

BREEDING AND GENETICS

Variation of Chicken Technological Meat Quality in Relation to Genotype and Preslaughter Stress Conditions

M. Debut,* C. Berri,* E. Baéza,* N. Sellier,* C. Arnould,* D. Guémené,* N. Jehl,†
B. Boutten,‡ Y. Jégo,§ C. Beaumont,* and E. Le Bihan-Duval*¹

**Station de Recherches Avicoles, Institut National de la Recherche Agronomique-Centre de Tours, 37380 Nouzilly, France;*
†*Institut Technique Avicole, 28 rue du Rocher, 75008 Paris, France;* ‡*Centre Technique de Salaison Charcuterie Conservation des Viandes, 7 avenue du Général de Gaule, 94704 Maisons-Alfort, France;* and §*Hubbard, 35820 Chateaubourg, France*

ABSTRACT The present study was aimed at estimating the genetic variability between lines of breast and thigh meat quality (pH decline, color, drip loss, and curing-cooking yield) by comparing a slow-growing French label-type line (SGL) and a fast-growing standard line (FGL) of chickens exposed to different preslaughter stress conditions. The birds were slaughtered under optimal conditions or after exposure to 2 h of transport or acute-heat stress (2 h at 35°C). Relationships between meat quality and stress sensitivity were investigated by measuring struggle during shackling and tonic immobility (TI) duration, 1 wk before slaughter, as an indicator of the basal level of fear of the birds. Although most of the meat quality indicators varied between the 2 lines, differences were muscle dependent. In concordance with a lower ultimate pH, curing-cooking yield of thigh meat was decreased for the FGL birds. In contrast, these birds

had a higher curing-cooking yield and a lower drip loss of breast meat resulting from a less rapid pH decline in this muscle compared with SGL birds. Thigh meat characteristics were influenced by both preslaughter stresses, but no significant effects were detected for breast meat. The main effect of heat stress in thigh meat was a decrease of the ultimate pH and led to paler color and lower curing-cooking yield; opposite effects were obtained for transport. Breast meat was much more sensitive to physical activity of birds on the shackle line. Longer durations of wing flapping on the shackle line gave more rapid initial pH decline. Whatever the line, no relationship between TI duration and meat quality characteristics or activity was observed. The present study suggested that SGL birds could be at disadvantage due to more struggle during shackling and accelerated postmortem glycolysis, which is detrimental to the quality of breast meat.

(*Key words:* behavioral activity, chicken genotype, postmortem metabolism, preslaughter stress, processing quality)

2003 Poultry Science 82:1829–1838

INTRODUCTION

In the 1960s in the United States, 17% of broilers were sold as parts or further-processed products; that percentage increased to 90 in 1998 (Mandava and Hoogenkamp, 1999). In France, the same trends were confirmed with nearly 50% of chickens sold as parts or further-processed products in 1998 (Magdelaine and Philippot, 2000). This trend shows the importance of controlling meat quality for the poultry industry. Recent results obtained in poultry have shown that meat quality is, in part, determined genetically. Very significant heritabilities were obtained for breast meat quality traits in chickens slaughtered under experimental conditions (Le Bihan-Duval et al., 2001). Meat quality is also affected by environmental factors,

including stressful preslaughter conditions favoring meat defects (Holm and Fletcher, 1997; Owens and Sams, 2000).

Environmental variability leads to moderate heritabilities of meat quality traits in turkeys slaughtered under commercial conditions (Le Bihan-Duval et al., 2003). The aim of the present study was to estimate the genetic variability between lines of breast and thigh meat quality by comparing a slow-growing line (SGL) and a fast-growing line (FGL) of chickens facing different preslaughter stress conditions. The variability of poultry meat quality among lines has already been studied (Berri et al., 2001, for chickens; Fernandez et al., 2001, for turkeys), but the impact of preslaughter stress was not taken into account in these comparisons. For the first time, a behavioral component

©2003 Poultry Science Association, Inc.

Received for publication June 10, 2003.

Accepted for publication August 29, 2003.

¹To whom correspondence should be addressed: lebian@tours.inra.fr.

Abbreviation Key: a* = redness; b* = yellowness; FGL = fast-growing line; IDWF = initial duration of wing flapping; L* = lightness; PCA = principal component analysis; pHu = muscle pH 24 h postslaughter; pH15 = muscle pH 15 min postslaughter; PY = processing yield; SGL = slow-growing line; SU = straightening up; TDWF = total duration of wing flapping; TI = tonic immobility.

TABLE 1. Composition of diets distributed during the rearing period for the 2 lines

| Item | Slow-growing line | | | Fast-growing line | |
|------------------------------|-------------------|--------|---------|-------------------|--------|
| | 0–4 wk | 4–8 wk | 8–12 wk | 0–2 wk | 2–6 wk |
| Composition (%) | | | | | |
| Maize | 52.4 | 36.6 | 46.0 | 41.8 | 34.1 |
| Wheat | 12.9 | 38.4 | 30.7 | 12.0 | 30.0 |
| Rapeseed oil | | | | 5.0 | 4.2 |
| Soyabean meal | 30.4 | 18.7 | 16.2 | 30.6 | 24.1 |
| Corn gluten meal | | 2.3 | 3.2 | 0.7 | 3.8 |
| Calcium carbonate | 1.3 | 1.36 | 1.4 | 1.3 | 1.2 |
| Dicalcium phosphate | 1.8 | 1.5 | 1.4 | 1.9 | 1.5 |
| Sodium chloride | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 |
| Trace minerals | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Vitamins | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| DL-Methionine | 0.14 | 0.10 | | 0.14 | 0.03 |
| L-Lysine | 0.06 | 0.14 | 0.15 | | |
| Anticoccidial | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Calculated composition | | | | | |
| Metabolizable energy (MJ/kg) | 11.5 | 11.8 | 11.8 | 12.5 | 12.5 |
| Crude protein (g/kg) | 197 | 171 | 164 | 217 | 193 |
| Lysine (g/kg) | 10.6 | 8.6 | 8 | 11.5 | 9 |
| Methionine + cystine (g/kg) | 8 | 7 | 6 | 8 | 7 |
| Calcium (g/kg) | 12.6 | 11.9 | 11.6 | 13.2 | 11.4 |
| Available phosphorus (g/kg) | 4.14 | 3.9 | 3.6 | 4.4 | 3.8 |

was introduced in the present study to estimate the relationships between meat quality and stress sensitivity measured by the activity of the birds on the shackle line or their tonic immobility (TI) duration as a predictor of the basal level of fear of the birds.

