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REVIEW

Injury and mortality in broilers during handling and transport to slaughter

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Abstract: Multiple factors affect the risk of broiler injury and mortality during loading, transport, and lairage. These include the physical and pathophysiological condition of broilers before loading and the type of handling procedures used. The external environmental conditions have a major influence on the risk of mortality. Combinations of high stocking density, insufficient ventilation, and high temperature and humidity pose a risk of hyperthermia. Combinations of wet conditions, cold temperature, and air movement, increase the risk of hypothermia. However, protection from cold and wet conditions involves the use of side protection that restricts the trailer ventilation that can cause heat and moisture to build up in the load, increasing the risk of hyperthermia. Modular systems reduce the risk of injury and facilitate unloading into a lairage where temperature and ventilation can be controlled. The duration of loading, transport, and lairage increases the mortality risk. Deaths can occur during each stage and interactions between the duration of the preslaughter stages, the thermal environment, fasting, ill-health, and injury can reduce the physiological capacity of the birds to maintain homoeostasis resulting in exhaustion and death. Quality control and action on the identified risk factors should reduce injury and mortality during preslaughter handling and transport.

Key words: broilers, DOA, handling, injury, mortality, transport.

Résumé : De multiples facteurs ont un effet sur le risque de blessure des poulets à griller pendant le chargement, le transport et la stabulation. Ceux-ci comprennent la condition physique et physiopathologique des poulets avant le chargement et le type de procédures de manutention utilisées. Les facteurs environnementaux externes ont une influence importante sur le risque de mortalité. La combinaison de chargement à grande densité de stockage, une ventilation insuffisante, ainsi que des niveaux élevés de température et d'humidité présente des risques d'hyperthermie. Les combinaisons de conditions mouillées, températures froides et mouvement de l'air augmentent le risque d'hypothermie. Par contre, la protection des conditions froides et mouillées exige l'utilisation de protection latérale qui restreint la ventilation de la remorque, ce qui peut provoquer une accumulation de chaleur et d'humidité dans la cargaison, ce qui augmente le risque d'hyperthermie. Les systèmes modulaires réduisent les risques de blessures et facilitent le déchargement dans la stabulation où la température et la ventilation peuvent être contrôlées. La durée du chargement, du transport et de la stabulation augmente les risques de mortalité. La mort peut survenir pendant chaque étape et les interactions entre la durée des étapes avant l'abattage, l'environnement thermique, le jeûne, la mauvaise santé et les blessures peuvent réduire la capacité physiologique des poulets à maintenir l'homéostasie et peuvent se solder par l'épuisement et la mort. Le contrôle de qualité et les gestes concrets envers les facteurs de risque identifiés devraient réduire les blessures et la mortalité pendant la manutention et le transport avant l'abattage. [Traduit par la Rédaction]

Mots-clés : poulets à griller, DOA, manutention, blessure, mortalité, transport.

Introduction

Poultry handling and transport have recently been reviewed by Schwartzkopf-Genswein et al. (2012) and Weeks (2014). This review is focused on risk factors for injury and mortality in broilers and the underlying pathophysiology. Although each stage of the process from

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rearing in the barn, catching/handling/loading, transportation, and lairage until slaughter will be considered in turn in this review, there are multiple factors that affect the risk of injury and mortality at each stage. Many of these factors interact with each other in an additive manner and there are carry-over effects from one stage to the next. Therefore, the review concludes with a consideration of the potential influence of these factors on the responses of the birds to fasting duration, journey duration, and holding barn duration.

Mortality/Dead-on-Arrivals (DOAs)

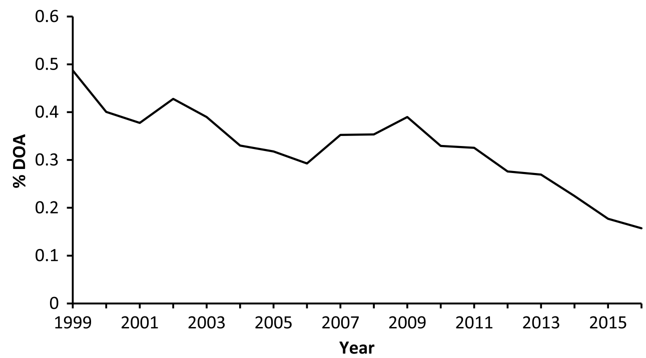
Mortality can occur at any time after loading on-farm, during the journey to the processing plant or at the processing plant during lairage or in a holding barn. The percent dead-on-arrival or % DOA represents the cumulative deaths that occurred between the time of loading and the end of lairage rather than just those that occurred up to the time of arrival at the processing plant (Warriss et al. 2005). As these dead birds are condemned as unfit for human consumption, they represent an economic loss. In addition, the meat quality from birds that survive problematic journeys is likely to be reduced (Dadgar et al. 2010, 2011) and this can have economic consequences.

The % DOA in a load of birds provides one indication of the severity of animal welfare issues experienced by the birds during their journey to slaughter. If death is quick and without suffering, death is not a welfare issue, but when it is prolonged and associated with suffering, such as pain and distress, it is a welfare concern. High mortality rates also indicate that the birds that survived will likely have suffered ill effects for part or all of the duration of the journey (Broom 1988).

The % DOA for poultry transported in Canada has declined in recent years (Fig. 1) to about 0.2%. This is compatible with reports from various studies conducted in Europe since 1990, where most studies have reported a % DOA of broilers transported to slaughter of 0.2% with a range from 0.1% to 0.6% (Bayliss and Hinton 1990; Gregory and Austin 1992; Warriss et al. 1992; Hunter et al. 2001; Nijdam et al. 2004; Warriss et al. 2005; Petracci et al. 2006; Haslam et al. 2008; Chauvin et al. 2011; Jacobs et al. 2017*a*).

There are many variables that can affect the risk of injury and mortality. The % DOA in a load is considered to be influenced by three main factors: (a) health status of the flock, (b) thermal stress, and (c) physical injury during catching and loading (Bayliss and Hinton 1990). The relative proportions of DOAs that die from these three main factors vary greatly depending on the environmental conditions experienced by the birds during the journey. For example, when the journey characteristics are such that the thermoregulatory capacities of the birds for homeothermy are exceeded, the percentage of birds per load that die due to thermal stress increases (Hunter et al. 1997, 2001). Multivariable studies of broilers transported in Canada and Europe have identified a range

Fig. 1. Percentage of poultry slaughtered at federally inspected poultry processing plants in Canada that were condemned due to dead-on-arrival (DOA) (Agriculture and Agri-Food Canada 2017).



of risk factors that can increase the % DOA in a load. These include (a) mortality rate during the rearing period, method of catching, crate stocking density, and weather conditions (Chauvin et al. 2011); (b) breed, catching team, loading, and transporting during the day compared with the night, ambient temperatures ≤5 °C or >15 °C and increasing flock size, live weight, module stocking density, journey duration, and lairage duration (Nijdam et al. 2004); (c) mortality rate during the rearing period, live weight, starting loading later in the day, and ambient temperature during unloading at the processing plant (Whiting et al. 2007); and (d) bird sex, age, and weight, duration of feed withdrawal before loading, catching team, crate stocking density, external temperature, journey duration, and holding barn duration (Caffrey et al. 2017). In a study conducted in Manitoba, Canada, a high % DOA (>1.9%) compared with a lower % DOA (0.18%) was associated with higher ambient temperature (25 versus 20 °C), greater crate/drawer stocking density (138 versus 121 kg m^{-2}), heavier birds (1.99 versus 1.91 kg), shorter journey duration (0.8 versus 1.4 h), and slaughtering birds later in the morning (Whiting et al. 2007). Some of the variability between studies in which factors are identified as significantly affecting injury and mortality is due to differences between studies in the range of some variables, e.g., temperature and journey duration, the characteristics of the handling and transport procedures, and the robustness of the multivariable analyses.

