Risk Factors for Abattoir Condemnation of Turkey Carcasses Due to Cyanosis in Southern Ontario

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ABSTRACT Cyanosis is a category of condemnation for poultry, as defined by Agriculture and Agrifood Canada. A retrospective study to examine the seasonal patterns and trends for turkey cyanosis condemnation was conducted for the years 1987 to 1995 with the use of condemnation records made available by a single abattoir in Ontario. Condemnation for cyanosis had a significant seasonal pattern, with major losses occurring in the colder months (October to March). A prospective longitudinal study was conducted during January to March and October to December 1996 in the same abattoir and the 75 turkey farms that contracted to process their birds through it and all the 913 truckloads of turkeys processed in these two 3-mo periods. The data from this prospective study were used for multivariate modeling of the effects of potential risk factors on the incidence of cyanosis. Risk factors (at $P \leq 0.05$) included bird type (broiler age turkeys, mature toms, and mature hens compared to toms and hens), ambient temperature (cold: –9.9 to 0.0 C and very cold: ≤–10.0 C compared to mild: >0.0 C), clean-out lot (the last shipped from a poultry house), shipping time ≥8 h, and emaciation (proportion of turkeys in the lot condemned for insufficient muscle mass). The crate density was a sparing factor, and an increase in turkey density during shipping resulted in a lower incidence of cyanosis. This study suggested that the number of turkeys condemned for cyanosis was associated with cold, shipping stress, and subclinical syndromes.

(*Key words*: cyanosis, turkeys, abattoir condemnations, risk factors)

2000 Poultry Science 79:831–837

INTRODUCTION

Cyanosis is one of the leading causes of condemnation of poultry in Canada; however, there are essentially no reports in the peer-reviewed scientific literature that examine risk factors for this condition. Hypotheses for its etiopathogenesis have been put forward by personnel working in the field, including 1) the dark color may be one of the symptoms of septicemia-toxemia, 2) the dark color may be due to the emaciated condition of the carcass, and 3) stress, particularly that of transport or temperature extremes, may be a risk factor for cyanosis (Mallia, 1998). There is no published evidence available with which to accept or refute these hypotheses.

Many workers have linked stress of one type or another with color changes in meat. Stress factors that stimulate striated muscle through an adrenergic mechanism or a contractile mechanism are known to result in dark, firm, and dry (DFD) meat in mammals (Bendall and Swatland, 1988; Tarrant 1989). It has been noted that meat from turkeys condemned for cyanosis had DFD traits (Mallia et al., 1996), therefore risk factors of importance for DFD in other species may be similar to those for cyanosis in turkeys. Several reports in the literature suggested that a DFD-like condition may occur in chickens, and putative risk factors include temperature extremes, food deprivation (Freeman, 1971; Wood and Richards, 1975), and the presence of intercurrent disease (Josephson et al, 1949; Chubb et al., 1964; Kendler and Harry, 1967). Cold stress due to increased air movement and low ambient temperatures during shipping resulted in the increased use of glycogen reserves in poultry (Nicol and Saville-Weeks, 1993; Webster et al., 1993). Low glycogen reserves at the time of slaughter are believed to be the only prerequisite for the occurrence of DFD (Nielsen, 1981). Risk factors for DFD in various species have been discussed in several studies: swine (Bendall and Swatland, 1988), cattle (Tarrant, 1989), sheep (Apple et al., 1995), rabbits (Jolley, 1990), turkeys (Mallia et al. 1996), and chickens (Mallia et al., 1997).

Stress is a challenging phenomenon to define or assess in a scientific context, but many aspects of poultry production may exert some degree of stress, perhaps sufficient

Received for publication June 16, 1999.
Accepted for publication February 23, 2000.
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Abbreviation Key: DFD = dark, firm, and dry; SUMCOND = proportion of carcasses condemned for airsacculitis, cellulitis, peritonitis, septicemia, and synovitis per 10,000 birds.

in magnitude to contribute to cyanosis, and which vary enough under natural conditions to allow us an opportunity to elucidate their role. Among the plausible management factors that fall into this category are the length of time that birds are required to remain within crates prior to slaughter and the ambient temperature on the day of transport.

