Factors Influencing Bruises and Mortality of Broilers During Catching, Transport, and Lairage

E. Nijdam,*[,1] P. Arens,† E. Lambooij,† E. Decuypere,‡ and J. A. Stegeman*

*Department of Farm Animal Health, Faculty of Veterinary Medicine, Utrecht University, P.O. Box 80151, 3508 TD Utrecht, The Netherlands; †Animal Science Group of Wageningen University and Research Centre, P.O. Box 65, 8200 AB Lelystad, The Netherlands; and ‡ Laboratory of Physiology and Immunology of Domestic Animals, Faculty of Agricultural and Applied Biological Sciences, Catholic University of Leuven, 3001 Heverlee, Belgium

ABSTRACT A multilevel analysis was performed to identify and quantify risk factors associated with mortality and bruises occurring between catching and slaughter of broiler flocks. The effect of each factor in the final model was expressed as an odds ratio (OR). Data included 1,907 Dutch and German broiler flocks slaughtered in 2000 and 2001 at a Dutch processing plant. The mean dead on arrival (DOA) percentage was 0.46. Percentage of bruises was corrected for economic value. The mean corrected bruises percentage was 2.20. Factors associated with corrected bruises percentage were season, moment of transport, and ambient temperature. Unfortunately, these factors are quite difficult to manipulate. Factors associated with DOA percentage were ambient temperature, moment of transport, catching company, breed, flock size, mean BW, mean compartment stocking density, transport time, lairage time, and the interaction term transport time × ambient temperature. The most important factors that influence DOA percentage, and which can be reduced relatively easily, were compartment stocking density (OR = 1.09 for each additional bird in a compartment), transport time (OR = 1.06 for each additional 15 min), and lairage time (OR = 1.03 for each additional 15 min). In particular, reduction of transport and lairage times might have a major influence due to their large variations. Reducing or removing these factors will reduce DOA percentage. Consequently, profitability and animal welfare will increase.

(*Key words*: broiler, downgrading, risk factor, welfare, transportation)

2004 Poultry Science 83:1610–1615

INTRODUCTION

Worldwide, tens of billions of broilers are slaughtered annually. Before they are slaughtered, the broilers are subjected to an array of events on the last day of their life. The birds are feed withdrawn to reduce fecal contamination, and then they are caught and put into crates or containers. After being transported to the processing plant, they have to wait in the lairage of the processing plant before they are slaughtered. Birds that have died between catching and the moment of slaughter are termed 'dead on arrival' (DOA). Published mean DOA percentage ranges from 0.05 to 0.57% (Löliger and Torges, 1977; Bingham, 1986; Bayliss and Hinton, 1990; Gregory and Austin 1992; Warriss et al., 1992; Ekstrand, 1998). The reported mean percentage of birds that arrive at the processing plant with bruises ranges from 0.022 to 25% (Farsaie et al., 1983; Ekstrand, 1998). The latter range is difficult to interpret, because it may be biased by differences in the methods of meat inspection and carcass grading (Knowles and Broom, 1990). Nevertheless, given the huge numbers of broilers that are slaughtered worldwide, financial losses due to these mortality and injury rates are enormous. Moreover, it implies that the welfare of broilers during this phase of their life is threatened.

The variability within published mortality and injury rates suggests the existence of multiple risk factors. Broilers exposed to such factors are more likely to die or get injured than unexposed birds. According to the literature, factors that influence DOA percentage are catching crew or method (Bayliss and Hinton, 1990; Ekstrand, 1998), transport time (Bayliss and Hinton, 1990; Warriss et al., 1992), lairage time (Bayliss and Hinton, 1990), type of transport crates (Stuart, 1985), time of day of catching and transport (Bayliss and Hinton, 1990), stocking density per crate (Bayliss and Hinton, 1990), age, and sex of the birds (Bayliss and Hinton, 1990). Catching method (Farsaie et al., 1983; Lacy and Czarick, 1994; Ekstrand, 1998), transport time (Scholtyssek and Ehinger, 1976), ambient

Received for publication October 27, 2003.
Accepted for publication June 1, 2004.
[1]To whom correspondence should be addressed: e.nijdam@vet.uu.nl.

