

JOURNAL OF ANIMAL SCIENCE

The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Influence of increasing slaughter age of chickens on meat quality, welfare, and technical and economic results

E. Baéza, C. Arnould, M. Jlali, P. Chartrin, V. Gigaud, F. Mercierand, C. Durand, K. Méteau, E. Le Bihan-Duval and C. Berri

J ANIM SCI 2012, 90:2003-2013.

doi: 10.2527/jas.2011-4192 originally published online December 28, 2011

The online version of this article, along with updated information and services, is located on the World Wide Web at:

<http://jas.fass.org/content/90/6/2003>



American Society of Animal Science

www.asas.org

Influence of increasing slaughter age of chickens on meat quality, welfare, and technical and economic results¹

E. Baéza,^{*2} C. Arnould,[†] M. Jlali,^{*} P. Chartrin,^{*} V. Gigaud,[‡]
F. Mercierand,[§] C. Durand,^α K. Méteau,[#] E. Le Bihan-Duval,^{*} and C. Berri^{*}

^{*} INRA, UR 83 Recherches Avicoles, F-37380 Nouzilly, France; [†] INRA, UMR 85 Physiologie de la Reproduction et des Comportements, F-37380 Nouzilly, France; CNRS, UMR 6175 Physiologie de la Reproduction et des Comportements, F-37380 Nouzilly, France; Université François Rabelais de Tours, F-37041 Tours, France; IFCE, F-37380 Nouzilly, France; [‡] ITAVI, UR 83 Recherches Avicoles, F-37380 Nouzilly, France; [§] INRA, UE 1295 Plate-forme Expérimentale Avicole de Tours, F-37380 Nouzilly, France; ^α Fleury Michon, Montifaut Jambon, 85700 Pouzauges; and [#] INRA, UE 1206 Elevage Alternatif et Santé des Monogastriques, Saint-Pierre d'Amilly, BP 52, F-17700 Surgères, France

ABSTRACT: Because of the increasing demand for raw cuts and processed products, there is a trend to producing very heavy broilers. Breeds that are used for such kinds of production have been intensively selected for growth rate and breast meat yield, and birds are reared for a longer period than standard broilers. This study was to evaluate the effects of increasing slaughter age on technical and economic factors, including production efficiency and environmental costs, bird welfare, and breast meat quality in a modern heavy broiler line. Five groups of 300 male Ross 708 chickens were reared until slaughter ages of 35, 42, 49, 56, or 63 d. Increasing age at slaughter from 35 to 63 d resulted in a 7.4-fold increase ($P < 0.01$) in mortality rate (5.21 vs. 0.70%). It also increased ($P < 0.001$) the slaughter weight and ADFI of birds 2.5- and 1.4-fold, respectively, without affecting their G:F. Under our experimental conditions, economic profit evaluated through the net gain reached a maximum at 42 d. The moisture and

ammonium content of litter increased ($P < 0.05$ and $P < 0.01$, respectively) rapidly during rearing concomitantly with increased ($P < 0.05$) occurrence and severity of contact dermatitis and decreased ($P < 0.05$) walking ability and activity of birds. Thermal comfort also decreased ($P < 0.05$) greatly as early as 42 d of age. Changes in carcass quality occurred mainly between 35 and 56 d of age, with a progressive increase ($P < 0.001$) in breast and leg yield, whereas body fatness was barely affected by age. Major changes in breast meat traits were observed between 35 and 49 d of age, with an increase in muscle pH at 15 min ($P < 0.01$) and 24 h ($P < 0.001$) postmortem and reduced ($P < 0.001$) lightness and drip loss. The protein and lipid content of raw breast meat also increased ($P < 0.05$ and $P < 0.01$, respectively) with age. Taking into account the main aspects of sustainability, we could recommend slaughtering chickens of heavy line at 42 d of age.

Key words: chicken, litter, meat quality, production efficiency, slaughter age, welfare

© 2012 American Society of Animal Science. All rights reserved.

J. Anim. Sci. 2012.90:2003–2013
doi:10.2527/jas2011-4192

INTRODUCTION

¹The authors thank the staff of the INRA experimental poultry unit (UE609 PEAT, Nouzilly, France) for rearing animals and the technicians of the research unit (UR083 Recherches Avicoles, Nouzilly, France) for measurements on birds, especially Thierry Bordeau in charge of the experimental slaughter plant facilities. We also thank Paul Constantin and Christine Leterrier (INRA, UMR 85 PRC, Nouzilly, France) for recording gait scores on broilers. This study was supported by grants from the “Conseil Régional du Centre” and INRA (Department of Animal Physiology and Rearing Systems).

²Corresponding author: Elisabeth.Baeza@tours.inra.fr

Received April 20, 2011.

Accepted December 20, 2011.

Because of the increasing demand for cuts and processed products, there is a trend to producing broilers of very heavy BW. Broiler lines that are used for such kinds of production have been intensively selected for growth rate and breast meat yield, and are reared for a longer period than usual standard broilers. However, the consequences of increasing age and BW at slaughter, in terms of profitability, product quality, and animal welfare, have received little attention, es-

pecially for the modern broiler strains that are currently used. As reported by Suto et al. (1998) and Young et al. (2001), the yields of meatier parts increased with bird age. Increasing age at slaughter also affected cooking yield and the shear force value of the cooked meat but not in a linear manner (Northcutt et al., 2001). Some aspects of broiler chicken welfare, for example lameness (Sørensen et al., 2000; Knowles et al., 2008), thermal discomfort (Mc Lean et al., 2002), and behavioral activity such as time spent lying (e.g., McLean et al., 2002) or distance moved per hour (Newberry and Hall, 1990) are also affected by age. The effects of age are less well established for contact dermatitis, due to confounding factors such as rearing conditions, growth rate, and genotype (Jones et al., 2005; Meluzzi et al., 2008; Allain et al., 2009), and litter quality is one of the underlying factors for all of them (Ekstrand et al., 1997). Although the effects of age on behavior and several aspects of welfare have been established, very few studies have been performed on very heavy broilers.

This study was to evaluate the effects of increasing slaughter age from 35 to 63 d on production sustainability in a heavy breed used for raw portioned and processed products by considering technical and economic factors, bird welfare, and meat quality.

MATERIALS AND METHODS

All experimental procedures were performed in accordance with the French National Guidelines for the Care and Use of Animals for Research Purposes (Certificate of Authorisation to Experiment on Living Animals N°37-005, Ministry of Agriculture and Fisheries).

Animals

Five groups of 300 male Ross 708 chickens (provided by Grelier-Perrot, Saint-Laurent de la Plaine, France) were reared in a closed building at the experimental unit **PEAT** (Pôle Expérimental Avicole de Tours, INRA, Nouzilly, France). The groups of birds were reared on wood shavings under standard conditions starting at 1 wk intervals so that they could be slaughtered together at 35, 42, 49, 56, or 63 d of age, respectively. From 0 to 21 d of age, the 5 groups were reared in 5 similar contiguous rooms (17.50 m², 17.6 birds/m²) to adapt the temperature and lighting program according to bird age. From 21 d of age, all groups were transferred into 2 similar contiguous rooms. Each group was then distributed into 9 pens (3 m²/ pen) of 32 birds (representing a total of 288 birds per age group) with the aim of achieving the same average BW and SE per pen in any 1 group. To have no more than 34 kg/m² at the end of the rearing period, we

removed 4, 4, and 3 birds per pen when the chickens reached 42, 49, and 56 d of age, respectively, taking into account mortality rate, morbidity, and sex error of each pen. Each pen contained 1 feeding trough and 4 nipple drinkers without cups. Three diets were used, based on recommendations for this breed: a starter diet (2,850 ME kcal/kg and 217 g CP/kg) from 0 to 10 d, a growing diet (2,850 ME kcal/kg and 198 g CP/kg) from 11 to 20 d, and a finishing diet (3,069 ME kcal/kg and 180 g CP/kg) from 21 d of age to slaughter.