Despite the fact that cyanosis is among the most important of the categories of turkey condemnation at slaughter in Canada, no published studies have described the temporal pattern of this condition or its incidence among the various types of turkeys (toms, hens, and broilers) that are marketed. Given this background, the objectives of this study were to examine the association between cyanosis and potential risk factors and to examine the seasonal pattern of cyanosis in turkeys with a substantive data set collected over several years.

MATERIALS AND METHODS

The study population comprised turkeys slaughtered at a single abattoir in southern Ontario, processing birds from all over the southern portion of the province and the state of Michigan. A retrospective study examined seasonal patterns for cyanosis condemnation during the years 1987 to 1995 by using condemnation records from this abattoir. A prospective longitudinal study was conducted during January to March and October to December 1996, collecting data from this abattoir for multivariate modeling of the effects of potential risk factors on the incidence of cyanosis.

Data Collection

Carcasses were condemned based on criteria established by Agriculture and Agrifood Canada (AAFC). Incidence of condemnation for cyanosis was expressed as the number of birds condemned per truckload, standardized to 10,000 turkeys. The various other condemnation categories were expressed as the proportion condemned per truckload. Ambient daily temperatures during the study period were obtained (Weather Office, Environment Canada; http://www.weatheroffice.com). As part of its own management system, the study abattoir maintained a database that identified various factors (Tables 1 and 2), and information on other potential risk factors were recorded on a report sheet designed in conjunction with personnel from the slaughter plant. Several potential levels of animal aggregation (clustering) were identified: various numbers of birds were loaded into trucks for transport to slaughter and truckload was the unit of analysis and concern. For the purposes of this study, lot, the lowest level of aggregation of truckloads, was defined as the group of one or more truckloads of turkeys originating from the same barn, loaded and shipped to the plant simultaneously, and processed as one unit; truckloads within a lot were, therefore, considered to be repeat measurements for the same lot. The next level of aggregation, flock, was defined as a single placement of turkeys, housed in one or more poultry houses. A flock may give rise to multiple lots. Farm was the highest level of aggregation and was defined as one or more flocks on the same premise and under similar management.

Data Handling and Analysis

Data were initially entered into database files and subsequently converted into SAS[2] files for statistical analysis (SAS Institute, 1997). Nine years of data (1987 to 1995) were used to examine seasonality, which was formally measured with the ranks test, a nonparametric ANOVA procedure (Friedman, 1937; Kendall et al., 1983, Kendall and Ord, 1990).

The distribution of the data for the multivariate model fitted the special case of an extremely small binomial probability (Steel et al., 1997), which, coupled with a large sample size, was consistent with the Poisson distribution. A log linear model was built (link function = log) with the response variable being a count of cyanosis per truckload using PROC GENMOD. The total number of birds per truckload was used as the offset variable. A random effects model was fitted in the PROC VARCOMP with the Type 1 method and was utilized to establish the relative proportions of variability of the outcome due to each of the possible levels of clustering (farm, flock, and lot). The components of variability due to each of the three possible levels of clustering were also estimated by fitting the random effects model (Snedecor and Cochran, 1980) in PROC MIXED. This procedure suggested that correction for over-dispersion was most appropriate at the lot level, achieved by the specification of a scale parameter (Dscale) in PROC GENMOD to fit the overdispersed Poisson distribution. The contribution of each main effect in a model was assessed by the use of the chi-squared statistic and F-statistic from the Type 3 analysis. The difference in the scale parameter from unity was used as an indicator of the goodness of fit of the model (SAS, 1997). For comparative purposes, two other models were built, one each correcting for aggregation of data at the farm and barn levels, respectively. This comparison allowed for assessment of the standard errors of the coefficients for a given variable by the adjustment for overdispersion in the three models. The repeated statement (in SAS) was therefore specified as farm, flock, or lot.