Abbreviation Key: AET = apparent equivalent temperature; DOA = dead on arrival; OR = odds ratio.

temperature (Mayes, 1980), stocking density per crate (Scholtyssek and Ehinger, 1976), age at slaughter (Bingham, 1986), mean BW (Mayes, 1980; Griffiths and Nairn, 1984), and sex of the broilers (Mayes, 1980) have been reported to influence bruising.

Thus, the main risk factors are known from previous research; however, in most of the studies referred to above, only one or a few factors for DOA or bruising percentage were investigated. Moreover, the effect of the factors was established using a univariate analysis. Therefore, because these were observational studies, confounding may have occurred (Noordhuizen et al., 1997). As a result, the effect of risk factors may have been overestimated, underestimated, or risk factors may have been missed completely. To take confounding into account, all potential risk factors would have to be analyzed at the same time in a multivariate model.

The aim of this study was to identify factors associated with the mortality and injury rate occurring between catching and slaughtering of broiler flocks slaughtered at a Dutch processing plant, and to quantify their effect by using multilevel analysis. Such knowledge may be helpful to indicate measures to reduce the numbers of DOA birds and bruises. Therefore, profitability and bird welfare could increase.

MATERIALS AND METHODS

Study Population, Data Collection, and Variable Description

The study population comprised 1,907 Dutch and German broiler flocks, originating from 149 broiler farms. These flocks had been slaughtered at one Dutch processing plant in 2000 and 2001. Professional catching companies caught all broiler flocks, and the birds were transported in transport vehicles with container modules. The container modules were a metal frame type containing 8 compartments. After transport, the vehicles were unloaded and the containers with the broilers were laired in a waiting area with fans and sprinkler systems. After lairage, the containers were tipped over automatically and the broilers were dropped onto a conveyor. The broilers were conveyed onto a carousel table where they were hung on a shackle line. Dead broilers were removed at the carousel table.

The bruises of each flock were recorded according to the legislative standards of the Dutch Product Boards for Livestock, Meat and Eggs (PVE, 2001). According to that standard, a bruise is a discoloration of the skin or under the skin due to the presence of blood that is larger than 1 cm^2 for breast and leg, and larger than 2 cm^2 for the wing. Each individual leg and wing can contribute to the total number of bruises in a flock (PVE, 2001).

From each flock the following data were recorded:

1) The number of DOA birds;
2) The percentage of bruises on wings, legs, and breast;
3) Age at slaughter (d);
4) Mean BW (g);
5) Breed (A, B, or C) [broiler flocks of mixed breeds were excluded];
6) Flock size (number of broilers/flock);
7) Catching company (A, B, C, D, or E) [flocks caught by other catching companies or by untrained persons were excluded because of the small number of observations];
8) Loading time (min) of the first transport vehicle;
9) Mean compartment stocking density (birds/compartment);
10) Moment of transport (1 = last load departed from farm before 0800 h., 2 = intermediate, 3 = first load departed from farm after 0800 h)
11) The transport time (min) of the first transport vehicle from the broiler farm to the processing plant;
12) Lairage time (min) of the broilers transported with the first transport vehicle;
13) Season;
14) Ambient temperature (if moment of transport = 1, then minimum temperature at a neighboring meteorological center was used; if moment of transport = 3, then maximum temperature at the center was used; if moment of transport = 2, then the mean of minimum and maximum temperature at the center was used.

Statistical Analyses

Statistical analyses were performed in the SAS-PC System Version 8.1 for Windows

(SAS Institute, 1999) using broiler flock as the statistical unit. The PROC FREQ and PROC MEANS procedures were used for the descriptive analyses, and PROC MIXED was used for the multilevel analyses. The dependent variable DOA was calculated as a percentage, with the total number of dead broilers per flock counted at the processing plant as numerator and the total number of transported broilers per flock as denominator. The assumption of normality of the outcomes was assessed using stem-and-leaf plots and normal probability plots. The distribution of the DOA percentage was skewed, and therefore a logarithmic transformation was applied.