Bird Factors

Sex (cockerels versus pullets), increased age, and increased weight can in some circumstances increase the mortality risk (Nijdam et al. 2004; Drain et al. 2007; Whiting et al. 2007; Haslam et al. 2008; Chauvin et al. 2011; Caffrey et al. 2017). However, in cold conditions, increased age can sometimes reduce the mortality risk (Dadgar et al. 2011). In response to heat stress, pullets have a lower body temperature rise than heavier cockerels (el-Gendy and Washburn 1995). As cockerels are heavier than pullets, and weight increases with age, it is likely that body weight is a major influence on mortality risk. A lighter body weight would make a bird less prone to death from heat stress and the risk of femoral hip dislocation when carried inverted during loading, would be lower (Ritz et al. 2005). Gregory and Austin (1992) identified that hip dislocation in DOAs was the main cause of death in birds heavier than 3 kg. However, it is possible that both sex and age could have effects separate from those of weight alone. For example, age might affect the thermoregulatory ability of the birds and the feather covering of the birds is likely to vary with both age and sex, and this could affect the ability of the birds to respond to thermal extremes. The risk of injury can also be affected by bird factors. Mayes (1980) found a greater prevalence of bruising in pullets than in cockerels and increased bruising with bird age and weight.

Health

The influence of the health of broilers on the risk of mortality during handling and transport has been examined by consideration of the health status during rearing, by examining pathology in broilers that were DOA, and in those slaughtered, but subsequently condemned as not fit for human consumption. In one study, Hunter et al. (2001) reported that for loads with a relatively low % DOA of 0.12%, 71% of these DOA birds were considered to have had pre-existing pathological conditions that increased their risk of mortality. If there are major health problems during rearing some of the affected birds will die and this is recorded as the percent of mortality during rearing, but some of the birds will survive. These birds may have been weakened and (or) still have pathology that affects their physiological ability to respond to the challenges of handling and transport to the extent that they are more likely to die during handling and transport than healthy birds. In a study in Canada, where the mortality during rearing was 6.9%, a significant effect of rearing mortality on % DOA was found and gross pathological lesions were identified in about half of the birds that were DOA (Drain et al. 2007; Whiting et al. 2007). In the United Kingdom, Haslam et al. (2008) reported a significant correlation between mortality during rearing and % DOA and in a study in France; Chauvin et al. (2011) found a significant influence of mortality during the rearing period on % DOA. Jacobs et al. (2017*a*) found that when rigorous culling to remove unfit birds during rearing was included in the percent of mortality during rearing, there was a negative relationship with % DOA. If producers cull sick and disabled birds during rearing (Ansong-Danquah 1987) and catchers identify birds that are either not fit for transport or are too small for slaughter, there are fewer birds at risk of mortality during transport due to pre-existing conditions. Lupo et al. (2009) found significant relationships between (a) the % DOA and the percent of birds condemned after slaughter as not fit for human consumption due the presence of macroscopic abnormalities, and (b) the percent of mortality during rearing and the percent of birds condemned after slaughter, as not fit for human consumption. Broilers can be weakened during rearing due to infectious diseases causing pathophysiological changes and this can place them at a greater risk of mortality during transport (Nijdam et al. 2006). For example, in Denmark in 2010, septicaemia or systemic infections were present in 4% of DOAs (Lund et al. 2013). Skeletal disorders causing lameness can cause birds difficulty in obtaining access to feed and water (Brigden and Riddell 1975) and this might affect the ability of some broilers to cope with prolonged periods without feed and water. In addition, the breeding of broilers for rapid growth and increased muscle mass has predisposed broilers to several conditions that affect their ability to survive during the rearing period and transportation. In-barn mortality increases with broiler age and with the associated increase in weight (Baéza et al. 2012). Some of the birds that die during transportation might have died from these pre-existing health issues even if they had been left on the farm for the equivalent period and not subjected to handling and transportation.

Cardiovascular disease is common in broilers during rearing and makes a significant contribution to mortality (Julian 2005; Olkowski 2007). Kittelsen et al. (2015*a*) identified that 36% of the mortalities that occurred during the 3 d before transport could be attributed to sudden death syndrome, 18% to ascites, and 28% to endocarditis. Sudden death syndrome is thought to arise from acute heart failure following ventricular arrhythmias that can be precipitated by stressors (Olkowski 2007; Olkowski et al. 2008). In Norway, in 2012/2013, postmortem examinations of broilers that (a) died in the barn within 3 d of transportation to slaughter and (b) were DOA at the processing plant (Kittelsen et al. 2015*a*) showed that lung congestion in DOAs (57% of DOAs) was more prevalent than in broilers that died on the farm (38% of the deaths on-farm during the 3 d before transport). In Denmark in 2010, lung congestion was identified in 66% of DOAs and was considered to have been the only likely pathological cause of death in 52% of DOAs (Lund et al. 2013).

Heart and lung size in proportion to body weight has decreased in modern broiler strains, and this effect becomes more apparent in older and heavier birds (Havenstein et al. 2003). If the heart has to work harder than normal to maintain effective blood flow throughout the body, a bird can develop chronic congestive heart failure (Wideman 2001). Fluid can collect in the lungs and abdomen (ascites) resulting in respiratory difficulties. One study showed that the prevalence of ascites was greater in DOAs than in those that survived transport and were subsequently slaughtered (Nijdam et al. 2006). Nijdam et al. (2006) found that the ratio of the right ventricle to the total ventricular mass was (a) greater in broilers that died during loading, transport, or lairage than in those that arrived at the processing plant alive and were subsequently slaughtered and (b) was greater in cockerels DOAs than in pullet DOAs. In the Netherlands (Nijdam et al. 2006) and the UK (Gregory and Austin 1992), cardiovascular disorders were found in 42% and 51% of DOAs, respectively. In Canada, acute heart failure was identified in 36% of DOAs, air sacculitis/pneumonia in 1% and chronic heart failure/ascites in 12% of the DOAs (Whiting et al. 2007).

Manual catching, handling, and transportation are stressful, and broilers show increased heart rate during these stages (Duncan et al. 1986; Mitchell et al. 2000). Manual catching of broilers followed by crating for 3 h increases the plasma corticosterone concentration (Kannan and Mench 1996; Nijdam et al. 2005*b*; Zulkifli et al. 2009). The stress associated with catching, loading, and transport could exceed the capacity of the cardiovascular system of birds that have a pre-existing condition (Gregory 1994); some birds die from sudden death syndrome, and others die because of the effects of stress on chronic cardiovascular system conditions. As a broiler responds to either heat or cold stress, both the respiration rate and heart rate of the bird increases initially (Whittow et al. 1964, 1965). However, reduced heart and lung capacity can affect the bird's physiological ability to deal with thermal stress (Mitchell and Kettlewell 2009).

Management Factors During Rearing

Although the system of broiler rearing is relatively consistent between farms, and between barns within farms, there is potential for differences in the physical environment between barns and for some differences in the management of the birds. For example, the manner of supervision of stockmen during broiler rearing can affect broiler mortality (de Alencar et al. 2006). However, no effect of floor stocking density during rearing on the % DOA was found by Chauvin et al. (2011).