Factors were considered for use in multivariable modeling, if significant on screening (univariate analysis) at $P < 0.20$. Bird type, suspected a priori to be a confounder, was forced into the multivariate model. An assessment of missing values and collinearity (Dohoo et al., 1996) was also performed. Although collinearity between variables was fairly low, with r mainly in the 0.20–0.35 range, multicollinearity among variables was evident by the lack of convergence of the model during the iterative process when running several variables concurrently. If neces-

[2]Statistical Analysis Systems Inc., Cary, NC.

TABLE 1. Categorical bird, shipping, and lairage factors examined as potential risk factors for cyanosis (n = 913 truckloads of turkeys)

Variable description and levels	Truckloads (no.)	Birds condemned per truckload of 10,000 (no.)			
		Mean	Minimum	Maximum	*P*-value[1]
Bird type (age)					
Broiler (9–10 wk)	203	16	0	579	0.65
Hen (13–14 wk)	194	13	0	694	0.01
Mature tom	9	68	0	301	0.06
Mature hen	46	47	0	750	0
Tom[2] (16–21 wk)	460	19	0	833	NA[3]
Clean-out lot (last lot from barn)					
Yes	238	27	0	579	0
No[2]	616	15	0	833	NA
Shipping time: travel between farm and plant					
Long time ≥8 h	14	55	0	269	0.02
Short time <8 h[2]	898	18	0	833	NA
Lairage time: wait at plant prior to slaughter					
Long time ≥8 h	406	20	0	833	0.79
Short time <8 h[2]	506	18	0	750	NA
Tarp (during shipping)					
No	478	12	0	278	0
Yes[2]	375	27	0	833	NA
Shelter doors: closure during lairage					
No	532	9.9	0	301	0.01
Yes[2]	321	33	0	833	NA
Fans: on during lairage					
Yes	51	11	0	278	0.1
No[2]	803	19	0	833	NA
Temperature: ambient					
Very cold ≤–10.0 C	105	36	0	230	0
Cold = –9.9 C to 0.0 C	332	26	0	833	0
Mild ≥+0.1 C[2]	475	10	0	301	NA

[1]From univariate Poisson regression, with the number of birds condemned for cyanosis per 10,000 birds as the outcome.

[2]Reference level.

[3]NA = not available.

sary, and if meaningful biologically, variables showing multicollinearity were grouped together to form a single summary variable. Otherwise, one or more variables were excluded from the model—usually those that were the least biologically plausible.

The remaining significant variables were subjected to a backward elimination Poisson regression analysis procedure until only variables with $P \leq 0.05$ and the forced variable (bird type) were left in the model. Biologically meaningful interaction terms were constructed from significant main effects and were offered for inclusion in the final model.

The relative significance of each factor was expressed with e^{β} values. In essence, this value is the equivalent of the relative risk, assessing each specific factor such as hen in comparison with its reference unit (tom for this example). Hence, a 95% confidence interval excluding 1.0 indicated statistical significance at the <0.05 level.

RESULTS

Seasonality

A significant seasonal effect was present in the proportion of carcasses condemned for cyanosis ($\chi^2 = 41.7$; 11 d.f.). Additional noteworthy points are 1) the 3 mo with the highest proportion of condemnations for cyanosis were within the November to March period for all nine years; 2) a sudden drop in condemnations in late September to early October, followed by a rapid increase in numbers after mid-October; 3) December proportions were considerably lower than those for January, despite similarities in minimum, maximum, and average monthly temperatures; and 4) from 1992 to 1995, the 3 mo with the highest proportions condemned for cyanosis have consistently been winter months after December.

Variability Within Various Levels of Bird Aggregation

Most of the variability in the outcome (number of cyanotic turkeys per truckload) was present at the lot level; this outcome was evident in the variance components and mixed model procedures that were used for this analysis. Lot-level variation, as determined by the variance component procedure, was relatively more important in explaining the occurrence of cyanosis (60.2%) than the barn-level variation (0.0%) or the farm-level variation (14.1%). The random mixed-model approach used to assess the relative proportions of variation resulted in values of 30.5, 8.9, and 4.1%, respectively, for lot-level, barn-level, and farm-level variation. Both methods indicated that the largest component of variability was attributable to the lot level, therefore model interpretation was conducted at the lot level.

