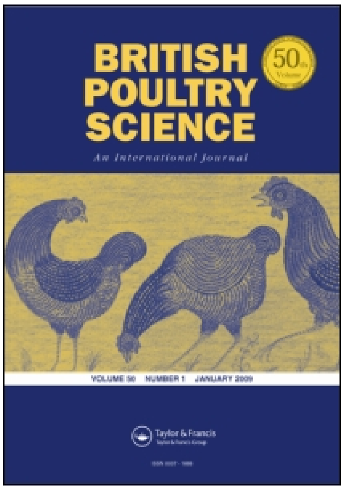

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Genetic parameters of ascites-related traits in broilers: effect of cold and normal temperature conditions

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Abstract 1. Ascites syndrome is a growth-related disorder of broilers that occurs more often in fast-growing birds and at low temperatures. The objective of this study was to estimate genetic and phenotypic correlations among ascites-related traits measured either under cold or under normal temperature conditions, and to estimate genetic correlations between ascites-related traits measured under cold and normal conditions.

2. Several traits related to ascites were measured on more than 4000 chickens under cold conditions and on more than 700 chickens under normal conditions.

3. The heritability estimates for body weight (BW) measured under cold and normal conditions were 0·42 and 0·50, respectively, for haematocrit value 0·46 and 0·17, respectively, and for ratio of right to total ventricular weight 0·45 and 0·12, respectively.

4. The genetic correlation between BW and haematocrit value under cold conditions was −0·23 and between BW and ratio of right to total ventricular weight −0·27. Under normal conditions, however, these genetic correlations were 0·55 and 0·50, respectively.

5. These results demonstrate that the heritability estimates of ascites-related traits as well as genetic correlations between ascites-related traits and BW depend on the temperature conditions under which animals are kept.

6. Strong positive genetic correlations (around 0·8) were observed between total mortality, fluid in the abdomen and ratio of right to total ventricular weight under cold conditions. The genetic correlation between ratio of right to total ventricular weight under cold and normal conditions was 0·91.

7. These results suggest that the ratio of right to total ventricular weight measured under normal temperature conditions might serve as a good indicator trait for ascites.

INTRODUCTION

Ascites, also known as water belly, is a growth-related disorder of broilers that occurs more often in fast-growing birds, at high altitudes and low temperatures. The most critical trigger for ascites in broilers is a high oxygen requirement (Julian, 1998). The ascites syndrome 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). For developing selection strategies to reduce ascites, genetic parameters such as heritabilities and genetic correlations among ascites-related traits should be known.

Several studies have reported moderate to high heritabilities for ascites-related traits (Lubritz *et al.*, 1995; Maxwell and Robertson, 1997; De Greef *et al.*, 2001; Pakdel *et al.*, 2002). This offers perspectives for selection against this syndrome. Only a few studies have reported genetic correlations among ascites-related traits and those studies only comprised a limited number of ascites-related traits. For instance, under normal climatic conditions, Moghadam *et al.* (2001) found a positive genetic correlation between ascites and body weight (BW). However, under cold conditions, De Greef *et al.* (2001) reported a negative genetic correlation between ascites and BW.

Deeb *et al.* (2002) found that birds that have a higher potential for growth rate under normal temperature conditions are more likely to suffer from ascites under cold-stress conditions as compared to birds with a lower potential for

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growth rate. Therefore, it seems that there is an interaction among traits such as BW and susceptibility to ascites and temperature. Ascites develops more often in low ambient temperatures (Shlosberg *et al.*, 1992; Yahav and Hurwitz, 1996; Yahav *et al.*, 1997), which increases the possibility of identifying birds that are susceptible to ascites. At present, selection for economically important traits in broilers is usually carried out under normal temperature conditions. However, for designing optimal selection strategies against ascites incidence it might be best to test birds under cold conditions. To decide which is the better strategy, correlations between traits measured under both conditions are required. The objective of this study was to estimate genetic and phenotypic correlations among ascites-related traits measured either under cold conditions or under normal temperature conditions, and to estimate genetic correlations between ascites-related traits measured under cold and normal conditions.

