PROCESSING AND PRODUCTS

Hemorrhages in Muscles of Broiler Chickens: The Relationships Among Blood Variables at Various Rearing Temperature Regimens

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ABSTRACT Hemorrhages in muscle tissue can be considered as major quality defects of broiler carcasses. They can be induced by stunning, especially electrical stunning. The underlying mechanism, however, is considered to be multifactorial. In this study, the effect of blood circulation disturbances on the severity of hemorrhages induced by electrical stunning was investigated. The disturbances were evoked in two genetically different, fast-growing broiler strains, Ross and Hybro, by rearing the broilers at low ambient temperatures. The broilers were slaughtered by two different electrical stunning methods. Broilers reared at low temperatures showed changes in blood variables and heart weight known to be associated with blood circulation disturbances. There was no effect of rearing temperature on hemorrhage severity. Ross broilers, being the most susceptible to low temperatures, had less severe hemorrhages than Hybro broilers. There was, however, a clear effect of the stunning method on hemorrhage severity. Whole body stunning caused more severe hemorrhages than head stunning in thigh and breast muscles. These results suggest that factors interfering with blood circulation have little or no effect on the occurrence of hemorrhages induced by electrical stunning.

(*Key words*: hemorrhages, muscles, blood circulation disturbances, electrical stunning, broiler)

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INTRODUCTION

Hemorrhages in muscle tissue can be considered as major quality defects of carcasses from slaughter animals (Warrington, 1974; Griffiths and Nairn, 1984; Bilgili, 1992a; Veerkamp, 1992; Hillebrand, 1993). Kirton *et al.* (1981) showed that stunning method affects the incidence of blood splash in carcasses of lambs. Electrical stunning caused the most severe hemorrhages. Veerkamp (1988) and Gregory and Wilkins (1989) reported that scores for blood spots in breast meat of broilers increased significantly at higher stunning currents. Leet *et al.* (1977) proposed that supercontraction of muscle fibers, caused by electrical stunning, places severe stress on adjacent blood vessels, occasionally leading to their rupture and hence to hemorrhages. This theory is supported by studies of Gilbert and Devine (1982) and Lambooy and Sybesma (1988), which showed that muscle hemorrhages can be avoided by applying methods interfering with nerve-induced muscle movement, prior to electrical stunning. According to some authors, however, there is no clear relationship between electrical current and carcass quality of broilers (Griffiths, 1985; Schneider and Pingel, 1985; Weise *et al.*, 1987; Bilgili, 1992b). Apparently, causes of muscle hemorrhages in broiler carcasses are multifactorial (Veerkamp, 1992; Hillebrand, 1993). One of these factors may be the occurrence of blood circulation disturbances in the broiler chicken.

Blood circulation disturbances associated with the ascitic syndrome have become a considerable problem in fast-growing meat-type chickens (Julian, 1990, 1993; Griffin and Goddard, 1994). In birds suffering from these disorders, venous blood pressure and volume are increased. Consequently, congestion of the peripheral microcirculation occurs. Histological studies showed lesions and focal hemorrhages in lung, heart, and liver of ascitic birds (Maxwell *et al.*, 1986a,b, 1990; Wilson *et al.*, 1988; Witzel *et al.*, 1990). These observations indicate that the endothelial cell layer of the (micro)vasculature is damaged and that the vascular wall may be weakened. Leakage of plasma protein from the circulatory system indicates that the endothelial permeability is increased in these birds (Maxwell *et al.*, 1992; Julian, 1993). Blood circulation disturbances appearing in fast-growing meat-type chickens therefore may have an effect on the incidence and severity of hemorrhages induced by electrical stunning preceding slaughter.