Because the economic value of breast, wings, and legs is not equal, this processing plant gives 5, 3, and 6 credit points to the broiler farmer if no bruises are seen on breast, wings, and legs, respectively. Consequently, corrected bruises percentage was calculated with the formula: $(5/14 \times \text{percentage breast bruises}) + (3/14 \times \text{percentage wing bruises}) + (6/14 \times \text{percentage leg bruises})$. The distribution of the corrected bruises percentage was also skewed. To correct this, a logarithmic transformation was applied.

The 2-tailed partial *F*-test (type III) was used as the elimination criterion for the model building, and the fit of the models was assessed by the –2log likelihood. The flock size was used as weight variable to include each flock proportional to the number of broilers. Poultry farm was used as random effect in the model to take into account that most farms occurred in the data set more than once. All independent variables and biological meaningful 2-way interaction terms were included in the

TABLE 1. Summary statistics of technical characteristics of the 1,907 broiler flocks in the data set included in the study

Factor	Mean	SD	Minimum	Maximum
Flock size	20,433	8,872	1,001	59,431
Age (d)	48.3	1.4	41	57
BW (g)	2,437	144	1,836	3,065
Ambient temperature (°C)	10.8	7.3	–10	34
Stocking density (birds/compartment)	34.5	2.2	25.9	42.7
Loading time (min)	55	17	20	210
Transport time (min)	134	49	15	315
Lairage time (min)	150	84	0	955

preliminary multivariable model. Categorical variables were expressed as dummy variables. Next, the independent variables and 2-way interaction terms were removed manually one by one from the model if $P > 0.10$ (backward selection).

The effect of each factor in the final model was expressed as an odds ratio (OR). In essence, this value is the equivalent to the relative risk, assessing each specific factor relative to its reference class. Hence, a 95% confidence interval excluding 1.0 indicates statistical significance at the $P < 0.05$ levels. The fit of the final model was analyzed by assessing normal probability plots.

RESULTS

Descriptive Results

The 1,907 flocks included in this study were kept on 149 broiler farms. The number of flocks delivered to the processing plant per farm ranged from 1 to 47, with a median of 11. The descriptive results of the 1,907 broiler flocks are given in Table 1. The mean DOA percentage was 0.46, with minimum and maximum values of 0.00 and 16.61%, respectively. The mean corrected bruises percentage was 2.20, with minimum and maximum values of 0.25 and 5.75%, respectively.

Multivariate Analysis for DOA Percentage

In the multivariate model for DOA percentage, 9 variables were associated with the log transformed DOA percentage (Table 2), in addition to one interaction term. A significantly increased percentage of DOA birds were associated with high (>15°C) and low (≤5°C) ambient temperatures. Moreover, a significantly increased percentage of DOA birds were found if the broilers had been transported during the morning (OR = 1.28), or daytime (OR = 1.46), compared with the night. In addition, the percentage of DOA birds increased with increasing BW (OR = 1.10, for each 100-g increase in BW), increasing number of birds per compartment (OR = 1.09 for each additional bird in a compartment), increasing flock size (OR = 1.04 for each additional 10,000 broilers), increasing transport time (OR = 1.06 for each additional 15 min), and increasing lairage time (OR = 1.03 for each additional 15 min). Furthermore, one of the catching companies showed a significantly higher percentage of DOA birds (OR = 1.63) compared with the reference catching company. Breeds B and C showed a significantly lower percentage of DOA birds (OR = 0.67 and 0.76, respectively) in comparison with the reference breed. Finally, the interaction term between ambient temperature and transport time indicated a decreased percentage of DOA birds when the temperature during transport was above 15°C and lower or equal to 20°C, with an OR of 0.96 (95% confidence interval: 0.92, 0.99), and when the temperature was above 20°C and lower or equal to 25°C with an OR of 0.94 (95% confidence interval: 0.91, 0.98).