MATERIAL AND METHODS

Birds and traits

Birds

The experimental population was the result of a cross between two genetically different broiler dam lines (Hybro) 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. Thirty-six birds (18 males and 18 females) from the two lines were crossed to produce the F_1. From the F_1, 29 birds were parents of the F_2 generation of 829 birds, which in turn were used to produce the F_3 offspring.

The birds of the F_3 generation were divided into different groups. The first consisted of 4202 birds, hatched in 6 different weeks in 1994 and 1995. Feathering phenotype (fast or slow) was recorded at hatch. These birds were kept in 4 pens and 9 batches were created on the basis of hatching day and pen number. To identify individuals susceptible to ascites, a cold-stress temperature schedule was applied (Figure 1) to this group. At hatching the temperature was 30°C and was gradually decreased to 10°C by 22 d of age. The temperature remained at 10°C until the end of the experiment. Except for the adjusted temperature, birds were kept under circumstances that closely resembled commercial practice: a standard commercial feed, artificially lighted housing for 23 h/d and group housing with 20 birds/m^2.

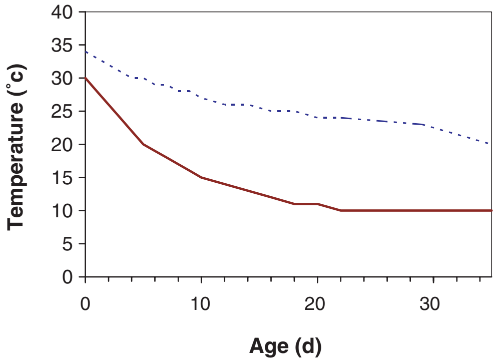

Figure. *The normal temperature schedule (------) and the cold-stressed temperature schedule (——).*

The second group consisted of 795 F_3 birds kept under a normal temperature schedule. About 85% of the sires and more than 88% of dams with offspring kept under cold temperature conditions also had offspring kept under normal temperature conditions. The normal temperature schedule started at 33 to 34°C and then gradually decreased to 17 to 18°C by 35 d of age (Figure). Except for temperature, the two groups were kept under similar conditions. The birds under normal temperature conditions hatched in two different weeks and were kept in two different pens. Two batches were created on the basis of hatching day and pen number. All work was conducted strictly in line with the regulations of the Dutch law on the protection of animals.

Traits

Birds exposed to cold-stress conditions were slaughtered at 5 weeks of age. The BW and haematocrit value (HCT) of birds were measured one day before slaughtering. After slaughtering, a number of ascites-related traits were measured. Livers and hearts were removed and visually inspected. Liver abnormalities (LIVER) were scored as follows: 0 = no abnormalities observed, 1 = an abnormal liver and 2 = serious liver abnormalities. Liver abnormalities were a lighter colour, an irregular liver surface or both. Accumulation of fluid in the heart sac (HEART) was scored 0 = no fluid, 1 = some fluid accumulation and 2 = serious accumulation of fluid. Further, the weight of right ventricle (RV) and total ventricles (TV) were measured. From these measurements the ratio of RV:TV, RV as a percentage of total BW (%RV) and TV as a percentage of total BW (%TV) were derived. The accumulation of fluid in the abdomen (ABDOMEN) was scored as follows: 0 = no fluid, 1 = some fluid and 2 = a serious accumulation of fluid.

For colour of the breast (BREAST), a score of 0 = normal colour, 1 = colour deviation and

2 = serious colour deviation. In general a deviation meant that the colour was more red. Total mortality (MORT-TOT) was recorded as 0 or 1. A score of 0 = a bird that was alive at the end of the experiment and a score of 1 = a bird that died before the end of the experiment.

The birds exposed to normal temperature conditions were slaughtered at 7 weeks of age and the measurements for BW, HCT, RV, TV and RV:TV were available for these animals. BW and HCT of this group of birds were also measured one day before slaughtering.