Blood circulation disturbances can be evoked by rearing meat-type chickens at conditions at which hypoxia occurs. Hypoxia can be induced by low ambient

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temperatures and is dependent on the genetic constitution of the chickens (Scheele *et al.*, 1991; Scheele, 1992). Under these conditions, meat-type chickens need additional energy to maintain their body, with an extensive musculature, homeothermic. They have to increase their metabolic rate and, therefore, they require more oxygen (Scheele *et al.*, 1991; Scheele, 1992). Consequently, the oxygen carrying capacity of the blood circulation has to be elevated, using two major mechanisms: 1) increase of blood flow through the capillary bed of the lungs by an elevation of the cardiac output, and 2) stimulation of erythropoiesis leading to polycythemia (Moye *et al.*, 1969; Shlosberg *et al.*, 1992; Julian, 1993).

Increase of blood flow can cause volume and pressure overload in the pulmonary arteries. Polycythemia increases blood viscosity and consequently blood pressure overload (Somer and Meiselman, 1993; Julian, 1993). The overall result is pulmonary hypertension (Julian, 1987, 1989; Maxwell *et al.*, 1992). The bird's heart responds very rapidly to the chronically increased work load caused by the hypertension. Hypertrophy of both the right heart ventricle and the right heart valve occurs, leading to valvular insufficiency and right ventricular failure (Burton and Smith, 1967; Julian, 1987, Witzel *et al.*, 1990, Odom *et al.*, 1992, Shlosberg *et al.*, 1992; Stolz *et al.*, 1992). Venous and capillary pressure and blood volume increase, resulting in edema in many organs (Levy, 1979; Julian, 1987, 1993). The peritoneal edema, caused by leakage of plasma fluid from the abdominal organs, especially the liver, is called ascites.

The purpose of this study was to investigate the effect of changes in blood variables and relative heart weight, induced by low ambient temperatures, on the occurrence of hemorrhages in muscle tissue of carcasses from electrically stunned meat-type chickens from two commercial, genetically different broiler strains.

MATERIALS AND METHODS

Rearing and Processing

Male broilers from two commercial genetically different, fast-growing strains, Hybro and Ross, were reared at two temperature regimens (Figure 1): 1) thermoneutral: a gradual reduction of the ambient temperature from 33 C at Day 0 to 19 C at Day 40, remaining constant until slaughter, and 2) low temperature: a gradual reduction of the ambient temperature from 30 C at Day 0 to 15 C at Day 27, then constant until slaughter.

At Day 0, the day of hatching, 512 broilers (256 from each strain) were placed in 32 floor pens, each containing 16 broilers. The pens were distributed within four climate rooms, two rooms per temperature regimen. Each room contained eight pens, four pens per strain. Relative humidity was kept constant at 60%. During the first 3 d

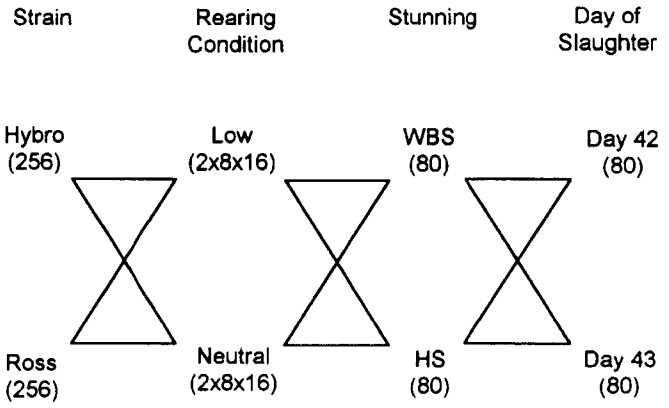

FIGURE 1. Diagram of experimental design. The total number of broilers is given between brackets. Per group (strain by rearing condition) 40 broilers were used for stunning and subsequent slaughter. WBS = whole body stunning; HS = head stunning.

continuous light was provided. After that time, a light regimen of 2 h light followed by 1 h dark was applied. Feed and water were provided for *ad libitum* consumption. Dead birds were removed daily. Necropsy was carried out the following day, in order to determine mortality due to ascites.

