Welfare of end-of-lay hens transported for slaughter: effects of ambient temperature, season, and transport distance on transport-related mortality

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ABSTRACT The transport of end-of-lay hens for slaughter presents a particular cause for concern in relation to hen welfare due to their less robust condition. During the period of 1 January 2010 to 31 December 2017, 17,436,074 end-of-lay hens transported for slaughter in 3,144 consignments were monitored, i.e., all hens transported from Czech farms to slaughterhouses in the Czech Republic in the monitored period. The overall mortality of hens during transport for slaughter was 0.516%. A significant ($P < 0.05$) impact of outside temperature and month of the year on transport-related mortality was found. Lower outside temperature was connected with the increased hen mortality and vice versa. Correspondingly, more deaths of end-of-lay hens occurred in the cold winter months of January (0.717%) and December (0.695%); on the contrary, the lowest death rates were recorded in August (0.364%). Differences were also found when comparing transport-related mortality rates according to the transport distance. The lowest mortality (0.338%) was found in hens transported for distances up to 50 km; longer distances were associated with increasing ($P < 0.05$) death rates, with the greatest losses (0.801%) recorded for distances from 201 to 300 km. These findings document the need for increased care for end-of-lay hens during their transport for slaughter in the winter at lower outside transport temperatures, in particular below 0°C (e.g., by adequate temperature regulation in the means of transport), and of hens transported over longer distances (if the transport distance cannot be reduced).

Key words: hen, transport, mortality, temperature, distance

INTRODUCTION

Transportation is an essential component of the poultry industry, and can cause different degrees of stress to birds, ranging from mild discomfort and aversion up to death (Schwartzkopf-Genswein et al., 2012). Mortality during transport is an indisputable indicator of welfare as any animal that dies in transit can be expected to have experienced some degree of suffering before death (Smulders and Algers, 2009; Nielsen et al., 2011). Studies comparing mortality during the transport to a slaughterhouse in different types and categories of livestock have shown a different sensitivity to the transport stress for each species and category of poultry and hence different death rates occurring in connection with their transport to the slaughterhouse (Petracci et al., 2006; Voslarova et al., 2007a; Di Martino et al., 2017). Compared to other species and categories of poultry (especially broiler chickens), however, only few studies have been published analyzing laying hens' mortality during transport and the factors that affect it. However, transport of end-of-lay hens is of a great welfare concern. These birds are notorious for their low economic value and the low profit margins to be obtained from their sale. The cost of carcass processing can even exceed any profit from the sale of meat (Berg et al., 2014). Thus, there is little economic incentive to encourage careful handling and good welfare (Petracci et al., 2006). The fact that the number of commercial slaughter plants accepting end-of-lay hens is limited often means that they are transported for longer distances and exposed to transport conditions longer than other poultry (Weeks et al., 2012). Despite some end-of-lay flocks being killed inside barns (Berg et al., 2014), the majority of end-of-lay hens worldwide are transported for slaughter to poultry processing plants.

Previous studies publishing data on transport-related mortality in end-of-lay hens reported varying mortality rates. Petracci et al. (2006) surveyed 19 hen abattoirs during a 4-yr period (2001 to 2005) in Italy. The data included 54 million slaughtered hens representing 28.4% of the national production and the overall average incidence of dead-on-arrival (**DOA**) was found to be 1.22%. Voslarova et al. (2007a) analyzed the number of hens and cockerels transported for slaughter in the Czech Republic and the number of birds that died during

transport from 1997 to 2006. Altogether, 1.013% out of 51.8 million hens and cockerels transported died during transport. More recent studies indicated a much lower percentage of DOA. In a survey of 13.3 million hens transported during 2009 to 5 slaughter plants, which accounted for about 65% of the hens processed from mainland Britain, the average mortality was 0.27% (Weeks et al., 2012). Di Martino et al. (2017) reported a median DOA of 0.38% among the 3,241 loads of end of lay hens (21,788,124 birds) transported to 3 large abattoirs in northern Italy from 2010 to 2012.

Several factors were identified to affect the mortality of poultry during transport. Main risk factors for DOA include distance travelled (Voslarova et al., 2007a,b; Weeks et al., 2012; Caffrey et al., 2017), season or month of the year (Petracci et al., 2006; Voslarova et al., 2007b), and climatic conditions (Nijdam et al., 2004; Chauvin et al., 2011; Weeks et al., 2012; Caffrey et al., 2017).

The aim of the study was to assess the mortality rates in end-of-lay hens during transportation to slaughterhouses, and the factors that can affect the mortality rates, in particular the ambient temperature, season (month) of the year and transport distance.

