selection (Bulmer, 1971), and corrects selection intensities for finite population size and for the correlation between index values of family members (Meuwissen, 1991).The program predicts the rate of genetic gain using multi trait pseudo-BLUP (Villanueva et al., 1993). SelAction uses a hierarchical mating structure in which dams are nested within sires and random mating of selected animals is applied. Prediction of the rate of inbreeding is based on the long-term contribution theory, which was introduced by Wray and Thompson (1990) and further developed by Bijma and Woolliams (2000).

Population and Breeding Scheme

A population with discrete generations was simulated in which 100 males were randomly mated with 500 females with a mating ratio of 1 male to 5 females (Figure 1). Each female produced 24 offspring (12 males and 12 females). The total number of progeny of each sex was $500 \times 12 = 6{,}000$. All birds were reared in group housing until 3 wk of age (males and females separately). Then 50% of the males (3,000) were randomly assigned to the feed conversion test and moved to individual cages. At the end of the feed conversion test (6 wk), 100 males out of 3,000 available males were selected as parents for the next generation (selected proportion = 0.033). The remaining males were kept in the group housing until 6 wk of age and were then slaughtered to collect their direct carcass measurements (DCM) including carcass percentage (CP) and breast meat percentage

(BMP). The female birds were weighed at 6 wk of age, and 500 females out of 6,000 available females were selected as parents for the next generation (selected proportion = 0.083).

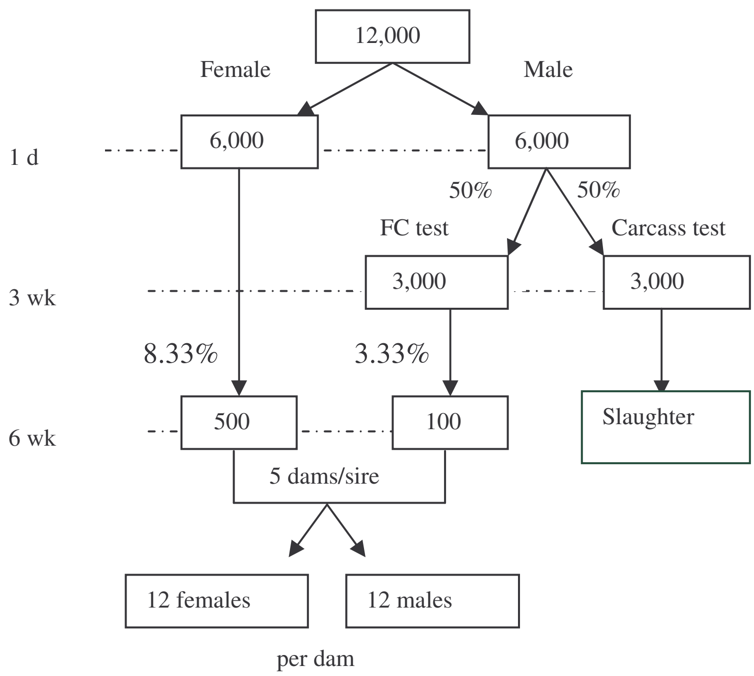

FIGURE 1. Base broiler breeding program, 50% of the male birds in feed conversion (FC) test and the other 50% in the carcass test

Selection intensities in males and females were chosen close to values in a practical broiler breeding program to take into account selection based on other traits such as reproduction and health, as is performed in practical breeding.

The present breeding scheme was likely designed for a male line program, in which the breeding goal consisted of BW at 6 wk (BW_6), adjusted feed conversion (FCA = feed conversion adjusted for BW), and BMP:

$$H = \mathrm{EV}_1 \times A_{\mathrm{BW}_6} + \mathrm{EV}_2 \times A_{\mathrm{FCA}} + \mathrm{EV}_3 \times A_{\mathrm{BMP}}$$

where H is the breeding goal, EV_1, EV_2, and EV_3, are the economic values for BW_6, FCA, and BMP, respectively, and A_{BW6}, A_{FCA}, and A_{BMP} are the true breeding values for BW_6, FCA, and BMP, respectively. Jiang et al. (1998) derived the economic values for BW_6 (0.33), FCA (–0.3), and BMP (0.06) based on profit equations. These economic values (euros/marketable bird per unit) were used for all breeding schemes.

Alternative Breeding Schemes

Three alternative breeding schemes were simulated to investigate the effect of indirect carcass measurements, including indirect carcass percentage (INCP) and indirect breast muscle percentage (INBMP), on genetic gain for BMP and the rate of inbreeding. First, methods with 100% accuracy of carcass measurement were evaluated to determine the potential for using these techniques. Subsequently, indirect carcass methods with lower accuracy of measurements were investigated. The following alternative schemes were considered:

1) Scheme A: indirect carcass traits and direct (actual) feed conversion were measured on male selection candidates (3,000). The information on relatives for carcass and feed conversion traits was available for female selection candidates [male indirect carcass measurement scheme (MICM)].
2) Scheme B: in order to combine direct and indirect carcass measurements, indirect carcass traits and direct (actual) feed conversion were measured on male selection candidates (3,000) and direct carcass traits were measured on the remaining males (3,000) after slaughter. Consequently, sires were selected based on their own performance information for carcass and feed conversion as well as information on relatives for carcass traits. Dams were selected based on the information on relatives for carcass and feed conversion traits [male indirect carcass measurement + direct carcass measurement scheme (MICM + DCM)].
3) Scheme C: for further application of indirect carcass measurements in both sexes, indirect carcass traits were measured on male (3,000) and female (6,000) selection candidates. Direct (actual) feed conversion was measured on male selection

candidates and direct carcass traits were measured on the remaining males after slaughter. Therefore, sires were selected based on their own performance information for carcass and feed conversion traits as well as the information on relatives for carcass traits. Dams were selected based on their own performance information for carcass traits and the information on relatives for carcass and feed conversion traits [male and female indirect carcass measurement + direct carcass measurement scheme (MICM + FICM + DCM)].

Table 1 gives the traits recorded, and the number of full-sib and half-sib groups in the different breeding schemes. For BW_6, FCA, INBMP, and INCP, in addition to the average phenotypic performance of the full sibs and half sibs, the own performance of selection candidates was available. The BMP and CP were not available for selection candidates.

Accuracy of Indirect Measurements

The accuracy of the various indirect carcass methods differs. The MRI is a very accurate method (Scollan, 1998), whereas a method like ultrasound is less accurate (Stavrev. 1997). Accuracy of measurement influences the accuracy of selection and subsequently determines the genetic gain for breeding goal traits. To investigate the effect of accuracy of indirect measurements on genetic gain and the rate of inbreeding, a range of accuracy from 100 to 20% was simulated in alternative schemes.

TABLE 1. The number of full-sib (FS) and half-sib (HS) birds available for different breeding strategies

Selection candidates (n)			Trait[2]											
Scheme[1]	Males	Females	BW_6		FCA		BMP		CP		INBMP		INCP	
			FS	HS	FS	HS	FS	HS	FS	HS	FS	HS	FS	HS
Base	3,000	6,000	17	70	5	25	6	24	6	24	–	–	–	–
A	3,000	6,000	11	48	5	24	–	–	–	–	5	24	5	24
B	3,000	6,000	17	70	5	24	6	24	6	24	5	24	5	24
C	3,000	6,000	17	70	5	24	6	24	6	24	16	70	16	70

[1]Base scheme = direct carcass measurements for male relatives; scheme A = indirect carcass measurements on male selection candidates; scheme B = indirect carcass measurements on male selection candidates as well as direct carcass measurements on male relatives; and scheme C = indirect carcass measurements for male and female selection candidates as well as direct carcass measurements on male relatives.

[2]BW_6 = BW at 6 wk (kg), FCA = adjusted feed conversion (point), BMP = breast meat percentage (%), CP = carcass percentage (%), INBMP = indirect BMP measurement (%), and INCP = indirect CP measurement (%).

Genetic Parameters

Except for indirect carcass traits (INCP and INBMP), the genetic parameters of the traits in the simulation were based on an analysis of actual experiments, including birds kept in group housing for the carcass test and birds kept in individual cages for the feed conversion test (Ask et al., 2002; Zerehdaran et al., 2004).

The accuracy of indirect measurements is defined as the genetic correlation (r_g) between direct and indirect carcass traits. When the results of direct and indirect measurements for one trait are equal, the accuracy of the indirect method is considered to be 100% and, consequently, r_g between direct and indirect carcass traits is unity; therefore, the genetic parameters of indirect carcass traits (INBMP and INCP) with 100% accuracy of measurement would be the same as the genetic parameters for direct carcass traits (BMP and CP). For indirect methods with accuracy lower than 100%, r_g between direct and indirect carcass traits is determined based on the accuracy of the indirect carcass measurement. The accuracy also influences r_g between indirect carcass traits and other index traits. The following equation was used to incorporate accuracy in the genetic correlations among indirect carcass traits and index traits:

$$r_{g3} = r_{g1} \times r_{g2}$$

where r_{g3} was the genetic correlation between indirect carcass trait and index trait, r_{g1} was the genetic correlation between direct carcass trait and index trait, and r_{g2} was the genetic correlation between direct and indirect carcass traits (= accuracy). Although the accuracy of indirect measurement may influence the heritability of indirect carcass traits, in this simulation, heritability of indirect traits with variable accuracy of measurement was assumed to be the same as direct carcass traits.

The phenotypic and r_g matrices were tested for consistency and bending was used to obtain positive definite matrices. The parameters applied are given in Table 2.

TABLE 2. Phenotypic variances, economic values and genetic parameters of traits used in simulation study

Traits[1]	V_P [2]	EV[3]	Genetic parameters[4]					
			BW_6	FCA	BMP	CP	INBMP	INCP
BW_6 (kg)	0.06	0.33	0.35	0.05	0.15	0.16	0.15	0.16
FCA (point)	0.17	–0.3	0.04	0.41	0.03	0.26	0.03	0.26
BMP (%)	0.95	0.06	0.18	0.01	0.48	0.60	1.00	0.60
CP (%)	0.92	–	0.12	0.02	0.55	0.42	0.60	1.00
INBMP (%)	0.95	–	0.18	0.01	1.00	0.55	0.48	0.60
INCP (%)	0.92	–	0.12	0.02	0.55	1.00	0.55	0.42

[1] BW_6 = BW at 6 wk (kg), FCA = adjusted feed conversion (point), BMP = breast meat percentage (%), CP = carcass percentage (%), INBMP = indirect BMP measurement (%), and INCP = indirect CP measurement (the accuracy of indirect measurement for INBMP and INCP is 100%).

[2] V_P = phenotypic variance.

[3] EV = economic value (euros marketable $bird^{-1}$ $unit^{-1}$).

[4] Heritabilities are given on the diagonal and genetic and phenotypic correlations are given above and below the diagonal, respectively. The SE for heritabilities was in the range of 0.02-0.09, for genetic correlations, was in the range of 0.03 to 0.15, and for phenotypic correlations, was in the range of 0.03 to 0.05. The estimated parameters are based on 100% accuracy of indirect measurements for INBMP and INCP.

Results

Base Breeding Scheme

The economic response, genetic response per breeding goal trait, and the rate of inbreeding for the base and alternative schemes are given in Table 3. In the base scheme, in which own performance information for carcass traits was not available for selection candidates, the economic response was €0.106 and the genetic responses for BW_6, FCA, and BMP were about 0.076 kg, –0.21, and 0.3% per generation, respectively. The estimated rate of inbreeding was 0.963% per generation.

TABLE 3. Economic and genetic responses of breeding goal traits and rate of inbreeding of different schemes

Scheme[1]	Traits in index[2]	Description[3]	Response[4]				
			ΔG	BW_6	FCA	BMP	ΔF[5]
Base	BW_6 , FCA, BMP,CP	DCM	0.106	0.076	–0.211	0.296	0.963
A	BW_6, FCA, INBMP, INCP	MICM	0.110	0.075	–0.209	0.380	0.852
B	BW_6, FCA, BMP, CP, INBMP, INCP	MICM + DCM	0.112	0.075	–0.208	0.412	0.853
C	BW_6, FCA, BMP, CP, INBMP, INCP	MICM + FICM + DCM	0.116	0.073	–0.207	0.492	0.789

[1]Base scheme = direct carcass measurements for male relatives; scheme A = indirect carcass measurements on male selection candidates; scheme B = indirect carcass measurements on male selection candidates as well as direct carcass measurements on male relatives; and scheme C = indirect carcass measurements for male and female selection candidates as well as direct carcass measurements on male relatives.

[2]BW_6 = BW at 6 wk (kg), FCA = adjusted feed conversion (point), BMP = breast meat percentage (%), CP = carcass percentage (%), INBMP = indirect BMP measurement (%), and INCP = indirect CP measurement (the accuracy of indirect measurement for INBMP and INCP is 100%).

[3]DCM = direct carcass measurements; MICM = male indirect carcass measurements; and FICM = female indirect carcass measurements.

[4]Economic response for the breeding goal (ΔG) and genetic response for BW_6, FCA, and BMP.

[5]ΔF = rate of inbreeding.

Indirect Carcass Measurement Strategies

The effect of using indirect carcass measurements on birds was investigated in schemes A, B, and C. When indirect carcass measurements were applied to male selection candidates, the response for BMP increased by 28.4% compared with the base breeding scheme, and the rate of inbreeding decreased to 0.852% per generation in scheme A (Table 3). In scheme B, the combination of direct and indirect carcass measurements for male selection candidates provided a 39.1% higher response for BMP than the base breeding scheme, and the rate of inbreeding decreased to 0.853% per generation. Application of indirect carcass measurements for male and female selection candidates (scheme C) increased the response for BMP by 66.2% compared with the base breeding scheme, and the predicted rate of inbreeding declined to 0.789% per generation. Genetic responses for BW_6 and FCA hardly changed in the alternative schemes. The increase in BMP was associated with small economic losses due to reduced response in BW_6 and FCA. The losses amounted to 0.84%, 1.1%, and 1.9% of the economic gain due to increased BMP in schemes A, B, and C, respectively.

Effect of Accuracy of Indirect Carcass Measurements

The effect of accuracy of indirect carcass measurements (100 to 20%) on the genetic response for BMP and the rate of inbreeding were investigated in schemes A, B, and C (Table 4, Figures 2 and 3). When the accuracy of measurements decreased from 100 to 20%, genetic responses for BMP decreased by 56% in scheme A, 33% in scheme B, and 43% in scheme C. The rate of inbreeding increased to 1.01% in scheme A, 0.97% in scheme B, and 0.96% in scheme C, relative to 100% accuracy. Table 4, shows that in the scheme incorporating only indirect carcass measurements (scheme A), the genetic gain for BMP improves with high accuracy indirect methods (higher than 70%). However, schemes with a combination of direct and indirect measurements improve the genetic gain for BMP through low accuracy indirect methods (30%).