Genetic analysis

A model was used to calculate heritabilities and genetic correlations of ascites-related traits:

$$Y_{ijklm} = \mu + \mathrm{Sex}_i + \mathrm{Feather}_j + \mathrm{Batch}_k + \mathrm{Group}_l + a_m + e_{ijklm}$$

where Y_{ijklm} = the dependent variable on chicken m of sex i, feathering class j from batch k in group l; Sex_i = fixed effect of sex i ($i = 1$, 2 female or male); $\mathrm{Feather}_j$ = fixed effect of feathering j ($j = 1, 2$ fast or slow); Batch_k = fixed effect of batch k ($k = 1, 2, \ldots, 9$ for birds kept under cold conditions and $k = 1, 2$ for birds kept under normal conditions), classes were formed based on a combination of hatching day and pen; Group_l = fixed effect of group ($l = 1, 2, \ldots, 46$ for birds kept under cold conditions and $l = 1, 2, \ldots, 18$ for birds kept under normal conditions), classes were formed based on the age of the dam and the hatching day of the experimental animals; a_m = random direct genetic effect of individual m; e_{ijklm} = random residual effect. The fixed and random effects used were the same for all the traits under study. Bivariate analyses were performed to compute correlations between all combinations of traits. Estimates of variance components were obtained using the ASREML software (Gilmour *et al.*, 2000).

RESULTS AND DISCUSSION

Descriptive statistics

Descriptive statistics of the traits measured under cold and normal conditions are presented in Table 1. Under cold conditions and at 5 weeks of age, the broilers weighed 1604 g on average and total mortality was 16%. Under normal conditions and at 7 weeks of age, the broilers weighed 2060 g on average. In general, the standard deviation of traits measured under cold conditions was higher than the standard deviation of traits measured under normal conditions. However, this was not the case for BW: this trait showed a higher coefficient of variation under cold conditions. Although birds exposed to cold conditions were younger than birds exposed to normal conditions, they showed higher RV:TV which is mainly due to higher values for RV. The HCT of birds kept under cold conditions was also higher. The data in Table 1 show that there is a marked difference between the means and the standard deviations of ascites-related traits measured under cold and normal conditions. This difference can either be due to the effect of temperature or the difference in age. Shlosberg *et al.* (1992) concluded that there is no significant difference between HCT values at

Table 1. *Descriptive statistic of the traits measured under cold and normal conditions*

Traits	Abbreviation	Cold[1]			Normal[2]		
		Number	Mean	SD	Number	Mean	SD
Body weight (g)	BW	3693	1604	263	770	2060	310
Haematocrit value (%)	HCT	3547	35·40	4·21	780	28·28	2·30
Right ventricular weight (g)	RV	3660	1·95	0·68	659	1·15	0·31
Total ventricular weight (g)	TV	3658	6·97	1·17	746	5·60	0·94
Ratio of right ventricular weight to total ventricular weight (%)	RV:TV	3658	27·93	8·07	659	20·63	4·66
Right ventricular weight as percentage of BW (%)	%RV	3646	0·125	0·05	652	0·06	0·01
Total ventricular weight as percentage of BW (%)	%TV	3644	0·439	0·07	738	0·27	0·04
Total mortality[3]	MORT–TOT	2494	0·16	0·37	–[4]	–	–
Fluid in the abdomen[5]	ABDOMEN	3697	0·08	0·38	–	–	–
Colour of the breast[5]	BREAST	3697	0·03	0·18	–	–	–
Liver abnormalities[5]	LIVER	3697	0·07	0·29	–	–	–
Fluid in the heart sac[5]	HEART	3696	0·59	0·62	–	–	–

[1]Traits measured at 5 weeks of age under cold conditions.
[2]Traits measured at 7 weeks of age under normal conditions.
[3]Trait scored as 0 or 1. The number of animals for every class: $N_0 = 2095$ and $N_1 = 399$.
[4]Scored traits were not recorded under normal conditions.
[5]Trait scored as 0, 1 or 2. The number of animals for every class: fluid in the abdomen: $N_0 = 3542$, $N_1 = 23$ and $N_2 = 132$, colour of the breast: $N_0 = 3585$, $N_1 = 110$ and $N_2 = 2$, liver abnormalities: $N_0 = 3488$, $N_1 = 170$ and $N_2 = 39$, fluid in the heart sac: $N_0 = 1781$, $N_1 = 1653$ and $N_2 = 262$.

