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# Risk factors associated with pig pre-slaughtering losses

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**A B S T R A C T**

The incidence of non-ambulatory non-injured (NANI), non-ambulatory injured (NAI) and dead pigs on-arrival at three Brazilian slaughterhouses were evaluated in 37,962 pigs to identify risk factors linked to them, besides carcass bruises and limb fractures. Total pre-slaughtering losses were 1.18%, in which NAI (0.39%) and NANI (0.37%) incidences contributed the most. A positive relation between **on farm** steeper ramp slope **greater than 20 degrees** and the incidence of NAI, NANI and dead pigs at unloading was found. Farm size, pigs/pen, enthalpy at loading, transportation time, truck loading order, muscle thickness and carcass weight, were identified as risk factors for pre-slaughtering losses. Loading procedures influenced the occurrence of limb fractures and bruises (which are a welfare issue and should be reduced). Therefore, personal training on pre-slaughter handling is essential to reduce the risk factors to improve animal welfare and avoid losses during the pre-slaughter process.

**Key words:** bruises, carcass condemnation, dead on-arrival, fatigued pigs, non-ambulatory pigs.

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## 1. Introduction

Pre-slaughtering procedures are extremely stressful for animals (Brandt & Aaslyng, 2015; Dokmanović et al., 2014) and may compromise the whole production cycle. Injured, dead or fatigued (non-ambulatory, non-injured, NANI) pigs on arrival at the slaughterhouses are important concerns to the swine production chain due to animal welfare problems and significant economic losses. These losses have been estimated in € 65 million annually affecting half million pigs (Miranda-de la Lama, Villarroel, & María, 2014). An incidence of about 0.27 to 0.44% of NANI pigs was reported between 2000 and 2007 in United States of America (USA) and Canada (Ritter et al., 2009). In USA, for instance, pig losses during transport have been estimated in one million animals per year (Johnson et al., 2013). However, there is no information on the incidence of NANI and NAI pigs in Brazil, and little is known about pig mortality worldwide.

Multifactorial causes have been attributed to the incidence of incapacitated or dead pigs (Johnson et al., 2013). The literature usually reports on isolated effects of these factors on losses, instead of considering a multifactorial approach. In addition, most of the reports were conducted under experimental conditions.

This research was carried out to evaluate the occurrence of NAI, NANI and dead pigs during pre-slaughter handling (from farm to slaughter), including carcass losses related to bruises, limbs/sacral fractures and identification of their risk factors.

## 2. Material and methods

All research procedures performed in this study were approved by the Committee of Ethical Use of Animals (Embrapa Swine and Poultry Protocol number: 002/2012).

### 2.1. Animals, farm facilities and handling

An observational study included the evaluation of 37,962 pigs (gilts and barrows from commercial lineages, LW = 119 kg) sent to slaughter involving 307 truck loadings, 60 farms and three different slaughterhouses under Southern Brazilian commercial conditions. Data were collected randomly along the year and farms selected according to the distance to the slaughterhouse and the number of housed animals (Table 1).

All pre-slaughtering procedures (loading, transporting and unloading) were carried out according to practices adopted by farms, transporters and slaughterhouses. Pigs were transported directly from farm pen into the truck using plastic/wood boards and rattles (Dalla Costa, Dalla Costa, & Cardoso, 2013). There was no use of electric shock in any procedure of pre-slaughter handling. On-farm fasting time varied from six to eight hours in all farms as recommended in the literature (Dalla Costa, Dalla Costa, Coldebella, Lima, & Ferraudo, 2018). The operational capacity of slaughterhouses 1, 2 and 3 was respectively 310, 220, and 200 animals/hour. All pigs were head-to-back stunned, using the following stunner models: Slaughterhouse 1) Fluxo®, FX 6000 model, Brazil; Slaughterhouse 2) AlfaComp®, unique model, Brazil; Slaughterhouse 3) Sulmaq®, 11202-1 model, Brazil.