Descriptive Statistics and Variable Screening

Bird, shipping, temperature, and lairage categorical risk factors are presented in Table 1 with mean (= variance for a Poisson distribution) numbers of birds on truckloads condemned for cyanosis per 10,000 birds processed (the outcome variable). Similarly, Table 2 shows the continuous risk factors and associated descriptive statistics. The results of screening for simple association with the outcome (univariate analysis) are also presented in these tables.

Variable Selection, Multicollinearity, and Interaction

Multicollinearity was encountered among several variables. A number of the condemnation categories were multicollinear, consequently airsacculitis, cellulitis, peritonitis, septicemia, and synovitis were grouped to form SUMCOND, the sum of these categories of bacteria-related condemnations per 10,000 turkeys. Emaciation and hepatitis were not collinear and were modeled separately. Temperature maximum, minimum, and average were highly correlated, and temperature average was selected. Temperature average was also highly correlated with tarping of truckloads, closing of shelter doors, and use of fans. Although the latter three variables were probably intervening variables, they were not considered further because of this high correlation. Lairage time was not found to be significant by the univariate analysis. The interaction term ambient temperature × shipping time was also subsequently modeled once the main effects were established but was not significant.

Multivariate Models

The final Poisson regression models based on clustering adjustment at the lot, barn, and farm levels are presented in Tables 3 to 5, respectively. Because these models are similar, most of the interpretation is based on Table 3, whereas important differences in the models that can be attributed to clustering at the various levels are described subsequently. Bird type, ambient temperature, number of birds per crate, clean-out, shipping time, and proportion of carcasses condemned for emaciation per 10,000 were significant factors in the final model. All but one were associated with increased risk of cyanosis; the number of birds per bay was negatively associated with the outcome variable.

On average, a truckload of birds traveling during very cold or cold ambient temperatures was likely to have a 4.2 ($e^{\beta} = 4.27$) and 2.2 ($e^{\beta} = 2.24$) unit increase, respectively,

TABLE 2. Continuous bird, shipping, and lairage factors examined as potential risk factors for cyanosis (n = 913 truckloads of turkeys)

	Birds condemned per truckload of 10,000 (no.)			
Description and categories[1]	Mean	Minimum	Maximum	*P*-value[2]
Airsacculitis: unilateral or bilateral, acute or chronic inflammation of the air sacs with spread into the bones	107.4	0	4,372	<0.01
Cellulitis: inflammation of the subcutis	33.8	0	958	<0.01
Cyanosis: dark carcass, no other condemnable lesion	18.9	0	833	NA
Emaciation: reduced muscle mass, especially of Pectoralis major; reduced body fat	5.9	0	541	<0.01
Hepatitis: alteration of the liver/no systemic involvement	16.7	0	426	<0.01
Peritonitis: inflammation of the peritoneal lining of the coelom	21.9	0	1,750	<0.01
Septicemia-toxaemia: nonspecific generalized infections or toxic conditions	15.8	0	435	<0.01
Synovitis: inflammation of the synovial membranes of the hock and signs of systemic involvement	3.8	0	164	0.07
Sumcond: summed numbers condemned[3]	205.2	0	4,758	<0.01
Crate density (number of birds per crate)	11.1	3	20	0.18

[1]As defined by Herenda and Franco (1996).

[2]From univariate Poisson regression with the number of birds condemned for cyanosis per 10,000 birds as the outcome.

[3]Sum of carcasses on a liner condemned for airsacculitis, cellulitis, peritonitis, septicemia, and synovitis.