5, 6 and 7 weeks of age. This suggests that the difference in HCT values in Table 1 is the result of the effect of temperature. Further, Shlosberg *et al.* (1992) indicated that there is a significant increase of RV:TV from weeks 5 to 7. In the current study, the younger birds under cold conditions (5 weeks) showed higher RV:TV values than the older birds under normal conditions (7 weeks) which also points to a clear effect of temperature.

Effects of sex and feathering

The estimated effects of the male sex and slow-feathering on ascites-related traits obtained from the univariate analysis are presented in Table 2. In the analysis, the effects of female sex and fast-feathering were fixed at zero. Sex had significant effects on most of the ascites-related traits under cold as well as under normal conditions. Under both temperature conditions male broilers had lower HCT values and higher values for BW, RV and TV than the females. Under cold conditions, RV increased more in male than in female birds, which resulted in a higher RV:TV value for males (data not shown).

Under cold conditions feathering also had a marked effect on most of the ascites-related traits (Table 2). Under these conditions slow-feathering birds had a lower BW and higher values for HCT and RV:TV. However, under normal conditions the effect of feathering on these traits was not significant. This suggests that under cold conditions slow-feathering birds are more susceptible to the ascites syndrome, probably due to their increased sensitivity to the cold temperature.

Table 2. *The estimated effect of male sex and slow-feathering on ascites-related traits under cold and normal conditions*[1]

Traits[2]	Sex effect		Feathering effect	
	Cold[3]	Normal[4]	Cold	Normal
BW (g)	191·46***[5]	263·74***	−55·95***	−8·14[NS]
HCT (%)	−1·10***	−0·57***	1·13***	0·25[NS]
RV (g)	0·51***	0·30***	0·15***	0·06*
TV (g)	1·17***	1·24***	0·15***	0·13*
RV:TV (%)	2·62***	0·79*	1·79***	0·59[NS]
%RV	0·018***	0·007***	0·014***	0·003**
%TV	0·024***	0·029***	0·025***	0·010**

[1]In the analysis the effects of female sex and fast-feathering were fixed at zero.
[2]HCT = haematocrit value; RV = right ventricular weight; TV = total ventricular weight; RV:TV = ratio of right ventricular weight to total ventricular weight; %RV = right ventricular weight as percentage of BW; %TV = total ventricular weight as percentage of BW.
[3]Trait measured at 5 weeks of age under cold conditions.
[4]Traits measured at 7 weeks of age under normal conditions.
[5]Significance of sex or feathering effect: *$P<0{\cdot}05$; **$P<0{\cdot}01$; ***$P<0{\cdot}001$; NS = non-significant.

Genetic parameters under cold conditions

Heritability estimates obtained from the univariate analyses (Table 3) were generally consistent with estimates from the bivariate analyses. However, for bivariate analyses involving mortality, deviating estimates were obtained, for example, for ABDOMEN the estimated heritability was 0·21. The reason for this might be that birds which died during the experiment provide no data for the other traits. The standard errors for the heritability estimates were between 0·02 and 0·05.

The estimated genetic and phenotypic correlations among ascites-related traits under cold conditions are presented in Table 3. The standard errors for genetic correlations were 0·01 to 0·30 and for phenotypic correlations were 0 to 0·04. The standard errors of estimated genetic correlations were high for those bivariate analyses where one or both traits were scored traits. Some of the estimated genetic correlations

Table 3. *Estimates of genetic parameters of ascites-related traits measured under cold conditions*[1]