MATERIALS AND METHODS

During the period from January 1, 2010 to December 31, 2017, the inspectors of the State Veterinary Administration of the Czech Republic recorded all end-of-lay hens transported for slaughter in the Czech Republic, i.e., a total of 17,436,074 hens transported within 3,144 consignments from 183 Czech farms (operated by 83 business owners) to 15 slaughterhouses in the Czech Republic. In cooperation with the State Veterinary Administration, we analysed deaths of hens, i.e., the number of hen deaths during transport and shortly after at slaughterhouses during the individual years. The data for the whole Czech Republic was collected in database form in the Information Centre of the State Veterinary Administration. The data was analyzed with a programme specially created for these purposes, which generated upon request from this database the reports about the numbers of transported hens having died and converted them into Excel format for further statistical processing.

The total mortality rate was calculated as a percentage of the number of hens having died during transport from the total number of hens transported for slaughter. The mortality rate was also calculated for each consignment separately. We recorded the number of transported and dead hens in each consignment. From the obtained values, we calculated the death rate of laying hens in each consignment.

According to the mortality rate, the consignments were divided into 7 categories: 0.0 to 0.5%, 0.6 to 1.0%, 1.1 to 1.5%, 1.6 to 2.0%, 2.1 to 2.5%, 2.6 to 3.0%, 3.1% and more dead hens per consignment. For each cate-

gory, the number of consignments was determined and we thus received the number of transports for each mortality rate.

To assess the effect of ambient temperature on the death rate of end-of-lay hens during transport to slaughter, ambient temperatures were determined retrospectively in co-operation with the Czech Hydrometeorological Institute, Prague, Czech Republic. Retrospective data on daily average ambient temperatures related to times and locations of transports monitored in our study were obtained from the archives of the Czech Hydrometeorological Institute. For the purposes of our study, all hen shipments were divided into 9 categories (temperature intervals): -6 to -3.1, -3 to -0.1, 0 to $+2.9$, $+3$ to $+5.9$, $+6$ to $+8.9$, $+9$ to $+11.9$, $+12$ to $+14.9$, $+15$ to $+17.9$, and $+18$ to $+21°C$. For each temperature interval, we calculated the hen mortality rate.

To assess the impact of the season in which the consignment took place, we surveyed the total number of transported hens and the number of hens having died in the connection with their transport in each month of the year. The mortality rates in percentages were calculated for the individual months for the whole monitored period.

In order to assess the impact of the transport distance, the consignments were divided into 6 categories (transport distances): up to 50 km, 51 to 100 km, 101 to 200 km, 201 to 300 km, 301 to 400 km, and above 400 km. For the individual transport distances, we recorded the number of transported and the number of dead hens throughout the monitored period. For each transport distance, we calculated the transport-related mortality of the hens.

The data were analysed using the statistical package Unistat v. 6.5. (Unistat Ltd., London, England). Statistical comparisons between the frequencies of the categorical variables of interest were performed with the Chi-square test (with Yates correction) within the 2×2 Contingency table procedure. When the frequencies in the contingency table were lower than 5, a Fisher exact test was used instead of Chi-square test (Zar, 1999). To assess the changes in mortality rates during the monitored years, a Spearman rank correlation coefficient including its significance was calculated (Zar, 1999). A P-value of 0.05 in tests was considered significant.

RESULTS

In the period from 2010 to 2017, a total of 17,436,074 end-of-lay hens were transported, out of which 89,891 (0.516%) hens died in connection with the transportation. The number of dead laying hens in individual consignments differed significantly (Table 1). The average mortality rate per consignment was $0.620 \pm 0.022\%$ (mean $\pm$ standard error of mean), but in 62% of shipments the mortality did not exceed 0.5%, while in 2% of the consignments the mortality was more than 3%. The

Table 1. The pairwise comparisons (*P*-value) of numbers of consignments by transport-related mortality rate of end-of-lay hens.

Mortality (%)						
	0.0 to 0.5					
0.6 to 1.0	0.000	0.6 to 1.0				
1.0 to 1.5	0.000	0.000	1.0 to 1.5			
1.6 to 2.0	0.000	0.000	0.000	1.6 to 2.0		
2.1 to 2.5	0.000	0.000	0.000	0.000	2.1 to 2.5	
2.6 to 3.0	0.000	0.000	0.000	0.000	0.103	2.6 to 3.0
>3.0	0.000	0.000	0.000	0.001	0.163	0.002