Broilers were slaughtered on Days 42 and 43. Each day of slaughter, 20 broilers were used from each group (strain by rearing condition). They were distributed randomly over the stunning methods. Two different electrical stunning methods were applied: 1) Head stunning (HS): Birds were immobilized in a cone, leaving their heads free. Wing movement was restrained, but not leg movement. Two sharp electrodes attached to a pair of tongs were placed on the skull, thereby penetrating the skin. Upon connection of a current source of 25 V, 200 Hz for 4 s an average current of 80 mA was applied through the brain. 2) Whole body stunning (WBS): Birds were hung by their legs on steel shackles. Leg movement was restrained, but not wing movement. The birds were passed through a water bath for 4 s. A voltage of 100 V, 50 Hz resulted in a current of approximately 100 mA flowing through the entire body (Figure 1). Neck cutting was carried out 30 s after stunning. The birds were bled for 3 min, scalded, plucked, and eviscerated. At 1 d post-mortem, both pectoral (breast) muscle pairs were excised and legs were separated from the carcasses.

Measurements

Mean body weight was determined, from the pooled weight of all birds within a pen, at Days 20 and 40. At Days 21, 28, 35, and 41, one previously randomly selected bird from each pen (eight birds per group, strain by rearing condition) was used for sampling. The selected animals were separated the day before sampling. Feed was withdrawn at least 8 h before sampling. The birds were anesthetized by intravenous administration of 0.2 to 0.8 mL ketamin hydrochloride[2] solution (100 mg/mL).

[2]Ketaset®, Intervet, 5830, Boxmeer, The Netherlands.

Subsequently, the body weight was determined, followed by venesection of the jugular vein. Blood samples were taken during bleeding.

Birds were judged to be ascitic upon exhibition of a dilated, hypertrophic heart, a hydropericardium, and an edema of the abdomen. The incidence of ascites is defined as the number of birds being ascitic on the various sampling days, as a percentage of the total number of birds used for sampling (32 per group). Ascites mortality was calculated as the number of birds dying of ascites, as a percentage of the total number of birds per group.

Venous blood was taken from the jugular vein immediately after venesection. About 5 mL blood was collected in polystyrene tubes containing 10 mg EDTA dissolved in 200 mL demineralized water and another 2 mL in tubes containing dried heparin,[3] to keep the blood isovolumetric.

Blood from the heparinized tubes was used for the determination of the hematocrit. After centrifugation (5 min, 3,000 × *g*, at room temperature), the hematocrit was measured using a hematocrit reader.[4] After centrifugation of the blood within the heparinized tubes (15 min, 1,400 × *g*, at 4 C), total protein concentration of the plasma was determined according to the protocol of the bicinchoninic acid (BCA) protein assay.[5] Absorbency was read at 570 nm. Bovine serum albumin was used as a standard.

After agitation, shear stress of 3 mL blood from the polystyrene tubes was measured at increasing shear rate (0 to 300 per second) at 40 C, the approximate body temperature of broilers, using a rotation viscometer.[6] Data were analyzed using Haake Rotation software. Regression analysis was performed on the 100 to 300 per second shear rate interval of the shear stress curves. Analysis is based on the least square method, using linear equations upon data input in a linear, logarithmic or exponential form. Viscosity was calculated at a shear rate of 300 per second and expressed as millipascals per second; the ratio of shear stress (Newtons per square meter = pascal) and shear rate (per second). During slaughter, blood loss was measured immediately after neck cutting and expressed as the difference in body weight before and after 3 min of bleeding as a percentage of the body weight before bleeding.

Hearts were removed at slaughter. Residual blood was squeezed out and the major blood vessels (*Vena cava* branches, pulmonary veins, pulmonary arteries, brachiocephalic arteries, and the aorta) were dissected. Subsequently, the weight of the organ was determined. The heart weight was expressed as the relative heart weight, i.e., the heart weight as a percentage of the body weight.

At 1 d post-mortem, hemorrhages of breast muscles and thighs were scored. Breast muscles were graded from the transverse-dorsal view and thighs from the medial view. Hemorrhages were scored independently by three observers. For classification, a threshold model consisting of a discontinuous 5-point scale with 4 cutoff points was used. Cutoff points were formed by photographs of breast and thigh muscles showing a particular severity of hemorrhages; class 1: hemorrhage free; class 5: numerous and severe hemorrhages.