Traits[2]	BW	HCT	RV	TV	RV:TV	%RV	%TV	MORT−TOT	ABDOMEN	BREAST	LIVER	HEART
BW	**0·42**	−0·23	0·06	0·58	−0·27	−0·41	−0·50	−0·06	0·00	−0·38	−0·17	−0·12
HCT	−0·37	**0·46**	0·54	0·20	0·56	0·63	0·52	0·72	0·66	0·61	0·66	0·67
RV	0·06	0·40	**0·47**	0·60	0·89	0·86	0·59	0·43	0·74	0·48	0·75	0·91
TV	0·63	−0·03	0·49	**0·46**	0·15	0·26	0·40	−0·25	0·22	−0·03	0·18	0·40
RV:TV	−0·30	0·50	0·86	0·01	**0·45**	0·94	0·50	0·62	0·82	0·62	0·85	0·90
%RV	−0·46	0·57	0·79	0·09	0·92	**0·45**	0·77	0·70	0·81	0·64	0·85	0·91
%TV	−0·53	0·44	0·46	0·29	0·39	0·70	**0·46**	0·58	0·34	0·36	0·44	0·57
MORT−TOT	0·42	0·34	0·04	−0·11	0·11	0·37	0·53	**0·32**	0·96	1·00	0·97	0·78
ABDOMEN	−0·33	0·29	0·29	−0·15	0·46	0·51	0·30	0·57	**0·08**	0·87	1·01	0·70
BREAST	−0·11	0·09	0·10	−0·04	0·16	0·19	0·11	0·88	0·28	**0·03**	0·96	0·13
LIVER	−0·29	0·27	0·26	−0·11	0·40	0·46	0·29	0·67	0·72	0·31	**0·08**	0·76
HEART	−0·15	0·27	0·36	0·05	0·41	0·42	0·26	0·19	0·43	0·14	0·41	**0·18**

[1]Genetic correlations above, phenotypic correlations below and heritabilities (bold) on the diagonal. Heritabilities obtained in univariate analysis, but genetic and phenotypic correlations obtained in bivariate analysis. The SE for genetic correlation were 0·01 to 0·30, for phenotypic correlation were 0 to 0·04 and for heritabilities were 0·02 to 0·05.
[2]HCT = haematocrit value; RV = right ventricular weight; TV = total ventricular weight; RV:TV = ratio of right ventricular weight to total ventricular weight; %RV = right ventricular weight as percentage of BW; %TV = total ventricular weight as percentage of BW; MORT-TOT = total mortality; ABDOMEN = fluid in the abdomen; BREAST = colour of the breast; LIVER = liver abnormalities; HEART = fluid in the heart sac.

among scored traits were outside the parameter space. With a few exceptions, the genetic correlations reported in Table 3 are all positive. However, BW had negative genetic correlations with HCT (−0·23) and RV:TV (−0·27), indicating that, under cold-stress conditions, those broilers that have a higher genetic potential for growth have a lower genetic potential for HCT and RV:TV. The positive genetic correlation between BW and TV (0·58) indicates that fast-growing birds have a greater total ventricular weight.

At first sight, the correlations between BW and ascites-indicator traits like HCT and RV:TV might seem unexpected, because research generally shows that higher productivity in broilers leads to higher oxygen requirements and consequently results in an increased incidence of the ascites syndrome (Julian, 1993; Summers, 1994; Moghadam *et al*., 2001). Therefore, one might expect faster-growing birds to have higher HCT values and higher values of RV:TV, corresponding to a higher incidence of ascites. Apparently, under cold-stress conditions, these relationships are influenced by susceptibility to ascites: birds can only achieve a high BW when they show a degree of resistance against ascites. These results are in agreement with the results obtained by De Greef *et al*. (2001) and Deeb *et al*. (2002). De Greef *et al*. (2001) estimated a negative genetic correlation between 5-week BW and ascites candidate traits; −0·54 between BW and HCT and −0·26 between BW and RV:TV. However, in the non-diseased subpopulation De Greef *et al*. (2001) estimated a positive genetic correlation between BW and RV:TV of 0·29. Therefore, De Greef *et al*. (2001) concluded that the genetic correlation between productivity and ascites is sensitive to the disease status of the birds. Deeb *et al*. (2002) found that chickens that reached a higher BW at 37 d under normal temperature conditions had greater mortality due to ascites under cold-stress conditions. Furthermore, Deeb *et al*. (2002) reported that the correlation between sire family means for potential growth rate and actual growth rate (weight gain between 37 to 47 d) changed from positive (0·43) under normal conditions to negative (−0·12) under cold conditions and demonstrated that fast-growing birds are more susceptible to cold stress than slow-growing birds.