Catching and Handling

Catching and handling of birds can cause trauma that can result in injury and sometimes death. In some studies, injury was identified as a significant factor in 30%–35% of postmortem examinations of DOAs (Gregory and Austin 1992; Nijdam et al. 2006). These injuries included fractures, dislocations, ruptured liver, and head trauma. In Norway, in 2012/2013, trauma was considered to have been the most probable pathological cause of death for 25% of DOAs (% DOA was 0.1%, range 0.01%–0.3% per flock). Fractures were identified in 7% of the DOAs; these were composed of fractures of the vertebrae (3.6% of DOAs), skull (1.2%), wings (0.5%), and femur/tibia (1.5%). Liver rupture was found in 6.1% of DOAs and muscle injury in 1.5% (Kittelsen et al. 2015*a*). Variation between catching teams can affect % DOA (Nijdam et al. 2004) and the percent of birds with bruised wings or breasts (Taylor and Helbacka 1968; Langkabel et al. 2015).

The prevalence of injury reported in various studies is affected by the method of recording, e.g., the size and type of injury, whether the data were recorded specifically for the study, the stage at which the birds were observed, e.g., after slaughter, whether the birds were observed directly or indirectly, or whether the data were obtained from meat inspection or quality control information (Knowles and Broom 1990). Although this variability in the method of recording will obviously affect the numerical values reported, the literature has consistently shown that injury is a routine finding in slaughtered broilers. However, when signs of injury are recorded post mortem, after feather removal, it can be difficult to attribute the injury to a particular stage in the process. Bruising and fractures observed after slaughter need not have occurred during catching and loading as damage can also occur at the plant. However, consideration of the location and type of injury can allow judgements to be made on the likely cause of some injuries. There is potential for injury during any pre-catching movement/"driving" of the birds within the barn, catching, carrying, and any transfer of birds between handlers, loading of the birds into crates or modules, loading of crates or modules onto the trailer or vehicle, transport to the plant, unloading of crates or modules, removal of birds from crates or modules, and pre-slaughter handling. Some injury might occur during transportation. For example, plasma creatine kinase activity can be increased in broilers, after manual catching, loading in modules with drawers, at stocking densities of 46–51 kg m^{-2} and transport for about 3.5 h. An increase in plasma creatine kinase activity occurs slowly after trauma and indicates release of the creatine kinase from muscle to the circulation following muscular damage. However, this muscle injury may not have been entirely attributable to handling. It could have occurred during the journey, following impacts during vehicle movement, muscle strain from balancing in response to vehicle movement, or from hyperthermia (Mitchell et al. 1992). Jespersen (1982) identified that the procedures at one processing plant prior to shackling could involve a crate of birds dropping 2 m, potentially resulting in injury to the breast and back of the birds. Jacobs et al. (2017*b*) did not identify any birds with leg fractures, but recorded an increase in the percent of broilers with wing fractures from 0.12% before loading, to 1.88% after, either manual or mechanical catching and loading into modules. After transport and lairage, there was no significant increase in the percent of birds with wing fractures. Shacking (Gregory and Bell 1987; Gregory et al. 1989; Gregory 1994) and stunning and slaughter procedures, can cause wing flapping, sudden muscular contraction, haemorrhage, and bone fractures (Raj et al. 1990). Post-slaughter, mechanical treatment of carcasses, can also cause damage (Kettlewell and Turner 1985).

Bruising is a superficial injury that occurs after trauma (Hamdy et al. 1961*b*). The skin is not pierced, but the cells and capillaries beneath the skin are ruptured causing blood to accumulate in perivascular tissue (Northcutt et al. 2000). Any red discolouration caused by haemoglobin in extravascular tissue appears as a bruise. If the vascular wall is damaged haemoglobin can enter the extravascular tissue as erythrocytes or in plasma (following cell lysis) (Kranen et al. 2000). However, it can difficult to differentiate bruising from trauma with haemorrhage in muscles that can occur from other potential causes unrelated to trauma that can occur between rearing and processing (Kranen et al. 2000). The size of a bruise is affected by the force applied and the size of the area that is traumatised (Taylor and Helbacka 1968). Following trauma, signs of bruising can occur immediately (Hamdy et al. 1961*b*) and a bruise can appear as a red colour within 2 min of the trauma (Hamdy et al. 1961*a*), reaching maximum darkness after about 6 h (Northcutt et al. 2000). Although there is considerable variation, between 12 and 24 h after trauma, the bruise is often dark red to purple. Bruising that occurs during rearing can potentially be identified by a green colouration that occurs 24–48 h after trauma, followed by yellowing, between 72 and 96 h after trauma (Hamdy et al. 1961*a*).

Bruising can still occur if trauma is inflicted for 5–10 s after the start of exsanguination, but trauma, inflicted 20 s after exsanguination or after scalding and defeathering does not cause bruising (Hamdy et al. 1961*b*). However, postmortem effusion of haemoglobin into the tissues can occur during processing of carcasses (Kranen et al. 2000). The degree of postmortem effusion is considered to depend on the amount and distribution of any residual blood in the carcass, the extent of haemolysis, and the degree of coagulation of intravascular blood (Kranen et al. 2000). Depending on the manner of application, electrical stunning can cause sufficient muscular and vascular spasms for haemorrhage to occur (Kranen et al. 2000). Wilson and Brunson (1968) showed that the method of stunning could affect the severity of leg bruising. Methods that avoid struggling during shackling, such as carbon dioxide stunning, can result in less bruising than after shackling, followed by electrical stunning. Kittelsen et al. (2015*b*) observed a greater prevalence of wing injuries in broilers after shackling and electrical stunning than was present in birds examined in the lairage.

In Canada, most broilers are still caught, picked up from the barn floor and handled manually before loading, but in some countries, mechanical catching, handling, and loading are used. Catchers are organised into experienced catching teams that move from farm to farm as required. The team often consists of about 4–10 people including a supervisor and for modular handling systems, a fork-lift truck driver. Broilers are caught by a handler grasping the legs of the bird, picking the bird up from the floor, inverting it and catching other birds until several birds are held in each hand. The birds are then carried to a receptacle consisting of a crate or module placed either inside or outside of the barn. In some situations, the birds are transferred between handlers. Depending on the genetics and experience of the birds, and environmental factors, broilers can be fearful of humans resulting in withdrawal during approach and raised plasma corticosteroid concentration (Hemsworth et al. 1994). Catching, lifting, and holding a broiler inverted by its legs for 30 s then carrying it for a further 60 s can cause wing flapping and struggling (Newberry and Blair 1993). The manner in which the birds are carried and placed in the receptacle is likely to affect the risk of injury and mortality (Gerrits and De Koning 1982). When birds are dropped into the crate or module, they can flap and injure their wings (Knowles and Broom 1990). Jacobs et al. (2017*a*) reported a significant association between the percent of broilers observed to be lying on their back after placement into modules and the % DOA. In containers with a lid and in those that require a drawer to slide into a module, there is a risk of birds getting trapped and injured. In Germany, after birds had been caught and carried by one leg for 5 m and then loaded into modules with drawers, for light birds (1.9 kg) and for heavy birds (2.5 kg), the percent of the flock with leg damage was 0.26% and 0.47%, respectively, and with wing damage it was 5.83% and 12.26%, respectively (Langkabel et al. 2015).