Statistical Analysis

A 2 × 2 × 4 factorial model was used to investigate the effects of rearing temperature regimen, strain, and age on the blood variables, hematocrit, whole blood viscosity, and plasma protein concentration. A 2 × 2 × 2 × 2 factorial model was used for the analysis of the effect of temperature regimen, strain, stunning procedure, and slaughter day on the relative heart weight, occurrence and severity of hemorrhages in muscle tissue, and blood loss as a result of slaughter. Body weight, blood loss, and heart weight data as well as logarithmic transformed hematocrit and plasma protein concentration data were analyzed by ANOVA.

Whole blood viscosity data were analyzed using a generalized linear fixed model. An approximate inverse normal distribution was used for determination of the systematic effects, i.e., the effects of temperature regimen, strain, and processing day. The dispersion parameter was estimated by determination of random errors of climate room, cage, and individual animals of the nontransformed data. Transformed data were statistically analyzed using the Student's *t* test, with a critical *t* value = 2. The confidence interval of 95% is an estimation because the *t* distribution is only approximate.

Hemorrhage scores from a multinomial distribution with j classes (j = 1...5), were fitted within the proportional odds/threshold model (McCullagh and Nelder, 1989). Treatment effects and their interactions were analyzed in the systematic part: $\log(\tau_j/(1-\tau_j)) = \Theta_j + T_i + S_k + N_l + P_m + Q_n$ + interactions; where τ_j = cumulative probability, i.e., probability (*P*) that a classification of one observation is smaller than or equivalent to a particular cutting-point Θ_j (j = 1...4) on the continuous scale Z, constructed according to the model:

$$\tau_j = P(Z \leq \Theta_j),$$

where T_i is the effect of the i^{th} temperature regimen, S_k, the effect of the k^{th} broiler strain, N_l, the effect of the l^{th} stunning method, P_m, the effect of the m^{th} observer, and Q_n, the effect of the n^{th} slaughter day. Wald statistics were calculated and tested within a χ^2 test, ($\alpha = 5\%$), because the asymptotic χ^2 distribution approximates the Wald statistics distribution.

[3]Vacutainer®, Becton Dickinson Vacutainer Systems Europe, Meylan Cedex, France.

[4]Hawksley and Sons Ltd., Lansing, UK.

[5]Pierce, Rockford, IL 61105.

[6]Rotovisco RV20 fitted with RC20 rheocontroller, CV100 device and the ME30 measurement cylinder, Haake Mess-Technik, GmbH und Co., W-7500, Karlsruhe, Germany.

TABLE 1. Effects of strain and rearing temperature regimen on blood and performance variables

Variables	Age	Hybro		Ross	
		Low[1]	Neutral[2]	Low[1]	Neutral[2]
	(d)				
Body weight, kg, n = 8	20	0.73 ± 0.02[c][5]	0.79 ± 0.02[b]	0.67 ± 0.03[d]	0.75 ± 0.03[c]
	40	2.33 ± 0.10[a]	2.38 ± 0.07[a]	2.07 ± 0.09[b]	2.25 ± 0.09[a]
Ascites, %					
Incidence		0	0	6.3	0
Mortality		1.6	0	3.9	0
Hematocrit, %, n = 32	21 to 41	34.0 ± 3.2	31.7 ± 2.7	36.4 ± 5.1[a]	32.0 ± 2.8[b]
Viscosity, mPas, n = 8	21	2.13 ± 0.23	1.94 ± 0.16	2.12 ± 0.18[c]	1.99 ± 0.24[c]
	28	2.21 ± 0.26	1.94 ± 0.12	2.33 ± 0.36[b]	2.00 ± 0.14[c]
	35	2.19 ± 0.20	2.03 ± 0.09	2.35 ± 0.44[b]	2.01 ± 0.10[c]
	41	2.30 ± 0.60	2.00 ± 0.12	2.72 ± 0.69[a]	2.15 ± 0.28[bc]
Plasma protein concentration, mg/mL, n = 8	21	35.0 ± 3.3	34.7 ± 5.0	35.1 ± 2.7	30.0 ± 5.0
	28	38.2 ± 4.8	33.5 ± 2.3	39.1 ± 2.9	33.6 ± 4.3
	35	34.9 ± 4.2	31.0 ± 3.8	37.6 ± 4.3	34.6 ± 4.8
	41	37.6 ± 7.5	34.2 ± 3.8	39.3 ± 5.5	37.7 ± 5.5
Relative heart weight, %, n = 40	42/43	0.45 ± 0.05[a]	0.37 ± 0.04[b]	0.50 ± 0.07[a]	0.41 ± 0.05[b]
Blood loss, %	42/43				
WBS,[3] n = 20		3.57 ± 0.41[b]	2.91 ± 0.37[c]	4.44 ± 0.81[a]	3.27 ± 0.57[b]
HS,[4] n = 20		3.80 ± 0.55[a]	3.28 ± 0.28[b]	4.51 ± 0.58[a]	3.39 ± 0.28[b]