P < 0.05 means a statistically significant difference.
P < 0.01 means a statistically highly significant difference.
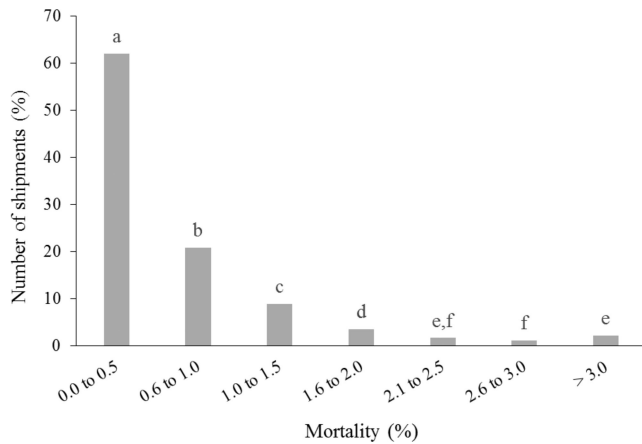
Figure 1. Number of consignments by transport-related mortality rate of end-of-lay hens. [a-f] Mortality in columns with different superscripts differ significantly at *P* < 0.01.
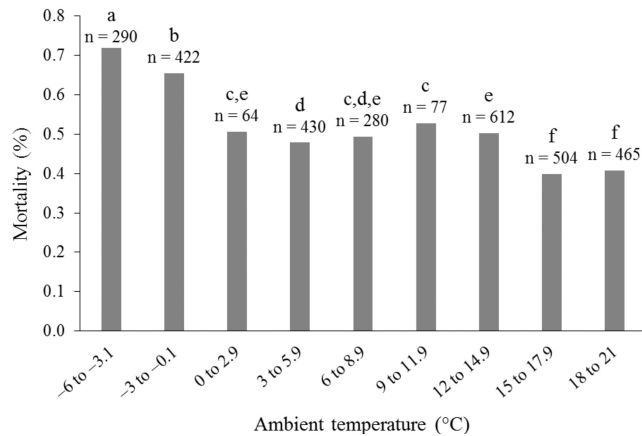
Figure 2. Transport-related mortality of end-of-lay hens as affected by the ambient temperature (n = number of shipments). [a-f] Mortality in columns with different superscripts differ significantly at *P* < 0.01.

distribution of the number of consignments according to the mortality rate of the hens is shown in Figure 1.

End-of-lay hens' transport-related mortality according to the average ambient temperature at which the transport took place, is presented in Figure 2. The results show that the greatest number of deaths occurred at a temperature of −6.0 to −3.1°C (0.718%, i.e., 15% of all deaths) and at a temperature of −3.0 to −0.1°C (0.655%; i.e., 18% of all deaths), i.e., at the lowest temperatures in the monitored period. When transport-

ing at temperatures above 0°C, there were significantly (*P* < 0.01) less deaths of transported hens. The lowest transport-related mortality was found when the average temperature was between 15 and 21°C (the highest average temperature in the monitored period). The pairwise comparisons are given in Table 2.

In addition, different mortality rates were observed during different months of the year (Figure 3). The largest number of deaths was found during the months of January (0.717%) and December (0.695%). On the contrary, the lowest death rates were recorded during August (0.364%). Transport-related mortality rates during August were significantly (*P* < 0.05) lower compared to transports during the other months of the year (Table 3).

The deaths of end-of-lay hens during transportation were also affected by the transport distance (Figure 4). The lowest mortality (0.338%) was found in hens transported for distances up to 50 km; longer distances were associated with increasing (*P* < 0.05) death rates, with the greatest losses (0.801%) recorded for distances from 201 to 300 km. Significantly (*P* < 0.05) lower death rates were recorded for transport over 300 km, but only 30 consignments were transported over a distance of more than 300 km. The pairwise comparisons are given in Table 4.

Transport-related mortality rates in end-of-lay hens in individual years from 2010 to 2017 are shown in Figure 5. The highest mortality was found in 2010 (0.783%) whereas the lowest mortality in hens transported for slaughter was in 2013 (0.376%). However, no statistically significant correlation (r = −0.357, *P* = 0.193) was found between hen mortality rates and monitored years.

DISCUSSION

Ensuring animal welfare is important from a legal, economic and ethical point of view. In activities where welfare disruption is suspected such as the transport of animals to slaughterhouses, it is desirable to identify the risk factors in order to limit their negative effects. One way to achieve this is to evaluate the death rate of animals transported to slaughterhouses and to identify the factors that affect these deaths. Regulating these

Table 2. The pairwise comparisons (*P*-value) of transport-related mortality of end-of-lay hens as affected by the ambient temperature.