If hand catching is undertaken carefully, injuries need not occur (Kettlewell and Turner 1985). However, manual catching is a labour intensive and unpleasant task that is often undertaken during unsocial working hours, in poor lighting and hot and dusty conditions requiring the use of a face mask (De Koning et al. 1987; Berry et al. 1990; Gittins and Canning 2006). Repetitive work, such as that involved in repeatedly bending/crouching down to pick broilers up over several hours, can result in fatigue (Faucett et al. 2007). It is likely that the manner in which birds are carried and handled differs between catching teams. In Belgium, Jacobs et al. (2017*b*) reported differences between catching teams in the percent of birds with bruised wings or breasts. Speed during catching and loading is required for economic reasons, and this could potentially result in rough handling and injuries to the birds. The duration available to complete loading onto one trailer can be limited by the requirement to minimise the duration that a partially loaded trailer is stationary without adequate ventilation (De Koning et al. 1987). In some circumstances, increased loading duration can be a consequence of inefficiencies and handling problems. Jacobs et al. (2017*b*) found a positive correlation between the percent of birds with wing fractures and the duration taken to catch and load the flock. Chauvin et al. (2011) found a univariate effect of loading duration on % DOA, in that durations longer than 2 h increased the % DOA.

In most codes of practice, it is recommended that birds be carried by two legs rather than by one leg (Humane Slaughter Association 2011). The reasoning behind this is that carrying the bird inverted by only one leg places the entire weight of the bird on one leg, rather than across two legs. Wilson and Brunson (1968) showed that after carrying a broiler by only the right leg, the severity of bruising in the right thigh was greater than in the left thigh. The inverted posture places an unnatural strain on the joints, especially the hip joint, predisposing to dislocation, injury, haemorrhage, and death (Mitchell and De Boom 1986; Gregory 1994). Hip dislocation associated with thigh bruising is thought to be a consequence of trauma during catching and pre-existing pathology, such as dyschondroplasia, can increase susceptibility to dislocation (Duff and Randall 1987).

The main manual handling systems used in Canada are loose crates or modules (Schwartzkopf-Genswein et al. 2012). In most loose crate systems, the empty crates are brought into the barn either manually or on a fork-lift truck. The birds are placed into the crates through a flap that does not allow the birds to escape easily. When the required numbers of birds have been placed in the crate, the flap is closed, and the crate carried out of the barn either manually or via fork-lift truck. In other systems, the birds are caught and carried out of the barn to the vehicle where they are transferred to another handler who places the birds into crates that are then arranged on the vehicle when they are full (Kettlewell and Turner 1985; Bayliss and Hinton 1990).

Compared with loose crates, a module system should reduce the need to transfer birds between handlers and reduce the distance that the birds are carried (Bayliss and Hinton 1990). Unloading and handling at the processing plant are also facilitated by the use of modules (Bayliss and Hinton 1990). Although there are few detailed studies, modular systems have been reported to reduce the % DOA compared with crates (Bayliss and Hinton 1990). Loading broilers into modules that are moved by a fork-lift truck causes less damage to the birds (1.2% of birds with breast bruising) than carrying crates from the barn to the trailer (2% of birds with breast bruising) (De Koning et al. 1987). In Norway, Kittelsen et al. (2015*b*), found wing injuries (fractures and dislocations) in 0.88% (range 0.34%–1.44%) of flocks that were examined in the lairage, after manual catching loading into modules with drawers and transport at a stocking density of 50 kg m^{-2}.

In Belgium, after birds had been caught and loaded into modules, unloaded at the plant onto a conveyor and shackled before slaughter, Nijdam et al. (2004) identified the following factors as significantly increasing the percent of the flock with bruising: loading and transport in the summer compared with the autumn or spring, and in daytime compared with night time, and at an ambient temperature of ≤5 °C compared with warmer temperature. However, Hamdy et al. (1961*b*) found that after trauma, bruising was less apparent when the ambient temperature was low (e.g., 7 °C) and more apparent when it was high (e.g., 30 °C). Presumably increased blood flow to the skin surface to aid heat dissipation in warm conditions and restriction of blood flow to the surface to conserve heat in cold conditions can influence the severity of superficial haemorrhage after trauma. There are several advantages for night-time loading of broilers compared with day-time loading. For many journeys, by the time that the birds have been loaded and transported, they are delivered to the plant in time for an early morning shift and vehicle transport at night is more predictable than during the day. The temperature at night is lower than during the day, thereby reducing the risk of heat distress during loading and transportation (Gittins and Canning 2006). There are also advantages to the birds in that it is easier to reduce light intensity in the barn, and this is thought to make it easier to catch and handle the birds (Knowles and Broom 1990). Broilers are less active when the light intensity is 1 lx than when it is 10–40 lx (Deep et al. 2012). Jones et al. (1998) found that when broilers were inverted and shackled, the frequency and duration of struggling increased with increasing light intensity. Although one recent study found evidence that loading during the night compared with during the day, increased the risk of bruising in the wings and breasts (Jacobs et al. 2017*b*), this is in contrast to previous work that showed a slight reduction in the percent of bruising in birds loaded in the dark compared with those loaded during daylight hours (Taylor and Helbacka 1968).

Mechanical catching using a machine to collect the birds from the floor and move them into a receptacle for loading onto a transport trailer is used in some countries (Scott 1993). Although mechanical catching does not always realise these benefits (Ekstrand 1998; Nijdam et al. 2005*b*), the potential benefits are increased efficiency and reduced stress and injury to the birds (Jaiswal et al. 2005). One reason for the lack of adoption of mechanical systems for catching and handling broilers is the difficulty in matching the requirements of the machinery with the design of broiler houses (Bayliss and Hinton 1990; Berry et al. 1990). Knierim and Gocke (2003) did not find a significant reduction in the % DOA after mechanical catching (0.54%) compared with after manual catching (0.39%). When broilers were manually placed into modules with compartments, the % DOA (0.32%) was similar, but there were fewer bruising injuries (0.02%) and fractures (0.02%) than when a mechanical catching and handling system was used to place the birds into the modules (DOA 0.39%, bruising 0.04%, and fractures 0.4%). Some studies (Delezie et al. 2006; Chauvin et al. 2011) found an increased % DOA if birds were caught and loaded using mechanical catching versus manual catching (e.g., caught by one-leg and carried inverted three birds per hand). Ekstrand (1998) and Delezie et al. (2006) suggested that one reason for a greater number of DOAs after mechanical catching was that birds that were unfit or dead prior to catching and had not been removed by the producer, would have been loaded, whereas these birds would not be loaded with manual catching, and this artificially increased the % DOA.

In Belgium, manual catching resulted in bruising on the breast (0.26%), legs (0.20%), and wings (7.7%), whereas the use of mechanical catching decreased the percentage of birds with wing bruising to 4.2% (Delezie et al. 2006). The reduction in wing bruising might have been due to reduced fear-related wing flapping, as there was no human handling and no inversion of the birds (Delezie et al. 2006). A mechanical system of catching can reduce injuries, especially the number of leg injuries, compared with manual catching and carrying (Lacy and Czarick 1998; Knierim and Gocke 2003). In Belgium, Nijdam et al. (2005*b*) compared manual catching of 6–8 broilers (2.3–2.8 kg) followed by carrying inverted for ≤10 m and loading into modules with containers, with machine catching. There was no significant effect of catching method on the percent of the flocks with breast, leg, and wing bruising. In Denmark, in 2010, in broilers caught using a mechanical catching system and then transported using a module system with compartments, % DOA was 0.3%. In 23% of the DOAs, mortality was associated with trauma: liver rupture (15% of DOAs), fractures of the skull (6%), sternum (2%), pelvis (1%), and ribs (1%) (Lund et al. 2013).