Ascites is defined as accumulation of fluid in the abdominal cavity and therefore is best described by the trait ABDOMEN. The genetic correlation between ABDOMEN and MORT-TOT was very strong (0·96). In the present experiment, MORT-TOT was defined as total mortality, but most mortality was due to ascites. Also there was a high genetic correlation between ABDOMEN and other scored traits which suggests that these traits all represent a similar phenomenon. The high genetic correlation between ABDOMEN and RV:TV (0·82) suggests that RV:TV is a good indicator trait for ascites. The ratio of RV:TV quantifies the degree of hypertrophy of the heart and is an index of pulmonary hypertension (Huchzermeyer and de Ruyck, 1986). Lubritz *et al*. (1995) found genetic correlations between ABDOMEN and RV:TV in broilers exposed to cold temperatures varying from 0·46 to 0·78, depending on broiler line and growth rate.

HCT is a physiological regulator of oxygen transport capacity. A high value for HCT in broilers with a high metabolic rate and under cold stress is an adaptive advantage because the blood's oxygen carrying capacity is enhanced. However, the downside of high HCT values is that the blood becomes more viscous and resistant to flow and as a result pulmonary vascular pressure increases (Maxwell *et al*., 1992). In the current study the genetic correlation between HCT and MORT-TOT was relatively high (0·72). The genetic correlation between HCT and other traits was moderate: the genetic correlation between HCT and RV:TV was 0·56 and between HCT and ABDOMEN was 0·66. These results indicate that under cold conditions the incidence of ascites is higher in those birds that have a higher genetic potential for HCT. Shlosberg *et al*. (1996) showed that in cold conditions birds with high HCT were more susceptible to die due to ascites (41%), and birds with low HCT were more likely to die from other causes (26%).

Genetic parameters under normal conditions

The estimated heritabilities and genetic and phenotypic correlations among ascites-related traits measured under normal conditions are presented in Table 4. The accuracy of the

Table 4. *Estimates of genetic parameters of ascites-related traits under normal conditions*[1]

Traits[2]	BW	HCT	RV	TV	RV:TV	%RV	%TV
BW	**0·50**	0·55	0·90	0·79	0·50	0·41	−0·36
HCT	−0·08	**0·17**	0·80	0·59	0·71	0·61	0·09
RV	0·41	0·08	**0·13**	0·73	0·88	1·12	−0·50
TV	0·59	0·04	0·57	**0·54**	−0·19	0·73	0·39
RV:TV	0·11	0·08	0·72	−0·08	**0·12**	0·93	−0·69
%RV	−0·13	0·11	0·73	0·30	0·61	**0·05**	0·00
%TV	−0·51	0·14	0·16	0·40	−0·15	0·43	**0·17**

[1]Genetic correlations above, phenotypic correlations below and heritabilities (bold) on the diagonal. Heritabilities obtained in univariate analysis, but genetic correlations obtained in bivariate analysis. The SE for genetic correlation were 0·1 to 0·54, for phenotypic correlation were 0·02 to 0·05 and for heritabilities were 0·05 to 0·12.

[2]HCT = haematocrit value; RV = right ventricular weight; TV = total ventricular weight; RV:TV = ratio of right ventricular weight to total ventricular weight; %RV = right ventricular weight as percentage of BW; %TV = total ventricular weight as percentage of BW.

estimates under normal conditions was relatively low due to the smaller data-set: the standard errors for genetic correlations were 0·10 to 0·54, for phenotypic correlations 0·02 to 0·05 and for heritabilities 0·05 to 0·12. The heritability estimates of ascites-related traits under normal conditions were in general lower than under cold conditions, for example, the heritability estimate for HCT was 0·17, and for RV:TV, the estimated heritability was 0·12. This is probably because under cold conditions genetic differences in ascites susceptibility become more evident. Genetic correlations among ascites-related traits are shifted to more positive values under normal conditions as compared to the estimates under cold conditions. For instance, the genetic correlation between BW and HCT changed from −0·23 under cold conditions to 0·55 under normal conditions and the genetic correlation between BW and RV:TV changed from −0·27 to 0·50. The high and positive genetic correlations between BW and HCT or BW and RV:TV under normal conditions indicated that birds with high genetic potential for BW have a high genetic potential for HCT or RV:TV. These results also suggest that the genetic parameters for these traits are very sensitive to temperature schedule, which is related to the incidence of the disease. It should be noted, however, that birds under normal temperature conditions were older (7 weeks) than those under cold conditions (5 weeks). Therefore, they are expected to have a higher BW and part of the differences in correlations found under cold and normal temperature conditions might actually be due to the difference in age at which BW is recorded.