MATERIALS AND METHODS

Birds

Female chickens were obtained from an FGL and an SGL that were grandparental² and corresponded to standard and French label-type productions, respectively. Birds were reared in confinement in a conventional poultry house at the Poultry Research Center (Nouzilly, France) and were fed ad libitum with an appropriate allocation for each line (Table 1). The FGL used in the current study corresponded to a female line that had been selected for high body weight but not for breast yield or body conformation. The SGL was not selected for body weight, which was just maintained from one generation to the next. A total of 90 birds per line were weighed and slaughtered at the market ages of 6 wk (standard type) and 12 wk (label type) at a mean body weight of 2,381 g (SD of 220 g) and 1,927 g (SD of 135 g) for the FGL and the SGL, respectively. After 7 h of feed withdrawal, birds were slaughtered in the experimental processing plant of the Poultry Research Center. The birds were electrically stunned before being killed by neck cutting. After evisceration, whole carcasses were stored for 1 d at 2°C until used.

Preslaughter Conditions

Before slaughter, birds were randomly allocated to 2 stressful preslaughter conditions or to a stressless environment (control). A 2-h transport and acute heat stress were chosen as examples of stressful preslaughter conditions because they are commonly observed in commercial practice. For transport stress, 7 birds were placed per crate (73 × 53 × 26 cm) and driven for 2 h in a truck. For the heat stress, they were put in crates (10 birds per crate) and placed in a room at 35°C for 2 h. Crates were then brought to the slaughterhouse (2 to 3 min transport) where the birds were immediately killed. In the control group, stress before death was minimized as much as possible. These birds were taken out of the rearing room and placed in crates (7 birds by crate) that were immediately brought to the slaughterhouse (2 to 3 min transport). Each of these preslaughter conditions was applied to a total of 30 birds per line.

Behavior Measurements

TI Test. The TI tests were made for all birds 1 wk before slaughter to estimate their fearfulness. As described by Jones (1986), each bird was placed on its back in a V-shaped cradle and restrained by maintaining a light pressure on the sternum and neck for 15 s. The duration of TI was defined as the interval between the moment when the bird entered into TI until it righted itself. If TI was not induced after 5 trials, the bird was given a score of 0 for TI. A maximum duration of 10 min was imposed for the test.

Preslaughter Struggle. Activity of the birds on the shackle line was estimated by different measurements: straightening up (SU) of the body (head over the legs) was recorded from the hanging to the electrical stunning

²Hubbard, Chateaubourg, France.

and noted as a binary variable equal to 0 when the bird did not try to stand up (absence) and 1 otherwise (presence). Vocalizations were recorded when the bird was hung and were classified into 4 categories: 0 when the bird did not vocalize, 1 when the bird vocalized briefly and weakly, 2 when it vocalized weakly for a long time, and 3 when the bird vocalized strongly for a longer time. The categories 0 and 1 were pooled for further analyses in order to have enough birds per class. The initial duration of wings flapping (IDWF) was recorded at the time of the hanging. The total duration of wings flapping (TDWF) was recorded from hanging to electrical stunning of the birds.

Muscle Characteristics and Meat Quality Measurements

The pH at 15 min and 24 h postmortem was recorded from left breast (pectoralis major) and left thigh (ilio tibialis) muscles according to Le Bihan-Duval et al. (1999). Color was measured at 24 h postmortem on the ventral side of the left breast muscle and on external side of the left ilio tibialis muscle by using a Miniscan Spectrocolorimeter.³

Color was measured by the CIELAB trichromatic system as lightness (L^*), redness (a^*), and yellowness (b^*) values. Higher L^* values indicated paler meat. Higher a^* and b^* values indicated more red and more yellow the meat, respectively. At 72 h postmortem, drip loss of the left breast (p. major) was measured as described in Le Bihan-Duval et al. (1999). Processing yields (PY) of the right P. major and I. tibialis muscles were measured at the Centre Technique de la Salaison de la Charcuterie et des Conserves de Viandes⁴ using the protocol of Naveau et al. (1985) initially established for pig meat. A 30-g sample of the P. major muscle or the entire I. tibialis muscle was removed, packed, and stored for 24 h at 4°C. The samples were cut into 1-cm cubes and vacuum-packed with 20 g of brine (136 g of nitrite salt/L of water) for 24 h. Each sample was then cooked for 10 min and dripped 2 h 30 min in order to eliminate the brine. The PY was estimated as the weight of the cooked and dripped meat divided by initial muscle weight.

Statistical Analysis

Effects of genotype, preslaughter condition, and possible interaction on the muscles and meat characteristics were tested by a 2-way ANOVA using the general linear models procedure of the SAS Institute (1999). Pairwise comparisons of means for each significant effect of the ANOVA were performed by Scheffe test using the least squares means statement of the general linear models procedure. The effect of genotype on categorical behavioral variables was tested by chi-squared test using the

FREQ procedure of the SAS Institute (1999) after appropriate categorization of TI and TDWF variables into 3 and 4 classes, respectively. Finally, the relationships among some of the muscle characteristics [muscle pH 15 min postslaughter (pH15), drip loss, and a^*] and measurements of IDWF and TDWF (expressed in seconds) were estimated by the Spearman ranks correlation using the CORR procedure of the SAS Institute (1999).

In order to determine the relationships between muscle characteristics (pH decline) and meat quality traits (color, drip loss, or processing yield), a principal component analysis (PCA) within each line was performed with the SPAD 4.0 software.⁵ In the PCA technique, the whole set of initial correlated variables is transformed into fewer uncorrelated factors. Linear functions of the original measurements explain the largest variation among individuals. Projections of initial measurements on PCA axes (i.e., factors) allow the relationships between variables to be easily visualized. Provided that they are far from the graphic center, variables are significantly positively correlated when they show the same direction, negatively correlated when they show opposite directions, and not correlated when they show orthogonal directions. Projections of individuals on PCA axes also allow discrimination between groups (i.e., different lines or treatments). Groups with close positions on one axis are similar for characteristics contributing to this axis, whereas groups with opposite positions differ for these characteristics.

Muscle and meat characteristics were introduced as active variables, from which the PCA axes were derived. Preslaughter conditions and behavioral measurements were treated as illustrative variables after appropriate categorization of IDWF, TDWF, and TI variables whose distributions were far from normality, into 2, 3, and 3 categories of nearly equal frequencies, respectively. The average position of each category of each illustrative variable was tested by a *t*-test, a value greater than 2 indicated that its mean position significantly differed from the origin of the axis.