Temperature (°C)								
	−6 to −3.1							
−3 to −0.1	0.000	−3 to −0.1						
0 to 2.9	0.000	0.000	0 to 2.9					
3 to 5.9	0.000	0.000	0.004	3 to 5.9				
6 to 8.9	0.000	0.000	0.207	0.076	6 to 8.9			
9 to 11.9	0.000	0.000	0.064	0.000	0.001	9 to 11.9		
12 to 14.9	0.000	0.000	0.658	0.000	0.224	0.003	12 to 14.9	
15 to 17.9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	15 to 17.9
18 to 21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.115

P < 0.05 means a statistically significant difference.
P < 0.01 means a statistically highly significant difference.
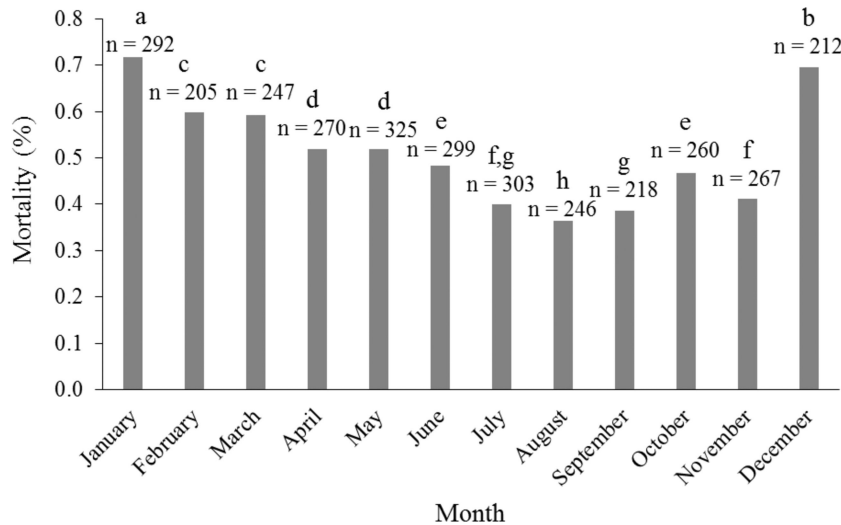
Figure 3. Transport-related mortality of end-of-lay hens as affected by the month of the year (n = number of shipments). [a-f] Mortality in columns with different superscripts differ significantly at *P* < 0.05.

Table 3. The pairwise comparisons (*P*-value) of transport-related mortality of end-of-lay hens as affected by the month of the year.

| Month											
	I										
II	0.000	II									
III	0.000	0.627	III								
IV	0.000	0.000	0.000	IV							
V	0.000	0.000	0.000	0.997	V						
VI	0.000	0.000	0.000	0.000	0.000	VI					
VII	0.000	0.000	0.000	0.000	0.000	0.000	VII				
VIII	0.000	0.000	0.000	0.000	0.000	0.000	0.000	VIII			
IX	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.004	IX		
X	0.000	0.000	0.000	0.000	0.000	0.560	0.000	0.000	0.000	X	
XI	0.000	0.000	0.000	0.000	0.000	0.000	0.112	0.000	0.005	0.000	XI
XII	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

P < 0.05 means a statistically significant difference.
P < 0.01 means a statistically highly significant difference.

negative effects can then lead to a reduction in animal deaths during transport to slaughter.

End-of-lay hens transported for slaughter may be particularly sensitive to increased stress and unsuitable transport conditions (e.g., overcrowding, temperature extremes, excessive or inadequate ventilation, and aversive vibration). The incidence of DOA broiler chickens has been reported to vary from around 0.18% (Chauvin et al., 2011) to values as high as 0.30%
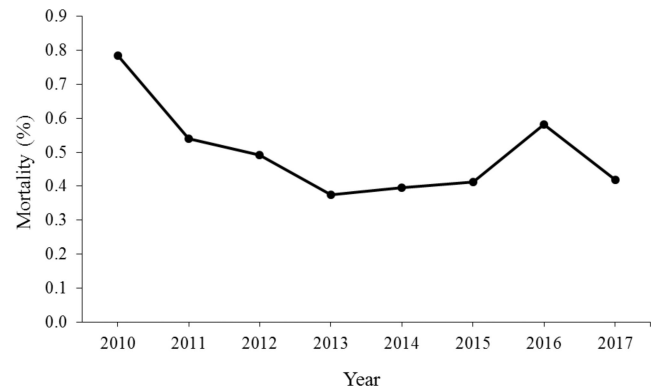
(Jacobs et al., 2017) or even up to 0.46% (Nijdam et al., 2004) within a load in Europe. The published DOA percentages for turkeys varied from 0.147 (Machovcova et al., 2017) to 0.38% (Petracci et al., 2006). Higher mortality of hens during transport to slaughterhouses compared to broiler chickens and turkeys transported for slaughter in Italy during the same period was found by Petracci et al. (2006). They reported an average incidence of DOA 1.22% in
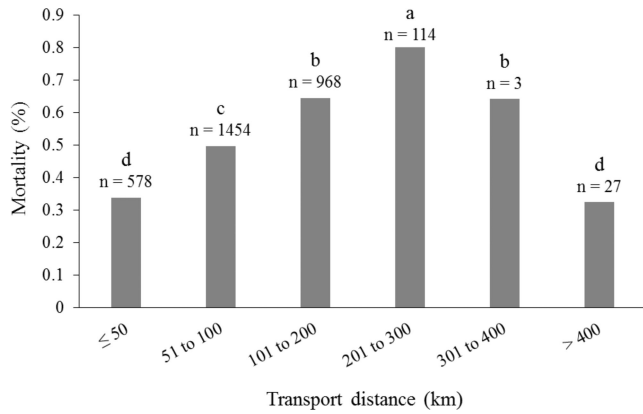
Figure 4. Transport-related mortality of end-of-lay hens as affected by transport distance (n = number of shipments). [a-d] Mortality in columns with different superscripts differ significantly at $P < 0.05$.