Multivariate Analysis for Corrected Bruises Percentage

In the multivariate model for corrected bruises percentage, 3 variables were shown to be associated with the dependent variable (Table 3). The corrected percentage of bruises percentage was lower in autumn (OR = 0.37) and spring (OR = 0.49) than in summer. Moreover, transporting the broilers in the daytime resulted in a significantly higher (OR = 1.07) percentage of corrected bruises compared with transporting them at night. Furthermore, ambient temperatures of 5°C and lower increased the risk for bruises (OR = 1.26), whereas ambient temperatures between 20 and 25°C reduce this risk (OR = 0.72) in comparison with the reference category (10 to 15°C). None of the interaction terms in the preliminary model appeared to be significantly associated with the corrected percentage of bruises.

DISCUSSION

In this study, we identified factors associated with DOA and bruises percentages of broilers per flock at a Dutch processing plant, and we quantified their effects by a multivariate analysis. Ambient temperature, catching company, number of broilers in the flock, mean BW, mean compartment stocking density, transport time, and lairage time were all associated with the DOA percentage of broilers. Season, moment of transport, and ambient temperature were associated with the bruises percentage of broilers.

During the last decades, several studies have been published on the relationship between broiler catching and

TABLE 2. Factors associated with the percentage of dead on arrival (DOA) birds in 1,907 broiler flocks slaughtered at a Dutch processing plant in 2000 and 2001

Variable	Percentage of flocks	Odds ratio[1]	95% Confidence interval	
Moment of transport[2]				
Night	42.3	1		
Morning	9.8	1.28***	1.14	1.43
Daytime	48.0	1.46***	1.33	1.61
Ambient temperature[3]				
≤5°C	23.7	1.45*	1.04	2.03
>5°C to ≤10°C	28.6	1.23	0.92	1.65
>10°C to ≤15°C	20.9	1		
>15°C to ≤20°C	16.3	1.54*	1.10	2.14
>20°C to ≤25°C	7.3	2.78***	1.91	4.06
>25°C	3.2	2.52**	1.43	4.45
Catching company				
A	32.0	1		
B	28.4	0.78	0.75	1.00
C	19.9	1.63***	1.44	1.84
D	9.2	0.85	0.72	1.02
E	10.5	0.97	0.80	1.18
Breed				
A	77.1	1		
B	12.3	0.67***	0.59	0.75
C	10.6	0.76***	0.67	0.87
Flock size				
Per 10,000-bird increase	—	1.04*	1.00	1.09
BW				
Per 100-g increase	—	1.10***	1.07	1.14
Compartment stocking density				
Per bird increase	—	1.09***	1.07	1.11
Transport time				
Per 15-min increase	—	1.06***	1.02	1.08
Lairage time				
Per 15-min increase	—	1.03***	1.02	1.03

[1]Odds ratio of 1 = reference value for that variable.

[2]Moment of transport: Night = last load departed from farm before 0800 h; morning = intermediate; daytime = first load departed from farm after 0800 h.

[3]Ambient temperature: If moment of transport = night, then minimum temperature at a neighboring meteorological center was used; if moment of transport = daytime, then maximum temperature at the meteorological center was used; if moment of transport = morning, then the mean of minimum and maximum temperature at the meteorological center was used.