Crate/Module Stocking Density

The crate stocking density is adjusted by varying the number of birds within a crate or module compartment and is determined by several factors including bird weight, number of birds to be loaded in relation to the capacity of the trailer, and the weather conditions (Bayliss and Hinton 1990). The stocking density could affect the thermal conditions within the crate, the severity of stress, the behaviour of the birds, the risk of injury, and the risk of suffocation. After handling, the body temperature of broilers can increase (Yalçin et al. 2004; Edgar et al. 2013) making them more susceptible to hyperthermia and mortality. Nijdam et al. (2004) reported an increased % DOA with increased module stocking density. However, Caffrey et al. (2017) showed that a high stocking density can reduce % DOA during exposure to very cold conditions. Increased stocking density would result in more metabolic heat production than at a lower stocking density. This would have a beneficial effect in warming the air at very low temperatures and thereby reducing the risk of death from hypothermia (Strawford et al. 2011). However, unless this extra metabolic heat and moisture is effectively removed by ventilation, it would be detrimental at warmer temperatures and could predispose to death from hyperthermia (Delezie et al. 2007). Broilers, 5 wk of age, placed in a crate at 28 kg m^{-2} for 0.75 h at an air temperature of 43 °C, experienced a rise in body temperature of 1.5 °C (el-Gendy and Washburn 1995). During summer conditions, Yalçin et al. (2004) found that crating broilers at a high stocking density for 1 h in a holding barn caused a rise in rectal temperature that was greater than that experienced during a 1 h journey when the vehicle was moving.

Kannan and Mench (1996) observed that after broilers were placed in a crate for 4 h, they remained in sternal recumbency for 85% of the time. An increase in the height of module drawers from 23 to 46 cm allows broilers to adopt a more natural standing posture with their head raised above the back and to remain standing for longer before they squat down. However, the provision of extra height appeared to result in the broilers reacting more to changes in vehicle speed and direction with more wing flapping and climbing on top of each other. This activity was associated with increased scratches and bruising of the wings, breast, and thighs (Vinco et al. 2016).

Transport

Vehicle motion

During transport, birds are exposed to vibration arising from vehicle movement (Randall et al. 1993). If the vibration is close to the whole body resonant frequency of broilers while standing or sitting (Randall et al. 1996), it is aversive (Randall et al. 1997; Abeyesinghe et al. 2001) and can increase body temperature (Warriss et al. 1997). This extra metabolic heat would contribute to the thermal load experienced by broilers during transportation (Abeyesinghe et al. 2001). Carlisle et al. (1998) found that exposure of broilers to vibration resulted in (a) increased plasma creatine kinase activity, possibly as a result of muscular fatigue arising from postural instability, (b) increased plasma corticosterone concentration, indicative of stress, and (c) decreased plasma glucose concentration, possibly as a result of increased energy expenditure. However, Warriss et al. (1997) did not find a statistically significant reduction in liver or muscle glycogen concentration after 3 h of vibration.

Thermal conditions

When broilers are transported to slaughter, the environmental conditions can affect the % DOA. For example, external temperatures >18 °C can cause a steep increase in the % DOA (Warriss et al. 2005). In a study of condemnations at a processing plant in New Brunswick, Canada, between 1980 and 1985, Ansong-Danquah (1987) reported that % DOA tended to be higher during the winter months (December, January, and February) than during the rest of the year. In the Czech Republic, Vecerek et al. (2006) reported that % DOA was highest during the winter months (December, January, and February) and the summer months (June, July, and August). Whereas, a study at one processing plant in the United Kingdom, in 2000–2002, showed that the daily % DOA peaked during the summer months. The % DOA was greatest in the spring and summer compared with the fall and winter months (Warriss et al. 2005).

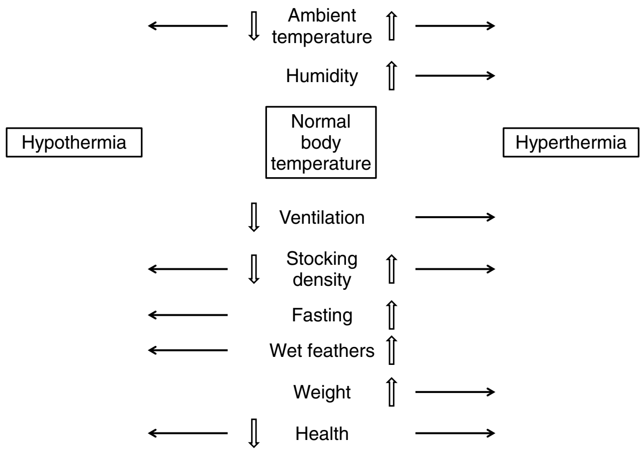
Several studies have examined the complex factors affecting the thermal conditions within a trailer containing broilers (Kettlewell et al. 1993; Knezacek et al. 2010; Burlinguette et al. 2012). Most types of vehicles that have been used to transport broilers in Canada do not provide controlled environmental conditions for the birds. The conditions experienced by the birds during a journey are dependent on the ambient environmental conditions, manual adjustments to the ventilation, and choice of stocking density. The trailer temperature during a journey is not uniform throughout the vehicle and extremes of thermal conditions are possible within the load (Knezacek et al. 2010; Burlinguette et al. 2012). The pattern of ventilation and the trailer temperatures within a load depend on factors such as the vehicle design, the arrangement of the crates or modules on the vehicle, and the ventilation configuration selected by the driver. The internal environment experienced by birds in crates or modules within a trailer is different from the external environmental conditions. The large numbers of birds transported in crates or modules, at a high stocking density produce a great deal of metabolic heat and moisture during a journey (Mitchell and Kettlewell 1998). Some of this metabolic heat and moisture is removed by airflow through and between the crates or modules produced by external pressure differences during vehicle motion, by wind and by passive thermal buoyancy (Hoxey et al. 1996). The highest trailer temperatures occur when the vehicle is stationary (Dalley et al. 1996). The internal thermal environment within a trailer is highly variable due to the passive ventilation providing either too little or too much air movement at different locations. When the metabolic heat and humidity produced by the birds are not effectively removed by the ventilation, localised “thermal cores” are created in which the temperature and humidity are sufficiently high to put these birds at risk of thermal distress (Mitchell and Kettlewell 1998). As air enters a moving trailer mainly at the rear and then as it is heated by the birds, it rises, “thermal cores” tend to occur in the top and front sections of a trailer (Hunter et al. 2001). Maximum ventilation is required to remove the metabolic heat and moisture that builds up within the crates. During warm and dry conditions, maximum ventilation is provided by leaving as much as possible of the surface area on the sides of the vehicle open.

During journeys in cold conditions, the birds require protection from the cold external temperatures, and it is essential that the birds kept near the sides of the vehicle do not become wet or exposed to excessive air movement (Hunter et al. 1999). Chauvin et al. (2011) identified an increased % DOA when the birds were transported in rainy or windy conditions. In cold conditions, and (or) precipitation, wet road conditions or excessive wind, the driver uses side protection (e.g., screens, curtains, and tarpaulins) around part or all of the vehicle/trailer. This reduces the ventilation flow and the internal trailer temperature rises. In extremely cold conditions this temperature rise can be beneficial in that it raises the internal temperature above the potentially lethal cold external temperature. However, in a closed or partially closed ventilation configuration, internal thermal cores consisting of pockets of raised temperature and moisture from the birds can occur at one or more locations within the vehicle (Kettlewell et al. 1993; Mitchell and Kettlewell 1998; Burlinguette et al. 2012). If the internal temperature and humidity within areas in the core of the vehicle rises too high, some of the birds can experience hyperthermia that can be severe enough to cause mortality, even though the external temperature is so low that it would otherwise have caused hypothermia (Hunter et al. 1997; Mitchell and Kettlewell 1998). In a “closed” ventilation configuration, the air entering the vehicle through air inlets is at the low external temperature and might be accompanied by moisture and excessive air movement. The parts of the vehicle near air inlets and those on the sides of the vehicle close to the cold external temperature will expose the birds to low air temperature (Burlinguette et al. 2012) and this could potentially result in hypothermia of sufficient severity to cause death (Hunter et al. 1997). Hunter et al. (2001) showed that when broilers were transported in modules on a 3.45 h journey in conditions with high humidity, the adjustment of the side curtains according to external temperature and precipitation resulted in marked variations in the temperature within modules at different locations on the vehicle that was reflected in the change in the rectal temperature of the birds during the journey and in the % DOA within the load (Hunter et al. 2001). Figure 2 shows potential interactions between temperature and humidity, and management and bird factors affecting the risk of mortality due to hypothermia and hyperthermia.