RESULTS

Between Lines Variability of Muscles and Meat Characteristics and Impact of Preslaughter Conditions

Elementary statistics of the variables used for the ANOVA analysis are described in Table 2. As shown in Table 3, significant differences between the 2 lines were observed for most of the breast and thigh characteristics. Preslaughter conditions exhibited significant effects only for the thigh characteristics and showed significant interactions with lines for the L^* and the b^* variables.

A large difference in the pH15 between the 2 lines was observed in breast muscle with SGL birds showing the lowest pH15 values (Table 3). Even though smaller, this difference was also observed in thigh muscle. Impact of the line on the ultimate pH varied according to muscle.

³Hunterlab, Reston, VA.

⁴Maison-Alfort, France.

⁵Cisia, Montreuil, France.

TABLE 2. Elementary statistics of muscle characteristics and meat quality measurements for the overall population

| Variable ¹ | Muscle | n | Mean | SEM | Skewness | Kurtosis |
|-----------------------|--------|-----------------|-------|------|----------|----------|
| pH15 | thigh | 178 | 6.58 | 0.01 | 0.19 | 0.49 |
| | breast | 178 | 6.45 | 0.02 | -0.20 | -1.10 |
| pHu | thigh | 179 | 6.14 | 0.01 | -0.26 | -0.07 |
| | breast | 179 | 5.76 | 0.01 | 0.27 | 0.64 |
| L* | thigh | 179 | 50.64 | 0.16 | 0.20 | 0.15 |
| | breast | 179 | 51.78 | 0.23 | 0.14 | 0.00 |
| a* | thigh | 179 | 2.15 | 0.08 | 0.33 | -0.35 |
| | breast | 179 | 0.35 | 0.06 | 0.22 | 0.04 |
| b* | thigh | 179 | 7.85 | 0.11 | 0.27 | -0.06 |
| | breast | 179 | 10.79 | 0.09 | -0.15 | -0.35 |
| DL (%) | thigh | ND ² | ND | ND | ND | ND |
| | breast | 170 | 0.86 | 0.03 | 0.53 | -0.48 |
| PY (%) | thigh | 174 | 85.58 | 0.25 | 0.03 | 0.20 |
| | breast | 175 | 83.46 | 0.23 | -0.09 | -0.40 |

¹a* = redness at 24 h postmortem; b* = yellowness at 24 h postmortem; DL = drip loss (% of initial breast weight); L* = lightness at 24 h postmortem; pHu = muscle pH 24 h postslaughter; pH15 = muscle pH 15 min postslaughter; PY = processing yield (% of initial muscle weight).

²ND = not determined.

Indeed, muscle pH 24 h postslaughter (pHu) was significantly lower in the thighs of FGL birds, whereas no difference was observed in breast muscle between the 2 lines. Between-line differences in PY also varied according to the muscle. PY was significantly higher in the SGL birds for thigh muscle, whereas the opposite result was observed in breast muscle. In addition, drip loss of SGL breast muscle was significantly higher than that of the FGL.

Significant differences between the 2 lines were observed for some of the color indicators, with a lighter color for the FGL birds breast muscle (higher L* value)

and a redder color for FGL thigh muscle (Table 3). Moreover, in contrast with the results obtained for breast muscle, significant interactions between genotype and preslaughter stress condition were obtained for L* and b* values of thigh muscle.

Preslaughter stress conditions mainly influenced ultimate pH of the thigh meat and subsequently its L* value and PY (Table 3). In comparison with control birds, final pH of the thigh meat was significantly increased by transportation. A significant interaction between lines and transport stress was observed for the L* value of thigh meat, which tended to be decreased by transport for FGL

TABLE 3. Muscles characteristics and meat quality traits of 2 muscles for the 2 lines (SGL = slow-growing line and FGL = fast-growing line) and the 3 preslaughter conditions (H = heat stress, C = control group, and T = transport stress) and probabilities of the ANOVA

| Muscle | Variable ¹ | Line | | Preslaughter condition | | | Pooled SEM | Line effect | Preslaughter condition effect | Line × preslaughter condition interaction |
|--------|-----------------------|--------------------|--------------------|------------------------|---------------------|--------------------|------------|-------------|-------------------------------|---|
| | | SGL | FGL | H | C | T | | | | |
| Thigh | pH15 | 6.56 ^b | 6.60 ^a | 6.57 | 6.58 | 6.59 | 0.01 | ** | NS | NS |
| | pHu | 6.24 ^a | 6.04 ^b | 6.07 ^c | 6.13 ^b | 6.21 ^a | 0.01 | *** | *** | NS |
| | L* | 50.07 | 51.22 | 51.36 | 50.31 | 50.26 | 0.16 | *** | *** | * |
| | a* | 1.62 ^b | 2.69 ^a | 2.37 ^a | 2.12 ^{ab} | 1.95 ^b | 0.08 | *** | * | NS |
| | b* | 7.33 | 8.38 | 8.14 | 7.94 | 7.49 | 0.11 | *** | * | *** |
| | PY (%) | 86.08 ^a | 85.11 ^b | 84.80 ^b | 85.34 ^{ab} | 86.68 ^a | 0.25 | *** | ** | NS |
| Breast | pH15 | 6.31 ^b | 6.60 ^a | 6.44 | 6.44 | 6.46 | 0.02 | *** | NS | NS |
| | pHu | 5.76 | 5.76 | 5.75 | 5.79 | 5.74 | 0.01 | NS | NS | NS |
| | L* | 50.76 ^b | 52.82 ^a | 51.66 | 52.15 | 51.57 | 0.23 | *** | NS | NS |
| | a* | 0.42 | 0.27 | 0.44 | 0.16 | 0.44 | 0.06 | NS | NS | NS |
| | b* | 10.97 ^a | 10.60 ^b | 10.68 | 10.71 | 10.96 | 0.09 | * | NS | NS |
| | PY (%) | 82.87 ^b | 84.06 ^a | 83.11 | 83.55 | 83.72 | 0.23 | *** | NS | NS |
| DL (%) | 0.93 ^a | 0.79 ^b | 0.88 | 0.87 | 0.81 | 0.03 | * | NS | NS | |

^{a-c}Means with no common superscripts in the same row and main effect differ ($P < 0.05$).