*P < 0.05; **P < 0.01; ***P < 0.001.

transport and mortality rates, bruises percentage, or both (Scholtyssek and Ehinger, 1976; Mayes, 1980; Farsaie et al., 1983; Griffiths and Nairn, 1984; Stuart, 1985; Bingham, 1986; Bayliss and Hinton, 1990; Warriss et al., 1992; Lacy and Czarick, 1994; Ekstrand, 1998). However, in these studies, risk factors were only identified and the sizes of their effects were not quantified. Knowledge of the magnitude of effects is necessary to establish the reduction of DOA birds or bruises percentage of broilers that could be obtained by removing or reducing these risk factors. In contrast to our study, the studies above were not analyzed by a multivariate statistical model and consequently, were unable to deal with confounding and interaction (Noordhuizen et al., 1997). Finally, our analysis took into account that some flocks originated from the same farm, whereas other studies did not (Scholtyssek and Ehinger, 1976; Mayes, 1980; Farsaie et al., 1983; Griffiths and Nairn, 1984; Stuart, 1985; Bingham, 1986; Bayliss and Hinton, 1990; Warriss et al., 1992; Lacy and Czarick, 1994; Ekstrand, 1998). Consequently, the variance of the parameters estimated in those studies may have been underestimated and, as a result, the statistical tests may have been too liberal (SAS Institute, 2000). Warriss et al. (1992) found that the mean DOA percentage was 1.81 times higher when broilers had been transported for more than 4 h compared with transports of shorter duration. In this study, transport time was taken into account as a continuous variable, which gives more detailed information, so a real comparison is not possible. In the present study, an OR of 1.04 per 15 min increase in transport time was found. For a transport time of 4 h, the OR would be 1.87. In our study, the maximum transport time was 315 min, which gave an OR of 2.27.

In the present study, the maximum lairage time was 955 min. The OR was 1.03 per 15 min increase in lairage time, which means an OR of 6.57 for a lairage time of 955 min. These results show that the risk of death during transport or lairage increases enormously as time increases. Improvement in logistics and planning in the lairage area of the processing plant will lead to a decrease of mortality; for example, by accepting only broilers of farms within 2 h of the processing plant and keeping lairage time as short as possible.

Handling (Knowles and Broom, 1990), crating (Kannan and Mench, 1996), and transport (Freeman et al., 1984)

TABLE 3. Factors associated with the percentage of corrected bruises in 1,907 broiler flocks slaughtered at a Dutch processing plant (2000–2001)

Variable	Percentage of flocks	Odds ratio[1]	95% Confidence interval	
Season				
Summer	26.5	1		
Autumn	26.1	0.37**	0.20	0.68
Winter	24.2	1.12	0.59	2.12
Spring	23.2	0.49*	0.25	0.94
Moment of transport[2]				
Night	42.3	1		
Morning	9.8	1.04	1.00	1.08
Daytime	48.0	1.07***	1.03	1.11
Ambient temperature[3]				
≤5°C	23.7	1.26**	1.06	1.50
>5°C to ≤10°C	28.6	1.15	0.99	1.33
>10°C to ≤15°C	20.9	1		
>15°C to ≤20°C	16.3	0.98	0.83	1.16
>20°C to ≤25°C	7.3	0.72**	0.57	0.90
>25°C	3.2	0.85	0.62	1.17

[1]Odds ratio of 1 = reference value for that variable.

[2] Moment of transport: Night = last load departed from farm before 0800 h; morning = intermediate; daytime = first load departed from farm after 0800 h.

[3] Ambient temperature: If moment of transport = night, then minimum temperature at a neighboring meteorological center was used; if moment of transport = daytime, then maximum temperature at the meteorological center was used; if moment of transport = morning, then the mean of minimum and maximum temperature at the meteorological center was used.

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

are known stressors. Apart from stress caused by these factors, broilers suffer metabolic exhaustion due to feed and water withdrawal during a large part of the last day of their life. Broilers may lose live weight (Veerkamp, 1986), glycogen stores may be depleted (Warriss et al., 1988), and hyperthermia can occur during lairage (Warriss et al., 1999). The stress and metabolic exhaustion most likely contributes to mortality during transport and lairage.