TABLE 4. Effect of indirect measurement accuracy on genetic response of breast meat percentage (BMP) and rate of inbreeding in schemes A, B, and C[1]

Accuracy (%)[2]	Scheme A		Scheme B		Scheme C	
	BMP (%)	ΔF^3 (%)[3]	BMP (%)	ΔF (%)	BMP (%)	ΔF (%)
100	0.380	0.852	0.412	0.853	0.492	0.789
90	0.352	0.916	0.385	0.875	0.460	0.831
80	0.333	0.940	0.375	0.894	0.441	0.859
70	0.308	0.958	0.369	0.910	0.428	0.882
60	0.257	0.973	0.343	0.924	0.409	0.903
50	0.232	0.986	0.329	0.936	0.381	0.922
40	0.201	0.995	0.314	0.946	0.349	0.937
30	0.185	1.002	0.306	0.957	0.324	0.948
20	0.169	1.011	0.276	0.965	0.279	0.959

[1]Base scheme = direct carcass measurements for male relatives; scheme A = indirect carcass measurements on male selection candidates; scheme B = indirect carcass measurements on male selection candidates as well as direct carcass measurements on male relatives; and scheme C = indirect carcass measurements for male and female selection candidates as well as direct carcass measurements on male relatives.

[2]Accuracy of indirect carcass measurement.

[3]ΔF = rate of inbreeding.

Discussion

Different sources of information on carcass performance were included in alternative schemes to increase the genetic gain for BMP. Evaluation of the alternative schemes was based on genetic responses for the breeding goal traits and the rate of inbreeding per generation. The results of the current study indicate that including indirect carcass measurements increase the genetic gain for carcass traits and decrease the rate of inbreeding per generation.

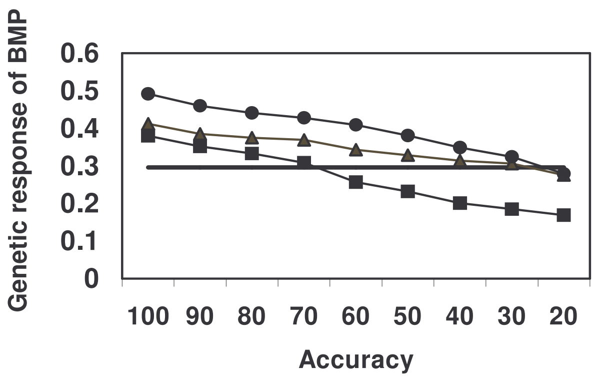

FIGURE 2. The effect of accuracy of indirect carcass measurements on genetic response of breast meat percentage (BMP) in schemes A (squares), B (triangles), and C (circles) compared to the base scheme (solid line). Base scheme = direct carcass measurements for male relatives; scheme A = indirect carcass measurements on male selection candidates; scheme B = indirect carcass measurements on male selection candidates as well as direct carcass measurements on male relatives; and scheme C = indirect carcass measurements for male and female selection candidates as well as direct carcass measurements on male relatives.

Genetic Gain

The current study showed that indirect carcass measurements provide own performance information for selection candidates, which increase the accuracy of selection and consequently improve the genetic gain. Indirect carcass methods, such as ultrasonic measures of body composition for genetic evaluation, along with the relationship to carcass traits have been shown to be valuable tools for genetic improvement of carcass traits (Wilson et al., 1998; Reverter et al., 2000; Crews and Kemp, 2001; Devitt and Wilton, 2001).

The accuracy of indirect carcass measurements influences the accuracy of selection with possible consequences for the genetic responses. There are various indirect carcass measurement methods with different accuracy of measurements. Stavrev (1997) found that the accuracy of the ultrasound method (r^2 = 0.6 for muscle weight) was lower than the accuracy of imaging methods

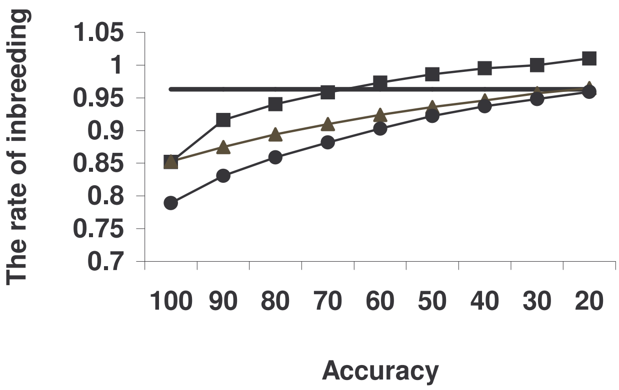

FIGURE 3. The effect of accuracy of indirect carcass measurements on the rate of inbreeding for schemes A (squares), B (triangles), and C (circles) compared to the base scheme (solid line). Base scheme = direct carcass measurements for male relatives; scheme A = indirect carcass measurements on male selection candidates; scheme B = indirect carcass measurements on male selection candidates as well as direct carcass measurements on male relatives; and scheme C = indirect carcass measurements for male and female selection candidates as well as direct carcass measurements on male relatives.

The accuracy of the ultrasound method was affected by the refining algorithms used to estimate the distance to the fat–meat boundary. Scollan et al. (1998) found that the accuracy of MRI for prediction of breast muscle weight (g) from breast muscle volume (cm^3) in broilers is very high (r^2 = 0.99). The results of the present study indicate that indirect carcass methods with higher accuracy of measurement increase the accuracy of selection and consequently improve the genetic responses more than methods with lower accuracy of measurements. Theoretical studies in sheep predicted increases in genetic progress that may be as high as 50% (Simm and Dingwall, 1989) or close to 100% (Jopson et al., 1995) through use of CT scanning in combination with ultrasound scanning.

Rate of Inbreeding

SelAction calculates the rate of inbreeding for the Bulmer equilibrium situation accounting for the effect of selection (Rutten et al., 2002). Prediction of the rate of inbreeding is based on the long-term genetic contribution theory (Wray and Thompson, 1990; Woolliams and Bijma, 2000). It has been generally recommended that the rate of inbreeding should be kept below 1% (Morris and Pollott, 1997). High selection intensity and more emphasis on sib information in the index increase the probability of co-selection of relatives, which in turn increases the rate of inbreeding (ΔF). In the current simulation, ΔF was lower than 1% for all schemes. In the base scheme, selection intensities were chosen close to practical poultry breeding to allow selection for other traits not correlated to the current breeding goal traits, and, consequently, because of low selection intensities, the rate of inbreeding was lower than 1%. In alternative schemes, application of indirect carcass measurements made the own performance of selection candidates available, and less sib information was used in the index. The own performance information reduced the rate of inbreeding in alternative schemes compared with the base scheme, which is favorable for long-term selection.

Quinton et al. (1992) reported that comparisons between breeding schemes should be made at the same level of inbreeding rather than at the same selection intensity due to adverse effects of inbreeding depression. Van Arendonk and Bijma (2003) demonstrated that in the short term, inbreeding and genetic gain have an unfavorable relationship. If schemes are compared that have the same rate of inbreeding, the extra genetic gain for BMP in alternative schemes will be even higher than the base scheme, as has been shown by Pakdel et al. (2005) for ascites related traits.

Cost

Application of indirect carcass measurements will involve extra costs. However, the current system of raising male birds for carcass tests and dissecting their carcasses might be costly. It is to be expected that the cost of schemes in which direct carcass measurements are replaced by indirect carcass measurements (scheme A) can be lower than in the base scheme because there is no raising and dissection of the carcass of relatives. However, the costs of schemes with direct and indirect carcass measurements (schemes B and C) are likely to be higher than the base scheme especially when imaging methods are used. Whether the cost of indirect carcass measurement methods will be compensated by the additional profit of extra genetic gain remains to be investigated. Costs of using expensive equipment can be reduced by pre-screening of candidates or reduction of measurement time (Young et al., 1996). Jopson et al. (1995) showed that in sheep the use of CT scan in a terminal sire breeding program is economically beneficial.

Further Considerations

Early research highlighted the potential of indirect carcass measurements, specially imaging methods, e.g., CT scanning, for the study and evaluation of carcass composition of animals (Vangen and Skjervold, 1981; Young et al., 1996). Apart from indirect carcass evaluation, imaging methods have some other advantages:

1) More intensive data collection through electronic devices such as repeated ultrasound and other imaging methods will provide repeated observation on broilers which can be analyzed with random regression models; this is now being implemented in beef improvement (Meyer, 1999; Brenoe and Kolstad, 2000; Schenkel et al., 2002).
2) Imaging techniques may enable the user to improve the carcass uniformity, which is important for processing (Basarab. et al., 1997).
3) The imaging techniques could offer opportunities to improve the health of the birds (Matinea-lemus, et al., 1998; Bartels et al., 1989; Zhang et al., 1998). Using such information enables the user to have more balance between support and demand tissues for birds, which are selected for higher and more efficient production.

Apart from the cost of imaging techniques, the method of data collection needs to be considered before implementation in practice. For imaging methods animals need to be restrained to minimize movement and ensure animal safety. For sheep, a mild tranquilizer is administered, and animals lie on their back restrained by broad webbing straps and soft foam pads (Young et al., 1996). For chickens, 3 at the same time are fixed in a stretched position with belts in a specially designed holder and without using anesthetic (Andrassy-

Baka et al., 2003). Imaging methods at present require very expensive equipment. However, they offer interesting opportunities for genetic improvement schemes in broilers.

In conclusion, indirect carcass measurements on selection candidates increase the genetic gain for carcass traits and reduce the rate of inbreeding per generation, which is desirable for long-term selection. The accuracy of indirect measurements influences the usefulness of these methods. The combination of direct and indirect carcass measurements is recommended for genetic improvement schemes when indirect measurements with low accuracy are available.

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Chapter 5

A Bi-variate Mixture Model Analysis of Body Weight and Ascites Traits in Broilers

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Abstract

The objective of the present study was to divide the population into a non-ascitic and an ascitic group of birds based on parameter estimations for ascites traits and to study the difference in the correlations between BW and ascites traits in each group of ascitic and non-ascitic birds. Existing data was used of an experiment in which birds were housed in two groups under different climate conditions. In the first group BW, the ratio of right ventricular weight to total ventricular weight (RATIO), and hematocrit value (HCT) were measured on 4,202 broilers, under cold conditions; in the second group, the same traits were measured on 795 birds under normal temperature conditions. Cold stress conditions were applied to identify individuals that were susceptible to ascites. RATIO and HCT were approximately normally distributed under normal temperature conditions, whereas the distributions of these traits were skewed under cold temperature conditions, which suggest underlying distributions. Fitting a bi-variate mixture model to the observations showed that there was only one homogenous population for ascites traits under normal temperature conditions, whereas there was a mixture of (two) distributions under cold conditions. One distribution contained non-ascitic birds and the other distribution contained ascitic birds. In the distribution of non-ascitic birds, the inferred phenotypic correlations (phenotypic correlations with two distinguishing underlying distributions) of BW with RATIO and HCT were close to zero (0.10 and –0.07, respectively), whereas in the distribution of ascitic birds, the inferred phenotypic correlations of BW with RATIO and HCT were negative (–0.39 and –0.4, respectively). The negative inferred correlations of BW with RATIO and HCT in the distribution of ascitic birds resulted in negative overall correlations (correlations without two distinguishing distributions) of BW with RATIO (–0.30) and HCT (–0.37) under cold conditions. The present results indicated that the overall correlations between BW and ascites traits are dependent on the relative frequency of ascitic and non-ascitic birds in the population.

Key words: ascites, broiler, cold conditions, correlation, mixture distributions, mixture model

Introduction

Ascites in broilers has been a worldwide source of concern to the poultry industry for several decades. It has been estimated that ascites accounts for losses of about US$1 billion annually worldwide (Maxwell and Robertson, 1997). The characteristic symptoms of the disease process are an enlarged heart, variable liver changes, and accumulation of water in the abdominal cavity. The enlarged heart is due to dilation and hypertrophy of the right ventricle and the right atrioventricular valve (Riddell, 1991). The primary stimulus of ascites syndrome is believed to be hypoxia (Julian, 1987, 1988). The bird's demand for oxygen exceeds its cardiopulmonary capacity, and pulmonary hypertension and right ventricular hypertrophy ensue (Julian et al., 1986). It has been suggested that selection for growth rate and feed conversion has resulted in a growing discrepancy between the oxygen required for metabolic processes and the oxygen that is available (Decuypere et al., 2000). During the development of the ascites syndrome, birds exhibit classic hematological changes and hematocrit increases dramatically (Hall and Machicao, 1968; Cueva et al., 1974; Maxwell et al., 1986, 1987; Yersin et al., 1992). As the disease progresses, the increase in hematocrit and the accompanying increase in apparent blood viscosity may worsen the pulmonary hypertension and, ultimately, the ascites (Fedde and Wideman, 1996).

Ascites traits, e.g., hematocrit and the ratio of the right ventricular weight to the total ventricular weight, have been used as indirect criteria in selection for reduced incidence of ascites in broilers (Peacock et al., 1989; Shlosberg et al., 1996; Wideman et al., 1997; Scheele et al., 2003; Pakdel et al., 2005b). The current methodology for estimating parameters for ascites related traits does not account for the differences in ascites between healthy and diseased birds. Methods may be available to distinguish between healthy and diseased animals. For example, in the case of mastitis in dairy cows, the parameter estimations were improved by dividing the heterogeneous populations into two more homogenous distributions, healthy and diseased. With these improved estimates, a better alternative for selection against susceptibility to mastitis was provided (Detilleux and Lorey, 2000). Mixture models have been widely used to separate heterogeneous populations into more homogeneous distributions (Everitt and Hand, 1981; Redner and Walker, 1984; Titterington et al., 1985; McLachlan and Khrishnan, 1997). The mixture model can be used for situations where it is unknown how to classify individuals between distributions. This is the case when analyzing ascites traits, because there are no clear criteria to distinguish between healthy and diseased birds (De Greef et al., 2001). Using mixture models, birds can be assigned to different distributions via probabilities estimated from trait observations (Detilleux and Leroy, 2000). For ascites traits, a mixture model in its simplest form may be used to assign observations to two components, i.e., ascitic and non-ascitic. Then, the identification and culling of birds could be based on the probability of putative ascites, given ascites indicator traits, rather than on crude ascites traits. The objective of the present study was to divide the population into non-ascitic and ascitic groups of birds based on parameter estimations for ascites traits, and to study the difference in the correlations between BW and ascites traits in each group of ascitic and non-ascitic birds.