¹a* = redness at 24 h postmortem; b* = yellowness at 24 h postmortem; DL = drip loss (% of initial breast weight); L* = lightness at 24 h postmortem; pHu = muscle pH 24 h postslaughter; pH15 = muscle pH 15 min postslaughter; and PY = processing yield (% of initial muscle weight).

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

TABLE 4. Repartition of the birds of the slow-growing line (SGL) and fast-growing line (FGL) into the classes of behavioral measurements and chi-squared probabilities

| Line and category | Behavior variables ¹ | | | | | | | | | | | | | |
|----------------------|---------------------------------|----|----|-------|----|---------|----|----|----|---------|----|---------------|----|----|
| | TI | | | IDWF | | TDWF | | | | SU | | Vocalizations | | |
| | 0 | 1 | 2 | 0 | 1 | 0 | 1 | 2 | 3 | 0 | 1 | 1 | 2 | 3 |
| SGL | | | | | | | | | | | | | | |
| n | 32 | 28 | 20 | 35 | 55 | 16 | 11 | 23 | 32 | 36 | 54 | 41 | 11 | 38 |
| In the line (%) | 40 | 35 | 25 | 39 | 61 | 20 | 13 | 28 | 39 | 40 | 60 | 46 | 12 | 42 |
| FGL | | | | | | | | | | | | | | |
| n | 21 | 26 | 34 | 51 | 37 | 22 | 33 | 18 | 8 | 63 | 25 | 22 | 32 | 34 |
| In the line (%) | 26 | 32 | 42 | 58 | 42 | 27 | 41 | 22 | 10 | 72 | 28 | 25 | 36 | 39 |
| χ^2 probability | 0.08 | | | 0.011 | | <0.0001 | | | | <0.0001 | | 0.06 | | |

¹TI = tonic immobility, categorized as 0 for the shortest durations (average of 60.8 s) to 2 corresponding to the longest durations (average of 503.8 s); IDWF = initial duration of wing flapping, noted as 0 in absence of initial duration of wing flapping and 1 otherwise; TDWF = total duration of wing flapping, categorized as 0 for the shortest durations (average of 0 s) to 3 for the longest durations (average of 18.8 s); SU = straightening up, noted as 0 in absence of straightening up and 1 otherwise; and Vocalizations = categorized as 1 when birds vocalized briefly and weakly to 3 when birds vocalized strongly during a longer time.

birds (from 51.44 to 50.26, NS) but increased for SGL birds (from 49.17 to 50.26, NS). Similarly, the b* value of thigh meat was not different for the SGL birds, whereas the b* value decreased for FGL birds (from 9.01 to 7.46, *P* < 0.05). By contrast to transport, heat stress led to a significant decrease of the final pH of the thigh meat. Red color of the thigh meat also varied with preslaughter conditions, with a slight increase for the heat-stressed birds and a slight decrease for the transported birds. There was no effect of the preslaughter stress conditions on any of the breast traits.

Between-Line Variability of Behavioral Measurements

Significant differences between the lines were observed for most behavior measurements (Table 4). Indeed, birds of the SGL were the most frequently observed in category 1 of the SU variable, meaning that birds straightened up their bodies, whereas FGL birds were more frequently observed in category 0 and did not move. Moreover, the percentage of birds observed in class 1 for IDWF, corresponding to presence of wing flapping when birds were hung, was greater for SGL birds than for FGL birds. Similarly, the highest frequency observed for class 3 of TDWF, which corresponded to the longest wing flapping durations, was found for SGL birds. In contrast, no significant differences between lines were observed for vocalization or TI.

Relationships Between Muscle and Meat Characteristics

Results of the PCA in FGL and SGL are presented in Figure 1 for the 2 first axes (noted as PCA1 and PCA2), which explained 45.28 and 48.14% of the total variability in the 2 lines, respectively. Whatever the line, PCA1 was mainly explained by pHu, PY, L*, and drip loss. Indeed, the correlation between pHu and PY in the FGL and SGL was estimated to be 0.43 and 0.58, respectively, in breast

muscle and 0.64 and 0.58, respectively, in thigh muscle. The L* and pHu were highly negatively correlated, with r values of 0.64 and 0.66 in breast muscle and of 0.68 and 0.65 in thigh muscle for FGL and SGL birds, respectively. The L* and PY were thus negatively correlated with r values of 0.45 and 0.66 in breast muscle and of 0.49 and 0.47 in thigh muscle of FGL and SGL birds, respectively. Significant negative correlations of 0.52 and 0.60 were observed between pHu and drip loss of the breast meat in FGL and SGL birds, respectively. Yellowness of the breast meat also contributed to variability of PCA1 within each line. Indeed, negative correlations of 0.40 and 0.56 were obtained between pHu and b* of breast meat in the FGL and SGL, respectively. Positive correlations of 0.47 and 0.40 were observed between L* and b* values of the breast in the same lines, respectively. The b* value of thigh meat also contributed to the variability of PCA1 but only in the FGL population. Moderate correlations were obtained between b* and pHu (-0.38) and L* (0.31) of thigh meat.

Significant contributions of pH15 and a* of breast meat to the variability of PCA2 were obtained within each line. An antagonism was observed between both traits, with correlations of -0.27 and -0.51 in FGL and SGL birds, respectively. A similar antagonism was obtained for these traits measured in thigh meat but only in the FGL (-0.25). The b* value of thigh meat also contributed to PCA2 within each line. Indeed, in this muscle, significant positive correlations of 0.31 and 0.51 were estimated between a* and b* values in the FGL and SGL, respectively. Little more information was given by the other PCA axes, such as the moderate antagonism between pH15 and drip loss of breast meat shown on PCA4 within each line (data not shown). Indeed, correlations of -0.21 and -0.31 were obtained between pH15 and drip loss in the FGL and SGL, respectively. Moreover, results on PCA1 and PCA2 showed that there were moderate positive correlations between the characteristics of breast and thigh muscles, with mean correlations for the 2 lines of 0.35 for pHu, 0.30 for L*, 0.32 for PY, 0.20 for pH15, 0.28 for a*, and 0.41 for b*.