[a–d]Means in a row within one strain with no common superscript differ significantly ($P < 0.05$).

[1]Low = broilers reared at a low temperature regimen.

[2]Neutral = broilers reared at a thermoneutral regimen.

[3]WBS = whole body stunning.

[4]HS = head stunning.

[5]± SD.

RESULTS

Body Weight, Occurrence of Ascites, and Blood Variables

The results of the measurements of body weight, ascites occurrence, and blood variables related to blood circulation disturbances and the statistical analyses are presented in Table 1. Hybro broilers had a significant higher body weight than Ross broilers at 20 and 40 d of age. At Day 20, there was an additional temperature effect; the broilers reared at low temperatures had a lower body weight than those grown under thermoneutral conditions. As there was no interaction with strain, this effect was similar for both Ross and Hybro broilers. At 40 d of age, there was an interaction between temperature and strain ($P < 0.05$) At this particular age, 2 d before slaughter, there was only a temperature effect for Ross. Broilers of this strain that were reared at low temperatures had a lower body weight than those reared under thermoneutral conditions. Body weight of both Hybro groups did not differ at 40 d of age.

Under cold conditions, 3.9% of the Ross and 1.6% of the Hybro broilers died during the rearing period. The ascites mortality and incidence of the broilers reared at thermoneutral conditions was 0%. The incidence of ascites in the Hybro broilers reared at low temperatures was also 0%. However, up to 6.3% of the Ross broilers grown under the low temperature regimen were ascitic on the sampling days.

Hematocrit was affected by temperature regimen and strain. The factors appeared to interact ($P < 0.05$); however, there was no effect of age. Therefore, the results of the different ages were pooled. Broilers of both strains reared at thermoneutral conditions had a hematocrit of approximately 32%. Due to cold treatment, the hematocrit increased significantly to 36.4% in Ross broilers, but it was not significantly affected in Hybro broilers.

Rearing at low temperatures increased blood viscosity in both Hybro and Ross broilers. In Hybro broilers the only main effect was temperature regimen ($P < 0.05$). Differences in blood viscosity were not significant at the various ages. There was a clear effect of age for the Ross broilers. At 21 d of age, blood viscosity of the broilers reared at either temperature regimen was the same, after Day 28 it differed significantly. At Day 41, the mean viscosity of the cold-treated group was increased to a level significantly higher than that of the preceding sampling days.

Plasma protein concentrations of both Hybro and Ross were dependent on temperature regimen and age. The differences in concentration were due to the main effects only. The protein concentration was significantly increased in broilers reared at low temperatures as compared to birds held under thermoneutral conditions. There were no significant differences at the various ages.

Relative Heart Weight and Blood Loss at Slaughter

The relative heart weight was affected by strain and temperature. It was significantly enhanced in cold-treated broilers as compared to broilers reared under ther-

TABLE 2. Hemorrhage scores in broiler muscle tissue

Variable	Breast	Thigh
Strain		
Hybro	3.0 ± 1.4[a]	1.9 ± 1.0
Ross	2.6 ± 1.4[b]	1.9 ± 0.9
Rearing temperature[2]		
Low	2.8 ± 1.4	2.0 ± 1.0
Neutral	2.7 ± 1.5	1.8 ± 0.9
Stunning method[3]		
WBS	3.6 ± 1.3[a]	2.5 ± 0.9[a]
HS	2.0 ± 1.1[b]	1.3 ± 0.5[b]

[a,b]Means ± SD of hemorrhage scores from either breast or thigh muscles with no common superscript differ significantly for the factor indicated ($P < 0.05$), n = 80.