For DOA and corrected bruises percentages, catching and transporting during daytime was found to be a risk factor. Duncan and Kite (1987) found increased tonic immobility, which is an indicator of increased fear, when broilers were handled in bright light (88 lx) compared with handling in the dark (0.35 lx). This phenomenon might be an explanation for the higher DOA percentage in broilers caught and transported during daytime. Moreover, the increased percentage of bruises may have resulted from higher activity of broilers during daytime.

Both low and high temperatures increase the DOA percentage. A good explanation for this increase might be thermal stress. Mitchell and Kettlewell (1998) linked physiological stress to thermal microenvironment during transport with a combined index called "apparent equivalent temperature" (AET). This parameter combines the dry-bulb temperature and vapor density, which can be calibrated by physiological indicators to give a measure of stress. An AET value <50°C is considered safe for the transport of poultry. Apparent equivalent temperature values between 50 and 70°C are potentially stressful if maintained for prolonged periods and may lead to some mortality. Values >70°C are considered stressful with a high risk of mortality. During a normal summer journey of 3 h, with an ambient temperature around 21°C, the AET value can be 62.3°C. However, AET may become too high when the curtains of transport vehicles are closed at low ambient temperatures. Mitchell and Kettlewell (1998) found a maximum AET of 81.7°C during winter journeys of 3 h with closed curtains, with an ambient temperature around 10°C. At an AET value of 80°C or more, hyperthermia (>1.5°C) is profound and may become life threatening (Mitchell and Kettlewell, 1998). A high AET may be a part of the explanation for mortality both at high and low temperatures. Another part of the explanation may be high temperatures in the broiler house during catching.

The interaction between ambient temperature and transport time resulted in a smaller increase of DOA percentage than would have been expected from the separate effects of ambient temperature between 15 and 25°C and transport time. This is in accordance with data produced by Webster et al. (1992), who observed that broilers transported in an open transport vehicle would be thermally comfortable when the ambient temperature was between 18 and 26°C. Longer transport times are more severe outside this zone.

An increase of the compartment stocking density likely results in an increase of the environmental humidity, due to water evaporation from the respiratory tract, skin, and excreta. Under these circumstances, heat loss will be more difficult, which can lead to hyperthermia. A heavier BW makes it also more difficult to lose heat (Dawson and Whittow, 1994).

It is unclear why fewer bruises were observed during spring and autumn. Other factors not included in our data set, such as rain or wind, could have an effect. Bruises may originate in the broiler house several days before slaughter.

A member of a catching company has to load between 1,000 and 1,500 birds/h. Larger flocks mean an increased catching time. For a member of a catching team, it could be difficult to maintain concentration and exercise care throughout a longer catching time. To do the job optimally, the size of a catching crew would need to be increased, which increases labor costs. Bayliss and Hinton (1990) reported that 35% of the mortality in DOA broilers could be accounted for by catching and transport injuries. Besides the human factor, which influences the mortality in large flocks, the longer feed withdrawal time might have an influence on mortality.

In conclusion, changing management at the processing plant can reduce the effects of some of the factors that impact mortality or corrected percentage of bruises. Mortality can be reduced by reducing transport and lairage time. Controlling AET (and only using the curtains of the transport vehicle when the AET is low) may reduce the effect of low ambient temperatures on mortality. Finally, processing plants can change the time at which they slaughter the birds. To reduce DOA broilers, it is recommended that processing begin around midnight rather than at 0500 h. Changing the processing time may also reduce the corrected bruises percentage.

Better insight into the effect of these risk factors on the physiology of broilers is necessary to reduce stress and suffocation and thereby reduce DOA percentage; such changes would improve the welfare of the broilers during the last day of life.

REFERENCES

Bayliss, P. A., and M. H. Hinton. 1990. Transportation of broilers with special reference to mortality rates. Appl. Anim. Behav. Sci. 28:93–118.

Bingham, A. N. 1986. Automation of broiler harvesting. Poult. Int. 25:41–42.

Dawson, W. R., and G. C. Whittow. 1994. Regulation of body temperature. Pages 343–390 in Sturkie's Avian Physiology. 5th ed. G. C. Whittow, ed. Academic Press, London.