TABLE 3. Poisson regression model for cyanosis clustered by lot[1]

Variable	β	SE(β)	Z	e^{β}	95% CI for e^{β}
Constant	–6.76	0.3	0	0	0.00, 0.00
Bird type[2]					
Broiler	0.81	0.39	0	2.25	1.05, 4.83
Hen	0.02	0.32	1	1.02	0.54, 1.92
Mature hen	1.03	0.34	0	2.79	1.44, 5.39
Mature tom	1.05	0.51	0	2.86	1.06, 7.75
Ambient temperature[3]					
Very cold	1.45	0.19	0	4.27	2.97, 6.15
Cold	0.81	0.22	0	2.24	1.46, 3.44
Birds per bay	–0.09	0.03	0	0.9	0.86, 0.97
Clean out lot	0.68	0.17	0	1.96	1.41, 2.74
Shipping time (≥8 h)	0.66	0.23	0	1.93	1.23, 3.02
Emaciation[4]	0.01	0	0	1.01	1.01, 1.01

[1] β = regression coefficient, Z = Z-score from the PROC GENMOD output found in the statistical software package (SAS, 1997), and CI = confidence interval.

[2] Reference level (the unit used for comparison) is tom.

[3] Reference level is mild = +0.1 C or warmer, cold = –9.9 to 0.0 C, and very cold = –10.0 C or colder.

[4] Proportion of carcasses condemned for emaciation per 10,000 birds.

in the outcome (cyanosis count), compared with a truckload traveling at a milder temperature. A truckload with a shipping time of 8 h or more, on average, had a 1.9 (e^{β} = 1.93) unit increase in the outcome than one with a shipping time of less than 8 h. Truckloads composed of broilers, mature hens, and mature toms had a unit increase in the outcome, when compared to toms, of 2.3, 2.8, and 2.9, respectively (e^{β} = 2.25, e^{β} = 2.79, e^{β} = 2.86); truckloads composed of hens did not have a significant difference in the cyanosis count. On average, a clean-out truckload had a unit increase of outcome of almost 2.0 when compared to liners with regular turkeys (e^{β} = 1.96). Increasing the density of birds on the truckload by the addition of a single bird per crate resulted in a unit decrease in the outcome by 10% (e^{β} = 0.90). An increase of one emaciated bird per 10,000 birds processed did not result in an increase in cyanosis (e^{β} = 1.01). However, an increase of three cyanotic carcasses per 10,000 birds would be observed for an increase of 100 emaciated birds per 10,000 birds (e^{β} = 2.72). The variable estimates from the Poisson regression, clustered by lot, are summarized in Table 3. The models constructed with aggregation at the farm and barn levels had similar variables to those discussed for lot level clustering. The magnitude for the estimates was also comparable, and the direction of the estimates was the same for all significant variables. Relative to the model clustered for lot, that for flock did not include shipping time, but included SUMCOND; the model clustered for farm included both these parameters. An increase of slightly more than two cyanotic carcasses per 10,000 birds was observed for an increase of 2,000 birds condemned for airsacculitis, cellulitis, peritonitis, septicemia, or synovitis per 10,000 birds (e^{β} = 2.23 when clustered by barn, and e^{β} = 2.72 when clustered by farm).

TABLE 4. Poisson regression model for cyanosis clustered by flock[1]

Variable	β	SE(β)	Z	e^{β}	95% CI for e^{β}
Constant	–6.78	0.28	0	0	0.00, 0.00
Bird type[2]					
Broiler	1.03	0.51	0.05	2.8	1.02, 7.65
Hen	0.2	0.28	0.49	1.22	0.70, 2.13
Mature hen	0.7	0.31	0.02	2.02	1.10, 3.70
Mature tom	–0.25	1.76	0.89	0.78	0.03, 24.63
Ambient temperature[3]					
Very cold	1.04	0.28	0	2.86	1.64, 4.96
Cold	0.73	0.21	0	2.08	1.38, 4.96
Birds per bay	–0.1	0.04	0	0.9	0.84, 0.97
Clean out lot	0.93	0.26	0	2.53	1.52, 4.20
Sumcond[4]	0	0	0	1	1.00, 1.00
Emaciation[5]	0.01	0	0	1.01	1.01, 1.01

[1] β = regression coefficient, Z = Z-score from the PROC GENMOD output found in the statistical software package (SAS, 1997), and CI = confidence interval.

[2] Reference level (the unit used for comparison) is tom.