Materials and Methods

Data

The data in this study was collected from an experiment in 1994. Details of the experiment are described by Pakdel et al. (2005a). In brief: the experimental population was the result of a cross between two genetically different outcross broiler dam lines originating from the White Plymouth Rock breed. The maternal line had a relatively high reproductive performance and was fast-feathering and the paternal line had a relatively high growth performance and was slow-feathering.

Birds in the third generation of the experiment were divided into two groups. In the first group, ascites traits were measured on 4,202 broilers, consisting of 1,736 females and 2,466 males. To identify individuals that were susceptible to ascites, a cold stress condition was applied. At the time of hatching, the temperature was 30 °C and then was gradually decreased to 10 °C by 22 d of age. The latter temperature was constant until the end of the experiment at 35 d. Except for the adjusted temperature schedule; birds were kept under circumstances that closely resemble commercial practice, i.e., a standard commercial feed (2,980 kcal/kg and 21% protein), artificially lighted housing for 23 h/d, and group housing with 20 birds/m^2. In the second group, ascites traits were measured on 795 birds kept under normal conditions, which started at 34 °C and then gradually decreased to 18 °C by 35 d of age. The latter temperature was maintained until the end of the experiment at 49 d. Birds under normal conditions were also kept under circumstances that closely resemble commercial practice.

Traits

For birds exposed to the cold stress conditions, BW and hematocrit value (HCT) were measured 1 d before slaughter. After slaughter (at 35 d), other ascites indicator traits, i.e., accumulation of fluid in the abdomen (ABDOMEN), liver abnormality (LIVER), and accumulation of fluid in the heart sac (HEART) were measured. ABDOMEN, LIVER, and HEART were scored as 0, 1, or 2. A score of 0 represented no accumulation of fluid, a score of 1 represented accumulation of fluid, and a score of 2 represented serious accumulation of fluid in the abdominal cavity or heart sac. For liver abnormality a score of 0 represented no abnormality, a score of 1 represented abnormality, and a score of 2 represented serious abnormality in the liver. Furthermore, the right ventricular weight (RV) and total ventricular weight (TV) were measured and then the ratio of RV:TV (RATIO) was derived. For birds exposed to normal conditions, BW and HCT were measured 1 d before slaughter. RATIO was measured after slaughter at 49 d.

Mixture model

The following bi-variate mixture of normal distributions was modeled:

$$L(\mu_{1,1},\mu_{1,2},\sigma_{1,1},\sigma_{1,2},\rho_1,\mu_{2,1},\mu_{2,2},\sigma_{2,1},\sigma_{2,2},\rho_2,p \mid x,y)=$$

$$p\left[\frac{1}{2\pi\sigma_{1,1}\sigma_{1,2}\sqrt{(1-\rho_1^2)}}\exp\left(\frac{-1}{2(1-\rho_1^2)}\left[\left(\frac{x-\mu_{1,1}}{\sigma_{1,1}}\right)^2-2\rho_1\left(\frac{x-\mu_{1,1}}{\sigma_{1,1}}\right)\left(\frac{y-\mu_{1,2}}{\sigma_{1,2}}\right)+\left(\frac{y-\mu_{1,2}}{\sigma_{1,2}}\right)^2\right]\right)\right]$$

$$+(1-p)\left[\frac{1}{2\pi\sigma_{2,1}\sigma_{2,2}\sqrt{(1-\rho_2^2)}}\exp\left(\frac{-1}{2(1-\rho_2^2)}\left[\left(\frac{x-\mu_{2,1}}{\sigma_{2,1}}\right)^2-2\rho_2\left(\frac{x-\mu_{2,1}}{\sigma_{2,1}}\right)\left(\frac{y-\mu_{2,2}}{\sigma_{2,2}}\right)+\left(\frac{y-\mu_{2,2}}{\sigma_{2,2}}\right)^2\right]\right)\right]$$

where $\mu_{1,1}$ and $\sigma_{1,1}$ are the mean and standard deviation of the first trait in distribution 1, $\mu_{1,2}$ and $\sigma_{1,2}$ are the mean and standard deviation of the second trait in distribution 1, $\mu_{2,1}$ and $\sigma_{2,1}$ are the mean and standard deviation of the first trait in distribution 2, $\mu_{2,2}$ and $\sigma_{2,2}$ are the mean and standard deviation of the second trait in distribution 2, *P* is the frequency of the birds in distribution 1, ρ_1 is the correlation between traits in distribution 1, and ρ_2 is the correlation between traits in distribution 2. A maximum likelihood approach was used to estimate the parameters based on experimental observations. Normality of data in each distribution is assumed in the mixture distribution.

Results and Discussion

Descriptive statistics of the traits measured in the F_3 generation are presented in Table 1. The data showed a clear difference between traits under cold and normal conditions. The average of RATIO and HCT was higher under cold conditions (27.9% and 35.4%, respectively) than normal conditions (20.6% and 28.3%, respectively). The coefficients of variation for all traits were higher in cold than normal conditions, which show that the population was more heterogeneous under cold than under normal conditions. There was a clear difference between the overall correlations (the correlation among unadjusted observations in the whole population ignoring the mixture of underlying distributions) of BW with RATIO and HCT under cold (–0.30, –0.37, respectively) and normal (0.11, –0.08, respectively) conditions (Table 2).

The distributions of HCT and RATIO under normal and cold temperature conditions are presented in Figures 1 and 2. HCT and RATIO were approximately normally distributed under normal temperature conditions, whereas the distributions of these traits were skewed under cold temperature conditions. This suggests that the population could consist of a mixture of distributions.

The average values of RATIO and HCT for each class of the categorical traits (HEART, LIVER, and ABDOMEN), after fitting the bi-variate model, are plotted in Figure 3. It suggests that there are two groups of birds under cold conditions. The first group of birds showed lower values for HCT and RATIO and no severe signs of ascites, i.e., a score of 0 for ABDOMEN, LIVER, and HEART. The birds in this group can be assumed to be non-ascitic birds. The second group of birds showed higher values for HCT and RATIO with clear signs of ascites, i.e., a score of 1 for the LIVER and ABDOMEN or a score of 2 for all score traits. The birds in this group can be assumed to be ascitic birds. However, Figure 3 indicates that birds with a score of 1 for HEART are non-ascitic birds. As a result, a bi-variate mixture model could be fitted to the observations.

TABLE 1. Statistical description of the ascites traits under cold and normal conditions

Traits[1]	Cold			Normal		
	Number	Mean	SD	Number	Mean	SD
BW (g)	3,693	1,604	263	770	2,060	310
HCT (%)	3,547	35.40	4.21	780	28.28	2.30
RATIO (%)	3,658	27.93	8.07	659	20.63	4.66
ABDOMEN	3,697	0.08	0.38	–[2]	–	–
LIVER	3,697	0.07	0.29	–	–	–
HEART	3,696	0.59	0.62	–	–	–

[1]HCT = hematocrit value; RATIO = ratio of right ventricular weight to total ventricular weights; ABDOMEN = fluid in abdominal cavity; LIVER = liver abnormality; HEART = fluid in heart sac.

[2]Score traits were not recorded under normal conditions.

TABLE 2. Overall correlations (ignoring the mixture distributions) between BW and ascites traits measured under cold and normal conditions

Trait[1]	BW_C	$RATIO_C$	BW_N	$RATIO_N$
$RATIO_C$	–0.30			
HCT_C	–0.37	0.48		
$RATIO_N$			0.11	
HCT_N			–0.08	0.08

[1]RATIO = the ratio of right ventricular weight to the total ventricular weight; HCT = hematocrit value; C = trait was measured under cold conditions, and N = trait was measured under normal conditions.

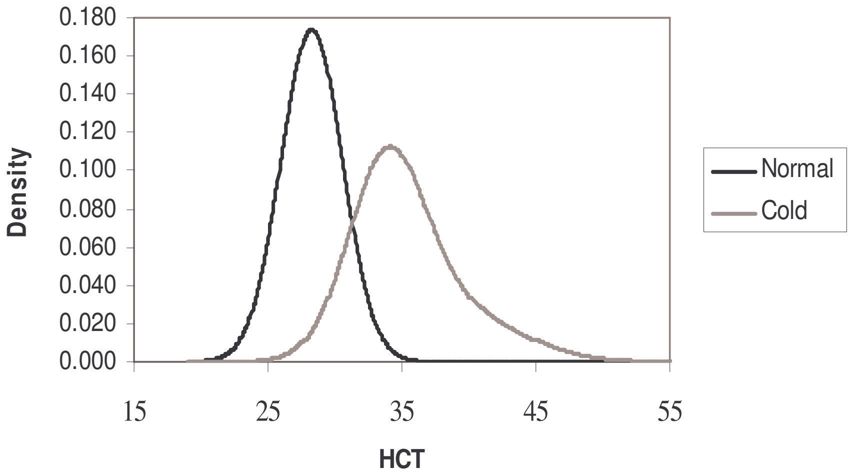

FIGURE 1. The distribution of hematocrit value (HCT) under cold and normal temperature conditions

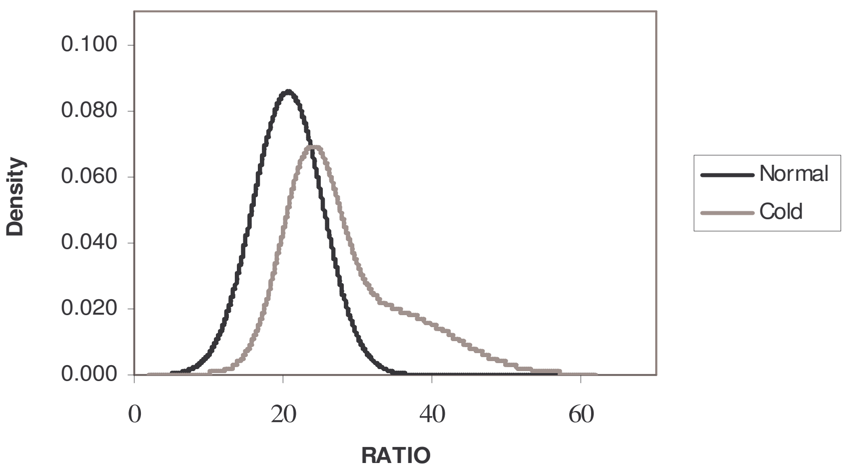

FIGURE 2. The distribution of right ventricular weight to total ventricular weight (RATIO) under cold and normal temperature conditions

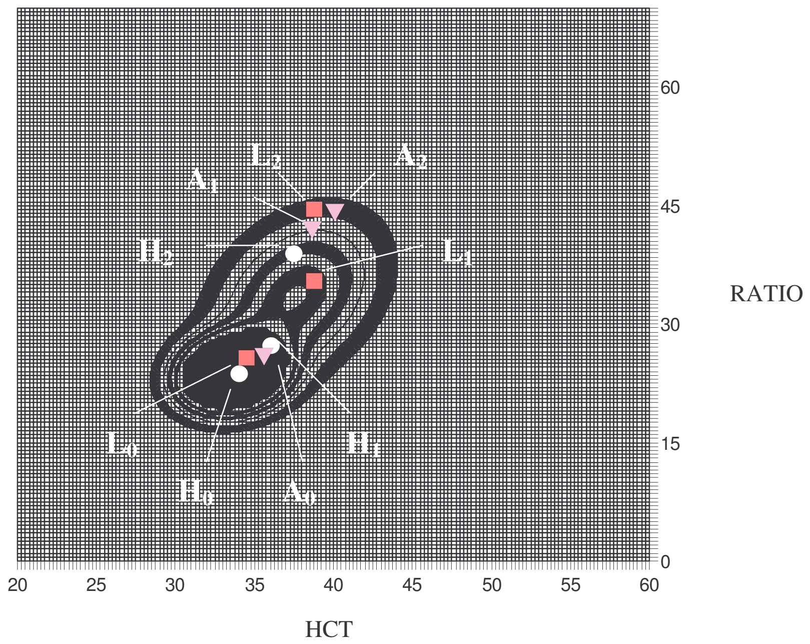

FIGURE 3. The average hematocrit value (HCT) and the ratio of right ventricular to total ventricular weight (RATIO) for different score classes of heart fluid (circles: H_0, no fluid; H_1, fluid; H_2, serious fluid), liver abnormality (squares: L_0, no abnormality; L_1, abnormality; L_2, serious abnormality), and abdominal fluid (triangles: A_0, no fluid; A_1, fluid; A_2, serious fluid), after fitting the bi-variate model.

Evaluation of ascites traits using mixture model

Fitting a bi-variate mixture model to the observations showed that the maximum likelihood estimation of *P* (frequency of the birds in distribution 1) was equal to 1 under normal temperature conditions. This indicates that there was only one, homogenous population for ascites traits under normal temperature conditions. However, the estimated *P* value was lower than 1 under cold conditions, which indicates that there was a mixture of (two) distributions under cold conditions (Figure 4). The mean and standard deviation of

BW, HCT, and RATIO, and the frequency of the birds in each underlying distribution are presented in Tables 3, 4, and 5.