Litter Quality and Environmental Value of Meat Production

From 21 d of age, the total weight of wood shavings distributed per pen was recorded, reaching 10 kg for groups reared until 35 and 42 d of age, 13 kg for the group reared until 49 d of age, 16 kg for the group reared until 56 d of age, and 19 kg for the group reared until 63 d of age. At the end of the experiment, the litter of 4 pens per group (chosen at random) was weighed to calculate the total amount of feces excreted between 21 d of age and slaughter per pen. The amount of feces was then calculated per day and per chicken taking into account mortality rate and number of birds removed per pen between 42 and 63 d of age.

For each of these pens (4 per group), about 1 kg of litter (representing a mix of samples taken from 3 locations in the pen) was sent to the LDA22 laboratory (Ploufragan, France) to determine DM, mineral matter, total OM, total and organic N, and total P and K content.

The amount of N and P in the litter per weight of meat produced was calculated per pen as follows:

$$(\text{litter weight} \times \text{DM, \%} \times \text{N or P, \%}) / [\text{total weight of chickens} \times (\text{breast\%} + \text{leg\%})], \text{ expressed in \% per kg of meat (breast + thigh) produced.}$$

Technical and Economic Performance

Birds were weighed at 21 d of age and then just before slaughter (i.e., at 35, 42, 49, 56, and 63 d of age according to the group). During the finishing period, between 21 d and slaughter, feed consumption and mortality rate were recorded on a pen basis. The ADG and G:F were then calculated on a pen basis.

Profitability, gain and net gain of the production system were estimated according to the duration of the finishing period. To calculate these variables, the price of feed was fixed at 0.22 USD/kg (0.30 euros/kg), the total rearing costs (i.e., depreciations, financial charges, heating, veterinarian costs, disinfection, water, electricity, taxes, management fees, chicken removal, litter purchase and removal costs, and chicks) without feed but

including the salary of the farmer (twice the minimum salary paid in France; Gallot et al., 2009) at 0.27 USD/kg (0.36 euros/kg), and the price of chicken paid to the farmer at 1.32 USD/kg (1.00 euros/kg). The profitability was calculated per group from the chicken weight produced per square meter of floor space. The gain represented profitability after deduction of the feed cost, and the net gain represented the gain after deduction of the other rearing costs.

Bird Welfare

Panting behavior was recorded 6 d before slaughtering. The number of birds panting in each pen was recorded once in the morning and once in the afternoon.

Bird activity was assessed on 2 birds per pen leaving a nipple drinker after drinking in the morning on the same day. This method has been used on commercial farms (Arnould and Colin, 2008). For each of these birds, we measured the number of steps before lying down and the distance traveled from the nipple drinker (i.e., none, less than 1 body length, less than 1 m, and more than 1 m). Five days before slaughter, walking ability was evaluated on 3 chickens per pen (i.e., 27 chickens per age group) using the gait scoring method described by Kestin et al. (1992). The gait scoring was performed by 2 trained people. They chose a focal bird by mutual agreement, and then a third person gently made all of the chickens in the pen walk. To avoid bias, the focal bird chosen could have been in a lying or a standing position. The procedure was repeated 3 times. Agreement between the 2 assessors for each bird was required before the score was recorded. Birds were scored from 0 to 4 corresponding to reduced walking ability. Each gait score is fully described in Kestin et al. (1992). Briefly, gait score 0 corresponded to birds walking normally with no detectable abnormality, gait score 1 to birds having a slight locomotor defect, gait score 2 to birds having a definite and identifiable gait defect but no problem in moving or competing for resources, gait score 3 to birds having an obvious gait defect affecting their ability to move, and gait score 4 to birds having a severe gait defect, able to move but only with difficulty.

Pododermatitis and hock burns were scored on carcasses during the slaughter procedure on 6 birds per pen, chosen at random (i.e., 56 birds per group). One leg per bird was scored (always the same leg). For pododermatitis, we used the 3-point scale scoring system derived for the 10-point scale proposed by Allain et al. (2009), score 1 corresponding to no lesion or keratosis but no discoloration, score 2 to brown discoloration or an erosion or both, and score 3 to black discoloration, deep lesions, split epidermis, or a combination of all 3. These scores corresponded to scores 0 to 3, 4 to 6, and 7 to 9 in

Allain et al. (2009). This merging of the scores has been previously justified by parallel analysis of histological and morphological characteristics of lesions (Michel et al., 2012). Hock burns were recorded using the 3-point scale scoring system described by Allain et al. (2009). The presence of dermatitis on breast skin and breast blisters was also recorded according to the scoring system of Allain et al. (2009).

Carcass and Breast Meat Quality Evaluation

All broilers were slaughtered the same day in an experimental slaughter plant (UE PEAT, INRA, Nouzilly). Measurements at slaughter, carcass processing, and fresh meat quality were performed as described in Berri et al. (2007). The pH of Pectoralis major (P. major) muscle was measured 15 min postmortem (2 g of tissue ground in 18 mL of 5 mM sodium iodoacetate/0.15 M KCl solution) from 18 birds per group chosen at random. Samples of P. major muscle from 9 birds per group chosen at random were quickly frozen in isopentane cooled with liquid nitrogen and stored at -80°C before histological analysis as previously described by Baéza et al. (1999). Samples of P. major were also directly frozen in liquid nitrogen and stored at -80°C before biochemical analysis.

Carcasses were cut and deboned after storage at 4°C for 24 h. The relative percentages of breast muscle, leg (thighs + drumsticks) and abdominal fat were determined on 54 birds per group chosen at random. The left breasts from 18 birds per group were stored at -20°C for chemical analysis (DM and lipid and protein; AOAC International, 2000). On all right P. major muscles, ultimate pH (pHu), color variables, lightness (L*), redness (a*), and yellowness (b*), and drip loss were measured as described by Berri et al. (2007). To determine cooking loss, breast muscles (n = 30) were trimmed by cutting the distal part to a weight of 200 ± 10 g, wrapped under vacuum in a plastic bag, and cooked in a water bath for 15 min at 80°C to an approximate core temperature of 72°C. The average Warner-Bratzler shear force value was determined on 3 strips ($1 \times 1 \times 3$ cm) for each cooked muscle sample (Honikel, 1998).

The cross-sectional area of fibers (n = 9) was determined after azorubin staining according to Berri et al. (2007) by using a computerized image analysis system (Buche, 1990). The P. major muscle glycogen, glucose-6-phosphate, free glucose, and lactate were measured by enzymatic procedures according to Dalrymple and Hamm (1973) from 1 g of frozen tissue sampled 15 min postmortem (n = 10). Glycolytic potential, which takes into account the main intermediate metabolites of glycogen degradation in live and postmortem muscle and, there-

fore, represents an estimate of the resting glycogen level (Monin and Sellier, 1985), was calculated as follows:

$$\text{glycolytic potential} = 2[(\text{glycogen}) + (\text{glucose}) + (\text{glucose-6-phosphate})] + (\text{lactate}), \text{ expressed as } \mu\text{mol of lactate equivalent/g fresh tissue.}$$

A total of 60 kg of breast meat from each age group stored at 4°C for 2 d was processed the same day into white cured-cooked meat by Fleury-Michon Company (Pouzauges, France) to obtain 1 churn and then 3 loaves per group. The chemical composition (samples from 3 loaves per group, each repeated 2 times) and the shear force value (samples from 3 loaves per group, each repeated 13 times) were also determined on white cured-cooked meat as previously described for breast meat.