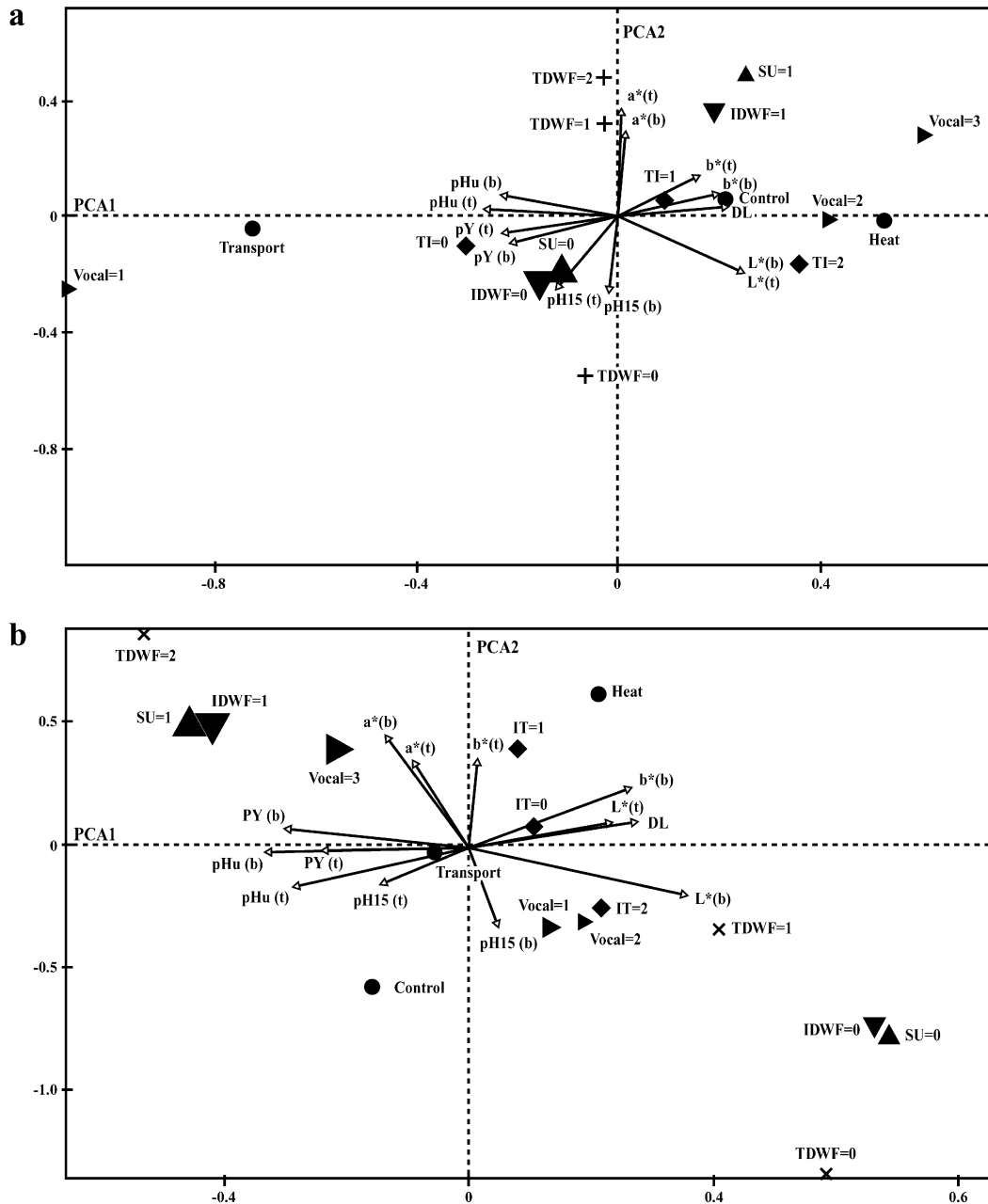


FIGURE 1. Principal component analysis (PCA) graphs (axes 1 and 2 noted as PCA1 and PCA2 a- for the fast-growing line and b- for the slow-growing line). The whole set of initial correlated variables was transformed into fewer uncorrelated factors—linear functions of the original measurements explaining the greatest part of the variation among individuals. The projections of initial measurements on PCA axes (i.e., factors) allow relationships among variables to be easily visualized. Providing that they are far from the graphic center, variables are significantly positively correlated when they show the same direction, negatively correlated when they show opposite directions, and not correlated when they show orthogonal directions. Projections of individuals on PCA axes also allow discrimination between groups (i.e., different lines or treatments). Groups with close positions on 1 axis are similar for the characteristics contributing to this axis, whereas groups with opposite positions differ for these characteristics. a^* = redness at 24 h postmortem; b^* = yellowness at 24 h postmortem; DL = drip loss (% of the initial weight of breast); L^* = lightness at 24 h postmortem; pHu = muscle pH 24 h postslaughter; $pH15$ = muscle pH 15 min postslaughter; PY = processing yield (% of the initial muscle weight); (b) = breast; (t) = thigh; heat = heat stress; transport = transport stress; control = control group; TI = tonic immobility, categorized as 0 for the shortest durations to 2 corresponding to the longest durations; $IDWF$ = initial duration of wing flapping, noted as 0 in absence of wing flapping and 1 otherwise; $TDWF$ = total duration of wing flapping, categorized as 0 for the shortest durations to 2 for the longest durations; SU = straightening up, noted as 0 in absence of straightening up and 1 otherwise; and vocal = vocalizations, categorized as 1 when the birds vocalized briefly and weakly to 3 when the birds vocalized strongly during a longer time.

Relationships Between Muscle or Meat Characteristics and Behavioral Traits

Characteristics of the behavioral measurements expressed as categorical traits are on Table 5. As shown

in Figure 1, the behavioral criteria corresponding to the highest activity (classes 1 of $IDWF$ and SU , class 2 of $TDWF$, and class 3 of vocalizations) were located on one side of $PCA2$, whereas those corresponding to the lowest (classes 0 of $IDWF$, SU , and $TDWF$ and class 1 of vocaliza-

TABLE 5. Behavioral measurements expressed as categorical traits for the principal component analysis in the fast-growing line (FGL) and in the slow-growing line (SGL)

| Line and variable | Category | n | Mean of initial variable | Minimum | Maximum |
|-------------------|----------|----|--------------------------|---------|---------|
| FGL | | | | | |
| IDWF | 0 | 51 | 0 | 0 | 0 |
| | 1 | 37 | 10.38 | 1 | 24 |
| TDWF | 0 | 29 | 0.24 | 0 | 1 |
| | 1 | 26 | 5.04 | 2 | 8 |
| | 2 | 26 | 13.8 | 9 | 26 |
| TI | 0 | 27 | 76 | 21 | 143 |
| | 1 | 27 | 254 | 149 | 414 |
| | 2 | 27 | 563 | 415 | 600 |
| SGL | | | | | |
| IDWF | 0 | 35 | 0 | 0 | 0 |
| | 1 | 55 | 15.78 | 1 | 40 |
| | 0 | 27 | 2.07 | 0 | 8 |
| | 1 | 29 | 13.75 | 10 | 16 |
| | 2 | 26 | 19.42 | 17 | 40 |
| TI | 0 | 26 | 51.77 | 0 | 80 |
| | 1 | 27 | 143.26 | 83 | 217 |
| | 2 | 27 | 414.37 | 229 | 600 |