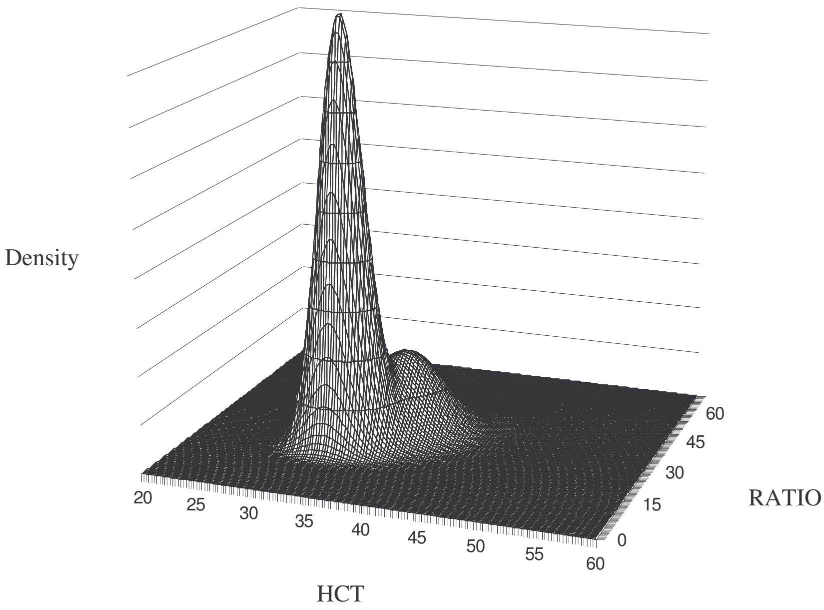

FIGURE 4. Fitted distributions of hematocrit value (HCT) and ratio of right ventricular weight to total ventricular weight (RATIO) under cold conditions

The average BW was different between the two distributions: 1,560 vs. 1,626 g. The average HCT (39.3%) and the average RATIO (36.2%) were also higher in the distribution with the lower average BW than in the distribution with the higher average BW (33.9% and 23.9%, respectively). One distribution contains birds with high growth rate and low values for ascites indicator traits; this is referred to as the distribution of non-ascitic birds. The other distribution contains birds with low growth rate and high values for ascites indicator traits; this is referred to as the distribution of ascitic birds. In the distribution of non-ascitic birds, the inferred phenotypic correlations (the correlations among unadjusted observations in each underlying distribution) of BW with RATIO and HCT were close to zero (0.10 and –0.07, respectively), whereas in the distribution of ascitic birds, the inferred phenotypic correlations of BW with RATIO and HCT were negative (–0.39 and –0.4, respectively) (Tables 3 and 4).

TABLE 3. Estimated parameters for BW and RATIO[1] under cold conditions using the bi-variate mixture model

Distribution	BW (g)		RATIO (%)		P^2	ρ^3
	Mean	SD	Mean	SD		
Non-ascitic	1,626	230	23.9	4.24	0.67	0.10
Ascitic	1,559	318	36.2	7.64	0.33	–0.39

[1]RATIO = ratio of right ventricular to total ventricular weight.

[2]P = the frequency of birds in each distribution.

[3]ρ = the correlation between BW and RATIO in each distribution.

TABLE 4. Estimated parameters for BW and HCT[1] under cold conditions using the bi-variate mixture model

Distribution	BW (g)		HCT (%)		P^2	ρ^3
	Mean	SD	Mean	SD		
Non-ascitic	1,642	226	33.9	2.92	0.74	–0.07
Ascitic	1,494	319	39.3	4.53	0.26	–0.40

[1] HCT = hematocrit value.

[2]P = the frequency of birds in each distribution.

[3]ρ = the correlation between BW and HCT in each distribution.

TABLE 5. Estimated parameters for RATIO and HCT[1] under cold conditions using the bi-variate mixture model

Distribution	RATIO (%)		HCT (%)		P^2	ρ^3
	Mean	SD	Mean	SD		
Non-ascitic	33.6	2.74	23.7	3.91	0.57	0.13
Ascitic	37.7	4.58	33.6	8.81	0.43	0.32

[1]RATIO = ratio of right ventricular weight to total ventricular weight; HCT = hematocrit value.

[2]P = the frequency of birds in each distribution.

[3]ρ = the correlation between RATIO and HCT in each distribution.

It seems that in the distribution of ascitic birds, birds with higher HCT and RATIO were more seriously affected by ascites and consequently had less growth than birds with lower HCT and RATIO (negative correlation). Van der Waaij et al. (2000) observed that production under constant infection pressure depends on the production potential and the level of resistance, which is in agreement with the present results. The negative inferred phenotypic correlations of BW with RATIO and HCT in the distribution of ascitic birds resulted in negative overall correlations (correlations without two distinguishing distributions) of BW with RATIO (–0.30) and HCT (–0.37) under cold conditions (Table 2). However, under normal conditions, with only one distribution, the overall correlations of BW with RATIO and HCT were 0.11 and –0.08, respectively (Table 2). In addition, the inferred phenotypic correlations of BW with RATIO and HCT in the non-ascitic birds (0.10 and –0.07, respectively) (Tables 3 and 4) were very close to the overall correlations of these traits under normal temperature conditions (0.11 and –0.08, respectively), which justifies referring to this group as non-ascitic birds (Table 2). This further indicates that the difference in overall correlations of traits between cold and normal temperature conditions is only because of the negative inferred phenotypic correlations between these traits in the distribution of ascitic birds. While positive overall correlations have been reported between production and ascites in the literature (Julian, 1993; Summers, 1994; Moghadam et al., 2001), negative inferred phenotypic and genetic correlations between production performance (BW) and ascites traits (HCT and RATIO) have been reported under cold conditions (De Greef et al., 2001; Pakdel et al., 2005a), which are in agreement with the results of the present study.

The overall correlations between traits, i.e., ignoring the mixture distributions, are the result of the corresponding inferred phenotypic correlations in the underlying distributions. Consequently, any change in the frequency of the distribution of ascitic or non-ascitic birds will influence the overall correlations between traits in the whole population. A simulation was applied to investigate the effect of change in the frequency of ascitic birds on the overall correlations using estimated parameters for mixture distributions. The results of the present simulation showed that the overall correlation between BW and RATIO under cold conditions changed from 0.11 to –0.35 when the frequency of ascitic birds increased from zero to 100% (Figure 5). In addition, the overall correlation between BW and HCT changed from –0.06 to –0.4 when the frequency of ascitic birds increased from zero to 100% (Figure 6).

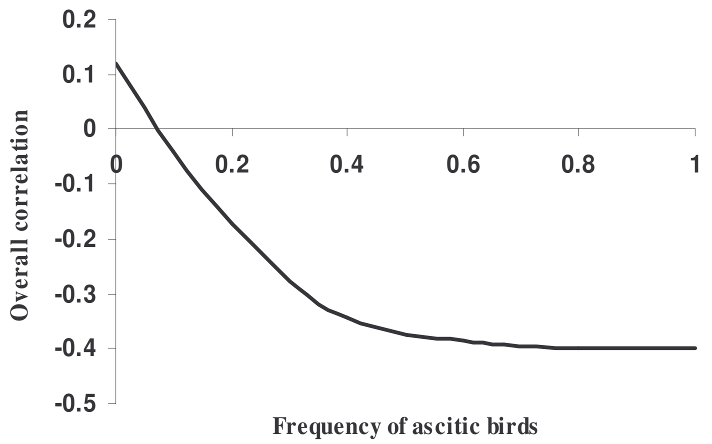

FIGURE 5. The effect of change in the frequency of ascitic birds on the overall correlation between BW and the ratio of right ventricular weight to total ventricular weight (RATIO)

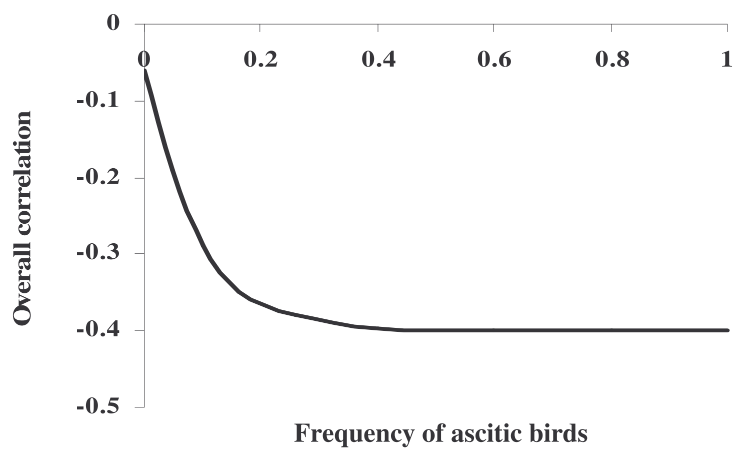

FIGURE 6. The effect of change in the frequency of ascitic birds on the overall correlation between BW and the hematocrit value (HCT)

The present results indicate that the overall correlations between BW and ascites traits are dependent on the frequency of the birds in the distribution of ascitic birds. The frequency of the ascitic birds is influenced by the severity of the cold stress and the sensitivity of the birds to ascites under cold stress conditions. De Greef et al. (2001) showed that the inferred genetic correlations between productivity and ascites traits varied considerably with the severity of the ascites syndrome under cold conditions. They also found a negative overall correlation between BW and RATIO under cold conditions, whereas the inferred correlation was positive in healthy birds. This indicates that the negative overall correlation was the result of negative inferred correlation in ascitic birds, which is in agreement with the results of the present study.

Large differences in the inferred phenotypic correlations, i.e., the correlation with two distinguishing underlying distributions, between RATIO and HCT in different underlying distributions were found under cold conditions (Table 5). RATIO and HCT showed a higher inferred phenotypic correlation (0.32) in the distribution of ascitic birds than in non-ascitic birds (0.13). When the available oxygen is not enough, HCT increases in ascitic birds to improve the oxygen carrying capacity as part of an adaptive mechanism (Maxwell et al., 1992). As a result birds with high RATIO values showed high HCT values. The higher inferred phenotypic correlations between RATIO and HCT in the distribution of ascitic birds increased the overall correlations between these traits under cold conditions (0.48) compared to the overall correlations under normal conditions (0.08) (Table 2). The overall correlations between RATIO and HCT are dependent on the severity of ascites symptoms and the level of sensitivity of birds to ascites.

The effect of disease status on the estimated parameters between production and disease is probably not unique for ascites and not even for production diseases. Each disease that is related to performance may show this phenomenon (De Greef et al., 2001). For example, Bishop and Stear (1998) showed that the correlation between productivity and resistance to nematode infection in sheep changes as the level of infection or larval challenge changes. Beilharz et al. (1993) demonstrated that there is a plateau in the total amount of energy an animal can utilize for all processes. When more energy is needed to overcome infections, leg problems, or metabolic disorders, less energy can be spent on production. There appears to be variation among animals in the energy needed to overcome the stress conditions, which is reflected in their resistance to different stress conditions (Van der Waaij et al., 2000). As a result, the overall correlations estimated between productivity and disease traits under stress conditions are likely to be lower than, or even in the opposite direction from, correlations estimated under normal conditions.

In conclusion, the present study shows that disease frequency can seriously affect relationships between traits.

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Chapter 6

General Discussion

Introduction

Genetic selection for growth, meat yield, and improved feed efficiency has resulted in substantial changes in broilers. The body composition of the birds has changed dramatically, especially the relative size of the breast muscles. However, selection of broilers for growth, yield, and efficiency is accompanied by a number of undesirable side effects (Julian, 1998). Commercial broilers today are showing higher mortality and higher susceptibility to suboptimal conditions than broilers that have been selected less extremely for growth, meat yield, and efficiency (Arthur and Albers, 2003). Increasing concerns on animal welfare and product quality among consumers have been the driving forces for poultry companies to put more emphasis on health traits to establish a sustainable poultry production. Increased emphasis on health traits needs to be integrated with emphasis on other (production) traits in the broiler breeding programs. Information on phenotypic and genetic parameters for production and health traits is required to develop a sustainable broiler breeding program. This thesis aims to support the development of breeding programs for balanced improvement of production and health traits in broilers. Phenotypic and genetic parameters of production traits were estimated in Chapters 2 and 3, the parameters estimated for production traits were used to design a more optimized breeding program in Chapter 4, and the phenotypic correlations between growth and ascites related traits were estimated in Chapter 5. In this general discussion, the following subjects are discussed:

- Developments in poultry production
- Sustainable breeding program in broilers
- Production traits in sustainable poultry production
- Poultry production in Iran

Developments in Poultry Production

Poultry production is a major source of meat throughout the world. The poultry meat industry contributed almost 30% of the total meat production just after the pig meat industry (39%) in 2003 (Food and Agriculture Organization of the United Nation, 2004). Broilers account for 86% of total poultry meat output worldwide, leaving other birds far behind (Executive Guide to World Poultry Trends, 2002). Tremendous developments have occurred in the poultry industry, largely the result of the economic and societal shifts in global business (Calabotta, 2002). In this section the factors influencing the developments in poultry production mainly in developed countries are discussed.

Economic factors

Poultry production companies are trying to keep the final products cheap and improve their profit by reducing production costs. Fully integrated broiler systems are designed to capture economies of scale that exist in broiler and feed processing by coordinating all the production, processing, and marketing activities needed to raise the bird and bring a final product to the consumer. This coordinated process across pricing points has gained some important efficiencies for the broiler industry, and has given the broiler industry a clear cost advantage over the beef industry (Von Bailey et al., 1995). Although in non-integrated systems, reproductive traits, feed conversion, and meat yield have the greatest impact on evaluation criteria for the hatchery, broiler and processing sectors, respectively, yield has a larger impact than any other single trait in an integrated system (Emmerson, 2003). Arthur and Albers (2003) expected a further consolidation of chicken meat production into large integrated national units because integrated systems are able to reduce the product prices through improvement in production efficiency. Lower prices will increase the market share of poultry meat in the future.

Societal factors

Consumer demands**:** The trends for total poultry meat production have been influenced by consumer behavior that has shown a very clear preference for poultry over other types of meat, especially in developed countries. As a result, the share of poultry meat in the total world meat production has increased by 4.4% during 1993–2000 (Gillin, 2003). This trend is largely attributable to consumer interest in low-fat, high quality, and more convenient foods, which has led to a major decline in the consumption of red meat (Fanatico and Born, 2002). In addition, the poultry industry has developed a wide range of broiler products to respond to the demand for more diverse foods. Twenty years ago, whole carcass was the only chicken product; nowadays, together with whole carcass, there are different cuts and many types of convenient foods at a reasonable price. Chicken chips, nibbles, nuggets, grilled breasts, smoked, and sauced chicken are just a few of the growing range of chicken meal options and this trend is expected to continue.

Diversity in market sectors: Poultry production has been transformed from a small family operation to an intensive, vertically integrated commercial enterprise that utilizes a combination of nutrition, genetics, management, and disease prevention strategies in response to the increased demand for cheap, safe, and nutritious poultry products. However, some consumers prefer the traditional home-grown chicken because they believe that these products are more natural and thus healthier than commercial broilers raised in a limited space. Some farmers recognize the market potential for poultry products raised in their natural environment. The Label Rouge market in France and drug-free market in North America represent niche markets that might have a significant impact on production practice in the broader markets (Emmerson, 2003).