[2]Low = broilers reared at a low temperature regimen. Neutral = broilers reared at a thermoneutral regimen.

[3]WBS = whole body stunning. HS = head stunning.

moneutral conditions (Table 1). Hybro broilers had a lower relative heart weight than Ross broilers. The difference between the two strains was present at both temperature regimens.

Blood loss was dependent on stunning method, strain, and temperature regimen. For both strains, it was significantly higher in head-stunned than in whole body-stunned broilers (Table 1). In Hybro broilers, the difference in blood loss between the stunning methods was significant for each temperature regimen, whereas in Ross broilers it was not. There was an interaction between temperature regimen and strain. Blood loss of Ross broilers reared at either temperature regimen was higher than that of broilers from both Hybro groups. However, the difference in blood loss was, although statistically significant, only moderate between the thermoneutral groups (0.23%), whereas it was considerable between the cold-treated groups (0.79%). Ross broilers reared at low temperatures lost 1.34 times more blood than those grown at thermoneutral conditions; Hybro broilers lost only 1.19 times more. The effect of temperature regimen on blood loss was most pronounced in Ross broilers.

Hemorrhage Scores

The stunning method had a marked effect on the occurrence of hemorrhages in both breast and thigh muscles (Table 2). Hemorrhage scores were 1.6 (breast muscles) and 1.2 (thighs) scale units higher in whole body-stunned than in head-stunned broilers. There were no interactions with strain or with temperature regimen. Breast muscles of Hybro broilers had a slightly higher ($P < 0.05$) hemorrhage score (0.4 scale units) than those of Ross broilers. However, there were no differences between the thighs of the two strains. No statistically significant differences in hemorrhage grading of breast muscles and thighs were present between days of slaughter and temperature regimens.

DISCUSSION

Blood Circulation Disturbances

Enhanced blood viscosity, hematocrit, and relative heart weight are symptoms of blood circulation disturbances associated with pulmonary hypertension, right ventricular failure, and the ascites syndrome (Burton and Smith, 1967; Hernandez, 1987; Julian, 1990, 1993; Maxwell *et al.*, 1992; Shlosberg *et al.*, 1992; Stolz *et al.*, 1992; Scheele and Kwakernaak, 1994). The protein concentration of plasma is an important factor in determining blood viscosity and blood flow characteristics in the microcirculatory system. Blood viscosity increases with protein concentration (Somer and Meiselman, 1993). Plasma protein concentrations in broilers kept at low temperatures are equal to or higher than those in broilers kept at higher temperatures (Deaton *et al.*, 1969). Rearing at low ambient temperatures caused an increase of whole blood viscosity and plasma protein concentration in both Hybro and Ross broilers. At slaughter, relative heart weight of the cold-treated broilers from both strains were significantly higher than that of the reference broilers.

The hematocrit was increased over the entire breeding period in Ross broilers reared at low temperatures. Blood viscosity increased with age and mean body weight measurements indicated that growth rate was reduced. Probably, right ventricular failure occurred in some of the broilers, because growth stops in birds suffering from this disorder (Julian, 1990). Some of the Ross broilers developed symptoms of ascites and some died of the syndrome. Compared to Ross broilers, Hybro birds were less affected by the low temperature regimen. Hematocrit of Hybro broilers was not increased and blood viscosity was not dependent on age. Although the mean body weight of the cold-treated broilers was lower at 20 d of age than the mean weight of those kept at thermoneutral temperatures, it was equal at the end of the rearing period (Day 40). Only a few Hybro birds died of ascites.