Heat stress

Genetic selection for muscle growth in broilers has reduced the ability of broilers to respond to heat stress (Sandercock et al. 2006). Nijdam et al. (2004) reported an increased % DOA when the ambient temperature was >15 °C compared with 10–15 °C. The effect of high temperatures on the risk of mortality is affected by a number of factors including the relative humidity, convective airflow, wetting of the birds to provide evaporative cooling, length of fasting, stocking density, the ability of the birds to lift and spread their wings, and the age and weight of the birds (Tao and Xin 2003*a*, 2003*b*). The greatest mortality risk occurs during aversive high temperature and high humidity (Mitchell and Kettlewell 1998; MacCaluim et al. 2003). Relative

Fig. 2. Summary of potential interactions between temperature and humidity, and management and bird factors affecting the risk of mortality due to hypothermia and hyperthermia.



humidity levels of 70%–80% are commonly encountered within a trailer and can result in the onset of severe physiological stress at temperatures ≥25–26 °C (Mitchell and Kettlewell 1998). A temperature of 38 °C, with a relative humidity of 23% and an air velocity of 2.2 m s^{-1}, can be fatal to some birds (Chepete 2008). Soleimani et al. (2008) recorded 8% mortality in cockerels and 4% mortality in pullets, aged 28–35 d, after they were placed in crates for 3 h at 35 °C and 65%–75% relative humidity. Tao and Xin (2003*a*) reported that exposure of broilers 46 d of age, to 35 °C at high humidity and an air velocity of 0.2 m s^{-1} caused a fatal hyperthermia within 1.5–4 h. Whereas increasing the air velocity to 0.7 m s^{-1}, or reducing the humidity, only increased rectal temperature by about 2 °C and this was not fatal.

The main mechanism available to birds to lose heat is evaporation of water via the respiratory tract and through the skin (Genç and Portier 2005). As air temperatures increases, the respiration rate increases and eventually panting occurs (Gleeson 1985). The ability of the bird to lose heat from evaporative cooling is dependent on a gradient in temperature and (or) moisture between the bird and the surrounding environment (Kettlewell 1989). For example at 2 °C, evaporative cooling only represents 30% of heat loss (Farrell and Swain 1977), at 25 °C and 71% relative humidity, latent heat loss is more important than sensible heat loss, but at 30 °C and 90% relative humidity, latent heat loss is minimal (Genç and Portier 2005). The concept of apparent equivalent temperature characterises the thermal responses of broilers to the combined effects of temperature and humidity by estimating the equivalent dry bulb temperature that would produce a similar physiological response. For example, a temperature of 22 °C and 100% relative humidity or a temperature of 40 °C and 21% relative humidity would both be equivalent to a dry bulb temperature of 65 °C (Mitchell and Kettlewell 1998, 2004). Charts have been constructed that indicate the combined effect of relative humidity and temperature in the form of safe (apparent equivalent temperature of ≤40 °C), alert, and danger (apparent equivalent temperature of ≥65 °C) zones. An apparent equivalent temperature of ≥70 °C results in hyperthermia (≥1 °C rise in body temperature) and one ≥80 °C could induce fatal hyperthermia (Mitchell and Kettlewell 1998).

Jacobs et al. (2017*a*) reported a significant association among the percent of birds observed to be panting either after loading into modules or after lairage at the processing plant and the % DOA. If a bird becomes hyperthermic and the body temperature approaches a lethal body temperature of about 46 °C, the depth of respiration increases, but the rate decreases (Kettlewell 1989). Death from hyperthermia is likely to be preceded by a period of respiratory distress and open-mouthed panting together with metabolic changes (circulatory and electrolyte imbalances) (Bogin et al. 1996; Borges et al. 2004). Hyperventilation results in loss of carbon dioxide from blood and tissues, and blood pH rises causing respiratory alkalosis. In birds that die from hyperthermia, there is an increase in serum concentrations of uric acid, potassium, and sodium (Bogin et al. 1996; Borges et al. 2004). The survival time for broilers before they collapse from heat prostration and die depends on the temperature rise, duration of exposure, and the thermal regulatory ability of individual birds, e.g., Borges et al. (2004) found that the time to collapse of 44-d-old cockerels, exposed to a relative humidity of 42% and a rise in air temperature from 24 to 41 °C over 2 h, was 8.4 h. In broilers, 45 d of age, exposed to an air temperature of 35–38 °C, the mortality rate was 12% (Arjona et al. 1988). In 56-d-old cockerels, exposed to a rise in air temperature from 21 to 41 °C, over a 2 h period, some birds died after 0.5 h of exposure to 41 °C, whereas others survived exposure for 2 h (Kubena et al. 1972). After 2.5 h, at 41 °C, the mortality rate can range from 15% to 41% (Deaton et al. 1986); it is increased by exposure to increased humidity and is greater in birds heavier than 1.9 kg than in those lighter than 1.9 kg (Reece et al. 1972). After 3.5 h, at 41 °C, the mortality rate can range from 30% to 60% (May et al. 1987).

Cold stress

The lower critical temperature of broilers at the time of slaughter is about 24 °C (Meltzer 1983; Freeman 1984) and at temperatures below this birds must reduce their heat loss and (or) increase heat production to maintain their body temperature. If the environmental temperature exceeds the capacity of the birds to maintain their body temperature, they become hypothermic and they will die when their body temperature decreases to 19 °C or 20 °C (Sturkie 1946). Nijdam et al. (2004) reported increased % DOA when the external temperature was ≤5 °C and Vecerek et al. (2016) reported increased

% DOA when the external temperature was −6 to −3 °C, compared with temperatures of ≤21 °C. Broilers can become wet from a number of causes including damp litter, precipitation during loading and in-transit, condensation of moisture from respired air when crated, and splashing from wet road surfaces. When exposed to cold temperature (−4 °C) for 3 h, wet broilers are susceptible to lethal hypothermia (a fall in body temperature of 14 °C), whereas for dry broilers, the hypothermia at this temperature is not as severe (a fall of 1 °C) (Hunter et al. 1999).