The poultry market ranges from the live bird market to the highly industrialized market, and even ready-to-eat convenience products. Consumers have different buying behaviors in different poultry markets. In the live bird market, the live weight and general health and appearance of the bird are important characteristics, whereas in the whole carcass market, a well-shaped carcass with a plump, rounded breast and more breast than leg are important indicators for consumers. In the cut-up market, the products should be uniform and moist without smell. However, the quality of the skin is important for the whole carcass or the cut-up market, because very thin (transparent) or mottled skin has a negative effect on the buying behavior of the consumers. In the further processed market, processing yield is the most important trait and, in general, the importance of product yield and efficiency increases with a higher rate of further processing. Further processed products have annual growth rates of at least 5% and more than 10% in some European countries (European Commission Report, 2000). As a result, producers continue to move toward further processed and value-added products to meet consumer demand for convenience, safety, and palatability at a reasonable price.

In addition, there is a growing demand for fresh rather than frozen products. The use of fresh products has led to shorter delays between slaughter and consumption, which influences the transportation of broiler meat and has consequences for countries that export poultry meat.

Food safety**:** Consumer demand in the area of food safety mainly appears to be for a product, without pathogens. Food safety concerns have dramatically increased in the past decade with regard to contaminated meat products, which can result in serious risk to the well being and health of consumers (Piggott and Marsh, 2004). Stefan (1997) demonstrated that the rules of food safety were changed in the United States, in 1996, to modernize the inspection system from a visual one, based only on what inspectors could see (e.g., evidence of animal diseases, defects, and visible contamination on meat) to a scientific system, based on the prevention of hazards and regular microbial testing. Until recently, long oven cooking times guaranteed the safety of the whole cooked chicken. However, the shorter cooking times for chicken cuts may not ensure the same safety. Therefore, although the industry has greatly improved the microbiological quality of its products, the safety image of chicken could be affected (European Commission report, 2000). Greater consumer awareness of food safety issues tends to lead to a greater demand for safety.

Animal Welfare**:** There is concern about the undesired side effects of selection for high production efficiency on animal health and welfare (Harper and Henson, 2001). The poultry industry is the largest (in terms of animal numbers) and the most highly intensified of the animal production industries. As a consequence, there has been a great deal of public concern about the welfare of poultry. However, there has been less consumer sensitivity to the welfare of broilers than the welfare of laying hens; cage is a strong sign for poor welfare in laying hens, whereas there is no clear sign for the mistreatment of broilers (European Commission report, 2000). In addition, processed products are more distant from the animal in the mind of the consumer. This indicates that many consumers are concerned about the way the animal has been reared when they are buying a whole chicken but very few consumers care when they are buying processed meat products. There is a growing awareness about the welfare of broilers by consumers, especially in the European Union (Blandford et al., 2000). High density of birds in flocks, feed restrictions (mainly in breeder stocks), leg and cardiovascular problems are the major welfare concerns for broilers (European Commission report, 2000). Animal welfare issues have created a demand for alternative broiler products raised in animal friendly conditions with no fear, stress, pain, and without routine antibiotics in the diet.

Expectations for the future

Consumers increasingly demand quality products, which are safe to eat and offer nutritional value. Economics and society also add extra demands on poultry production. The different perspectives lead to some conflicts with respect to the desired direction of change for broilers through breeding. The breeding organizations must consider the different perspectives when deciding on the desired direction for change. It is a matter of balancing performance specifically efficient production and growth rate with health and welfare needs. Breeding companies continuously improve pure lines with the proper balance of desirable traits to tailor the poultry products to consumer economic and societal demands. It is a complicated process and requires collecting detailed information on production and health traits at every stage in the production cycle to identify those birds that are most suitable for breeding. Disease resistance is becoming increasingly important especially after public objections on the use of antibiotics to prevent disease (McAdams, 2004). It indicates that more emphasis on disease resistance will be necessary within broiler breeding objectives.

As already mentioned there is also growing concern for broiler welfare, especially in the European countries. Leg and cardiovascular problems are the main causes of mortality and consequently they are the major concerns for broiler welfare. Genetic selection has the potential for positive as well as negative effects on welfare. Selection of breeding stock for strong legs and low incidence of cardiovascular problems has started and should be more strongly encouraged. Accurate monitoring of leg and cardiovascular conditions will provide the information needed for genetic improvement in these traits. Several techniques for monitoring leg and cardiovascular conditions have been presented in Chapter 4. Imaging techniques, e.g., X-ray and computer tomography scan (CT scan), have been introduced in breeding programs to assist in improving leg strength in broiler stocks (McAdam, 2004). Despite increased selection for welfare, reports show that improvements in broiler welfare are still desirable (Turner et al., 2003). The breeding companies must increase the impact of welfare in their breeding objectives.

As a result of these developments, commercial poultry production has become more complex and challenging because a wide range of objectives need to be considered simultaneously in order to reduce production costs, whilst improving health, welfare, and product quality. Consequently, breeding goals must include increased growth rate, increased breast muscle yield, decreased abdominal fat, improved development of the skeletal system, and overall fitness (Li et al., 2005). Breeding organizations are increasingly aware of this trend and are changing their breeding objectives by including traits related to animal welfare and quality of product (Van Arendonk and Liinamo, 2003). However, more attention to disease resistance and welfare is needed to make a sustainable broiler breeding program.

Sustainable breeding program in Broilers

In many countries, increasing concern on animal welfare and food safety has resulted in increased selection pressure on health traits such as traits related to leg strength and the cardiovascular system. To illustrate the consequences of including health related traits together with production traits in a sustainable broiler breeding program, different scenarios were simulated by deterministic simulation using the SelAction program (Rutten et al., 2002). The desired-gains approach was used in the simulation. A desired-gains index aims to maximize the absolute response for a predefined linear combination of relative genetic gains for breeding goal traits. See Walsh and Lynch (2000) for more details. This so-called sustainable scenario is compared to a breeding program in which traits are weighted based on their economic importance without attention to health and welfare traits. As a result, production traits such as BW, feed conversion, and breast meat yield received high attention, whereas traits related to health and welfare, e.g., leg strength and ascites were neglected.

In the present study, a population with discrete generations was simulated, in which 100 males were randomly mated with 500 females. Each female produced 24 offspring (12 males and 12 females). Half of the males were randomly assigned to be slaughtered for the carcass test, to measure breast meat yield (BMY), leg strength (LS) and ascites (AS), and were not available as selection candidates. The remaining males were assigned to the feed conversion test, to measure adjusted feed conversion (FCA). Finally, 100 out of 3000 available males were selected as parents. For females, 500 out of 6000 available females were selected as parents. Breeding goal traits were BW at 42 d, FCA, and BMY. In addition to these production traits, LS and AS were included in the breeding goal. The index traits were the same as the breeding goal traits. The heritabilities, genetic, and phenotypic correlations of production and health traits are presented in Table 1. Most of the parameters were based on analysis of recent experiments (Ask et al., 2002; Zerehdaran et al., 2004; Pakdel et al., 2005). The economic values for BW at 42 d (0.33), FCA (–0.3), and BMP

(0.06) were derived from a study by Jiang et al. (1998). The following scenarios were considered:

1) Economic scenario: selection was only for production traits and health traits such as LS and AS were ignored in the breeding goal (weights for LS and AS were both zero in the breeding goal).
2) Sustainable scenario: the economic values for production traits in the sustainable scenario were the same as the economic values in the economic scenario. The economic values of LS and AS were determined using the desired-gain approach in order to obtain a zero response in LS and AS (no deterioration for LS and AS).

The genetic responses for production and health traits and the total monetary responses in the economic and sustainable scenarios are presented in Table 2. In the economic scenario, despite improved responses for production traits, there was an unfavorable reduction in LS of about 0.133 points (approximately –0.19 genetic standard deviation, σ_g) and an unfavorable increase in AS of about 0.025 points (approximately +0.21 σ_g).

The results in Table 2 indicate that selection for production traits only without taking the leg strength and ascites traits into account will result in reduced health and welfare. In the sustainable scenario, with weights of 0.045 for LS and –0.3 for AS, the deterioration of leg strength and ascites were stopped. In the economic scenario with zero economic values for LS and AS in the breeding goal, the total monetary response was highest (approximately 0.104 €). Due to negative correlations between health and production traits, increased emphasis on health traits in the sustainable scenario, resulted in a reduction in the total monetary response (0.104– 0.097 = 0.007 €). A reduction of 6% of monetary response in production traits was sufficient to offset the negative response in health traits.

In calculating the monetary responses in Table 2, the economic consequences of changes in health traits were ignored. The economic values for health traits are the result of decrease in production costs per slaughtered broiler in the case of improvement in health conditions as well as the impact on acceptability of the products. In order to stop the increased incidence of diseases, traits should be included in the breeding goal and assigned appropriate values. Kanis et al (2005) reported that health traits have economic and non-economic values where non-economic values are the result of increasing societal pressure to

TABLE 1. Heritabilities on diagonal, genetic correlations above the diagonal, and phenotypic correlations below the diagonal for breeding goal traits

Variable[1]	BW	FCA	BMY	LS	AS
BW	0.35	0.05	0.15	–0.17	0.18
FCA	0.04	0.41	0.03	0.02	–0.05
BMY	0.18	0.01	0.48	–0.10	0.05
LS	–0.10	0.00	–0.05	0.12	–0.10
AS	0.14	-0.03	0.02	–0.07	0.10
SD	0.25	0.41	0.97	1.98	0.37
Unit	kg	point	%	point	point
Economic value[2]	0.33	–0.3	0.06	-[3]	-

[1.] FCA = adjusted feed conversion, BMY = breast meat yield, LS = Leg strength scored from 1 (bad) to 5 (good), AS = ascites scored from 0 (no abdominal fluid) to 2 (serious abdominal fluid), SD = phenotypic standard deviation.

[2.] Euros marketable bird^{-1} unit^{-1}.

[3.] The economic values for LS and AS were changed to obtain a zero response for these traits in the sustainable scenario.

improve animal welfare and the safety of animal production. Breeding organizations cannot neglect public concerns and must become convinced that a sustainable breeding goal should not only include the economic values of traits, but also non-economic values, such as emotional and societal values (Gamborg and Sandoe, 2003). Growing awareness of animal welfare and food safety in society may increase the willingness of consumers to pay for non-economic values in the future and make the sustainable scenario more beneficial than the economic scenario for the industry.

The consequences of including health traits in the breeding program will be influenced by the type of health traits and the genetic parameters of health and production traits. In Chapter 5 it was shown that correlations between health and production traits change with the frequency of diseased birds. The present simulation was just an example to illustrate the consequences of including health traits in a sustainable breeding program. It demonstrated that it is possible to avoid an unfavorable response in health traits with limited loss in response in production traits.

TABLE 2. The genetic response for production and health traits and the total responses (Euro per slaughter bird) in an economic and a sustainable scenario

Traits[1]	Economic scenario		Sustainable scenario	
	Economic Value	Genetic response	Economic value	Genetic response
BW	0.33	0.089	0.33	0.073
FCA	–0.3	–0.196	–0.3	–0.193
BMY	0.06	0.269	0.06	0.252
LS	0	–0.133	0.045	0
AS	0	0.025	–0.3	0
Total Monetary response (€)	0.104		0.097	

[1] FCA = adjusted feed conversion, BMY = breast meat yield, LS = leg strength, AS = ascites.

Production traits in a sustainable poultry production

In this section the consequences of selection for improved feed efficiency are demonstrated and the possibility of using indirect fat measurements to improve the production efficiency in broilers is discussed.

Intensive selection over many generations for economically important traits has been accompanied by significant changes in feed intake and energy balance. Nowadays, broilers exhibit hyperphagia leading to excessive accumulation of fat in the body (Richards, 2003). Excessive fat in broilers depresses feed efficiency, has no commercial value, and is less desirable by consumers. In several studies (Chambers, 1990; Le Bihan-Duval et al., 1998) and in chapters 2 and 3 high heritabilities (0.4–0.8) were estimated for abdominal fat. In addition, Leenstra and Pit (1987), and Cahaner (1988) provided experimental evidence that fat deposition in broilers can be reduced by selection. The main problem faced by broiler breeders when selecting against fat deposition is how to measure the total or abdominal fat levels in live chickens. Therefore, breeders have investigated alternative methods which could be used to predict the abdominal fat weight of live birds. Traits that are significantly correlated with fat deposition and can be measured in a live bird, were very low density lipoprotein content (VLDL) in plasma (Whitehead and Griffin, 1984) and feed efficiency (Leenstra and Pit, 1987). The VLDL measurement has been shown to have a high correlation with total body fat as well as with abdominal fat. VLDL measurement involves a relatively complicated assay and therefore it has generally not been applied in industrial settings (Emmerson, 1997).

Selection for improved feed efficiency reduces the body fat content and abdominal fat pad because of a high negative genetic correlation between feed efficiency and fat deposition (r_g = -0.5) (Leenstra and Pit, 1987). Selection for improved feed efficiency is the main criterion for indirect selection against fat deposition in broiler breeding programs today.

Feed efficiency is an indicator to show how efficiently the feed is being utilized by the bird. It is an economically important trait because feed represents about 65% of the total cost of production in broilers. Over the years, a steady decline has been found in feed efficiency from 2.34 in 1957 to 1.62 in 2001 at 42 d of age (Havenstein et al., 2003). However, feed efficiency is a functional and complex trait that is the net result of the interaction of many different components (Figure 1) (Emmerson, 1997). Selection for feed efficiency influences the underlying component traits in an uncontrolled manner. As a result, birds selected for growth and feed efficiency allocate most of their resources towards growth and less for other physiological functions, such as reproduction, disease resistance and adaptation to environmental change (Qureshi and Havenstein, 1994; Holder et al., 1999). In addition, selection for growth and feed efficiency resulted in increased metabolic disorders (e.g., ascites) and increased mortality (Buys et al., 1999; Havenstein et al., 2003).

The efficiency of poultry production has been improved through genetic selection on feed efficiency. However, continued selection for only improved feed efficiency is expected to result in reduced health, increased sensitivity to environmental stressors, increased mortality, and consequently reduced economic efficiency. Although, selection for improved feed efficiency reduces fat deposition, which is desirable for production efficiency and human health, it undesirably changes underlying traits, e.g., appetite, behavior, and basal metabolism Therefore, an alternative trait is required to replace feed efficiency in order to control fat deposition without undesirable changes on the underlying traits. Measurement of fat level is an interesting alternative.