It is concluded that rearing at low ambient temperatures induced changes in blood variables and relative heart weight indicative for blood circulation disturbances, associated with pulmonary hypertension and right ventricular hypertrophy, in both Ross and Hybro broilers. Ross broilers developed progressive circulation disturbances, as indicated by the age dependent increase of blood viscosity and the reduction of growth, in contrast to Hybro broilers. The Ross broilers probably suffered from right ventricular failure and to some extent from ascites. In this study, Hybro broilers were more capable of meeting the increased need for energy and oxygen to maintain homeothermy at low temperatures than the Ross broilers.

Ross and Hybro broilers can be used as models to study the extent of blood circulation disturbances associated with pulmonary hypertension, right ventricular hypertrophy and ascites, induced by low ambient temperatures, on the incidence and severity of hemorrhages caused by electrical stunning.

Hemorrhages in Breast and Thigh Muscles

Hemorrhage scores of breast and thigh muscles of carcasses from broilers reared at low temperatures were equal to those of broilers grown under thermoneutral conditions. Ross broilers, being most susceptible to low temperatures, had even lower hemorrhage scores than Hybro broilers. It is concluded that there is no effect of strain-dependent changes in blood variables and increase in relative heart weight on the incidence and severity of hemorrhages caused by either whole body or head electrical stunning. Other strain-dependent factors, therefore, have to be responsible for the differences in hemorrhage scores of the pectoral (breast) muscles.

The changes of the blood variables measured, the higher relative heart weight, and the reduction of growth indicate an interference with blood circulation in broilers reared under low temperature conditions. Ross broilers are particularly affected. Blood loss during the first 3 min following venesection at slaughter was significantly enhanced in cold-treated birds. Ross birds lost more blood than Hybro birds. Differences in blood loss correspond with variations in the blood variables measured. Apparently, these variations reflect the increase of venous pressure and venous blood volume within the affected birds. Factors interfering with circulation appear to have little effect on the occurrence of hemorrhages induced by electrical stunning of broilers. This suggestion is supported by the study of hemorrhages in lamb carcasses. In lambs, increase of blood pressure usually does not cause hemorrhages, although it can exacerbate the leakage of blood into the tissue (Kirton *et al.*, 1978; Gilbert and Devine, 1982).

There is a significant difference in muscle hemorrhage score between whole body- and head-stunned birds. The most severe hemorrhages are found in both breast and thigh muscles of whole body-stunned broilers, from both strains. Hemorrhages in muscle tissue, occurring upon electrical stunning, probably are due to shear force exerted by muscle contraction on the intramuscular blood vessels. Leet *et al.* (1977) found a small proportion of supercontracted muscle fibers in a splashed region of muscles from electrically stunned lambs.

In electrically stunned slaughter pigs, there is a clear effect of the restraining method on the severity of hemorrhages in the shoulders (Lambooy *et al.*, 1992). Shear force experienced during electrical stunning probably depends on the posture of the slaughter animals.

In whole-body-stunned broilers, an epileptiform seizure is induced. Consequently, tonic and clonic spasm potentials will be evoked by the brain (Wormuth *et al.*, 1981). Because the electrical resistance of muscle is lower than that of other organs, most of the electrical current will flow through this tissue (Woolley *et al.*, 1986a,b). Therefore, strong muscle contractions will be induced directly by the electrical current, applying whole body stunning. In head-stunned birds, often only clonic spasm potentials will be evoked (Wormuth *et al.*, 1981). There is no direct innervation of the muscles by the electrical current. Therefore, muscle contractions probably will be less forceful than in whole body stunning. Both the muscle force exerted and the magnitude of shear force due to restraining may affect the incidence and severity of muscle hemorrhages. These forces are probably higher in broiler subjected to whole body stunning than in head-stunned broilers.

In conclusion, there is no correlation between the (extent of) disturbance of blood circulation evoked by low temperatures and the occurrence of hemorrhages in breast and thigh muscles of Ross and Hybro broilers. There is, however, a marked effect of the stunning method applied. Electrical whole body-stunned broilers show significantly more hemorrhages in both breast and thigh muscles than do head-stunned birds.

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