¹IDWF = initial duration of wing flapping; TDWF = total duration of wing flapping; TI = tonic immobility.

tions) were on the other side within each line. According to these results, classes corresponding to the highest levels of activity appeared to be associated with lower pH15 and higher a* values in both muscles. This finding was confirmed by highly significant Spearman ranks correlations between breast pH15 and a* and the durations of wing flapping (TDWF and IDWF) (Table 6). In contrast, such correlations were not found in thigh (Table 6). Whatever the line, none of PCA axes significantly discriminated between the different classes of TI. Chi-squared analyses did not show any significant relationship between TI and any of the other behavioral variables (data not shown). On the other hand, Spearman ranks correlations between TI and muscles or meat characteristics were lower in absolute value than 0.14 and 0.22 in the FGL and SGL, respectively, (data not shown).

DISCUSSION

Although many results are available for turkey on factors causing variation of meat quality, much less is known for chicken. Moreover, to the authors' knowledge no

study has been conducted on the interaction between genotype and preslaughter stress in poultry.

Relationships Among Muscles Characteristics and Meat Quality Traits

The PCA achieved within each line enabled the identification of 2 principal causes of variation of the quality of chicken meat, a major one being the ultimate pH and a secondary one the initial rate of pH decline. The more acid the meat was, the paler it appeared and the lower the water-holding capacity of raw or cured-cooked products was. Moreover, lower pH15 was accompanied by greater a* and drip loss. Studies had previously shown a strong relationship between final pH and L* of breast meat in chicken (Allen et al., 1997; Barbut, 1997; Fletcher, 1999) and turkey (Barbut, 1996; McCurdy et al., 1996; Owens et al., 2000). More recently, very high genetic correlations were reported in chicken between pHu and L* (-0.91) and drip loss (-0.83) of breast meat (Le Bihan-Duval et al., 2001). In addition, the present study showed a strong positive phenotypic correlation between the final pH and

TABLE 6. Spearman rank correlations between pH at 15 min (pH15) and redness (a*) of breast and thigh meat and the initial (IDWF) and total duration (TDWF) of wing flapping (expressed in seconds) for the fast-growing line (FGL) and the slow-growing line (SGL)

| Variables | FGL | | SGL | |
|-------------|----------|-------|----------|--------|
| | Breast | Thigh | Breast | Thigh |
| pH15 – IDWF | -0.57*** | -0.16 | -0.62*** | -0.07 |
| pH15 – TDWF | -0.71*** | -0.19 | -0.77*** | -0.18 |
| a* – IDWF | 0.25** | -0.05 | 0.40*** | 0.29** |
| a* – TDWF | 0.30** | 0.01 | 0.54*** | 0.26* |

*P ≤ 0.05.

**P ≤ 0.01.

***P ≤ 0.001.

the curing-cooking yield of chicken meat, which is consistent with the significant correlation of -0.60 reported by McCurdy et al. (1996) between pHu and cook loss of turkey meat.

As well described in Offer (1991), the rapid postmortem pH decline described in the case of pale, soft, and exudative pork meat may affect the color, texture, and water-holding capacity of the meat. In the present study, the accelerated rate of pH decline (low pH15) was mainly associated with higher values of a^* and drip loss of the meat, whereas no significant correlations were found with L^* and curing-cooking yield. Studies already conducted in the turkey on the effect of the rate of pH decline on color (L^* , a^* , b^*) of the meat have not led to similar conclusions. When comparing turkeys characterized by a slow, a normal, or a rapid rate of pH fall, Rathgeber et al. (1999) and Hahn et al. (2001) did not observe any significant variation of L^* and b^* of the breast meat, whereas McKee and Sams (1997), Pietrzak et al. (1997), and Wynveen et al. (1999) observed higher L^* and b^* values in breasts of birds with low pH a short time after slaughter. If the 3 latter studies did not suggest any relationship between initial rate of pH decline and a^* value of the meat, other works, like the present study, revealed increased a^* associated with rapid glycolysis (Rathgeber et al., 1999; Hahn et al., 2001; Fernandez et al., 2002).

In accordance with the current results, several studies with turkey have shown that water loss of the raw meat (McKee and Sams, 1997; Pietrzak et al., 1997; Wynveen et al., 1999; Hahn et al., 2001; Sandercock et al., 2001) or the cured-cooked meat (Fernandez et al., 2002) was significantly higher for the birds with high initial rates of pH decline. According to some of these studies, the pH decline was also responsible for a deleterious effect on cooking yield. However, as already discussed by Rathgeber et al. (1999), it is difficult to determine whether these lower cooking yields were really due to accelerated postmortem glycolysis, to the differences of ultimate pH observed in all these studies, or to both factors. As illustrated by all of these results discussed, the relative impact of the ultimate pH and the initial rate of the pH decline on poultry meat quality could vary with environmental factors more or less favorable to the expression of pale, soft, and exudative defect. The present study did not enable identification of those environmental factors, as no effect of the preslaughter conditions on breast meat quality was detected.

Relationships Among TI, Activity on the Shackle Line, and Meat Quality

The TI test is an estimate of underlying fearfulness of birds (Jones, 1986). Very few results are available on the relationship between TI and the behavior of birds at slaughter and meat quality. Rémignon et al. (1998) took advantage of the existence of lines of quail divergently selected for TI to address this question. They observed that after an acute stress of contention in a crush-cage, plasma creatine kinase and drip loss of the breast meat

were increased in the line with the longest TI, which corresponded to the most fearful birds. According to those authors, removal of the most fearful birds from a population would be of economic interest and reduce the negative effect of stress sensitivity on meat quality. When working on the effect of shackling on chicken stress response and breast meat quality, Kannan et al. (1997) did not observe any relationship between TI and plasma corticosterone concentration or between TI and wing flapping duration. In the present study, TI did not show any significant relationship with the level of activity on the shackle line or with the meat characteristics. It, therefore, seems that the promising results obtained by Rémignon et al. (1998) are not easily extrapolated when birds are exposed to more practical preslaughter stress conditions than those used in the latter study on quails. Before definitely concluding on TI as predictor of meat quality, further investigations are necessary to optimize the conditions of application of this test, such as age of test and when measured before or after a stress.