The high genetic correlation between BW and heart characteristics like RV and TV suggest that under normal conditions those broilers with higher genetic growth potential have higher genetic values for RV and TV values as well. This agrees with Wideman (2001) who found that for clinically healthy broilers any increase in BW is associated with proportional increases in TV, cardiac output and stroke volume.

Cold and normal conditions

The unique set-up of the present experiment, where parents have offspring under both cold and normal temperature conditions, permits the estimation of genetic correlations between traits measured under both conditions (Table 5). Except for BW, the genetic correlations between the same traits measured under cold and normal temperatures were high, 0·93 for HCT, 0·89 for RV, 0·80 for TV and 0·91 for RV:TV. These results indicate that it is mainly the same genes which affect these traits in both environments. In contrast, the low genetic correlation for BW measured in different environments (0·29) suggests that this trait is very sensitive to temperature. However, this correlation is not only the result of differences in environmental conditions, but the difference in age between the groups of birds should also be considered. Most of the reported genetic correlations among body weights of broilers at various ages are high. Chambers *et al.* (1984) estimated genetic correlations larger than 0·8 among BW measured at 4, 6 and 7 weeks of age and Wang and McMillan (1991) estimated a genetic correlation of 0·94 between 4- and 6-week BW based on maternal relationships and a genetic correlation of 0·83 between these traits based on paternal relationships. Therefore, it can be concluded that the low genetic correlation between BW measured under cold and normal conditions in the present study is mainly due to the temperature effect. This correlation therefore indicates a genotype by environment interaction and broilers with high genetic values for BW under

Table 5. *Genetic correlation among ascites-related traits in cold and normal conditions*

	Traits[1]	Normal temperature conditions						
		BW	HCT	RV	TV	RV:TV	%RV	%TV
Cold temperature conditions	BW	**0·29**	0·15	−0·12	0·09	−0·07	−0·77	−0·14
	HCT	0·31	**0·93**	0·80	0·38	0·77	0·98	0·07
	RV	0·58	0·62	**0·89**	0·73	0·77	0·90	0·36
	TV	0·48	0·40	0·33	**0·80**	−0·29	−0·01	0·80
	RV:TV	0·40	0·46	0·91	0·41	**0·91**	0·94	−0·01
	%RV	0·38	0·44	0·86	0·59	0·73	**0·96**	0·35
	%TV	0·21	0·23	0·45	0·69	−0·20	0·74	**0·83**
	MORT-TOT	0·17	0·51	0·50	0·12	0·63	0·57	−0·33
	ABDOMEN	0·20	0·51	0·61	0·31	0·63	1·36	0·02
	BREAST	−0·08	0·45	1·29	−0·67	0·92	0·43	−0·68
	LIVER	0·21	0·58	0·70	0·29	0·76	0·77	−0·04
	HEART	0·30	0·57	0·77	0·53	0·64	0·87	0·31

[1]HCT = haematocrit value; RV = right ventricular weight; TV = total ventricular weight; RV:TV = ratio of right ventricular weight to total ventricular weight; %RV = right ventricular weight as percentage of BW; %TV = total ventricular weight as percentage of BW; MORT-TOT = total mortality; ABDOMEN = fluid in the abdomen; BREAST = colour of the breast; LIVER = liver abnormalities; HEART = fluid in the heart sac.

normal conditions do not necessarily have high genetic values for BW under cold conditions. Fast-growing broilers have high metabolic requirements for oxygen which requires a large volume of blood flow through their lungs (Julian, 1993). High oxygen requirement is the most critical trigger for ascites in broilers especially under cold-stress conditions (Julian, 1998). Also, to maintain normal body temperature in a cold environment the metabolic rate rises to increase heat production (Julian, 1998). Therefore, when environmental conditions give rise to ascites syndrome (cold stress or high altitudes), broilers with higher genetic potential for growth rate are especially affected.