Figure 5. Transport-related mortality of end-of-lay hens in individual years of the monitored period (r = −0.357, $P = 0.193$).

end-of-lay hens and confirmed that preslaughter management of hens was very critical for their welfare. Overall mortality among end-of-lay hens transported for slaughter in the Czech Republic from 2010 to 2017 was 0.516%. This is about half the values reported by Petracci et al. (2006) in Italy between 2001 and 2005, but also by Voslarova et al. (2007a,b) in the Czech Republic in the period from 1997 to 2006. Actually, in 62% of the consignments of end-of-lay hens the mortality did not exceed 0.5%. Weeks et al. (2012) reported even more favorable data for end-of-lay hens transported in Great Britain during 2009. They found the average mortality to be 0.27% and 0.5% mortality was not exceeded in more than 90% of the loads. However, they were able to gain access only to data on approximately 65% of the hens processed from mainland Britain with a bias towards free-range systems. In the Czech Republic, the majority of hens are housed in cages (conventional cages were replaced by furnished cages before their ban enforced from 2012). The impact of the laying hen farming system on their condition at the end of laying was described in a number of studies (e.g., Sherwin et al., 2010; Lay et al., 2011; Hartcher and Jones, 2017). It can therefore be assumed that laying hens transported from different housing systems will also have a different ability to withstand transport conditions.

Previous studies on the analysis of poultry mortality during transport to the slaughterhouse also highlight the impact of the outside temperature during transport. Ambient temperature has been identified as a risk factor for mortality during transportation, since it has a direct impact on the transport microclimate (Knezacek et al., 2010; Burlinguette et al., 2012; Richards et al., 2012; Barbosa Filho et al., 2014). Previously, summer transportation under high ambient temperatures was considered a main risk factor for poultry DOA. A number of studies describe the impact of heat stress on transported poultry, especially broiler chickens (e.g., Ritz et al., 2005; Vieira et al., 2011; Schwartzkopf-Genswein et al., 2012). Concurrently, the possibility of reducing the negative impact of high outside temperatures on poultry transported has been sought. Changes of practices used during summer transport might have lead to the decline in bird DOA rates associated with high summer ambient temperatures as suggested by Vecerek et al. (2006, 2016), who have analyzed broiler chickens' deaths during transport in the same region over a longer period of time. Fewer studies deal with the impact of cold stress during poultry transport. According to Schwartzkopf-Genswein et al. (2012) the reason for the increased attention paid to the impact of heat stress in the past was that the transportation studies were limited to those conducted in countries where winters are mild and the main problem with transportation occurs during the summer. Ritz et al. (2005) add as a reason that the occurrence of DOA during hot summer months resulted in a great financial loss whereas cold-stress-induced mortality during transport was perceived by the US industry as too rare to be a serious issue. However, this is particularly true for chickens kept for meat production, in which transport-related

Table 4. The pairwise comparisons (*P*-value) of transport-related mortality of end-of-lay hens as affected by transport distance.