When broilers are exposed to cold temperatures, they can respond by placing their head and feet under their body, huddling, ptiloerection, vasoconstriction, shivering, and increasing their metabolic rate (Whittow et al. 1965; Farrell and Swain 1977; Arieli et al. 1979; Strawford et al. 2011; Watts et al. 2011). They utilize glycogen stored in the liver and muscles and mobilise fat reserves to provide sources of energy to maintain their increased metabolic rate (Freeman 1976). If birds become severely hypothermic, shivering, respiration rate, and heart rate decrease, cyanosis occurs and the bird dies (Sturkie 1946; Whittow et al. 1965). Knezacek et al. (2010) reported that when 38-d-old broilers were transported at a stocking density of 60 kg m^{-2} for about 3 h during cold weather in a trailer with closed curtains (a) for two journeys at −27 °C, the trailer (crate) temperature was between 3 and 28 °C; on one journey, the birds experienced a 1 °C fall in rectal temperature and the % DOA on the journeys was between 0.9% and 1.4%, and (b) on one journey at −7 °C, the trailer (crate) temperature was between 11 and 31 °C, there was no fall in rectal temperature, and the % DOA was 0.7%. Dadgar et al. (2010) placed broilers in transport modules protected with tarpaulins and transported them at external temperatures that ranged between −27 and 11 °C for 3–4 h, followed by between 0.5 and 2 h of lairage. The temperatures in the modules ranged from −16 to 30 °C. No birds died; however, at temperatures <0 °C, most birds had a decreased body temperature of 1–2 °C, but some had a decrease of 7–9 °C. Dadgar et al. (2011) found in 35–37-d-old broilers that had been fasted for 7 h, and then kept singularly without feed for 3 h, experienced hypothermia after exposure to air temperatures of <−8 °C (one bird died and 9% became severely hypothermic at −11 °C), whereas no 40–42-d-old broilers, exposed to air temperatures of <14 °C, died, but they experienced hypothermia and one bird became severely hypothermic. Consistent with that found by Strawford et al. (2011), pullets experienced less severe hypothermia than cockerels, and this was attributed to better feather coverage and more abdominal fat. The 3 h of exposure to cold temperatures caused hypoglycaemia and the severity of the hypoglycaemia increased with the severity of the cold exposure. The severity of hypoglycaemia was lower in the older birds exposed to cold than in the younger birds. The authors attributed these age effects to larger body size and greater feather coverage. Exposure of birds to air temperatures of <−11 °C for 3 h can reduce liver glycogen concentration more than that in birds exposed to 20 °C. In a subsequent experiment, with a similar design, Dadgar et al. (2012) found that 35–36-d-old broilers experienced hypothermia at air temperatures <0 °C, and 42–43-d-old broilers experienced hypothermia at air temperatures <−8 °C. After exposure to air temperatures <−11 °C, the older birds had less severe hypothermia than the younger birds. The 42–43-d-old broilers experienced hypoglycaemia after exposure to air temperatures of <0 °C and the severity of the hypoglycaemia increased with the severity of the cold exposure.

Lairage/Holding Barn Conditions

During the period in the holding barn, the % DOA within a load is affected by a number of factors that affect the thermal conditions within the crates or modules. The type of handling system and the lairage design can have a major influence on the thermal environment experienced by the birds. If in a holding barn, the birds remain in crates on the trailer, the provision of adequate ventilation to all of the birds in the load can be challenging. The temperature within the crates can rise above the external temperature and cause increases in the rectal temperature of the birds (Hunter et al. 1998; Warriss et al. 1999). In warm conditions, an evaporative cooling system in addition to fan ventilation can be beneficial in reducing mortality in holding barns (Shackelford et al. 1984). One advantage of a modular handling system over crates is that modules can be unloaded and placed at appropriate locations in a lairage, but the birds are still at risk of heat stress (Quinn et al. 1998). In warm weather, the use of water sprays to provide evaporative cooling and wetting of the birds is effective (Tao and Xin 2003*b*) but it can increase the relative humidity, and this might impair the ability of the birds to lose heat via respiratory evaporative cooling (Quinn et al. 1998). In the lairage/holding barn, provision of adequate shade and insulation from solar radiation (Ritz et al. 2005) and protection from wind, precipitation, and extremely cold temperatures would be expected to reduce the % DOA. Knezacek et al. (2010) reported that after 38-d-old broilers crated at a stocking density of 60 kg m^{-2} had been transported for about 3 h, at −28 °C, with a trailer (crate) temperature of between 3 and 26 °C; the overall % DOA was 0.9%, the % DOA during the journey was 0.4%, but an additional 0.5% died during the time that the trailer remained in the holding barn.

Duration of Pre-slaughter Stages

Duration without feed before loading and effects of fasting

Feed withdrawal before loading is practised to allow time for the digestive tract to empty before processing, leaving less ingesta and faeces for potential carcass contamination. A significant reduction in the frequency of defaecation and weight of gut contents occurs within 4–6 h of fasting (May and Deaton 1989; Warriss et al. 2004; Kim et al. 2007). Summers and Leeson (1979) showed that broilers had an empty upper digestive tract after they had been fasted for 12 h with access to water. However, placing the birds directly into crates for up to 16 h, without prior fasting, did not completely empty the digestive tract (Summers and Leeson 1979; May and Deaton 1989). These results indicated that to empty the digestive tract, the period during which the birds are crated cannot completely substitute for a period of fasting prior to loading. Increasing the period of feed withdrawal above 8–9 h can be detrimental due to the development of a negative energy balance (Nijdam et al. 2005*a*) and a decreased ability to cope with cold temperatures (Berman and Snapir 1965). In 33-d-old broilers, kept at 24 °C, fasting for 6 h resulted in a decreased body temperature (Christensen et al. 2012). The requirements for metabolic heat production increase at cold temperatures below the lower critical temperature and fasted birds have higher lower critical temperatures, than animals with access to food (Berman and Snapir 1965). During fasting, birds have to mobilise their body energy reserves. If the total duration of pre-loading fasting, loading, transport, and lairage is too long, body energy reserves can become exhausted, thereby increasing the risk of hypothermia and death (Warriss et al. 1999; Dadgar et al. 2011, 2012; Caffrey et al. 2017). During fasting, energy required for metabolism is obtained initially from carbohydrates and then by catabolism of fat and proteins into glucose (Riesenfeld et al. 1981). Fasting for 10 h causes a significant reduction in the liver glycogen concentration (Warriss et al. 1993) and fasting for 12 h reduces the liver lipid content (Jensen et al. 1984; Trampel et al. 2005). In 7-wk-old broilers, fasted at 21 °C, some liver glycogen was present after 3 h, but after 6 h, the liver glycogen concentration was negligible (Warriss et al. 1988).

In broilers, fasted for 12 h, then caught, crated at a stocking density of between 38 and 49 kg m^{-2} (depending on the ambient temperature that ranged from 6 to 33 °C), and then transported for up to 3.7 h, there was no decrease in plasma glucose concentration during the journey (Yalçin and Güler 2012). However, in other circumstances, broilers can show metabolic effects within 6–8 h of fasting, and reduced plasma glucose concentration and raised plasma free fatty acid concentration after transportation for 2 h (Freeman et al. 1984). Nijdam et al. (2005*a*) found that 13 h of fasting caused a reduction in plasma concentrations of glucose and increased plasma concentration of free fatty acids compared with broilers with access to feed, but they did not find an additive effect of 3 h of handling, transport, and lairage, after 10 h without feed, before loading, compared with 13 h without feed and no handling transport and lairage. In broilers, transported in crates at a stocking density of 25 kg m^{-2}, at an internal air temperature of 27 °C, 76% relative humidity, with feed and water available up to the loading, the plasma glucose concentration and the muscle glycogen concentration were reduced when the total journey and lairage duration was 6 h compared with 1.5 h (Zhang et al. 2009).