Duncan, I. J. H., and V. G. Kite. 1987. Pages 30–36 in Annual Report for 1986–1987. AFRC Institute of Animal Physiology and Genetics Research, Edinburgh Research Station, Roslin, UK.

Ekstrand, C. 1998. An observational cohort study of the effects of catching method on carcass rejection rates in broilers. Anim. Welf. 7:87–96.

Farsaie, A., L. E. Carr, and C. J. Wabeck. 1983. Mechanical harvest of broilers. Trans. ASAE 26:1650–1653.

Freeman, B. M., P. J. Kettlewell, A. C. C. Manning, and P. S. Berry. 1984. Stress of transportation for broilers. Vet. Rec. 114:286–287.

Gregory, N. G., and S. D. Austin. 1992. Causes of trauma in broilers arriving dead at processing plants. Vet. Rec. 131:501–503.

Griffiths, G. L., and M. E. Nairn. 1984. Carcass downgrading of broiler chickens. Br. Poult. Sci. 25:441–446.

Kannan, G., and J. A. Mench. 1996. Influence of different handling methods and crating periods on plasma corticosterone concentrations in broilers. Br. Poult. Sci. 37:21–31.

Knowles, T. G., and D. M. Broom. 1990. The handling and transport of broilers and spent hens. Appl. Anim. Behav. Sci. 28:75–91.

Lacy, M. P., and M. Czarick. 1994. Field testing of a mechanized broiler harvesting system. Poult. Sci. 73(Suppl. 1):41. (Abstr.)

Löliger, H. C., and H. G. Torges. 1977. Tierschutzgerechter Transport beim Geflügel. 1. Umfang und Durchführung der Transporte. Du and das Tier 7:27–30.

Mayes, F. J. 1980. The incidence of bruising in broiler flocks. Br. Poult. Sci. 21:505–509.

Mitchell, M. A., and P. J. Kettlewell. 1998. Physiological stress and welfare of broiler chickens in transit: Solutions not problems! Poult. Sci. 77:1803–1814.

Noordhuizen, J. P. T. M., K. Frankena, C. M. van der Hoofd, and E. A. M. Graat. 1997. Application of Quantitative Methods in Veterinary Epidemiology. Wageningen Pers, Wageningen, The Netherlands.

PVE. 2001. Beoordelingssysteem kwaliteit vleekuikens. Product Boards for Livestock Meat and Eggs (PVE), Zoetermeer, The Netherlands.

SAS Institute. 2000. SAS/STAT User's Guide, Version 8, Volumes 1, 2, and 3. SAS Institute, Inc., Cary, NC.

Scholtyssek, S., and F. Ehinger. 1976. Transporteinflüsse auf broiler und deren schlachtkörper. Arch. Geflügelkd. 40:27–35.

Stuart, C. 1985. Ways to reduce downgrading. Worlds Poult. Sci. J. 3:16–17.

Veerkamp, C. H. 1986. Fasting and yield of broilers. Poult. Sci. 65:1299–1304.

Warriss, P. D., E. A. Bevis, S. N. Brown, and J. E. Edwards. 1992. Longer journeys to processing plants are associated with higher mortality in broiler chickens. Br. Poult. Sci. 33:201–206.

Warriss, P. D., S. C. Kestin, S. N. Brown, and E. A. Bevis. 1988. Depletion of glycogen reserves in fasting broiler chickens. Br. Poult. Sci. 29:149–154.

Warriss, P. D., T. G. Knowles, S. N. Brown, J. E. Edwards, P. J. Kettlewell, M. A. Mitchell, and C. A. Baxter. 1999. Effects of lairage time on body temperature and glycogen reserves of broiler chickens held in transport modules. Vet. Rec. 145:218–222.

Webster, A. J. F., A. Tuddenham, C. A. Saville, and G. B. Scott. 1992. Thermal stress on chickens in transit. Br. Poult. Sci. 34:267–277.