Distance (km)	≤50	51 to 100	101 to 200	201 to 300	301 to 400
51 to 100	0.000				
101 to 200	0.000	0.000			
201 to 300	0.000	0.000	0.000		
301 to 400	0.000	0.005	0.993	0.015	
>400	0.346	0.000	0.000	0.000	0.000

P < 0.05 means a statistically significant difference.
P < 0.01 means a statistically highly significant difference.

mortality is considered an impediment to maximal productivity. Due to low economic value of end-of-lay hens, it is much more difficult to motivate stakeholders to deal with the factors affecting the welfare of hens during transport. Although only few studies have been published analyzing the transport-related mortality rates of end-of-lay hens, most of them point out the increased mortality of hens transported during the cold season. Newberry et al. (1999) found the highest numbers of DOA among hens transported to Canadian processing plants during winter in 1996, with an average of 1.9% mortality rates. However, increased mortality of hens during transport in winter was also observed in areas with a milder (central European) climate. Voslarova et al. (2007b) reported the highest death rates of hens during transport to Czech slaughterhouses in the cold season in the period from 1997 to 2004. While monthly deaths during winter averaged around 1% (maximum at 1.031%), in the warmest months the average deaths fell below 0.4% (minimum at 0.251%). Similarly, Weeks et al. (2012) found that at lower temperatures the hens were at increased risk from dying of cold despite no extreme weather conditions were present in the UK in 2009, when their study was carried out. An exception is only a study by Petracci et al. (2006) who observed the higher DOA percentage in laying hens at the Italian poultry slaughter plants in the period from 2001 to 2005 in summer (1.62%) compared with autumn (1.16%), winter (1.06%) and spring (1.13%). However, a more recent study carried out in Italy between 2010 and 2012 has also confirmed a higher incidence of DOA in winter (Di Martino et al., 2017). Correspondingly, the results of our current study show that there are significant differences in transport-related mortality rates depending on the season of transport, although the numbers of end-of-lay hens transported for slaughter in each month of the year are approximately the same. In accordance with previous studies, the highest number of deaths of hens during their transport for slaughter occurred during winter months, while the lowest death rates were recorded in the summer months. This also corresponds to the analysis of the average outside temperature during transport in relation to transport-related mortality. The highest mortality rates were recorded on the coldest days which occurred in December and January. Our study shows that hens are at an increased risk of dying at temperatures below zero. Laying hens are often very poorly feathered at the point of transport. They may also be subject to physiological fatigue; this coupled with prolonged feed withdrawal before transport could compromise their ability to thermoregulate in the face of thermal challenges, particularly if ambient temperatures are low (Webster et al., 1993). Conversely, the lowest transport-related mortality was found at an average outside temperature of 15 to 21°C (the highest average temperature in the monitored period). Supposedly, the ambient temperature was not high enough to cause a heat stress. Petracci et al. (2006) who observed

increased numbers of hen deaths in summer reported higher summer temperatures than those measured during the monitored period in our study. Birds may become heat stressed if environmental temperature is at or above body temperature (Richards et al., 2012). The models evaluating the microclimate in poultry transport module drawers proposed by Richards et al. (2012) predict that most drawer temperatures will fall below 22°C except in hotter weather.

Differences in the impact of different outside temperatures on the welfare of end-of-lay hens are particularly noticeable when compared with studies assessing the mortality of other species and categories of poultry during transport under comparable conditions, i.e., in the same geographic location and in the same or similar period, hence under similar temperature conditions. Temperatures associated with the lowest risk of death for transported end-of-lay hens were associated with the highest death rates among turkeys transported for slaughter in the Czech Republic (Machovcova et al., 2017). Similarly, the highest death losses in Pekin ducks transported for slaughter in the Czech Republic were found in the summer (Voslarova et al., 2016). Loading and transporting of poultry to the slaughterhouse during early morning hours has a positive impact on the reduction of heat stress in the summer, but the risk of cold stress in cold weather in hens may be even higher. An increase in stocking density in winter transports (as opposed to a reduction in stocking density in the crates to allow better ventilation, reduce metabolic heat and humidity recommended in conditions of hot weather) has not proven to be an effective way to prevent the effects of cold (Strawford et al., 2011; Di Martino et al., 2017), thus it is necessary to seek other means. According to previous studies it is especially important to minimise wind chill by the use of curtains and parking in the lea of buildings or trees and to avoid birds becoming wet (Richards et al., 2012; Weeks et al., 2012).

In terms of transport distances, a similar trend was observed in hens when compared to other poultry species and categories transported to slaughterhouses in the Czech Republic (e.g., Vecerek et al., 2016 in broiler chickens; Machovcova et al., 2017 in turkeys; Voslarova et al., 2016 in Pekin ducks) and elsewhere in the world (e.g., Oba et al., 2009; Aral et al., 2014; Caffrey et al., 2017; Di Martino et al., 2017). The mortality rose with increasing transport distances, with mortalities of 0.338% in hens transported for distances up to 50 km and mortalities of 0.801% in distances from 201 to 300 km. Suprisingly, significantly lower mortality rates were found in hens transported for over 300 km. The reasons could be the increased requirements placed on the long-haul transportation of poultry by Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97 (Council of the European Union, 2005) and the higher levels of professionalism of hauliers during long-haul transport