More interestingly, the present study revealed an important impact of struggle on the shackle line on meat characteristics; the most active birds had the highest initial rates of pH decline. Although some research has already been conducted on the effect of shackling on welfare of the birds, few studies have considered its impact on meat quality. However, the few results available for turkeys are similar to those in the present study. Indeed, Froning et al. (1978) and Ngoka and Froning (1982) studied the impact of struggle on the shackle line on meat quality by comparing turkeys that had been immobilized before death by anesthesia to birds that could flap freely before slaughter. They observed that the initial rate of pH fall was accelerated, water-holding capacity was reduced, and a^* value was increased for birds that could struggle freely. According to Ngoka and Froning (1982), struggle increased pigment concentration by increasing the inflow of blood in muscles and in consequence gave a redder coloration to the meat. Furthermore, the current results showed that the impact of activity varied according to the type of muscle, correlation between duration of wing flapping and rate of initial pH decline, or a^* value of the meat being much more pronounced in breast muscle than in thigh muscle. This finding could at least partly be explained by the fact that breast muscle is more involved in wing flapping, whereas thigh muscle is less involved. Moreover, by being fully constituted of white glycolytic fibers (Rémignon et al., 1996), breast muscle is more sensitive to fast rate of pH decline.

Between-Line Variability

Most of the meat quality indicators differed between the 2 lines used in the present study. In concordance with a lower ultimate pH, curing-cooking yield of thigh meat was less in FGL birds than in SGL birds. In contrast, FGL birds exhibited lower breast drip loss as a result of their less rapid initial pH decline. They also exhibited a higher breast curing-cooking yield, but the reason for the differ-

ences in breast curing-cooking yield between lines was not obvious. Indeed, no difference in final pH between the 2 lines was observed, and differences in the initial rate of pH decline should not be responsible, as it appeared to be very poorly correlated with curing-cooking yield.

Color differences were also observed between the 2 lines, with FGL birds having lighter breast and thigh meats than SGL birds. Some differences in breast meat quality had already been observed by Culioli et al. (1990) in optimal slaughter conditions between fast-growing standard chickens and slow-growing label-type birds killed at 52 and 83 d of age, respectively. The rate of pH decline in the breast of label-type birds was slightly higher than that of standard birds, leading to significantly increased drip loss from meat.

More recently, Le Bihan-Duval et al. (1999) and Berri et al. (2001) confirmed that these differences in breast meat quality were related to selection for growth by comparing lines of chickens selected for body weight and breast muscle development and their unselected control lines killed at the same age. According to these studies, pH decline in high performance birds was delayed and led to a higher final pH, which was consistent with the lower drip loss of that meat. The current study showed that FGL birds could be fitted for industrial transformation as parts of further-processed products. Indeed, they presented the advantage of lower drip loss and higher yield of breast meat, which remains the most valuable part of the carcass. In addition, by measuring the behavior of birds at slaughter, the present study revealed that SGL birds could be placed at disadvantage by higher level of activity on the shackle line, resulting in an accelerated rate of postmortem glycolysis, which is detrimental to the quality of breast meat.

Impact of Preslaughter Conditions

Significant effects of preslaughter conditions on meat characteristics and some interactions with the genotype were observed in the present study. However, preslaughter conditions had an effect of lower magnitude than genotype and were limited to thigh characteristics. These results suggest that thigh meat is more sensitive to environmental factors than breast meat. The difference in sensitivity had been previously suggested by the genetic study of Le Bihan-Duval et al. (2003) on turkey meat quality, in which environmental factors appeared most dominant for some thigh characteristics (pH and color) that showed extremely low heritable features.

By reducing the final pH and the yield and increasing the L^* of thigh meat, acute heat stress appeared the most detrimental preslaughter condition. Similar trends were observed by Holm and Fletcher (1997) and Sandercock et al. (2001) on breasts of chickens exposed to acute heat stress and by McKee and Sams (1997) on breasts of turkeys subjected to chronic heat stress. Surprisingly, breast meat characteristics were unmodified by heat stress in the present study, which was also reported by Petracci et al. (2001), suggesting that the influence of acute heat stress

on meat quality could vary according to the conditions of application (duration or intensity) but also according to the genotypes and muscle used.

The transport did not appear detrimental to meat quality under the conditions of the current experiment, as a significant increase in the ultimate pH of thigh, leading to a decrease of L^* (only observed for the FGL birds) and increase in yield, were observed. Owens and Sams (2000) observed similar tendencies for the breast meat of turkeys that had been exposed to a 3-h transport. Rather than being major factors of the determination of meat quality, preslaughter stresses tested in the present study appeared as an additional source of variability among the birds, at least for the 2 genotypes used.

In conclusion, better understanding of the factors of variation of the chicken meat quality was obtained in the present study. Although thigh muscle responded to transport or heat preslaughter stresses, breast muscle was much more influenced by physical activity of the birds during shackling. Moreover, the current work confirms that in chickens as in pigs that postmortem pH decline strongly affects the quality of the meat, particularly by the strong effect of ultimate pH on processing yield. For the first time, the present study showed that struggle activity of the birds varied between genotypes, which could explain part of the variability of meat quality observed between lines.

ACKNOWLEDGMENTS

This work was supported by a financial help of the French agricultural agency OFIVAL. The authors acknowledge N. Millet, A. Boucard, T. Bordeau, P. Chartrin, M. Couty, M. Mills, and the Experimental Unit for their valuable technical assistance.

REFERENCES

- Allen, C. D., S. M. Russell, and D. L. Fletcher. 1997. The relationship of broiler breast meat color and pH to shell-life and odor development. *Poult. Sci.* 76:1042-1046.
- Barbut, S. 1996. Estimates and detection of the PSE problem in young turkey breast meat. *Can. J. Anim. Sci.* 76:455-457.
- Barbut, S. 1997. Problem of pale soft exudative meat in broiler chickens. *Br. Poult. Sci.* 38:355-358.
- Berri, C., N. Wacrenier, N. Millet, and E. LeBihan-Duval. 2001. Effect of selection for improved body composition on muscle and meat characteristics of broilers from experimental and commercial lines. *Poult. Sci.* 80:833-838.
- Culioli, J., C. Touraille, P. Bordes, and J. P. Girard. 1990. Caractéristiques des carcasses et de la viande du poulet "label fermier." *Arch. Geflügelkd.* 53:237-245.
- Fernandez, X., V. Santé, E. Baéza, E. LeBihan-Duval, C. Berri, H. Régnon, R. Babilé, G. Le Pottier, and T. Astruc. 2002. Effects of the rate of muscle post mortem pH fall on the technological quality of turkey meat. *Br. Poult. Sci.* 43:245-252.
- Fernandez, X., V. Santé, E. Baéza, E. LeBihan-Duval, C. Berri, H. Régnon, R. Babilé, G. Le Pottier, N. Millet, P. Berge, and T. Astruc. 2001. Post mortem muscle metabolism and meat quality in three genetic types of turkey. *Br. Poult. Sci.* 42:462-469.
- Fletcher, D. L. 1999. Broiler breast meat color variation, pH, and texture. *Poult. Sci.* 78:1323-1327.