[3] Reference level is mild = +0.1 C or warmer, cold = –9.9 to 0.0 C, very cold = –10.0 C or colder.

[4] Proportion of carcasses condemned for airsacculitis, cellulitis, peritonitis, septicemia, and synovitis per 10,000 birds.

[5] Proportion of carcasses condemned for emaciation per 10,000 birds.

TABLE 5. Poisson regression model for cyanosis clustered by farm[1]

Variable	β	SE(β)	Z	e^{β}	95% CI for e^{β}
Constant	–7.06	0.37	0	0	0.00, 0.00
Bird type[2]					
Broiler	1.21	0.53	0.02	3.34	1.18, 9.47
Hen	0.26	0.28	0.35	1.3	0.75, 2.27
Mature hen	1.07	0.26	0	2.9	1.74, 4.85
Mature tom	0.82	0.44	0.89	2.27	0.96, 5.37
Ambient temperature[3]					
Very cold	1.14	0.21	0	3.14	2.06, 4.76
Cold	0.85	0.29	0	2.23	1.32, 4.10
Birds per bay	–0.08	0.03	0	0.92	0.88, 0.97
Clean out lot	0.73	0.16	0	2.07	1.52, 2.82
Shipping time (≥8 h)	0.87	0.18	0	2.38	1.67, 3.38
Sumcond[4]	0	0	0	1	1.00, 1.00
Emaciation[5]	0.01	0	0	1.01	1.01, 1.01

[1]β = regression coefficient, Z = Z-score from the PROC GENMOD output found in the statistical software package (SAS, 1997), and CI = confidence interval.

[2]Reference level (the unit used for comparison) is tom.

[3]Reference level is mild = +0.1 C or warmer, cold = –9.9 to 0.0 C, and very cold = –10.0 or colder.

[4]Proportion of carcasses condemned for airsacculitis, cellulitis, peritonitis, septicemia, and synovitis per 10,000 birds.

[5]Proportion of carcasses condemned for emaciation per 10,000 birds.

DISCUSSION

The observations that cyanosis was more prevalent in the cold months of the year and that colder ambient temperatures during shipping was a risk factor is consistent with findings in previous studies in poultry. These studies have shown that cold stress due to increased air movement and low ambient temperatures during shipping results in increased use of glycogen reserves (Nicol and Saville-Weeks, 1993; Webster et al., 1993). The seasonal pattern of losses for cyanosis observed in the present study could reflect cold stress among poultry shipped to slaughter that could predispose them to DFD through an increased consumption of glycogen reserves. Conversely, the increased rate of glycolysis observed when birds are subjected to heat stress during transportation appears to favor the occurrence of pale, soft, exudative meat (Wood and Richards, 1975). Modifications of shipping and handling protocols of turkeys in the field could have most effect if enforced in this time period. Indeed, the relatively low losses for cyanosis in October and December compared with September and November, respectively, cannot be explained through climatic factors alone, as weather patterns for adjacent months are similar. Turkeys receive a premium price at Thanksgiving (October in Canada) and Christmas; it is possible that additional care given to flocks of turkeys in these periods, specifically during their raising or shipping, may account for the lower numbers of turkeys condemned for cyanosis.

Increased density could be sparing because the birds are less subject to thermal loss during shipping, lessening the reliance on energy reserves, such as glycogen, to stay warm. It is therefore unlikely that low oxygen tension during shipping is related to cyanosis, contrary to the assertion that the dark coloring of cyanotic carcasses may have been the result of overcrowding in poultry crates (Herenda and Franco, 1996).

Clean-out lots have a higher proportion of birds that do poorly for a variety of reasons, including disease. These lots, and also lots of birds with increased numbers of emaciated turkeys, were associated with the outcome. It is possible that lots of turkeys with a high proportion of subclinical disease or poor management conditions are less well adapted to cope with stressors such as shipping. Although bird type was forced into the model to control confounding, it is evident that variations in susceptibility related to bird type may also reflect differences in the ability to cope with stress on the basis of sex and age.