Sensory analyses of white cured-cooked meat were performed in 2 sessions by 12 trained panelists on a total of 16 slices per group stored at 4°C under vacuum for 18 and 21 d after processing, respectively. The panelists judged the color (beige to pinkish), slice homogeneity, tenderness, juiciness, fat texture, and chicken and rancid flavor on a continuous scale from 0 (low) to 10 (high). Before sensory analysis, the panelists had training sessions according a French normalized procedure (NF ISO 8586) to define and fix anchors to scale for each variable.

Statistical Analysis

For growth performance, except BW, and the production and characteristics of manure, pen was the experimental unit. For all other variables (except characteristics of processed products), bird was the experimental unit. There were 5 treatments representing factorial 1 (slaughter age). Those 5 treatments were repeated 9 times according to a plan in 9 randomized blocks. A block was established by 5 neighboring pens (corresponding to the 5 treatments) to avoid environmental effect due to the pen distribution in the room. The effects of age at slaughter on mortality rate were evaluated by χ^2 test. Measures of welfare (lesions and behavior) were analyzed using first the Kruskal-Wallis test and then the U Mann-Whitney test (Systat 8.0, SPSS Inc., Chicago, IL). Statistical analyses were performed on the mean scores per pen, and data are expressed as median and interquartile range (25 to 75%). Data from sensory analysis were tested by ANOVA (Minitab software) by comparing all age groups with a Tukey test and by using sensory session and panelists as co-variables. The effects of slaughter age on growth performance, carcass yield, muscle and meat characteristics, and litter composition were tested by ANOVA (Statview software). We also determined Pearson correlations between muscle and meat traits and Spearman correlations between welfare variables.

Table 1. Effects of age at slaughter on BW, ADG, ADFI, G:F, and mortality rate between 21 d and slaughter of a broiler heavy line

Age at slaughter, d	35	42	49	56	63	SEM ¹	P-value
Broiler performance							
BW ² , g	1,877 ^c	2,625 ^d	3,387 ^c	4,224 ^b	4,858 ^a	367	<0.001
ADG, g (n = 9)	77 ^c	87 ^b	91 ^b	96 ^a	95 ^a	3	<0.001
ADFI, g/d/chicken (n = 9)	141 ^c	163 ^d	173 ^c	193 ^b	199 ^a	4	<0.001
G:F, g/g (n = 9)	0.55 ^a	0.53 ^{ab}	0.52 ^b	0.50 ^c	0.48 ^c	0.02	<0.001
Mortality rate, % (n = 9)	0.70 ^b	1.04 ^b	3.82 ^a	3.13 ^{ab}	5.21 ^a	2.55	0.006
Economic costs and profits						Calculations	
Total weight of chickens produced, kg	536	748	914	1102	1196	A ⁴	
Profitability, ³ USD/m ² (euros/m ²)	26.33 (19.88)	36.69 (27.71)	44.85 (33.87)	54.05 (40.82)	58.68 (44.31)	B = (A*price of kg)/27	
Total amount of feed consumed, kg	566	983	1341	1746	2105	C	
Total feed cost, ^{3,5} USD/m ² (euros/m ²)	8.34 (6.30)	14.46 (10.92)	19.73 (14.90)	25.70 (19.41)	30.97 (23.39)	D = (C*0.30)/27	
Gain, USD/m ² (euros/m ²)	17.98 (13.58)	22.23 (16.79)	25.12 (18.97)	28.35 (21.41)	27.70 (20.92)	E = B - D	
Profitability/total feed cost	3.16	2.54	2.27	2.10	1.89	F = B/D	
Production costs without feed, ⁵ USD/m ² (euros/m ²)	9.48 (7.16)	13.22 (9.98)	16.14 (12.19)	19.45 (14.69)	21.12 (15.95)	G = (A*0.36)/27	
Net gain, USD/m ² (euros/m ²)	8.50 (6.42)	9.02 (6.81)	8.98 (6.78)	8.90 (6.72)	6.58 (4.97)	H = E - G	

^{a-c} Within a row, means without a common superscript differ ($P < 0.05$).

¹Pooled SEM.

²n = 282, 278, 245, 214, and 183 chickens at 35, 42, 49, 56, and 63 d of age.

³Each group was distributed into 9 pens (3 m²), which represented a total area of 27 m². For each group, we took into account the mortality rate and the number of birds removed at 42, 49, and 56 d of age.

⁴A represents the total weight of chickens produced.

⁵The average feed cost was fixed at 0.40 USD/kg (0.30 euros/kg), average standard production costs without feed but including the farmer's salary was 0.48 USD/kg (0.36 euros/kg), and the average price of a standard chicken paid to the farmer was 1.32 USD/kg (1.00 euro/kg).

RESULTS

Technical and Economic Variables

Body weight at slaughter increased ($P < 0.001$) progressively with age, 63-d-old broilers being 2.5-fold heavier than 35-d-old birds (Table 1). For the finishing period, from 21 d to slaughter, individual ADFI was 1.4-fold greater for 63-d-old than for 35-d-old broilers. The ADG and G:F for the same period increased 1.2 and decreased 1.1-fold, respectively ($P < 0.001$). Bird mortality increased ($P < 0.01$) from 49 d of age, reaching 5- to 7-fold greater values for broilers reared until 63 d than for broilers reared until 35 or 42 d.

The economic consequences were estimated with regard to broiler age at slaughter by taking into account broiler performance. Although the total weight of chickens produced, and therefore the profitability per square meter, greatly increased, the ratio between profitability and feed cost gradually decreased with age (Table 1). The net gain, which takes into account both the feed and rearing costs, reached a maximum between 42 and 49 d of age, and then decreased between 56 and 63 d of age.

Feces Excretion and Litter Quality

The individual amounts of feces excreted per day gradually increased ($P < 0.001$) with time during the finishing period, being almost 1.5-fold greater after 56 and 63 d of rearing than after 35 d (Table 2). The main increase (+26%) occurred between 35 and 42 d. For the to-

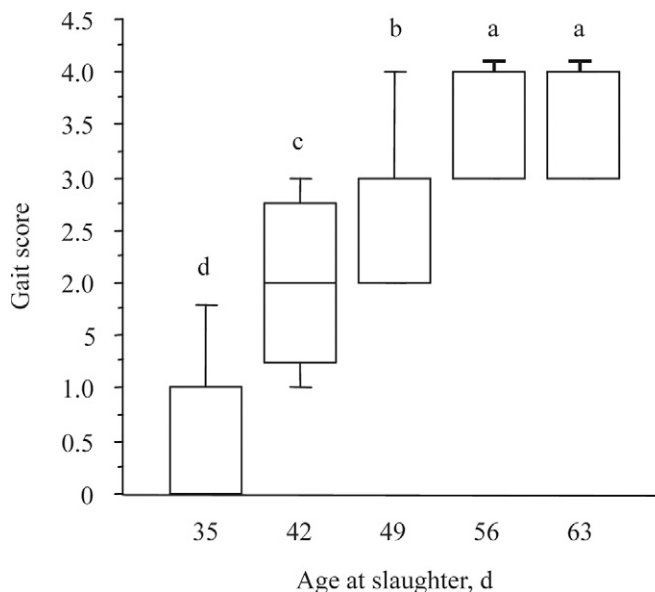


Figure 1. Effects of age at slaughter on broiler gait score (expressed as average score, $n = 9$). Observations were performed 5 d before slaughter. Scores 0 to 4 corresponded to increasing gait abnormalities. ^{a-d} Medians without a common superscript differ ($P < 0.05$).