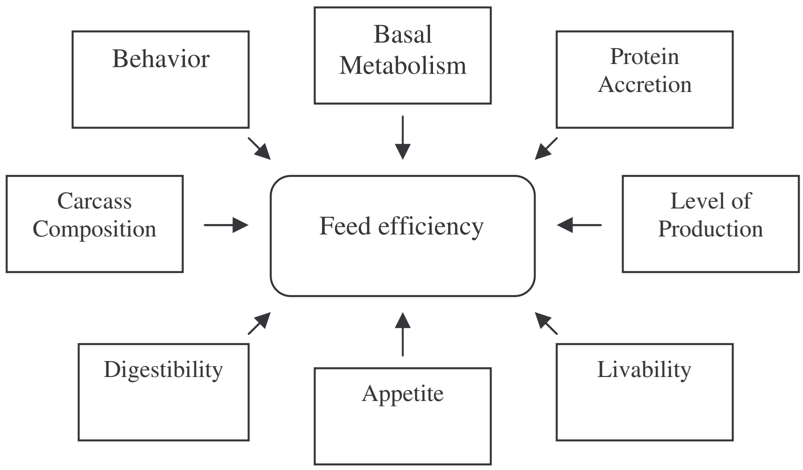

FIGURE 1. Underlying component traits contributing to feed conversion ratio (Emmerson, 1997)

Indirect fat measurement

Recently, electronic devices have been evaluated for their ability to detect body composition on live animals. Ultrasonic systems are being used to estimate the fat content of specific parts of cattle and pigs (Liu and Stoffer, 1995). X-ray absorptiometry (Mitchell et al., 1997), computer tomography scan (CT scan) (Brenoe and Kolstad, 2000), and magnetic resonance imaging (MRI) (Scollan et al., 1998) have been tested on chickens. Imaging methods, e.g., CT scan and MRI, offer the opportunity to measure the body components with very high accuracy, which could be a proper criterion for selection against fat deposition in meat-type poultry. The advantages of using imaging techniques to improve the genetic response for breast meat yield were presented in chapter 4. The fat and meat content can be simultaneously measured in broilers using imaging techniques. This indicates the relevance of imaging techniques to improve the carcass composition of broilers. In addition, imaging techniques can be used to measure health related traits such as ascites and skeletal problems on selection candidates and consequently direct selection for health related traits would be possible.

Unlike feed efficiency, selection against fat deposition (using imaging techniques) can improve the efficiency of poultry production and the health traits simultaneously.

Selection against fat deposition is expected to impact on the energy intake for fat deposition without affecting the amount of energy available for other functions. Availability of metabolic energy for functional activities will help to avoid metabolic disorders, reduced immune function, and reproduction problems. Therefore, modification of selection criteria from feed efficiency towards indirect fat content is expected to enhance the sustainability of poultry production. The expensive devices and the time required to scan each bird currently limit the application of imaging techniques in poultry breeding programs (Mitchell et al., 1997). Imaging techniques will also provide valuable information on other traits and implementation of these techniques is promising and deserves further attention.

Poultry production in Iran

The present thesis mainly concerns poultry production in developed countries. Poultry production in Iran, as an example of poultry production in developing countries, is presented in the following section.

Prior to 1954, poultry production in Iran was operated in a traditional way on a small scale. It mainly consisted of indigenous breeds grown for consumption by the local population. The modern poultry industry was started when the first batch of foreign industrial breeds (e.g., Plymouth Rock, Rhode Island Red, and New Hampshire) was imported into the country in the early 1950s (Anon, 1994). In the early 1980s, the production of grandparent stock of meat-type strains (Ross, Lohmann, and Hybro) had been established in the country and by 1993 a line of broilers called Arian, a branch of Hybro from the Netherlands, had started to appear. In addition, other broiler breeds, e.g. Ross, Arbor Acers, Lohmann, Hubbard, and Cobb, are being imported in the form of 1-day-old chickens (for grandparent stocks) or eggs (for parent stocks) into the country (H.R. Ziyaee, personal communication). There are three main broiler meat lines, i.e., Arian, which has a 78% share of the 1-day-old chicken market, and Lohmann and Ross grandparent stocks, with 5% and 13% market shares, respectively. The remaining 4% consists of indigenous breeds (Shariatmadari, 2000).

The increase in the human population together with the migration that has been taking place from villages to the cities has made an important contribution to the growth of the Iranian poultry industry. In addition, improvements in breeding and management (feed formulation and housing) have resulted in a considerable growth in the poultry industry. Today, the poultry industry plays a major role in the Iranian economy and is considered the largest industry sector after oil (Golbabaei and Islami, 2000). Iran has one of the largest poultry sectors in the Middle East and was ranked as the 16th largest poultry production country in the world in 2004 (Netiran, 2005). The industry comprises 700 million broiler 1-day-old chickens, 10 million broiler breeders, and 50 million layer 1-day-old chickens. In 2003, the industry yielded over 900000 tones of chicken meat and 600000 tons of eggs for consumption (Iranian agrifood sector report, 2004). Current production is expected to be about 70% of the full production potential, and it can be further improved through export of poultry meat to other countries (Mirzaei et al., 2003). Iranian broiler farms on average have the capacity to rear 20000 chickens in each production cycle. Broilers are slaughtered at the age of 48-52 d with 2.4 kg average BW and the average feed conversion is about 2.2. Automatic feeding systems are used in about 30% of Iranian poultry farms and the rest of the farms feed the chickens manually (H.R. Ziyaee, personal communication).

Whole carcass is the main poultry market in the country, and most consumers prefer a fresh carcass of at least 2 kg. However, there is a growing trend towards cut up and further processed products since the big supermarket chains appeared in the country (Shariatmadari, 2000).

After the commercialization of poultry production, the indigenous Iranian poultry breeds were ignored for a long time. However, despite many setbacks, local poultry production is again improving. Several research centers in different parts of the country have been established to evaluate the breeds and to encourage the farmers to grow indigenous poultry breeds (Anon, 1998), in order to efficiently use the local facilities and improve the economy of families in rural areas. The price of meat, and especially eggs, produced by indigenous breeds are about 2-3 times higher than commercial products. Despite the higher price, there is a growing demand for local meat and egg products in outdoor circumstances rather than those from commercial systems, because it is believed that the products of the indigenous breeds in outdoor production systems are natural and have higher quality than commercial broiler products. Iranian local broiler breeds have darker meat, better taste, and lower fat content than industrial breeds (H.R. Ziyaee, personal communication).

The growth in poultry production in recent years resulted in increased demand for feedstuffs, which could not be fully supplied by the national agriculture sector. As a consequence, substantial financing (about US$1 billion annually) is needed for the importation of feedstuffs into Iran, which is a real concern for the government (Shariatmadari, 2000). As a result, Iranian production costs are higher than corresponding global prices; this is a major disadvantage to the Iranian broiler and egg industry and limits its opportunities for export as well as stimulating import of cheaper products. In addition, huge fluctuations in market prices, non-optimal management, and lack of institutions for advising farmers are the main problems hindering the further development of the Iranian poultry industry today.

The current situation indicates that improving efficiency of production and increasing the export of poultry products are necessary for poultry production in Iran in order to meet the costs of imported feedstuffs. Integration of production systems would help to improve the efficiency of production. Although some integration exists in the poultry industry, further development of integrated systems is needed for poultry production in Iran. An integrated system with emphasis on common goals will result in reduced costs and increased profits for the whole production sector resulting in cheaper poultry meat and improved meat production market share in the region. Higher income due to exportation of poultry products can facilitate the importation of feedstuffs for the Iranian poultry industry. In addition, investigation of the possibilities for increasing local agricultural production of poultry diets would reduce the dependency on imported feedstuffs. The poultry breeding companies should improve poultry production efficiency together with the health and welfare of chickens in order to have a more successful and sustainable poultry industry. In addition, improved product quality and safety of both the commercial and the indigenous Iranian poultry breeds will improve the market share of Iranian poultry meat in the region.

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Summary

Summary

Selection for production traits in broilers has been accompanied by negative consequences on different aspects of the birds' physiology. The negative characteristics, such as fatness, ascites, leg deformity, and reproduction problems, have a large impact on animal welfare and on the economics of poultry production. This thesis aims to optimize the genetic improvement of production and health traits in broilers.

The objective of *Chapter 2* was to estimate genetic parameters for fat deposition in the three different parts of body and their relationships with other carcass traits. Abdominal and subcutaneous fat are regarded as the main sources of waste in the slaughterhouse, whereas fat stored intramuscularly is regarded a favorite trait related to meat quality. Fat and carcass traits were recorded on 1,752 female and 1,526 male chickens from a meat-type chicken line. Heritability estimates for abdominal fat percentage, skin percentage, as a measure of subcutaneous fat, and intramuscular fat percentage were 0.71, 0.24, and 0.08 respectively. Heritabilities of the other carcass traits were moderate to high (from 0.28 to 0.73). There was a high genetic correlation between abdominal fat weight and skin weight (0.54), whereas the genetic correlation between abdominal fat weight and intramuscular fat percentage was almost zero (0.02). Body weight (BW) at 49 days (d) showed a positive genetic correlation with fat production traits, which were high for intramuscular fat percentage (0.87) and moderate for skin percentage (0.17) and abdominal fat percentage (0.13). The results indicate that carcass traits could be improved by selection for increased breast muscle and reduced abdominal fat without decreased intramuscular fat.

The effect of age and housing system on genetic parameters for BW and carcass traits was investigated in *Chapter 3*. Traits were measured on broilers of different ages (48, 63, and 70 d). Birds in groups 48 and 70 d were raised in group housing, whereas birds in the 63 d group were raised in the same housing up to 22 d and in individual cages between 22 and 63 d. Each group consisted of ~2,000 individuals from a single group of parents. Carcass, breast meat, abdominal fat, and back half were expressed as percentage of BW. The heritability of BW at 48, 63, and 70 d was 0.31, 0.26, and 0.19, and the heritability of back half percentage at 48, 63, and 70 d was 0.42, 0.38, and 0.21, respectively. For other carcass traits, heritabilities were in the same range in different age groups. A positive genetic correlation was found between BW and valuable parts of carcass (breast meat and back half) at 48 d; these relationships were negative at 70 d. The genetic correlation between BW and abdominal fat percentage at 70 d was higher than at 48 d. The increase in growth at 48 d was

accompanied by increase in valuable parts; at 70 d it was accompanied by increase in abdominal fat percentage. Genetic correlation of BW at 48 d between individual cage and group housing demonstrated a genotype by environment interaction for performance of birds, which has consequences for design of breeding schemes.

The objective of *Chapter 4* was to determine the consequences of using indirect carcass measurements on the genetic response and rate of inbreeding in broiler breeding programs. In the base breeding scheme, selection candidates were evaluated based on direct carcass measurements on relatives. The possibilities of using indirect carcass measurements were investigated in alternative breeding schemes. Three alternative schemes, including indirect, own performance information for carcass traits on selection candidates, were evaluated by deterministic simulation. In the first scheme, indirect carcass traits were measured on male selection candidates. In the second scheme, indirect carcass traits were measured on male selection candidates and direct carcass traits were measured on relatives. In the third scheme, indirect carcass traits were measured on male and female selection candidates and direct carcass traits were measured on relatives. In the base scheme, the genetic response for breast muscle percentage (BMP) was 0.3% and the rate of inbreeding was 0.96% per generation. In the third alternative scheme, the response for BMP increased by 66.2% compared to the base scheme and the rate of inbreeding reduced to 0.79% per generation. The improved genetic gain resulted from an increase in the accuracy of selection. The use of own performance information for selection candidates reduced the rate of inbreeding in alternative schemes, which is desirable for long-term selection. The accuracy of the indirect carcass measurements had consequences on the response for BMP and the rate of inbreeding. The results indicated that in most cases an accuracy of 30% was sufficient to result in a higher gain for BMP and a lower rate of inbreeding as compared to the base scheme.

In *Chapter 5,* the objective was to divide the population into a non-ascitic and an ascitic group of birds based on parameter estimations for ascites traits and to study the difference in the correlations between BW and ascites traits in each group of ascitic and non-ascitic birds. Existing data was used of an experiment in which birds were housed in two groups under different climate conditions. In the first group BW, the ratio of right ventricular weight to total ventricular weight (RATIO), and hematocrit value (HCT) were measured on 4,202 broilers, under cold conditions; in the second group, the same traits were measured on 795 birds under normal temperature conditions. Cold stress conditions were applied to identify individuals that were susceptible to ascites. RATIO and HCT were approximately normally distributed under normal temperature conditions, whereas the distributions of these traits were skewed under cold temperature conditions, which suggest underlying distributions. Fitting a bi-variate mixture model to the observations showed that there was only one homogenous population for ascites traits under normal temperature conditions, whereas there was a mixture of (two) distributions under cold conditions. One distribution contained non-ascitic birds and the other distribution contained ascitic birds. In the distribution of non-ascitic birds, the inferred phenotypic correlations (phenotypic correlations with two distinguishing underlying distributions) of BW with RATIO and HCT were close to zero (0.10 and –0.07, respectively), whereas in the distribution of ascitic birds, the inferred phenotypic correlations of BW with RATIO and HCT were negative (–0.39 and –0.4, respectively). The negative inferred correlations of BW with RATIO and HCT in the distribution of ascitic birds resulted in negative overall correlations (correlations without two distinguishing distributions) of BW with RATIO (–0.30) and HCT (–0.37) under cold conditions. The results indicate that the overall correlations between BW and ascites traits are dependent on the relative frequency of ascitic and non-ascitic birds in the population.

In the general discussion (*Chapter 6*) the economic and societal factors influencing poultry production developments were discussed. In addition, to illustrate the consequences of including health related traits together with production traits in a sustainable broiler breeding program, an economic scenario was compared to a sustainable scenario. In the economic scenario selection was only for production traits and health traits such as leg strength (LS) and ascites (AS) were ignored in the breeding goal. In the sustainable scenario the economic values of LS and AS were determined using desired gain approach in order to obtain a zero response in LS and AS. The results indicate that selection for production traits without taking leg strength and ascites into account will lead to reduced health and welfare. In the sustainable scenario, with weights of 0.045 for LS and -0.3 for AS, the deterioration of leg strength and ascites was stopped. A reduction of 6% of monetary response in production traits was sufficient to offset the negative response in health traits. Furthermore, the consequences of using indirect fat measurements instead of feed efficiency in broiler breeding programs were demonstrated. It is expected that unlike feed efficiency, selection against fat deposition (using imaging techniques) can improve the efficiency of poultry production and health traits simultaneously. Finally poultry production in Iran as an example of poultry production in developing countries was described.