itself. However, only 30 consignments were transported over such long distances. Considering that previous studies (Newberry et al., 1999; Petracci et al., 2006; Weeks et al., 2012; Di Martino et al., 2017) point out the welfare consequences of long transports for end-of-lay hens due to the limited number of slaughterhouses that accept them, this is to be seen as a positive result. Furthermore, in our study, 64% of the end-of-lay hens were transported to a slaughterhouse located up to 100 km from the farm and 95% of hens were transported over distance up to 200 km. In view of the results of this and other studies, the shortening the transport distance clearly decreases the transport-related mortality rate in hens. From this point of view, the availability of slaughterhouses is critical, as well as the motivation of the farmers and slaughterhouse operators to carry out the slaughter as close as possible to the farm.

Despite smaller mortality rates of end-of-lay hens transported to slaughterhouses when compared to earlier studies (Petracci et al., 2006; Voslarova et al., 2007a,b), the current death rates in hens are still considerably higher than most of those published for other poultry species and categories. During the monitored period, there were visible fluctuations in transport-related mortality in individual years, but no significant trend towards reducing the mortality of hens transported for slaughter at the end of lay was detected. According to Weeks et al. (2012), overall losses in transported hens can be comparatively low despite their lower financial value and less robust condition. The authors propose to modify procedures for catching and transport of end-of-lay hens according to the risk factors. Our results show that, in particular, avoiding cold stress when transporting at below zero temperatures and reducing the length of transport would help to significantly reduce the transport-related mortality rates in end-of-lay hens. Alternatively, stricter requirements should apply to all transports not only to long journeys.

REFERENCES

Aral, Y., M. S. Arikan, A. C. Akin, C. Y. Kaya Kuyululu, S. C. Guloglu, and E. Sakarya. 2014. Economic losses due to live weight shrinkage and mortality during the broiler transport. Ankara Univ. Vet. Fak. Derg. 61:205–210.

Barbosa Filho, J. A. D., M. L. V. Queiroz, D. D. Brasil, F. M. C. Vieira, and I. J. O. Silva. 2014. Transport of broilers: load microclimate during Brazilian summer. Eng. Agric. 34:405–412.

Berg, C., J. Yngvesson, S. Nimmermark, V. Sandstrom, and B. Algers. 2014. Killing of spent laying hens using CO_2 in poultry barns. Anim. Welfare. 23:445–457.

Burlinguette, N. A., M. L. Strawford, J. M. Watts, H. L. Classen, P. J. Shand, and T. G. Crowe. 2012. Broiler trailer thermal conditions during cold climate transport. Can. J. Anim. Sci. 92:109–122.

Caffrey, N. P., I. R. Dohoo, and M. S. Cockram. 2017. Factors affecting mortality risk during transpoitation of broiler chickens for slaughter in Atlantic Canada. Prev. Vet. Med. 147:199–208.

Chauvin, C., S. Hillion, L. Balaine, V. Michel, J. Peraste, I. Petetin, C. Lupo, and S. Le Bouquin. 2011. Factors associated with mortality of broilers during transport to slaughterhouse. Animal. 5:287–293.

Council of the European Union. 2005. Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97. Off. J. Eur. Union. L3:1–44.

Di Martino, G., K. Capello, E. Russo, M. Mazzucato, P. Mulatti, N. Ferre, A. Garbo, M. Brichese, S. Marangon, and L. Bonfanti. 2017. Factors associated with pre-slaughter mortality in turkeys and end of lay hens. Animal. 11:2295–2300.

Hartcher, K. M., and B. Jones. 2017. The welfare of layer hens in cage and cage-free housing systems. World Poultry Sci. J. 73:767–781.

Jacobs, L., E. Delezie, L. Duchateau, K. Goethals, and F. A. M. Tuyttens. 2017. Broiler chickens dead on arrival: associated risk factors and welfare indicators. Poult. Sci. 96:259–265.

Knezacek, T. D., A. A. Olkowski, P. J. Kettlewell, M. A. Mitchell, and H. L. Classen. 2010. Temperature gradients in trailers and changes in broiler rectal and core body temperature during winter transportation in Saskatchewan. Can. J. Anim. Sci. 90: 321–330.

Lay, D. C., R. M. Fulton, P. Y. Hester, D. M. Karcher, J. B. Kjaer, J. A. Mench, B. A. Mullens, R. C. Newberry, C. J. Nicol, N. P. O'Sullivan, and R. E. Porter. 2011. Hen welfare in different housing systems. Poult. Sci. 90:278–294.