tal finishing period, the cumulated amount of feces produced was 4.3-fold greater for 63-d-old than 35-d-old broilers ($P < 0.001$; Table 2). The litter moisture content increased ($P < 0.05$) between 35 and 42 d, and then remained unchanged (Table 2). The dry mineral increased and total OM decreased ($P < 0.001$ for both) up to 49 d. For OM, NH_4 increased ($P < 0.01$) between 35 and 42 d of age, whereas total N increased ($P < 0.01$) between 49

Table 2. Effects of age at slaughter on manure production (from 21 d to slaughter) and chemical composition of litter of a heavy line of broiler chickens ($n = 4$)

Age at slaughter, d	35	42	49	56	63	SEM ¹	<i>P</i> -value
Daily amount of feces produced per chicken, g/d	54 ^c	68 ^b	71 ^b	79 ^a	78 ^a	1	<0.0001
Total amount of feces produced per chicken, g	756 ^c	1428 ^d	1988 ^c	2765 ^b	3276 ^a	28	<0.0001
Litter chemical composition, %							
Moisture	48.3 ^b	54.1 ^a	53.9 ^a	51.4 ^{ab}	52.7 ^a	2.4	0.0378
Crude ash ²	14.4 ^c	16.6 ^b	17.8 ^a	18.1 ^a	17.7 ^a	0.6	<0.0001
Total OM ²	85.6 ^a	83.4 ^b	82.3 ^c	81.9 ^c	82.4 ^c	0.6	<0.0001
Total N ²	1.78 ^b	1.87 ^b	1.84 ^b	2.06 ^a	2.03 ^a	0.09	0.003
NH_4 ²	0.45 ^b	0.57 ^a	0.60 ^a	0.61 ^a	0.62 ^a	0.04	0.001
Organic N ²	1.33	1.30	1.24	1.46	1.41	0.10	0.08
P_2O_5 ²	3.10 ^c	3.65 ^b	3.95 ^{ab}	4.10 ^a	3.98 ^{ab}	0.25	0.0006
K_2O ²	2.93 ^b	3.35 ^a	3.45 ^a	3.53 ^a	3.48 ^a	0.15	0.001
Environmental value of meat production ³							
N accumulated in litter, g/kg of meat	12.7 ^d	13.5 ^{cd}	15.0 ^c	20.7 ^b	22.5 ^a	0.10	<0.0001
P accumulated in litter, g/kg of meat	22.2 ^d	26.0 ^c	32.0 ^b	41.5 ^a	44.2 ^a	0.19	<0.0001

^{a-c} Within a row, means without a common superscript differ ($P < 0.05$).

¹Pooled SEM.

²Expressed in percentage of DM.

³Refers to the amounts of N and P accumulated in the litter in relation to the weight of meat produced.

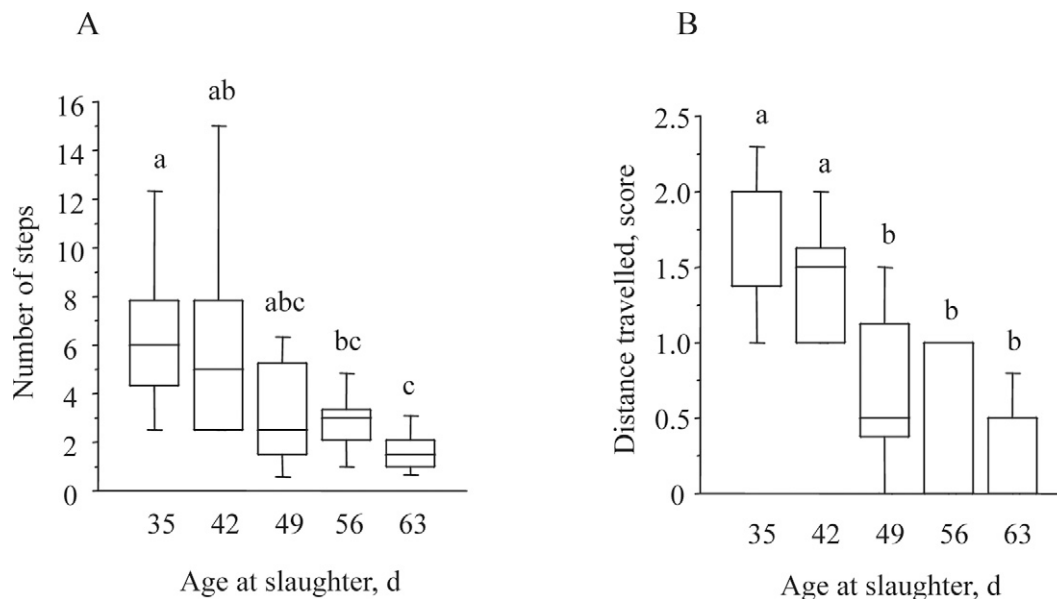


Figure 2. Effects of slaughter age on broiler activity observed after leaving nipple drinkers. A) Number of steps and B) Distance travelled (scoring system with scores 0 to 3 corresponding to increasing distance) before lying down. Observations were performed 6 d before slaughter. ^{a-d} Medians without a common superscript differ ($P < 0.05$).

and 56 d of age. Organic N was not affected by the duration of the finishing period. Potassium (K_2O) increased ($P < 0.01$) only between 35 and 42 d of age, whereas P_2O_5 increased ($P < 0.001$) with age and reached a maximum value at 56 d of age.

The amounts of N and P produced regularly and accumulated in the litter per kilogram of meat (breast and leg) increased ($P < 0.001$) with broiler age at slaughter, amounts being approximately doubled between 35 and 63 d of age for both components (Table 2).

Bird Welfare

The walking ability of chickens gradually decreased with age as indicated by increasing gait scores (Figure 1).

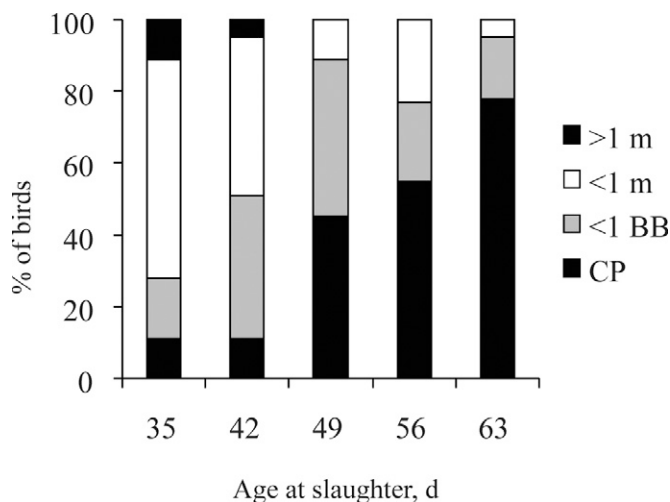


Figure 3. Effects of slaughter age on mean percentage of birds staying close to the nipple drinkers (CP), at less than one bird body length (BB), less than 1 m (< 1 m), and more than 1 m (> 1 m) from the nipple drinkers. Observations were performed 6 d before slaughter.