- Froning, G. W., A. S. Babji, and F. B. Mather. 1978. The effect of preslaughter temperature, stress, struggle and anesthetization on color and textural characteristics of turkey muscle. *Poult. Sci.* 57:630-633.
- Hahn, G., M. Malenica, W. D. Müller, E. Taubert, and T. Petrak. 2001. Influence of post-mortem glycolysis on meat quality and technological properties of turkey breast. Pages 325-328 in *Proceedings of XV European Symposium on the Quality of Poultry Meat, Kusadasi-Turkey*. WPSA Turkish Branch, Ismir, Turkey.
- Holm, C. G. P., and D. L. Fletcher. 1997. Ante mortem holding temperatures and broiler breast meat quality. *J. Appl. Poult. Res.* 6:180-184.
- Jones, R. B. 1986. The tonic immobility reaction of the domestic fowl: A review. *World's Poult. Sci. J.* 42:82-96.
- Kannan, G., J. L. Heath, C. J. Wabeck, and J. A. Mench. 1997. Shackling of broilers: Effects on stress responses and breast meat quality. *Br. Poult. Sci.* 38:323-332.
- LeBihan-Duval, E., C. Berri, E. Baeza, N. Millet, and C. Beaumont. 2001. Estimation of genetic parameters of meat characteristics and of their genetic correlation with growth and body composition in an experimental broiler line. *Poult. Sci.* 80:839-843.
- LeBihan-Duval, E., C. Berri, E. Baéza, V. Santé, T. Astruc, H. Rémignon, G. Le Pottier, J. Bentley, C. Beaumont, and X. Fernandez. 2003. Genetic parameters of meat technological quality in a pure commercial line of turkey. *Gen. Sel. Evol.* 35:(in press).
- LeBihan-Duval, E., N. Millet, and H. Rémignon. 1999. Broiler meat quality: Effect of selection for increased carcass quality and estimates of genetic parameters. *Poult. Sci.* 78:822-826.
- Magdelaine, P., and J. B. Philippot. 2000. Segmentation du marché du poulet: Différenciation qualitative et développement des produits élaborés. *Viandes Prod. Carnés* 21:31-37.
- Mandava, R., and H. Hoogenkamp. 1999. The role of processed products in the poultry meat industry. Pages 397-410 in *Poultry Meat Science, Poultry Science Symposium Series*. Vol. 25. R. I. Richardson and G. C. Mead, ed. CABI Publishing, Oxon, UK.
- McCurdy, R. D., S. Barbut, and M. Qinton. 1996. Seasonal effect on pale soft exudative (PSE) occurrence in young turkey breast meat. *Food Res. Int.* 29:363-366.
- McKee, S. R., and A. R. Sams. 1997. The effect of seasonal heat stress on rigor development and the incidence of pale, exudative turkey meat. *Poult. Sci.* 76:1616-1620.
- Naveau, J., P. Pommeret, and P. Lechaux. 1985. Proposition d'une méthode de mesure du rendement technologique "la méthode napole." *Techniporc* 8(6):7-13.
- Ngoka, D. A., and G. W. Froning. 1982. Effect of free struggle and preslaughter excitement on color of turkey breast. *Poult. Sci.* 61:2291-2293.
- Offer, G. 1991. Modeling of the formation of pale, soft and exudative meat: Effects of chilling regime and rate and extent of glycolysis. *Meat Sci.* 30:157-184.
- Owens, C. M., E. M. Hirschler, S. R. McKee, R. Martinez-Dawson, and A. R. Sams. 2000. The characterisation and incidence of pale, soft, exudative turkey meat in a commercial plant. *Poult. Sci.* 79:553-558.
- Owens, C. M., and A. R. Sams. 2000. The influence of transportation on turkey meat quality. *Poult. Sci.* 79:1204-1207.
- Petracci M., D. L. Fletcher, and J. K. Northcutt. 2001. The effect of holding temperature on live shrink, processing yield, and breast meat quality of broiler chickens. *Poult. Sci.* 80:670-675.
- Pietrzack, M., M. L. Greaser, and A. A. Sosnicki. 1997. Effect of rapid rigor mortis on protein functionality in pectoralis major muscle of domestic turkeys. *J. Anim. Sci.* 75:2106-2116.
- Rathgeber, B. M., J. A. Boles, and P. J. Shand. 1999. Rapid post-mortem pH decline and delayed chilling reduce quality of turkey breast meat. *Poult. Sci.* 78:477-484.
- Rémignon, H., V. Desrosier, and G. Marché. 1996. Influence of increasing breast meat yield on muscle histology and meat quality in the chicken. *Reprod. Nutr. Dev.* 36:523-530.
- Rémignon, H., A. D. Mills, D. Guémené, V. Desrosiers, M. Garreau-Mills, M. Marché, and G. Marché. 1998. Meat quality traits and muscle characteristics in high or low fear line of Japanese quails (*Coturnix japonica*) subjected to acute stress. *Br. Poult. Sci.* 39:372-378.
- Sandercock, D. A., R. R. Hunter, G. R. Nute, M. A. Mitchel, and P. M. Hocking. 2001. Acute heat stress-induced alterations in blood acid-base status and skeletal muscle membrane integrity in broilers chickens at 2 ages: Implications for meat quality. *Poult. Sci.* 80:418-425.
- SAS Institute. 1999. *SAS User's Guide*. Version 8 ed. SAS Institute Inc., Cary, NC.
- Wynveen, E. J., B. C. Bowker, A. L. Grant, B. P. Demos, and D. E. Gerrard. 1999. Effects of muscle pH and chilling on development of PSE-like turkey breast meat. *Br. Poult. Sci.* 40:253-256.