A number of the risk factors for cyanosis identified in this study could exert their effect by increasing stress. Reports in the literature have shown that longer feed withdrawal times resulted in lower levels of muscular and hepatic glycogen in broiler chickens (Kotula and Wang, 1994, Warris et al., 1988). It has also been shown in other studies that “resting” poultry after shipping (i.e., the lairage time) was found to further exhaust shipped birds, this outcome being due to the lowering of hepatic and muscle glycogen stores in broilers (van Hoof, 1979; Warris et al., 1988, 1990). The stressful environment for poultry during shipping was shown by increased plasma corticosterone levels (Freeman et al., 1984; Duncan, 1989). Stress in chickens raised the ultimate pH of breast muscle (Wood and Richards, 1975) and in another study resulted in darker meat than unstressed birds, possibly due to higher ultimate pH (Walker and Fletcher, 1993). A high ultimate pH and low glycogen reserves at the time of slaughter are the only prerequisite for the occurrence of DFD (Nielsen 1981).

The regression coefficients for emaciation and SUMCOND were very close to 0 in multivariate models in part because the scale refers to unit increase of only one more emaciated bird (or one more condemned bird in the case of SUMCOND) per 10,000. It was, therefore, useful to change the scale to 100 emaciated birds per

10,000 to facilitate interpretation, and when this was done, the corresponding β coefficient was multiplied by 100 to yield e^b of 2.72. The β coefficient for SUMCOND was multiplied by 2,000 for similar reasons with an e^b of 2.23. Although statistically significant, the magnitude of the scale adjustment for SUMCOND suggests that this is not a major risk factor in a biological sense.

The variables tarp, shelter doors, and fans were not modeled due to high collinearity with other variables. Note that these activities are performed on days that are very cold, and especially if the birds travel a long distance. One may speculate that if these activities were not enacted, truckloads traveling long distances on very cold days would sustain heavier losses. However, this study has shown that ambient temperature, crating density, and shipping time remained significantly associated with the outcome, which lends credence to the hypothesis that the dark carcasses that characterize this category of condemnation may be due to a stress-related condition. One such condition is DFD meat, as has been observed in association with transport and lairage stress in cattle and swine.

ACKNOWLEDGMENTS

This work was funded by the Poultry Industry Council, the Canadian Turkey Marketing Agency, and the Ontario Ministry of Agriculture and Food and Rural Affairs. The authors are also grateful to the participating farms and processing plant.

REFERENCES

Apple, J. K., M. E. Dikeman, J. E. Minton, R. M. McMurphy, M. R. Fedde, D. E. Leith, and J. A. Unruh, 1995. Effects of restraint and isolation stress and epidural blockade on endocrine and blood metabolite status, muscle glycogen metabolism, and incidence of dark-cutting Longissimus muscle of sheep. J. Anim. Sci. 73:2295–2307.

Bendall, J. R., and H. J. Swatland, 1988. A review of the relationship oh pH with physical aspects of pork quality. Meat Sci. 24:85–126.

Chubb, L. G., B. M. Freeman, and D. Wakeelin, 1964. The effect of Capillaria obsingnata on the vitamin A and ascorbic acid metabolism in the domestic fowl. Res. Vet. Sci. 5:154–160.

Dohoo, I., C. Ducrot, C. Fourichon, A. Donald, and D. Hurnik, 1996. An overview of techniques for dealing with large numbers of independent variables in epidemiological studies. Prev. Vet. Med. 29:221–239.

Duncan, I.J.H., 1989. The assessment of welfare during the handling and transport of broilers. Page 93 *in*: Proceedings of the 3rd European Symposium on Poultry Welfare, Tours, France.

Freeman, B. M., 1971. Stress and the domestic fowl: A physiological appraisal. World's Poultry Sci. J. 27:263–275.

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

Friedman, M., 1937. The use of ranks to avoid the assumption of normality implicit in the analysis of variance. J. Am. Stat. Assoc. 32:675–701.

Herenda, D. C., and D. A. Franco, 1996. Poultry Diseases and Meat Hygiene. Iowa State University Press, Ames, IA.