Serious problems (scores 3 and 4) were found in 56% of the birds slaughtered at 49 d of age and nearly 100% of those slaughtered at 56 and 63 d of age. For bird activity when leaving nipple drinkers, a significant effect of age at slaughter was observed on the number of steps ($P < 0.001$) and distance traveled ($P < 0.001$). The number of steps before lying down and the distance traveled decreased ($P < 0.01$) in the groups slaughtered from 56 and 49 d of age, respectively, compared with birds slaughtered at 35 d of age (Figure 2). About 70% of the chickens lay down at a distance of more than 1 body length from the nipple drinker in the group slaughtered at 35 d of age, whereas only 20% of the birds slaughtered at 49 d of age or more achieved this distance and only 6% of the birds slaughtered at 63 d of age (Figure 3). The Spearman correlation between gait scores and number of steps measured 5 and 6 d before slaughter, respectively, was -0.64 , and between gait scores and distance traveled 6 d before slaughter it was -0.73 . The percentage of birds panting was affected by slaughter age ($P < 0.001$). The percentage was small for birds slaughtered at 35 d of age and increased regularly with age, especially between 35 and 49 d of age (Figure 4). The median increased from 0% in the birds slaughtered at 35 d of age to 26% in the birds slaughtered at 63 d of age.

The incidence of pododermatitis increased ($P < 0.001$) between 35 and 42 d of age (Figure 5). No chickens scored 3 at 35 d, but the percentage increased to 33% at 42 d, 46% at 49 d, 57% at 56 d and 63% at 63 d of age. Hock burns also increased ($P < 0.001$) with age. The median scores were 1.00 (1 to 1.17), 1.84 (1.84 to 2.00), 2.33 (2.00 to 2.33), 2.50 (2.50 to 2.67), and 2.67 (2.50 to 2.83) at 35, 42, 49, 56, and 63 d of age,

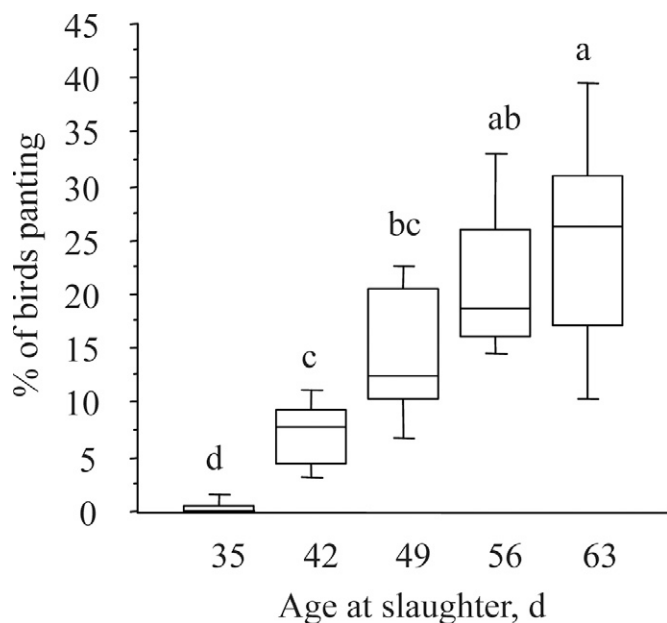


Figure 4. Effects of slaughter age on percentage of birds observed panting. Observations were performed 6 d before slaughter. ^{a-c} Medians without a common superscript differ ($P < 0.05$).

respectively. Differences between these groups were significant ($P < 0.05$ to $P < 0.001$), except for groups reared until 56 and 63 d of age. No chickens slaughtered at 35 d of age scored 3 for hock burns. The value was 1.9% at 42 d of age, and then increased to 28% at 49 d, 63% at 56 d, and 68% at 63 d of age. Of the birds exhibiting severe hock burns (score 3, $n = 87$), 53% also had severe pododermatitis (score 3) and only 7% had a pododermatitis score of 1. Only 1 of the 63-d-old chickens exhibited dermatitis on the breast skin. No breast blisters were recorded.

Carcass, Raw Breast, and White Cured-Cooked Meat Traits

The breast and leg meat yields increased ($P < 0.001$ for both) regularly with age until 56 d of age, whereas the percentage of abdominal fat only increased ($P < 0.001$) between 35 and 42 d of age and then remained stable (Table 3).

The pH measured 15 min postmortem (evaluating the initial rate of fall in muscle pH) in breast muscle increased ($P < 0.01$) between 35 and 42 d of age (Table 3). There was a concomitant decrease ($P < 0.001$) in the breast muscle lactate content with age measured at the same time. The correlation between age and lactate content was -0.67 ($P < 0.001$). The pHu of breast meat increased ($P < 0.001$) between 35 and 49 d of age then remained unchanged. The glycolytic potential of breast muscle was not affected ($P > 0.05$) by age, although 8 to 11% greater values were reported for 35-d-old broilers compared with the other age groups. Breast meat of broilers slaughtered at 35 d of age was lighter (greater

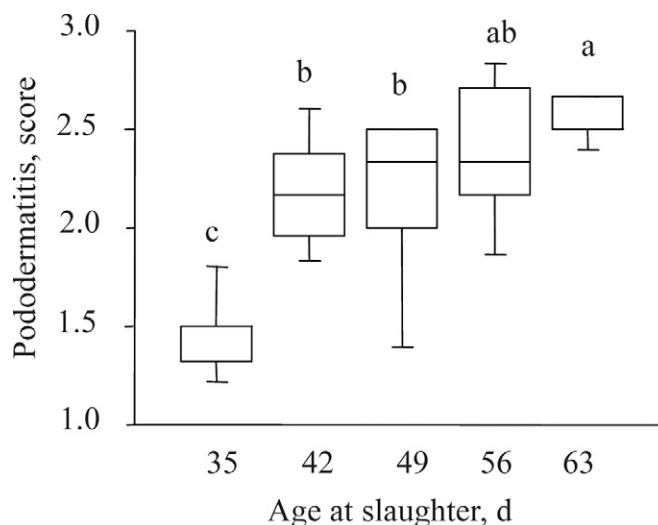


Figure 5. Effects of slaughter age on pododermatitis. Observations were performed just after slaughter. Scores 1 to 3 corresponded to increasing severity of pododermatitis. ^{a-c} Medians without a common superscript differ ($P < 0.05$).

L^* ; $P < 0.001$) than that of older broilers. The least and greatest redness intensities ($P < 0.001$ for both) were reported for birds slaughtered at 49 and 56 d of age, respectively. The intensity of yellowness of breast meat increased ($P < 0.001$) between 35 and 49 d of age, and then it decreased. Drip and cooking losses of breast meat decreased ($P < 0.001$) between 35 and 49 d of age and between 35 and 42 d of age ($P < 0.05$), respectively. The correlation between age and drip loss was -0.56 ($P < 0.001$). The shear force value of cooked breast meat was not affected ($P > 0.05$) by broiler age. Pearson correlations showed that pH 15 min postmortem was negatively correlated with muscle lactate content (-0.81 , $P < 0.001$), whereas pHu was negatively correlated with muscle glycolytic potential (-0.48 , $P < 0.01$) also estimated 15 min postmortem. The muscle pHu value was also negatively correlated with breast meat lightness (L^* ; -0.62 ; $P < 0.01$) and drip loss (-0.57 , $P < 0.01$). Also, pHu was positively correlated with the cross-sectional area of muscle fiber, breast weight, and breast yield ($+0.37$, $+0.48$, $+0.44$, respectively, $P < 0.001$). Based on histological analysis, there was a gradual increase in breast muscle fiber cross-sectional area with age, the difference being significant ($P < 0.001$) only between 42 and 49 d of age (Table 3). The moisture content of raw breast meat decreased ($P < 0.01$) with age, whereas the lipid content increased ($P < 0.01$) regularly, reaching a maximum at 56 d of age. There was a tendency for breast protein content to increase with age, the difference being significant ($P < 0.05$) between 35 d and 49 and 63 d of age for this trait. The correlations between age and lipid, protein, and moisture content in raw meat were 0.37, 0.31, and -0.44 , respectively ($P < 0.001$).