Pigs were transported in 42 trucks (density of 0.43 $m^2$/pig at 283 $kg_{liveweight}/m^2$) which were conducted by the same driver that received training regarding animal welfare and good transport practices before the study starts. Upon arrival at the slaughter houses, pigs were handled to lairage pens with the use of compressed air, plastic bottle rattles and air-containing bags. Animals with limited mobility were transported to the lairage pen or to the restrainer on a trolley (Dalla Costa, Dalla Costa, Buss, Ludtke, & Lupato, 2017) developed for this purpose. Emergency slaughtering was carried out by head electrical stunning followed by bleeding.

## 2.2. Risk factor evaluation

The risk evaluation comprised 96 explanatory variables related to animal handling, facilities, loading/unloading, transport, lairage time, carcass grading and environment (temperature and humidity). Temperature and humidity were recorded every 30 seconds at loading, transportation and unloading using data loggers (DS1923 *iButton® Hygrochron* Temperature/Relative Humidity Logger, Maxim Integrated Products Inc., Sunnyvale, CA), which were installed at the dock in each compartment of the truck and in the rear-view mirror of this vehicle. The average, maximum and minimum values of temperature, humidity and enthalpy during each journey and during loading and unloading of each load were considered as explanatory variables. The enthalpy was calculated based on the following formula:

$$\text{Enthalpy} = 4.18 \times \left(6.7 + 0.243 \times \text{DBT} + \frac{\text{RH}}{100} \times 10^{\frac{7.5 \times \text{DBT}}{237.3+\text{DBT}}}\right)$$

where DBT = dry bulb temperature; and RH = relative humidity.

At the day before animal loading, a trained team was in charge of collecting information by interviewing the producer or the responsible manager regarding facilities and on-farm handling.

At loading, the ramp slope was evaluated with the use of electronic measuring tape, considering the ramp angle on each floor of the truck. Two variables (continuous quantitative variable and classificatory variable) were created. The first considered the maximum degree of the ramp slope until the truck floor, while the second considered a slope < 20 ° and ≥ 20 °.

On-farm handling was inspected by two trained people (47 inspected vs. 13 non-inspected = 60 farms). The first was responsible for observing the handling procedures from farm pen before the loading area. The second person was positioned near the loading ramp, evaluating the handling procedures **(such as slip/falls, number of pigs moved in each group, NANI and NAI pigs, and pigs with any sanitary problem)** from the loading ramp until the truck.

During transport, truck speed was measured by electronic tracking system via satellite (*Pointer Brasil* Ltda., BR), installed in each truck. These data were used to calculate the percentage of records in which the truck moved at speeds below 40, 60 or 80 km/h and the mean speed. The transport time was calculated by the time difference between the loading start and the loading end, and therefore this period included the waiting period before unloading the animals at the slaughterhouse.

Carcass grading (hot carcass weight, fat thickness and muscle thickness) was measured 45 min after slaughter in the region of the last rib, by using a probe with a photoelectric sensor (*Hennessy Grading Systems* GP4/BP4, NZ). Mean measurements per journey were used as explanatory variables.

## 2.3. Evaluation of the pre-slaughter losses

Throughout all pre-slaughter period, pigs classified as NANI, NAI, deaths and those presenting problems such as hernias, rectal prolapses, or any other health problem were identified by the animal ear tag and recorded. When animals were unloaded, the occurrence of dead or incapacitated animals was evaluated by a person positioned near the ramp, helped by the supervisor in charge of animal inspection in each slaughterhouse.

Pigs were considered incapacitated when they were unable to stand, walk, or keep with the rest of the group due to injury or fatigue (Johnson et al., 2013). All dead animals on the way to the slaughterhouse, at transport, or during the lairage period were included in transport mortality record. The average loss took into account the number of dead animals in each truck multiplied by the average carcass weight of the group and divided by the number of transported animals. All NANI pigs submitted to emergency slaughter and those that recovered during the resting period were registered.

## 2.4. Evaluation of carcass condemnation

Carcasses deviated to meat inspection room were ear tagged to estimate total losses, defined as limbs and/or sacral fractures, bruises, sanitary condemnation which included peritonitis, pneumonia, pleurisy and pleuritis (PPPP), toilets and operational fails during *post-mortem* inspection.

### 2.5. Statistical analysis

In order to carry out the statistical analyses, each journey to the slaughterhouse was considered as the observational unit. A total of 302 journeys and 32,661 animals were included in the analysis of the risk factors.