Samenvatting

Selectie op productiekenmerken in slachtkuikens heeft altijd negatieve gevolgen gehad voor meerdere aspecten van de fysiologie van de dieren. Die negatieve eigenschappen, zoals vetzucht, ascites, misvormingen aan de poten en voortplantingsproblemen, hebben grote gevolgen voor het welzijn van de kippen en de economie van de pluimveeteelt. Dit proefschrift heeft als doel de erfelijke verbetering van slachtkuikens te optimaliseren voor productie- en gezondheidskenmerken.

Het doel van *Chapter 2* was het schatten van de genetische parameters voor vetaanzet in de drie delen van het lichaam, en hun relatie met andere karkaskenmerken. Abdominaal en subcutaan vet worden beschouwd als de voornaamste bronnen van verlies in het slachthuis, terwijl intramusculair vet wordt gezien als een goed kenmerk voor vleeskwaliteit. Vet- en karkaskenmerken zijn gemeten aan 1.752 vrouwelijke en 1.526 mannelijke kuikens van een vleestype-lijn. Erfelijkheidsgraden voor abdominaal vetpercentage, huidpercentage als maat voor subcutaan vet, en intramusculair vetpercentage waren respectievelijk 0,71, 0,24 en 0,08. Erfelijkheidsgraden van de andere karkaskenmerken waren matig tot hoog (van 0,28 tot 0,73). Er was een hoge genetische correlatie tussen abdominaal vetgewicht en huidgewicht (0,54), terwijl de genetische correlatie tussen abdominaal vetgewicht en intramusculair vetpercentage bijna nul was (0,02). Het lichaamsgewicht (BW) op 49 dagen (d) vertoonde een positieve correlatie met de vetproductiekenmerken, welke hoog waren voor intramusculair vet (0,87) en matig voor huidpercentage (0,17) en abdominaal vetpercentage (0,13). De resultaten geven aan dat karkaskenmerken verbeterd kunnen worden door selectie voor een grotere borstspier en verminderd abdominaal vet, zonder vermindering van intramusculair vet.

Het effect van leeftijd en huisvestingssysteem op genetische parameters voor BW en karkaskenmerken is onderzocht in *Chapter 3*. Kenmerken werden gemeten aan slachtkuikens van verschillende leeftijden (48, 63 en 70 dagen). Dieren in de groepen van 48 en 70 dagen groeiden op in groepshuisvesting; dieren in de 63-dagen groep in dezelfde huisvesting tot 22 dagen, en in individuele kooien tussen 22 en 63 dagen. Elke groep bestond uit ongeveer 2.000 individuen uit een enkele oudergroep. Karkas, borstfilet, abdominaal vet en het geheel van poten, onderste deel van de rug en het staartstuk ('achterhelft') werden uitgedrukt als percentage van lichaamsgewicht. De erfelijkheidsgraad van BW op 48, 63 en 70 d was respectievelijk 0,31, 0,26 en 0,19, en de erfelijkheid van achterhelft percentage op 48, 63 en 70 d was respectievelijk 0,42, 0,38 en 0,21. Voor andere

karkaskenmerken bleken de erfelijkheidsgraden in hetzelfde bereik te liggen voor de verschillende leeftijdsgroepen. Er werd een positieve genetische correlatie gevonden tussen BW en waardevolle karkasdelen (borstfilet en achterhelft) op 48 d; deze verbanden bleken negatief op 70 d. De genetische correlatie tussen BW en abdominaal vetpercentage op 70 d was hoger dan op 48 d. De groeitoename op 48 d ging gepaard met een toename in waardevolle delen; op 70 d ging het gepaard met een toename van abdominaal vetpercentage. De genetische correlatie van BW op 48 d tussen individuele kooien en groepshuisvesting vertoonde een genotype/milieu-interactie voor de prestatie van de dieren. Dit heeft gevolgen voor het ontwerp van fokprogramma's.

Het doel van *Chapter 4* was vast te stellen wat de gevolgen zijn van het gebruik van indirecte karkasmetingen op de genetische respons en inteeltsnelheid in slachtkuikenfokprogramma's. In het basisfokprogramma werden kandidaten voor selectie geëvalueerd op basis van directe karkasmetingen aan verwanten. De mogelijkheden van het gebruik van indirecte karkasmetingen werden onderzocht in alternatieve fokprogramma's. Drie alternatieve programma's, waaronder indirecte, eigen prestatie-informatie voor karkaskenmerken op kandidaten voor selectie, werden geëvalueerd met behulp van deterministische simulatie. In het eerste programma werden indirecte karkaskenmerken gemeten aan mannelijke selectiekandidaten. In het tweede programma werden indirecte karkaskenmerken gemeten aan mannelijke selectiekandidaten, en directe kenmerken werden gemeten aan verwanten. In het derde programma werden indirecte karkaskenmerken gemeten aan mannelijke en vrouwelijke selectiekandidaten en werden directe karkaskenmerken gemeten aan verwanten. In het basisfokprogramma was de genetische respons voor borstspierpercentage (BMP) 0,3% en de inteeltsnelheid was 0,96% per generatie. In het derde alternatieve programma steeg de respons voor BMP met 66,2% vergeleken met het basisprogramma, en de inteeltsnelheid daalde tot 0,79% per generatie. De verbeterde genetische vooruitgang was een gevolg van een hogere nauwkeurigheid van selectie. Het gebruik van eigen prestatie-informatie voor selectiekandidaten verminderde de inteeltsnelheid in de alternatieve programma's, wat wenselijk is voor selectie op de lange termijn. De nauwkeurigheid van de indirecte karkasmetingen had gevolgen voor de respons voor BMP en inteeltsnelheid. De resultaten gaven aan dat in de meeste gevallen een nauwkeurigheid van 30% voldoende was om een hogere toename van BMP en lagere inteeltsnelheid te krijgen in vergelijking met het basisprogramma.

In *Chapter 5* was het doel de populatie te verdelen in gezonde en ascites-lijdende groepen, gebaseerd op parameterschattingen voor asciteskenmerken, en het verschil te onderzoeken in de correlaties tussen BW en asciteskenmerken in elk van beide groepen. Er is gebruik gemaakt van bestaande data van een experiment waarin dieren werden gehuisvest in twee groepen onder verschillende klimaatsomstandigheden. In de eerste groep werden BW, de verhouding tussen het gewicht van de rechter ventrikel en de beide ventrikels (RATIO), en hematokrietwaarde (HCT), gemeten aan 4.202 slachtkuikens, onder koude omstandigheden; in de tweede groep werden dezelfde kenmerken gemeten aan 795 dieren, gehouden onder normale temperaturen. Dieren werden blootgesteld aan koudestress om de individuen te vinden die gevoelig waren voor ascites. RATIO en HCT waren redelijk normaal verdeeld onder normale temperaturen, en scheef onder lage temperaturen, wat onderliggende verdelingen suggereert. Het schatten van een bivariaat gemengd model toonde dat er slechts één homogene populatie was voor asciteskenmerken onder normale temperaturen, terwijl er een menging van twee verdelingen was onder koude omstandigheden. De ene verdeling bestond uit dieren zonder ascites, en de andere uit dieren met ascites. In de verdeling bij de dieren zonder ascites, waren de afgeleide fenotypische correlaties (fenotypische correlaties met twee onderscheiden onderliggende verdelingen) van BW met RATIO en HCT bijna nul (respectievelijk 0,10 en -0,07), terwijl deze in dieren met ascites negatief (respectievelijk -0,39 en -0,4) waren. De afgeleide negatieve correlaties van BW met RATIO en HCT in de verdeling van de dieren met ascites, resulteerde in negatieve algemene correlaties (correlaties zonder twee onderscheiden verdelingen) van BW met RATIO (-0,30) en HCT (-0,37) onder koude omstandigheden. De resultaten geven aan dat de algemene correlaties tussen BW en asciteskenmerken afhankelijk zijn van de relatieve frequentie van dieren met en zonder ascites in de populatie.

In de algemene discussie (*Chapter 6*) werden de economische en sociale invloeden op pluimveeteeltontwikkeling besproken. Daarbij werd een economisch scenario vergeleken met een duurzaam scenario, om de gevolgen te illustreren van het opnemen van gezondheidskenmerken samen met productiekenmerken in een duurzaam slachtkuikenfokprogramma. In het economische scenario werd alleen geselecteerd op produktiekenmerken; pootsterkte (LS), en ascites (AS) werden genegeerd in het fokdoel. In het duurzame scenario werden de economische waarden van LS en AS bepaald met behulp van een gewenste-toename-benadering om een nulrespons voor LS en AS te krijgen. De resultaten wijzen uit dat selectie op productiekenmerken, zonder rekening te houden met pootsterkte en ascites, leidt tot verminderde gezondheid en welzijn. In het duurzame scenario, met gewichten van 0,045 voor LS en -0,3 voor AS, stopte de verslechtering van pootsterkte en ascites. Een vermindering van 6% in financiële opbrengst aan productiekenmerken was voldoende om de negatieve respons van de gezondheidskenmerken op te heffen.

Verder is aangetoond wat de gevolgen zijn van het gebruik van indirecte vetmetingen in plaats van voederconversie in slachtkuikenfokprogramma's. De verwachting is dat, in tegenstelling tot voederconversie, selectie tegen vetaanzet (gebruikmakend van scantechnieken) de efficiëntie van zowel productie- als gezondheidskenmerken gelijktijdig kan verhogen. Tenslotte is pluimveeteelt in Iran gebruikt als een voorbeeld van pluimveeteelt in ontwikkelingslanden.

خلاصه

انتخاب برای بهبود صفات تولیدی در جوجه های گوشتی اثرات متعدد منفی بر فیزیولوژی این پرندگان داشته است. مسائلی نظیر تجمع چربی در بدن، آسیت، ناهنجاری پا و مشکلات تولید مثل، تاثیرات منفی بسزائی بر آسایش حیوان (Animal welfare) و همچنین بر اقتصاد پرورش طیور بر جای می گذارد. هدف این رساله، بهینه کردن انتخاب ژنتیکی برای صفات تولیدی و سلامت در جوجه های گوشتی می باشد.

در فصل دوم این تحقیق، پارامترهای ژنتیکی برای تجمع چربی در سه بخش مختلف بدن و روابط آنها با سایر صفات تولیدی در جوجه های گوشتی برآورد گردید. چربی محوطه شکمی (abdominal) و چربی زیر پوستی (subcutaneous) به عنوان منابع اصلی اتلافی در کشتارگاه های طیور در نظر گرفته می شوند، در حالی که چربی ذخیره شده در داخل ماهیچه (intramuscular) یک صفت مطلوب در ارتباط با کیفیت گوشت در نظر گرفته می شود. چربی ذخیره ای و صفات تولیدی بر روی ۱۷۲۵ جوجه ماده و ۱۵۲۶ جوجه نر اندازه گیری شد. توارث پذیری صفات تولیدی از ۰.۲۸ تا ۰.۷۳ برآورد گردید. علیرغم همبستگی ژنتیکی بالای بین چربی شکمی و چربی زیر پوستی (۰.۵۴)، همبستگی ژنتیکی بین چربی شکمی و چربی ماهیچه ای تقریبا صفر بود(۰.۰۲). وزن بدن در ۴۹ روزه گی همبستگی ژنتیکی مثبتی را با تولید چربی در نقاط مختلف بدن نشان داد. همبستگی وزن بدن با درصد چربی ماهیچه ای ۰.۸۷ و با درصد چربی زیر پوستی و درصد چربی شکمی به ترتیب ۰.۱۷ و ۰.۱۳ بود. بر اساس این نتایج، انتخاب جوجه های گوشتی با چربی شکمی کمتر، تغییری در میزان چربی ماهیچه ای و متعاقب ان کیفیت گوشت، ایجاد نخواهد کرد.

اثرات سنین و سیستم های نگهداری مختلف جوجه های گوشتی بر پارامترهای ژنتیکی وزن بدن و صفات تولیدی در فصل سوم این تحقیق مطالعه گردید. صفات بر روی جوجه ها درسه گروه مختلف با سنین ۴۸، ۶۳ و ۷۰ روزه گی اندازه گیری شدند. جوجه های گروه های ۴۸ و ۷۰ روز، در سیستم بستر و جوجه های گروه ۶۳ روز تا ۲۲ روزه گی در سیستم بستر و سپس از ۲۲ تا ۶۳ روزه گی در سیستم قفس انفرادی نگهداری شدند. هر گروه شامل تقریبا ۲۰۰۰ جوجه می شد و جوجه های هر سه گروه دارای والدین مشترک بودند. در این مطالعه، در صد لاشه، ماهیچه سینه، چربی شکمی و نیمه پشتی (نیمی از پشت بعلاوه یک ران) نسبت به وزن بدن اندازه گیری شد. توارث پذیری وزن بدن در۴۸، ۶۳ و ۷۰ روزه گی به ترتیب ۰.۳۱، ۰.۲۶ و ۰.۱۹ و توارث پذیری نیمه پشتی در۴۸، ۶۳ و ۷۰ روزه گی به ترتیب ۰.۴۲، ۰.۳۸ و ۰.۲۱ برآورد گردید. برای سایر صفات، توارث پذیری در سنین مختلف تقریبا مشابه بود. در ۴۸ روزه گی، همبستگی ژنتیکی مثبتی بین وزن بدن و بخش های با ارزش لاشه (ماهیچه سینه و نیمه پشتی) مشاهده گردید، در حالیکه این روابط در ۷۰ روزه گی منفی بود. از طرف دیگر، همبستگی ژنتیکی بین وزن بدن و درصد چربی شکمی در ۷۰ روزه گی بالاتر از ۴۸ روزه گی بود. این مطالعه نشان داد که افزایش رشد جوجه های گوشتی در سن ۴۸ روزه گی همراه با افزایش بخش های با ارزش و در سن ۷۰ روزه گی همراه با افزایش درصد چربی شکمی است. علاوه بر این، همبستگی ژنتیکی وزن بدن در ۴۸ روزه گی بین دو سیستم بستر و قفس بیانگر وجود اثر

متقابل ژنو تیپ و محیط (Genotype by environment interaction)بین سیستم های نگهداری مذکور می باشد که در طراحی برنامه های اصلاح نژادی تاثیر گذار خواهد بود.