Table 3. Effects of age at slaughter on carcass and raw breast meat traits of a heavy line of broilers

Age at slaughter, d	n	35	42	49	56	63	SEM ¹	P-value
Carcass traits, % BW								
Breast yield	54	18.7 ^d	19.7 ^c	21.2 ^b	22.2 ^a	22.3 ^a	1.4	0.001
Leg yield	54	22.5 ^c	22.9 ^c	23.4 ^b	23.9 ^a	24.2 ^a	1.0	0.001
Abdominal fat	54	2.2 ^b	2.5 ^a	2.4 ^a	2.6 ^a	2.6 ^a	0.5	0.001
Breast muscle traits								
pH 15 min	18	6.69 ^b	6.76 ^a	6.78 ^a	6.81 ^a	6.81 ^a	0.11	0.010
Ultimate pH	54	5.83 ^c	5.90 ^b	5.95 ^a	5.97 ^a	5.95 ^a	0.12	0.001
Lactate ²	10	52.8 ^a	48.0 ^{ab}	44.0 ^b	35.2 ^c	37.1 ^c	6.68	0.001
Glycolytic potential ²	10	93.3	83.9	84.2	86.0	86.7	9.10	NS
Lightness, L*	54	48.7 ^a	46.9 ^b	46.2 ^{bc}	45.3 ^c	46.9 ^b	2.68	0.001
Redness, a*	54	-0.04 ^b	-0.12 ^b	-0.38 ^c	0.29 ^a	-0.01 ^b	0.72	0.001
Yellowness, b*	54	8.7 ^{bc}	9.0 ^{ab}	9.4 ^a	8.3 ^{cd}	7.8 ^d	1.41	0.001
Drip loss, % of initial weight	54	2.02 ^a	1.19 ^b	0.86 ^c	0.93 ^c	1.00 ^c	0.46	0.001
Cooking loss, % of initial weight	30	18.8 ^a	16.3 ^b	17.5 ^{ab}	17.8 ^{ab}	17.4 ^{ab}	3.17	0.05
Shear force of cooked meat, Newtons	30	15.8	16.6	15.9	16.6	15.6	3.34	NS
Fiber cross-sectional area, μm^2	9	2430 ^b	2978 ^b	4132 ^a	4457 ^a	4848 ^a	852	0.001
Moisture, %	18	74.3 ^a	73.9 ^{ab}	73.8 ^{ab}	73.4 ^{bc}	73.1 ^c	0.82	0.005
Proteins, %	18	23.5 ^b	24.2 ^{ab}	24.4 ^a	24.1 ^{ab}	24.9 ^a	0.95	0.03
Lipids, %	18	1.29 ^c	1.42 ^{bc}	1.65 ^{ab}	1.92 ^a	1.68 ^{ab}	0.39	0.004

^{a-c} Within a row, means without a common superscript differ ($P < 0.05$).

¹Pooled SEM.

²Measured 15 min postmortem and expressed in $\mu\text{M/g}$ fresh tissue.

As for raw meat, the chemical composition of the white cured-cooked meat was affected by age. The moisture content decreased ($P < 0.01$) with age (Table 4). Moreover, the correlations between age and lipid, protein, and moisture content of processed meat were 0.43, 0.50 and -0.57 , respectively ($P < 0.001$). The shear force value of white cured-cooked meat increased ($P < 0.001$) with age. However, despite differences in chemical composition and product texture, slaughter age had no significant effects ($P > 0.05$) on the sensory properties of white cured-cooked meat evaluated by trained panelists (Table 4). We only found significant correlations between age and slice homogeneity and tenderness (-0.20 and -0.23 , respectively, $P < 0.05$).

DISCUSSION

By considering environmental and economic aspects, meat quality, and bird welfare, our study was designed to obtain an overall assessment of the consequences of increasing slaughter age from 35 to 63 d in broiler production. Producing heavy broilers by increasing the age at slaughter is advantageous for processors because it provides highly meaty animals. However, the effects on profit, meat product quality, the environment, and animal welfare have been little investigated.

As expected, meat yield increased regularly with age at slaughter. Taking into account both leg and breast muscles, the amount of meat produced per chicken was

tripled in 63-d-old compared with 35-d-old broilers (2.26 vs. 0.78 kg, respectively). However, estimation of the net gain based on the amount of chickens produced in relation to feed and other production costs was optimal at 42 d of age, remaining fairly stable until 56 d of age, declining thereafter and reaching a value more than 25% less than the optimal at 63 d of age. Although the calculation we performed was approximate and did not include all economic variables, such as meat yields, it highlights the limitations of increasing broiler age beyond 49 d, mainly because of increased mortality and decreased G:F which both affected the economic efficiency of broiler meat production.

In this study, we also evaluated the environmental impact of increasing slaughter age to produce heavy broilers, at least in terms of N and P production. This is particularly valuable because the demand for environmentally friendly animal production is growing. Based on manure analyses, the amounts of N and P in relation to the weight of meat produced increased regularly with age, amounts being almost doubled between 35 and 63 d of age. Although animal manure can be a valuable resource for farmers, providing nutrients, improving soil structure, and increasing vegetation, producing N and P in excess can potentially be associated with pollution of surface water. Our results regarding litter composition should therefore be considered by poultry producers to improve management of N and P loss in manure and to evaluate the environmental value of meat production.

Table 4. Effects of age at slaughter on chemical composition, shear force value, and sensory attributes of white cured-cooked meat of a heavy line of broilers

Age at slaughter, d	n	35	42	49	56	63	SEM ¹	P-value
Composition								
Moisture, %	6	74.4 ^a	74.0 ^{ab}	73.0 ^{bc}	73.6 ^{ab}	72.4 ^c	0.89	0.005
Proteins, %	6	21.7	22.1	22.4	23.1	23.3	0.81	0.08
Lipids, %	6	1.09	1.38	1.45	1.47	1.50	0.30	NS ²
Shear force value, Newtons	39	6.3 ^d	7.5 ^c	8.6 ^b	8.9 ^{ab}	9.4 ^a	2.71	0.001
Sensory attributes ³								
Color intensity	23	5.49	5.28	5.09	5.39	5.19	1.27	NS
Slice homogeneity		4.76	3.97	4.30	4.13	3.62	1.48	NS
Tenderness		6.21	5.87	5.60	5.30	5.44	1.30	NS
Fat texture		0.90	0.79	0.75	0.65	0.80	0.81	NS
Juiciness		3.08	2.76	2.94	2.70	2.50	1.70	NS
Chicken flavor		2.91	2.99	2.79	2.86	3.28	1.72	NS
Rancid flavor		0.34	0.44	0.28	0.29	0.36	0.50	NS

^{a-c} Within a row, means without a common superscript differ ($P < 0.05$).

¹ Pooled SEM.

² NS = not significant.

³ Sensory attributes were judged by 12 panelists on a continuous scale ranging from 0 to 10, corresponding to the least and greatest values, respectively.