Initially the data were submitted to exploratory analyses, including frequency distribution for the classificatory variables and distribution analysis for the quantitative variables using stem-and-leaf plots and box-plots. For the determination of the risk factors related to the occurrence of NAI, NANI and dead pigs during transport, logistic regression models were adjusted considering the possible risk studied (see tables 3–5). The response variable used was the number of animals with problems in relation to the number of animals that were shipped.

The analysis was performed by the LOGISTIC procedure from SAS® (2012), using the “stepwise” method to select risk factors, accomplished through specific programming and also manually, since many explanatory variables were qualitative/categorical, what is an impairment to use stepwise option in the own procedure. The model chosen with the respective risk factors was detailed by calculating the odds ratio of each factor. The variables evaluated of transport time, temperature, humidity and enthalpy during transport were considered for 47 farms (230 trips) where these evaluations were carried out.

In the regression model, the effect of “falls at loading, distance from pen to loading ramp, transport time and average enthalpy during loading” were evaluated within the variable “Supervise vs. did not supervise loading”. The logistic regression model for total mortality, NAI and NANI pig mortality included the factors already identified in the models of each of these variables, previously shown, except the number of pigs per finishing pen and the hot carcass weight that was not included in the model for this variable.

## 3. Results

### 3.1. Causes and occurrence of losses during transport

As demonstrated in Table 2, the incidence of incapacitated pigs (NAI + NANI) was the main cause of losses, accounting for 0.76% (NAI = 0.39%; NANI = 0.37%). The dead-on-arrival pigs totalized 1.17%, which means that 0.96 pig/shipment died or arrived incapacitated at the slaughterhouse. A total of 321 pigs were classified as NAI, NANI and dead on-arrival at the slaughterhouse, comprising all 307 journeys made.

At farm, the incidence of pigs showing problems was 0.46%, and from the total number of pigs classified as NAI at unloading, almost half (0.18%) were already in this situation before loading (Table 2). Caudophagia, hernia and rectal prolapse were among the other problems that presented the greatest impact. During transport, the losses accounted for 0.71%, that may be attributed to the incidence of NAI (0.21%) and NANI (0.37%) pigs. From the total number of NANI pigs, 91.5% recovered animals during the lairage period were able to move normally to the *restrainer* at the time of slaughter. Transport contributed the most (0.08%) to pre-slaughter losses, although among the slaughterhouses the mortality rate was different (Fig. 1). The incidence of NANI and NAI pigs presented a positive correlation between each other (0.18, $P < 0.01$) and only NAI had a significant positive correlation with death (0.12; $P < 0.05$).

### 3.2. Factors affecting pre-slaughter losses

There were twelve factors that impacted the most the pre-slaughter losses from the farm until the slaughterhouse. Table 3 shows the risk factors regarding pig mortality. With respect to ramp slope, the probabilities of dying during transport were four times higher when the ramp had a slope greater than 20 degrees compared to a ramp that was less than 20 degrees. In relation to transport time, the probability of dying is 1.56 times more for every additional hour that pigs spent during transport. Also, when animals had on-farm problems (i.e.: walking difficulties, arthritis, hernias), the probabilities of dying were 1.32 times more for each 1% of animals identified with problems. The maximum ramp slope found was $25^{o}$ which was present at the second floor loading.

All risk factors contributed to NANI pigs probability (Table 3), especially supervise/does not supervise pig loading (41.4), loading ramp slope (5.7) and longer transport time (1.6). Other important factors that may increase NANI pigs probability are the average enthalpy at loading, the truck loading order, the time that truck moved below 60 km/h and muscle thickness.

The factors that affect the percentage of NAI pigs also included loading ramp slope, percentage of pigs with problems on the farm, and transport time with speeds below 60 km/h (Table 3). The percentage of NAI pigs increased as the number of animals housed in each termination pen increased.

Also, farms with more than 800 housed animals were at least 2.17 times more likely to have NAI pigs during transport than those with up to 800 pigs.