The genetic correlation between BW measured under cold conditions and other ascites-related traits measured under normal conditions (Table 5) was higher than estimates among the same traits under cold conditions (Table 3), but lower than estimates among the same traits under normal conditions (Table 4). For other traits there was no obvious difference between estimates under cold, normal and cold + normal conditions. Because of the low genetic correlation between BW under cold and normal conditions these results were expected.

Maternal genetic effects

Pakdel *et al*. (2002) indicated that under cold conditions the traits BW, TV, RV:TV, %RV, %TV and MORT-TOT are significantly affected by maternal genetic effects and there is an overestimation of the direct heritability when the maternal genetic effect was neglected. In the current study, no significant maternal genetic effects could be detected for traits measured under normal conditions, which might be due to the smaller number of observations. Including maternal genetic effects in bivariate analyses leads to a large increase in the number of parameters that needs to be estimated and greatly complicates the calculations. Therefore, in the present study results are presented for a model without maternal genetic effects. When, under cold conditions, the maternal genetic effect was included in the model, the genetic correlations between BW and other ascites-related traits increased, for example, the correlation between BW and HCT changed from −0·23 (±0·10) to 0·06 (±0·17) and the correlation between BW and RV changed from 0·06 (±0·10) to 0·27 (±0·16). However, for most of the traits there was no obvious difference between genetic correlations estimated using a model with and without maternal genetic effects.

Prospects

Animals that are not fully resistant to a certain disease may show decreased production when infected. High infection pressure combined with low resistance may cause production to drop dramatically, while when resistance is high, infection may have little or no influence on performance (Van der Waaij *et al*., 2000). From the economic as well as ethical point of view it is important to increase ascites resistance in broilers to a level where the influence of this syndrome on production is negligible. In this study we report genetic parameters for traits which might serve as indicators for ascites susceptibility. Designing effective selection strategies for ascites resistance not only has to deal with the identification of good indicator traits, but also concerns the choice of the selection environment: normal and cold temperature conditions. Therefore, it is important to determine the degree of G × E interaction for BW and ascites indicator traits. This study is the second to report on genetic correlations among traits related to the ascites syndrome measured under cold and normal conditions. In spite of difference in age of measurement of the traits under both environmental conditions, the results suggest that there is an interaction between temperature and BW, which can be attributed to genetic variation in the susceptibility of birds to ascites. From the results it can be concluded that high production under cold conditions is due to a favourable combination of resistance to ascites and production potential. Under normal conditions, however, the production potential of animals is important whereas genetic differences in resistance to ascites syndrome are less relevant. The evidence for G × E interactions in modern broilers and various suboptimal conditions also emphasise the need for breeding programmes aimed at improving performance under particular stressful environments.

The results of our study show high genetic correlations between the same ascites-related traits measured under cold and normal conditions. Therefore, it is possible to select against ascites by measuring animals' ascites-related traits under normal conditions. Strong positive genetic correlations were found among total mortality, fluid in the abdomen and ratio of RV:TV (around 0·8) under cold conditions. The genetic correlation between RV:TV measured under normal conditions and ascites indicator traits (HCT, MORT-TOT, ABDOMEN, BREAST and LIVER) measured under cold conditions was relatively high. Because ascites is best described by the trait fluid in the abdomen, these results suggest that the ratio of RV:TV, which quantifies the degree of hypertrophy of the heart, is a good indicator for ascites. The results provide important information for developing an effective selection strategy to reduce the incidence of ascites syndrome, which could form the basis for the design of a well-balanced breeding scheme for broilers.

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ABBREVATIONS

HCT = haematocrit value; RV = right ventricular weight; TV = total ventricular weight; RV:TV = ratio of right ventricular weight to the total ventricular weight; %RV = right ventricular weight as a percentage of BW; %TV = total ventricular weight as a percentage of BW; MORT-TOT = total mortality; ABDOMEN = fluid in the abdomen; BREAST = colour of the breast; LIVER = liver abnormalities; HEART = fluid in the heart sac; G × E = genotype by environment interaction.

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