Upon litter analysis, we observed that the quality of the litter deteriorated fairly early as its humidity and ammonium content rose significantly between 35 and 42 d of rearing (+12 and +26%, respectively). These changes occurred concomitantly with the increase in occurrence of contact dermatitis (pododermatitis and hock burns) that was particularly high between 35 and 42 d of rearing. These 2 factors may have contributed to the increase in severity of contact dermatitis. Indeed, litter moisture has been reported to be 1 factor associated with increased incidence of contact dermatitis (Mayne, 2005; Meluzzi et al., 2008; Shepherd and Fairchild, 2010). Similarly, contact dermatitis can be caused by corrosive substances or irritants derived from the feces (Nairn and Watson, 1972), such as ammonia (Von Schmidt and Luders, 1976; Hemminga and Vertommen, 1985). When birds were slaughtered after 49 d of age the extent of severe dermatitis was particularly high (more than 50% of birds affected by pododermatitis and more than 60% by hock burns). These high levels of lesions were probably mainly due to increased time in contact with litter whose quality was already deteriorating. Indeed, walking ability was highly impaired at these ages, while litter moisture and N content did not vary significantly for groups slaughtered from 42 to 63 d of age. In this study, the walking ability of the birds deteriorated considerably between 35 and 42 d of age and was seriously impaired when birds reached 56 or 63 d of age. This corroborates previous reports (Skinner-Noble and Teeter, 2009) where increased breast weight appears to be highly positively related to field gait score and thus negatively to walking

ability. In fact, varying physical proportions of the broilers means that their way of walking changes to maintain their center of gravity during locomotion. In the present study, we did not perform physical measurements to determine breast muscle shape but we determined breast yield and muscle fiber cross-sectional area, which is a good indicator of muscle hypertrophy. Muscle fiber hypertrophy was particularly marked between 42 and 49 d of age, a period during which fiber area increased by 38%, whereas increases per week were only 22% between 35 and 42 d of age and less than 9% after 49 d of age. The great increase in fiber diameter between 42 and 49 d of age corresponded to the greatest increase in breast yield (+7.6%) observed during the entire period studied. It was also concomitant with the major changes in behavior, especially for walking ability, locomotion, and panting, all of which were significantly affected between 42 and 49 d of age. It has been reported that broilers spontaneously limit their physical activities even when a lot of space is available (Arnould and Faure, 2004) and that physical ability is the dominant determining factor for walking in birds with a high body weight (Bokkers and Koene, 2004). The reduced activity and the increased severe pododermatitis and hock burns at the oldest age may be also linked. Severe pododermatitis is associated with ulcers and inflammation (Mayne, 2005) and suggests that it is likely to be painful (Bradshaw et al., 2002), and therefore might reduce activity. Furthermore, birds with reduced activity spent a lot of time in contact with litter, thus increasing the probability of developing contact dermatitis, especially hock burns. As for gait

and locomotion traits, panting is also probably linked to the increase in BW and development of skeletal muscle. Indeed heart size has been shown to decrease with age in relation to BW (Havenstein et al., 2003) and this may affect the ability of modern broilers to meet the respiratory demands of their bodies and may contribute to the increased incidence of panting and mortality that was observed at the later age in the present study. The overall impairment of welfare and the increase in total N content of the litter may also contribute to a weakened state and explain the increase in mortality rate observed after 42 d of rearing. We are aware that several rearing factors might have exacerbated the effects of age observed on behavioral and welfare variables in the present study. This was the case for bird density, which increased with the age at slaughter, except between 56 and 63 d of age when density was similar, and the small pen area that limited the possibility of movement, affecting the walking ability of the birds and inducing the development of pododermatitis and hock burns.

In this study, meat processing ability was assessed through the measurement of several muscle characteristics, including pH, metabolites, chemical composition, and fiber size, and several classical meat quality traits such as color, water-holding capacity, and texture. Increasing age at slaughter affected the decrease in muscle pH after death. It was decreased, and the final pH value of meat was higher at later ages. Changes in pH mainly occurred between 35 and 49 d of age and were concomitant with changes in lactate and in glycolytic potential, both of which reached their greatest values in 35-d-old chickens. As already discussed above, increased age at slaughter significantly increased muscle fiber size. Previously, within a population of 6-wk-old heavy broilers, the pH of breast muscles exhibiting larger fiber size was higher 15 min postmortem, as was pH_u, and they produced breast meat with reduced L* and reduced drip loss (Berri et al., 2007). Our results confirm the existence of a positive relationship between meat pH and muscle fiber size and that the changes in muscle pH related to age affect certain fresh meat properties such as lightness and drip loss, both of which decreased at later ages. The effects of pH changes related to increasing age at slaughter were less obvious for cooked meat, although cooking loss was greatest for 35-d-old chickens that also exhibited the lowest pH values at 15 min and 24 h postmortem. The lack of impact of increased slaughter age on cooked-meat shear force is consistent with previous results obtained on deboned fillets after rigor, as in the current study (Northcutt et al., 2001). However, variation due to broiler age exists when fillets are harvested before rigor (< 2 h), which corresponds to usual practices in the broiler industry. In case of early deboning, the fillet texture is more tender if it originates from younger

birds instead of older broilers (Northcutt et al., 2001). Broilers slaughtered at 35 d of age had the palest breast meat. Touraille et al. (1981), in broilers, and Baéza et al. (2002), in ducks, reported increases in hemic pigment (myoglobin and hemoglobin) content in muscle and in redness and darkness of meat with age. Moisture content decreased regularly with age, whereas protein and lipid content increased. The greatest breast meat moisture content of chickens slaughtered at 35 d of age could also explain the greatest drip loss after cold storage or after cooking observed at this slaughter age. The increase in protein content of breast and thigh meat has been reported (Singh and Essary, 1974; Touraille et al., 1981; Grey et al., 1983; Zanusso, 2002). The results concerning the lipid fraction of muscle are more contradictory. According to Singh and Essary (1974), there is no drastic effect of age on breast muscle lipid content between 4 and 10 wk of age, whereas a decrease in lipids after 8 wk of age was reported by Touraille et al. (1981) and Grey et al. (1983). Zanusso (2002) reported that lipid levels increased regularly in breast and thigh muscles from 6 to 22 wk of age in chickens. However, all the studies cited are quite old and may be not representative of the strains currently used for heavy broiler production. The changes in fresh meat composition are likely to affect the composition of white cured-cooked meat. Indeed, although the effects of age were less obvious, there was a trend for white cured-cooked meat to contain less water and more protein and lipids with increased slaughter age. Another interesting result was that the shear force of the white cured-cooked meat significantly increased with age, but this variable was not affected in fresh meat. The physical and chemical changes such as decreased moisture and increased muscle fiber size could explain the greater toughness of white cured-cooked processed meat from older broilers. Despite the differences in moisture and shear force value, age had no significant effect on the sensory properties of white cured-cooked meat.

In conclusion, we have demonstrated that producing very heavy broilers by increasing age at slaughter is efficient in producing high amounts of meat presenting characteristics appropriate for further processing. However, such optimization in terms of meat production is counterbalanced by the rapid deterioration of broiler welfare (i.e., lameness, occurrence of contact dermatitis, and thermal comfort) with increasing age and by the environmental impact estimated via the amounts of N and P produced in relation to the weight of meat produced.

LITERATURE CITED

- Allain, V., L. Mirabito, C. Arnould, M. Colas, S. Le Bouquin, C. Lupo, and V. Michel. 2009. Skin lesions in broiler chickens measured at the slaughterhouse: Relationships between lesions and between the prevalence and rearing factors. *Br. Poult. Sci.* 50:407–417.