The effects of fasting are greater during cold conditions, e.g., plasma glucose concentration is reduced after 3.5 h of transport at −5 to 5 °C, but not at 25–35 °C (Vosmerova et al. 2010). During cold exposure, e.g., 0 to −17 °C, fasted birds show greater reductions in blood glucose concentration and liver glycogen concentration than those kept at 20–22 °C, and they are at an increased risk of hypothermia (Dadgar et al. 2011, 2012). However, in warmer temperatures, their metabolic heat production declines during prolonged fasting and this can be beneficial. When exposed to very high temperatures, e.g., ≥40 °C for up to 8 h, prior fasting for prolonged periods (24–72 h), compared with continued access to food and water, can (a) increase the time (e.g., 3 versus 2 h) before broilers become hyperthermic (Ait-Boulahsen et al. 1989), (b) increase their survival time (e.g., 3–5 versus 2 h), and (c) reduce the mortality rate (58% versus 100%) (McCormick et al. 1979). In broilers exposed to 32 °C and 55% relative humidity for 6 h, Teeter and Belay (1996) found that the mortality rate decreased with increased duration of prior fasting (48%–55% after no fasting, 32% after 3 h, 20%–30% after 6 h, 13%–18% after 12 h, and 8% after 24 h of fasting).

Duration without water

Current advice is to provide unlimited access to water for as long as possible before loading and remove water only when necessary. Birds have efficient mechanisms for dealing with prolonged water deprivation thereby avoiding significant reductions in plasma volume (Joshi and Link 1971; Koike et al. 1983). The period of water withdrawal that is normally associated with loading, transport, and lairage of broilers, is unlikely in itself to cause sufficient dehydration to cause death (Jones and Huston 1967). In response to dehydration, the plasma osmolality, plasma protein concentration, packed cell volume increase, and antidiuretic hormone is released, which restricts renal water loss (Stallone and Braun 1986). Voslarova et al. (2011) found no change in plasma total protein concentration during 2 h of crating. However, broilers are likely to experience increased thirst after 6 h without water (Sprenger et al. 2009).

Some DOAs are dehydrated and this could be associated with difficulty accessing drinking water during rearing (Gregory and Austin 1992; Butterworth et al. 2002). In one study, pathological signs of kidney disease and dehydration were found in 11% of DOAs (Lund et al. 2013). About half of these broilers had other pathology that indicated that they would likely have had reduced mobility in the barn before transportation (Lund et al. 2013). It is, therefore, likely that the health of the broilers can affect the ability of the birds to cope with periods of water restriction, especially if they were already dehydrated before loading. In addition, the consequences of prolonged periods without access to water might be more severe when birds are exposed to high temperatures, as they use water for evaporative cooling via respiration (Jones and Huston 1967). Knowles et al. (1995) found slight increases in plasma osmolality after 24 h without feed and water, in birds kept at 23 °C, but no increase in those kept at 17 °C. When exposed to high temperatures, birds without access to water for prolonged periods are likely to be at increased risk of dehydration and hyperthermia (Arad et al. 1985; Zhou et al. 1999). After 24 h without water, broilers kept at 21 °C can show a significant increase in plasma osmolality (Vanderhasselt et al. 2013). At air temperatures of up to 35 °C, no significant increase in the plasma total protein concentration was found after journey durations of up to 2.5 h (Vosmerova et al. 2010). In broilers fasted for 12 h, then caught and crated at a stocking density of between 38 and 49 kg m^{-2} (depending on the ambient temperature that ranged from 6 to 33 °C), and transported for up to 3.7 h, there was no increase in plasma total albumin concentration with journey duration (Yalçin and Güler 2012).

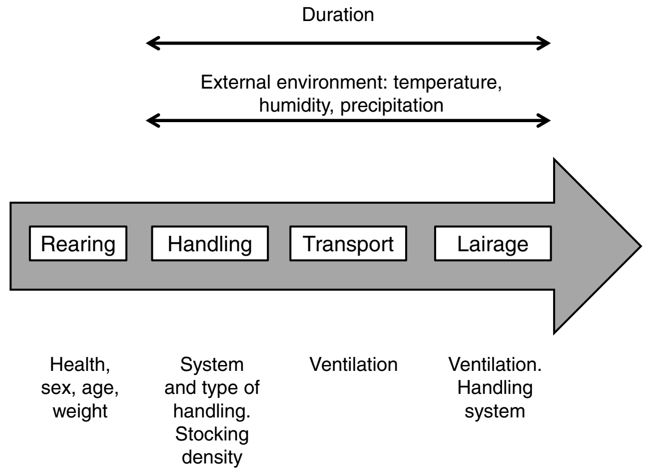
Journey duration

Warriss et al. (1992) reported an increase in % DOA from 0.1% after a journey of 2 h, to about 0.8%, after 8 h. In France, a significant univariate relationship between journey duration and % DOA, which was not present in a final multivariable model, showed a greater % DOA with journey durations longer than 2 h (Chauvin et al. 2011). Nijdam et al. (2004) and Caffrey et al. (2017) reported significant effects of both journey duration and lairage/holding barn duration on mortality risk. The longer the journey, the more opportunity there is for a bird to die (a) from a chronic disease that decreased the ability of the bird to cope with the transport conditions, (b) from an injury sustained during catching and loading, or (c) from environmental extremes possibly aggravated by the period without access to food and water. The % DOA recorded at unloading represents a cumulative count of deaths during all stages of transportation. Therefore, the longer the duration between loading and unloading, the higher the mortality risk will be.

Lairage/Holding barn duration

Although it is normally not possible to separate mortality that occurs during lairage from that during other stages of the process, birds are at risk of dying during the time that they spend in a holding barn (Knezacek et al. 2010). Some of the deaths during lairage will be a delayed consequence of injury during loading and others the result of problems experienced during the journey, e.g., hypothermia or hyperthermia. Chauvin et al. (2011) found a significant univariate relationship between lairage durations longer than 4.3 h and an increased

Fig. 3. Summary of risk factors affecting percent of birds dead-on-arrival during each pre-slaughter stage.



% DOA. The total duration from loading until slaughter is affected by the distance that the farm is from the processing plant, the complex logistics associated with the scheduling of the catching and transportation of broilers to slaughter, and the availability of broilers in the holding barn/lairage to maintain slaughtering capacity (Ljungberg et al. 2007). Ideally, logistical arrangements should schedule loads to be slaughtered as soon as they arrive at the plant. However, for the plant to operate efficiently, there needs to be a reserve supply of birds available to deal with unforeseen scheduling problems with the arrival of individual loads (Kettlewell and Turner 1985) and the scheduling of loads to minimise the waiting time in the holding barn is a complex operation. Many factors need to be taken into consideration including farm location, catching duration, availability of vehicles and drivers, weather, traceability of loads, plant processing timing, capacity, and line-speed (Ljungberg et al. 2007; Oliveira and Lindau 2012).

Conclusions

Although there are multiple risk factors that need to be considered within a challenging commercial and social environment, the reduction in the % DOA in recent years indicates that management changes are feasible and effective in achieving a reduction in mortality. Figure 3 provides an overview of the multiple factors affecting the risk of mortality during each pre-slaughter stage. The literature reviewed suggests that future developments to maintain this improvement should be directed towards increasing the environmental control of the thermal environment and ventilation within trailers during loading and transportation. The adoption of modular handling systems has the potential to improve on-farm handling and environmental control when birds are lairaged. As the presence of chronic pathological conditions and pathology following acute health events during rearing have the potential to affect the physiological ability of the birds to respond to stressors associated with handling and transport, management of flock health is a key aspect of continued improvement in the reduction of mortality during transport. Recording of relevant variables, quality control, and benchmarking to monitor and act upon the causes of variation in injury and mortality discussed in this review, together with optimal logistical arrangements to avoid delays during each pre-slaughter stage, should result in continued improvement.

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