هدف فصل چهارم بررسی اثرات استفاده از اندازه گیری های غیر مستقیم بر روی پاسخ ژنتیکی و میزان هم خونی (rate of inbreeding) در برنامه های اصلاح نژادی جوجه های گوشتی بود. در برنامه اصلاحی پایه، نامزدهای گزینشی (selection candidates) بر اساس اندازه گیری های مستقیم بدست آمده از خویشاوندان ارزیابی شدند. امکان استفاده از اندازه گیری های غیر مستقیم در سایر برنامه های اصلاحی مورد مطالعه قرار گرفت. سه برنامه ی اصلاحی جایگزین شامل اندازه گیری های غیر مستقیم صفات لاشه ای بر روی نامزدهای گزینشی از طریق شبیه سازی (deterministic simulation) مورد ارزیابی قرار گرفتند. در اولین برنامه اصلاحی جایگزین، صفات لاشه ای به طور غیر مستقیم روی نامزدهای گزینشی نر اندازه گیری شدند. در برنامه اصلاحی جایگزین دوم، صفات لاشه ای به طور غیر مستقیم روی نامزدهای گزینشی نر و به طور مستقیم روی خویشاوندان اندازه گیری شدند. در سومین برنامه جایگزین، صفات لاشه ای به طور غیر مستقیم روی نامزدهای گزینشی نر و ماده و به طور مستقیم روی خویشاوندان اندازه گیری شدند. در برنامه اصلاحی پایه، پاسخ ژنتیکی برای درصد ماهیچه سینه ۰.۳% و میزان هم خونی ۰.۹۶% بود. در برنامه اصلاحی سوم، پاسخ ژنتیکی برای درصد ماهیچه سینه به میزان ۶۶.۲ % در مقایسه با برنامه اصلاحی پایه افزایش یافت و میزان هم خونی به ۰.۷۹% در هر نسل کاهش یافت. افزایش پاسخ ژنتیکی در برنامه های اصلاحی جایگزین، ناشی از افزایش در دقت انتخاب در این استراتژی های اصلاحی بود. همچنین استفاده از اطلاعات مربوط به عملکرد انفرادی (own performance) نامزدهای گزینشی، میزان هم خونی را در برنامه های اصلاحی جایگزین کاهش داد که برای انتخاب بلند مدت بسیار مطلوب است. دقت روش های اندازه گیری غیر مستقیم، بر پاسخ ژنتیکی و میزان هم خونی موثر است. نتایج این تحقیق نشان داد که در اغلب موارد دقت ۳۰% برای حصول پاسخ ژنتیکی بالاتر و هم خونی پایین تر از برنامه اصلاحی پایه، کافی است.

در فصل پنجم، جوجه های گوشتی در یک آزمایش، به دو بخش جوجه های سالم و مبتلا به آسیت تقسیم گردید. هدف از این تحقیق مطالعه همبستگی بین وزن بدن و صفات مربوط به آسیت در هریک از این دو بخش بود. در این آزمایش، جوجه ها در دو گروه دمای متفاوت پرورش یافتند. در گروه اول وزن بدن، نسبت وزن بطن راست به وزن دو بطن (نسبت بطنی) و هماتوکریت بر روی ۴۲۰۲ جوجه در شرایط استرس سرمایی اندازه گیری شد. در گروه دوم صفات مذکور بر روی ۷۹۵ جوجه تحت شرایط دمای معمولی اندازه گیری شد. استرس سرمایی جهت تشخیص افراد مستعد ابتلا به آسیت مورد استفاده قرار گرفت. نسبت بطنی و هماتوکریت در دمای معمولی دارای توزیع نرمال بودند، در حالی که توزیع این صفات در استرس سرمایی، غیر نرمال (skewed) بود.توزیع غیر نرمال برای این صفات امکان وجود چند توزیع در درون توزیع اصلی را مطرح می سازد. که ممکن است حاصل چند توزیع جزئی باشد. استفاده از مدل دو متغیر مخلوط (bi-variate mixture model) نشان داد که در شرایط معمولی، تنها یک جامعه همگن برای صفات مربوط به آسیت وجود دارد، در حالی که در استرس سرما، ترکیبی از (دو) توزیع دیده می شود. یک توزیع شامل جوجه های سالم و دیگری شامل جوجه های مبتلا به آسیت. در جوجه های سالم، همبستگی فنوتیپی وزن بدن با نسبت بطنی و هماتوکریت نزدیک به صفر بود (به ترتیب ۰.۱ و ۰.۰۷-)، در حالی

که در جوجه های مبتلا، همبستگی فنوتیپی وزن بدن با نسبت بطنی و هماتوکریت منفی بود (به ترتیب ۰.۳۹- و ۰.۴-). همبستگی منفی وزن بدن با نسبت بطنی و هماتوکریت در جوجه های مبتلا منجر به منفی شدن همبستگی کلی وزن بدن با نسبت بطنی (۰.۳۰-) و هماتوکریت (۰.۳۷-) در بین مجموع جوجه ها (سالم و مبتلا) در شرایط استرس سرمایی می شود. بر اساس نتایج این تحقیق، همبستگی کلی وزن بدن و صفات مربوط به آسیت، به فراوانی نسبی جوجه های سالم و مبتلا در جامعه بستگی دارد.

در فصل ششم، عوامل اقتصادی و اجتماعی موثر بر توسعه پرورش طیور گوشتی مورد بررسی قرار گرفت. همچنین برای بیان اثرات وارد کردن صفات مربوط به سلامت طیور به همراه صفات تولیدی در یک برنامه اصلاحی پایدار (sustainable)، یک برنامه اصلاحی صرفا اقتصادی با یک برنامه اصلاحی پایدار مقایسه شد. در برنامه اقتصادی، انتخاب منحصر به صفات تولیدی بود وصفاتی نظیر استحکام پا و آسیت مد نظر قرار نگرفتند. در برنامه اصلاحی پایدار، ارزش های اقتصادی برای صفات استحکام پا و آسیت با استفاده از روش بهبود مطلوب (desired gain) تعیین گردید تا پاسخ ژنتیکی برای آنها صفر باشد. نتایج این بررسی نشان داد که انتخاب برای صفات تولیدی بدون در نظر گرفتن استحکام پا و آسیت، منجر به کاهش سلامت و آسایش طیور می شود. در برنامه اصلاحی پایدار، منظور کردن ارزش های اقتصادی ۰.۰۴۵ برای استحکام پا و ۰.۳- برای آسیت منجر به توقف وخامت وضعیت پا و آسیت شد.در نتیجه، کاهش ۶ درصدی در سود دهی صفات تولیدی برای جلوگیری از تهدید سلامت در جوجه های گوشتی کافی بود. بعلاوه، اثرات استفاده از اندازه گیری غیر مستقیم چربی به جای راند مان غذایی در برنامه های اصلاحی جوجه های گوشتی بیان گردید. به نظر می رسد بر خلاف راند مان غذایی، انتخاب برای کاهش چربی با استفاده از روش های غیر مستقیم می تواند راند مان تولید و سلامت را به طور همزمان بهبود بخشد. نهایتا پرورش طیور در ایران به عنوان نمونه ای از پرورش طیور در کشور های در حال توسعه مورد بررسی قرار گرفت.

Abbreviation key:

AFP	Abdominal fat percentage
AFW	Abdominal fat weight
BMP	Breast muscle percentage
BMW	Breast muscle weight
BW5	BW at 5 wk
BW7	BW at 7 wk
CP	Carcass percentage
CW	Carcass weight
IFP	Intramuscular fat percentage
SP	Skin percentage
SW	Skin weight.
BHP	Back half percentage
g	Group housing
G×E	Genotype by environment interaction
i	Individual cage.
BLUP	Best linear unbiased prediction
CT scan	Computed tomography scan
DCM	Direct carcass measurement
FCA	Adjusted feed conversion
FICM	Female indirect carcass measurement
INBMP	Indirect breast muscle percentage
INCP	Indirect carcass percentage
MICM	Male indirect carcass measurement
MRI	Magnetic resonance imaging
r_g	Genetic correlation.
ABDOMEN	Accumulation of fluid in the abdomen
HCT	Hematocrit value
HEART	Accumulation of fluid in the heart
LIVER	Liver abnormality
RATIO	The ratio of right ventricular weight to total ventricular weight
RV	The right ventricular weight
TV	The total ventricular weight.

List of Publications

Journals

S. Zerehdaran, A. L. J. Vereijken, J. A. M. van Arendonk, and E. H. van der Waaij. 2004. Estimation of Genetic Parameters for Fat Deposition and Carcass Traits in Broilers. Poultry Science 83:521-525.

S. Zerehdaran, A. L. J. Vereijken, J. A. M. van Arendonk, and E. H. van der Waaij. 2005. Effect of Age and Housing System on Genetic Parameters for Broiler Carcass Traits. Poultry Science 84:833-838.

S. Zerehdaran, A. L. J. Vereijken, J. A. M. van Arendonk, H. Bovenhouis, and E. H. van der Waaij. 2005. Broiler Breeding Strategies Using Indirect Carcass Measurements. Poultry Science 84:1214-1221.

S. Zerehdaran, E.M. van Grevenhof, E.H. van der Waaij, and H. Bovenhouis. 2005. A Bi-variate Mixture Model Analysis of Body Weight and Ascites Traits in Broilers. Submitted.

Proceedings

S. Zerehdaran, A.L.J. Vereijken, J.A.M. van Arendonk, and E.H van der Waaij. 2003. Relationships between intramuscular, abdominal and subcutaneous fat in broiler chickens. *In: Book of abstracts no. 9; 54th Annual meeting of the European Association for Animal Production (EAAP), 31Augest to 1 September.*

S. Zerehdaran, A.L.J. Vereijken, J.A.M. van Arendonk, and E.H van der Waaij, 2003. Genetic Correlations of Carcass Traits and Ascites in Broilers. *In: Book of abstracts of the 3rd European Poultry Genetics Symposium, Wageningen, The Netherlands. P.90*

S. Zerehdaran, A.L.J. Vereijken, J.A.M. van Arendonk, and E.H van der Waaij. 2004. Effect of age and housing system on genetic parameters for broiler carcass traits. *In: Book of Abstracts of the 55th Annual Meeting of the EAAP, Bled, Slovenia, 5-9 September.*

S. Zerehdaran, A.L.J. Vereijken, J.A.M. van Arendonk, H. Bovenhuis, and E.H van der Waaij,. 2005. Genetic improvement in broilers using indirect carcass measurements. *In: Book of abstracts of the 56th Annual Meeting of the European Association for Animal Production, No.11. Uppsala, Sweden, 5-8 June.*

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Saeed Zerehdaran

21 September 2005, Wageningen, the Netherlands

Curriculum Vitae

Saeed Zerehdaran was born on March 25, 1970 in Nishaboure, Iran. He completed his high school in the same city in 1988. He started his studies in Mashhad University and obtained a BSc degree in animal science in 1993. In September 1993, he was accepted for MSc education in animal science at Tarbiat Modaress University, Tehran, Iran. He received his MSc degree in 1996, with the thesis entitled "Estimation of Genetic Parameter for Production Traits in a herd of Holstein Dairy Cows". After graduation, he worked as an academic staff member in Gorgan University, Gorgan, Iran for 4 years. In 1999, he received a scholarship from Ministry of Science, Research and Technology (MSRT) of Iran to continue his education. In November 2001, he started his PhD project in Animal Breeding and Genetics at Department of Animal Science, Wageningen University, The Netherlands. He is now returning to work as an academic staff member in Iran.

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Complete PhD Education Plan		**Graduate School WIAS**
Name	Saeed Zerehdaran	
Group	Animal Breeding and Genetics Group	
Supervisor	Prof. dr.ir. J.A.M.van Arendonk	
Daily supervisor	Dr.ir. E.H. van der Waaij	
Period	November 2001 until September 2005	

	year	cp*
The Basic Package (minimum 2 cp)	year	cp*
• Course on philosophy of science and ethics (mandatory)	2002	1.0
• WIAS Introduction Course (mandatory)	2004	1.0
SUBTOTAL		**2.0**
Scientific Exposure (conferences, seminars and presentations, minimum 5 cp)	year	cp
• **International conferences** (minimum 2 cp)		
WCGALP in Montpelier, France	2002	1.0
54th Annual Meeting of the EAAP in Rome, Italy	2003	0.8
3rd European Poultry Genetics Symposium in Wageningen, the Netherlands	2003	0.6
55th Annual Meeting of the EAAP in Bled, Slovenia	2004	0.8
56th Annual Meeting of the EAAP in Uppsala, Sweden	2005	0.8
• **Seminars and workshops**		
Fine-tuning Animal Breeding (A farewell seminar for Theo. In ID-Lelystad)	2002	0.2
WIAS Science Day	2003	0.2
WIAS Science Day	2004	0.2
Farm Animal Genomics: from sequence to application	2004	0.1
WIAS Science Day	2005	0.2
Selection of chickens: approach to unravel specific and innate immune competence	2005	0.1
• **Presentations** (minimum 4 original presentations of which at least 1 oral)		
Oral presentation in EAAP Meeting in Rome, Italy	2003	0.5
Poster presentation in European Poultry Genetics Symposium in Wageningen	2003	0.5
Poster presentation in WIAS Science Day	2003	0.5
Poster presentation in EAAP Meeting in Bleb, Slovenia	2004	0.5
Oral presentation in EAAP Meeting in Uppsala, Sweden	2005	0.5
SUBTOTAL		**7.5**
In-Depth Studies (minimum 4 cp)	year	cp
• **Disciplinary and interdisciplinary courses**		
Managing diversity in living systems	2002	1.0
Genetic Algorithms applied to Animal Breeding	2003	0.2
Incorporation of competitive effects in breeding programs for improved performance and animal well-being	2004	1.0
• **Advanced statistics courses** (optional)		
Design of animal experiments	2002	0.6
• **Under graduate courses**		
Biological aspects of animal breeding	2002	2.0
Genome analysis	2002	2.0
Breeding program	2002	3.0
Breeding value Estimation	2002	3.0
SUBTOTAL		**12.8**
Professional Skills Support Courses (minimum 2 cp)	year	cp
WIAS Course Techniques for Scientific Writing	2002	0.8
English language course	2002	1.0
Project and Time Management	2004	1.0
SUBTOTAL		**2.8**
Research Skills Training (apart from carrying out the PhD project, optional)	year	cp
Preparing own PhD research proposal	2001	4.0
SUBTOTAL		**4.0**
Education and Training Total (minimum 21 cp)		**29.1**

* One credit point (cp) equals a study load of approximately 40 hours.

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