- AOAC International. 2000. Official Methods of Analysis of AOAC International. 17th ed. AOAC Int., Gaithersburg, MD.
- Arnould, C., and L. Colin. 2008. Relation between a simple measure of activity, lameness and pododermatitis in meat type chickens. Page 73 in Proc. 4th Int. Workshop on the Assessment of Animal Welfare at Farm and Group Level, Ghent, Belgium.
- Arnould, C., and J. M. Faure. 2004. Use of pen space and activity of broiler chickens reared at two different densities. *Appl. Anim. Behav. Sci.* 87:155–170.
- Baéza, E., C. Dessay, N. Wacrenier, G. Marché, and A. Listrat. 2002. Effect of selection on Muscovy duck meat quality. *Br. Poult. Sci.* 43:560–568.
- Baéza, E., G. Marché, and N. Wacrenier. 1999. Effect of sex on muscular development of Muscovy ducks. *Reprod. Nutr. Dev.* 39:675–682.
- Berri, C., E. Le Bihan-Duval, M. Debut, V. Santé-Lhoutellier, E. Baéza, V. Brunel, Y. Jégo, and M. J. Duclos. 2007. Consequence of muscle hypertrophy on Pectoralis major characteristics and breast meat quality of broiler chickens. *J. Anim. Sci.* 85:2005–2011.
- Bokkers, E. A. M., and P. Koene. 2004. Motivation and ability to walk for a food reward in fast- and slow-growing broilers to 12 weeks of age. *Behav. Processes* 67:121–130.
- Bradshaw, R. H., R. D Kirkden, and D. M. Broom. 2002. A review of the aetiology and pathology of leg weakness in broilers in relation to welfare. *Avian Poult. Biol. Rev.* 13:45–103.
- Buche, P. 1990. Racine: un système d'analyse multi-images de coupes sériées. Application à la caractérisation de fibres musculaires. PhD Diss. Rennes I Univ., France.
- Dalrymple, R. H., and R. Hamm. 1973. A method for the extraction of glycogen and metabolites from a single muscle sample. *Int. J. Food Sci. Technol.* 8:439–444.
- Ekstrand, C., B. Algers, and J. Svedberg. 1997. Rearing conditions and foot-pad dermatitis in Swedish broiler chickens. *Prev. Vet. Med.* 31:167–174.
- Gallot, S., C. Riffard, and P. Magdelaine. 2009. Performances techniques et coûts de production en volailles de chair, poulettes et poules pondeuses: résultats 2008. ITAVI, Paris, France.
- Grey, T. C., D. Robinson, J. M. Jones, S. W. Stock, and N. L. Thomas. 1983. Effect of age and sex on the composition of muscle and skin from a commercial broiler strain. *Br. Poult. Sci.* 24:219–231.
- Havenstein, G. B., P. R. Ferket, and M. A. Qureshi. 2003. Carcass composition and yield of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. *Poult. Sci.* 82:1509–1518.
- Hemminga, H., and M. H. Vertommen. 1985. Faecal burn-spots upon the breast-skin of broiler chickens. *Pluimveehouderij.* 15:12–14.
- Honickel, K. O. 1998. Reference methods for the assessment of physical characteristics of meat. *Meat Sci.* 49:447–457.
- Jones, T. A., C. A. Donnelly, and M. S. Dawkins. 2005. Environmental and management factors affecting the welfare of chickens on commercial farms in the United Kingdom and Denmark stocked at five densities. *Poult. Sci.* 84:1155–1165.
- Kestin, S. C., T. G. Knowles, A. E. Tinch, and N. G. Gregory. 1992. Prevalence of leg weakness in broiler chickens and its relationship with genotype. *Vet. Rec.* 131:190–194.
- Knowles, T. G., S. C. Kestin, S. M. Haslam, S. N. Brown, L. E. Green, A. Butterworth, S. J. Pope, D. Pfeiffer, and C. J. Nicol. 2008. Leg disorders in broiler chickens: Prevalence, risk factors and prevention. *PloS ONE*, 3, e1545.
- Mayne, R. K. 2005. A review of the aetiology and possible causative factors of foot pad dermatitis in growing turkeys and broilers. *Worlds Poult. Sci. J.* 61:256–267.
- McLean, J. A., C. J. Savory, and N. H. C. Sparks. 2002. Welfare of male and female broiler chickens in relation to stocking density, as indicated by performance, health and behaviour. *Anim. Welf.* 11:55–73.
- Meluzzi, A., C. Fabbri, E. Folegatti, and F. Sirri. 2008. Survey of chicken rearing conditions in Italy: Effects of litter quality and stocking density on productivity, foot dermatitis and carcass injuries. *Br. Poult. Sci.* 49:257–264.
- Michel, V., E. Prampart, L. Mirabito, V. Allain, C. Arnould, D. Huonnic, S. Le Bouquin, and O. Albaric. 2012. Histologically-validated footpad dermatitis scoring system for use in chicken processing plants. *Br. Poult. Sci.* (In press).
- Monin G., and P. Sellier. 1985. Pork of low technological quality with a normal rate of pH fall in the intermediate post mortem period: The case of Hampshire breed. *Meat Sci.* 13:49–63.
- Naim, M. E., and A. R. Watson. 1972. Leg weakness of poultry—A clinical and pathological characterisation. *Aust. Vet. J.* 48:645–656.
- Newberry, R. C. and J. W. Hall. 1990. Use of pen space by broiler chickens: Effects of age and pen size. *Appl. Anim. Behav. Sci.* 25:125–136.
- Northcutt J. K., R. J. Buhr, L. L. Young, C. E. Lyon, and G. O. Ware. 2001. Influence of age and postchill carcass aging duration on chicken breast fillet quality. *Poult. Sci.* 80:808–812.
- Shepherd, E. M., and B. D. Fairchild. 2010. Footpad dermatitis in poultry. *Poult. Sci.* 89:2043–2051.
- Singh, S. P., and E. O. Essary. 1974. Factors influencing dressing percentage and tissue composition of broilers. *Poult. Sci.* 53:2143–2147.
- Skinner-Noble, D. O., and R. G. Teeter. 2009. An examination of anatomic, physiologic, and metabolic factors associated with well-being of broilers differing in field gait score. *Poult. Sci.* 88:2–9.
- Sørensen, P., G. Su, and S. C. Kestin. 2000. Effects of age and stocking density on leg weakness in broiler chickens. *Poult. Sci.* 79:864–870.
- Süto, Z., P. Horn, J. F. Hensen, P. Sorensen, and J. Csapo. 1998. Carcass traits, abdominal fat deposition and chemical composition of commercial meat type chicken during a twenty week growing period. *Arch. Geflügelk.* 62:21–25.
- Touraille, C., F. H. Ricard, J. Kopp, C. Valin, and B. Leclercq. 1981. Qualité du poulet. 2. Evolution en fonction de l'âge des caractéristiques physico-chimiques et organoleptiques de la viande. *Arch. Geflügelk.* 45: 97–104.
- VonSchmidt, V., and H. Luders. 1976. Zehen- und Sohlenballengeschwüre bei Mastputen. *Berl. Munch. Tierarztl. Wochenschr.* 89:47–50.
- Young, L. L., J. K. Northcutt, R. J. Buhr, C. E. Lyon, and G. O. Ware. 2001. Effects of age, sex, and duration of postmortem aging on percentage yield of parts from broiler chicken carcasses. *Poult. Sci.* 80:376–379.
- Zanusso, J. 2002. Engraissement, structure des muscles et qualité de la viande de volailles: exemple du gavage chez le canard de Barbarie (*Cairina moschata*) et de la castration chez le poulet (*Gallus domesticus*). PhD Diss., Toulouse INP, France.

References

This article cites 29 articles, 10 of which you can access for free at:
<http://jas.fass.org/content/90/6/2003#BIBL>