Jolley, P. D., 1990. Rabbit transportation and its effects on meat quality. Appl. Anim. Behav. Sci. 28:119–134.

Josephson, E. S., D. J. Taylor, J. Greenberg, and E. M. Nodel, 1949. The ascorbic acid content of the adrenal glands of chicks infected with Plasmodium gallinaceum. J. Natl. Mal. Soc. 8:132–134.

Kendall, M. G., A. Stuart, and J. K. Ord, 1983. The Advanced Theory of Statistics. Vol. 3. 4th ed. Charles Griffin, London, UK.

Kendall, M. G., and J. K. Ord, 1990. Time Series. 3rd ed. Charles Griffin, London, UK.

Kendler, J., and E. G. Harry, 1967. Systemic Escherichia coli infection as a physiological stress in chickens. Res. Vet. Sci. 8:212–218.

Kotula, K. L., and Y. Wang, 1994. Characterization of broiler meat quality factors as influenced by feed withdrawal time. J. Appl. Poult. Res. 3:103–109.

Mallia, J. G., S. Barbut, J.-P. Vaillancourt, A. Muckle, R. Irwin, and S. A. McEwen, 1996. Safety and quality of dark turkey carcasses exhibiting dark, firm, dry characteristics. J. Am. Vet. Med. Assoc. 209:361.

Mallia, J. G., S. Barbut, J.-P. Vaillancourt, S. W. Martin, and S. A. McEwen, 1997. Broiler breast meat color and pH at time of slaughter and 24 hours post-mortem: A dark, firm, dry-like condition. Poultry Sci. 76(Suppl. 1):86. (Abstr.).

Mallia, J. G., 1998. Epidemiological studies of cyanosis in poultry in southern Ontario. Ph.D. Dissertation, University of Guelph, Guelph, Ontario, Canada.

Nicol, C. J., and C. Saville-Weeks, 1993. Poultry Handling and transport. Livestock Handling and Transport. CAB International, Wallingford, UK.

Nielsen, J. N. 1981. The effect of environmental factors on meat quality and on deaths during transportation and lairage before slaughter. Pages 287–297 *in*: Proceedings of the Symposium held at Refnes Gods, Jeloy, Norway.

SAS Institute, 1997. SAS/STAT Software: Changes and Enhancements through Release 6.12. SAS Institute Inc., Cary, NC.

Snedecor, G. W., and W. G. Cochran, 1980. Statistical Methods. Iowa State University Press, Ames, IA.

Steel, R.G.D., J. H. Torrie, and D. A. Dickey, 1997. Principles and Procedures of Statistics, A Biometrical Approach. 3rd ed. McGraw-Hill, New York, NY.

Tarrant, P. V., 1989. Animal behaviour and environment in the dark-cutting condition in beef—A review. Ir. J. Food Sci. Tech. 13:1–9.

van Hoof, J., 1979. Influence of ante- and peri-mortem factors on biochemical and physical characteristics of turkey breast muscle. Vet. Q. 1:29–36.

Walker, J. M., and D. L. Fletcher, 1993. Effect of antemortem epinephrine injections on broiler breast meat color, pH and heme concentration. Poultry Sci. 72(Suppl. 1):138. (Abstr.).

Warris, P. D., S. C. Kesten, S. N. Brown, and E. A. Bevis, 1988. Depletion of glycogen reserves in fasting broiler chickens. Br. Poult. Sci. 29:149–158.

Warris, P. D., C. S. Kestin, E. A. Young, E. A. Bevis, and S. N. Brown, 1990. Effects of preslaughter transport on carcass yield and indices of meat quality in sheep. J. Sci. Food Agric. 51:517–525.

Webster, A.J.F., A. Tuddenham, C. A. Saville, and G. B. Scott, 1993. Thermal stress on chickens in transit. Br. Poult. Sci. 34:267–277.

Wood, D. F., and J. F. Richards, 1975. Effect of some antemortem stressors on postmortem aspects of chicken broiler pectoralis muscle. Poultry Sci. 54:528–531.