Machovcova, Z., V. Vecerek, E. Voslarova, M. Malena, F. Conte, I. Bedanova, and L. Vecerkova. 2017. Pre-slaughter mortality among turkeys related to their transport. Anim. Sci. J. 88:705–711.

Newberry, R. C., A. B. Webster, N. J. Lewis, and C. Van Arnam. 1999. Management of spent hens. J. Appl. Anim. Welf. Sci. 2:13–29.

Nielsen, B. L., L. Dybkjaer, and M. S. Herskin. 2011. Road transport of farm animals: effects of journey duration on animal welfare. Animal. 5:415–427.

Nijdam, E., P. Arens, E. Lambooij, E. Decuypere, and J. A. Stegeman. 2004. Factors influencing bruises and mortality of broilers during catching, transport, and lairage. Poult. Sci. 83:1610–1615.

Oba, A., M. de Almeida, J. W. Pinheiro, E. I. Ida, D. F. Marchi, A. L. Soares, and M. Shimokomaki. 2009. The effect of management of transport and lairage conditions on broiler chicken breast meat quality and DOA (death on arrival). Braz. Arch. Biol. Techn. 52:205–211.

Petracci, M., M. Bianchi, C. Cavani, P. Gaspari, and A. Lavazza. 2006. Preslaughter mortality in broiler chickens, turkeys, and spent hens under commercial slaughtering. Poult. Sci. 85:1660–1664.

Richards, G. J., L. J. Wilkins, C. A. Weeks, T. G. Knowles, and S. N. Brown. 2012. Evaluation of the microclimate in poultry transport module drawers during the marketing process of end-of-lay hens from farm to slaughter. Vet. Rec. 171:474.

Ritz, C. W., A. B. Webster, and M. Czarick 2005. Evaluation of hot weather thermal environment and incidence of mortality associated with broiler live haul. J. Appl. Poultry Res. 14:594–602.

Schwartzkopf-Genswein, K. S., L. Faucitano, S. Dadgar, P. Shand, L. A. Gonzalez, and T. G. Crowe. 2012. Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: a review. Meat Sci. 92:227–243.

Sherwin, C. M., G. J. Richards, and C. J. Nicol. 2010. Comparison of the welfare of layer hens in 4 housing systems in the UK. Brit. Poultry Sci. 51:488–499.

Smulders, F. J., and B. Algers. 2009. Welfare of production animals: assessment and management of risks, 1st Edition, Wageningen Academic Publishers, Wageningen, The Netherlands.

Strawford, M. L., J. M. Watts, T. G. Crowe, H. L. Classen, and P. J. Shand. 2011. The effect of simulated cold weather transport on core body temperature and behavior of broilers. Poult. Sci. 90:2415–2424.

Vecerek, V., S. Grbalova, E. Voslarova, B. Janackova, and M. Malena. 2006. Effects of travel distance and the season of the year on death rates of broilers transported to poultry processing plants. Poult. Sci. 85:1881–1884.

Vecerek, V., E. Voslarova, F. Conte, L. Vecerkova, and I. Bedanova. 2016. Negative trends in transport-related mortality rates in broiler chickens. Asian Austral. J. Anim. 29:1796–1804.

Vieira, F. M. C., I. J. O. Silva, J. A. D. Barbosa Filho, A. M. C. Vieira, and D. M. Broom. 2011. Preslaughter mortality of broilers

in relation to lairage and season in a subtropical climate. Poult. Sci. 90:2127–2133.

Voslarova, E., T. Hytychova, V. Vecerek, K. Nenadovic, and I. Bedanova. 2016. Transport-induced mortality in Pekin ducks transported for slaughter in the Czech Republic. Acta Vet. Brno. 85:205–212.

Voslarova, E., B. Janackova, L. Rubesova, A. Kozak, I. Bedanova, L. Steinhauser, and V. Vecerek. 2007a. Mortality rates in poultry species and categories during transport for slaughter. Acta Vet. Brno. 76:S101–S108.

Voslarova, E., B. Janackova, L. Rubesova, F. Vitula, A. Kozak, and V. Vecerek. 2007b. Effects of transport distance and the season of the year on death rates among hens and roosters in transport to poultry processing plants in the Czech Republic in the period from 1997 to 2004. Vet. Med. Czech. 52:262–266.

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

Weeks, C. A., S. N. Brown, G. J. Richards, L. J. Wilkins, and T. G. Knowles. 2012. Levels of mortality in hens by end of lay on farm and in transit to slaughter in Great Britain. Vet. Rec. 170:647.

Zar, J. H. 1999. Biostatistical analysis. 4 ed. Prentice-Hall, Inc., New Jersey.