The significant risk factors comparing all the groups together (NAI, NANI and dead pigs - last three columns in Table 3) comprised the following probabilities: ramp slope (5.97), average temperature at transport (1.26), transport time (1.25), pigs with on-farm problems (1.22), muscle thickness (1.07) and time truck moved below 60 km/h (1.03).

### 3.3. Factors influencing occurrence of fractures and bruises on carcass

About 10.04% of carcasses were deviated to meat section room (Table 4). From this percentage, only 4.54% of carcasses were partially or completely condemned, while most of them returned to regular processing line. The main causes of condemnations were pre-slaughter handling problems and PPPP (Table 4). Occurrence of fractures and bruises was not correlated ($P > 0.05$). Among pre-slaughter causes of deviation to meat inspection room, limb fractures contributed the most for partial and total condemnation (Fig. 2).

Table 5 presents the variables included in the risk factor model for bruises and limb fracture occurrence. The probabilities of limb fractures were higher (3.26 and 3.19) in farms with larger herds (>800 animals), and where the position of loading ramp was at the extremities of the building (greater distance from pen to loading ramp) (Table 5). The probability of condemnation was also greater when the lairage period in slaughterhouse increased (ranged from 3-17 hours), when the percentage of animals that fell varied from 0 to 37% during loading, and also when the truck moved at speeds below 60 km/h during transport. In addition, there was an effect of density where the probabilities of limb fracture were 4.37 times higher for each extra pig allocated per $m^2$ in the truck. On the other hand, the risk of carcass condemnation due to limb fracture was influenced by a greater time spent at loading (0.93); muscle thickness (0.93); width of the pen gate (0.92); average temperature during transport (0.91); width of the aisle at farm (0.12) and density at the farm (0.03).

Regarding the probability of bruises, Table 5 shows that **shorter** distances (<160 km) from farm to slaughterhouse reduced the risk of carcass bruises (0.13 vs 0.24). The width of the pen gate and the width of the aisle at the farm were also significant factors responsible for increasing the probability of bruises in 1.31 and 12.3 times, respectively. On the other hand, the use of larger groups during loading resulted in lower chances (0.60) of carcass bruises. Also, muscle thickness decreased the probability (0.76) of bruises.

## 4. Discussion

### 4.1. Causes and occurrence of losses during transport

The greater number of animals housed per finishing pen increased the incidence of NAI pigs. Contrary, Gesing et al. (2011), although evaluating only 24 journeys, did not find an effect of the group size on the transport losses. Some studies that evaluated group size effects on pig welfare either on farm or transport are inconclusive (Gesing et al., 2011, 2010; Street & Gonyou, 2008). In Brazil, pigs are usually driven directly from the finishing pen to the truck. Large groups are hard to be handled, resulting in more injuries and stressed animals. There is a probability of NAI occurrence or dead pigs during transport when animals have any of the following on-farm problems: abscesses, walking difficulties, caudophagia, arthritis or hernias.

Injured pigs on-arrival at slaughterhouse (0.72%) already left the farm in this condition (Table 2), what shows on-farm welfare problem. The recommendations that should be followed when animals are injured still on-farm are to sacrifice them instead of loading and continue to slaughterhouse. As far as we are concern, no official reports are available on the occurrence of mortality and incapacitated pigs in slaughterhouses in Brazil. In our outcomes, the incidence of these losses represented < 1% of the animals transported, what is in agreement with other countries such as Canada and the USA (Ritter et al., 2009). Although 99% of the animals arrive without any health problem in the slaughterhouses, the remaining 1% may influence significantly the economics of a given country, depending on each country specific production scale.

Although heavier animals move with difficulty and their bone structure may be overloaded, no effects of hot carcass weight were observed on pre-slaughter losses. Otherwise, greater muscle thickness increases the incidence of NANI pigs and total loss. There is evidence that selected lineage directed for lean meat production, with greater muscle development, are more difficult to handle and more susceptible to stress. NANI syndrome is associated to a modified muscle fiber in these animals, which makes them more susceptible to muscle metabolism changes (Johnson et al., 2013). Also, induced genetic mutations and the presence of other genes, other than halothane, may have contributed to higher muscle ratio, mortality and NAI/NANI pigs.

Independently of the pre-slaughter phase, special care should be given to NAI/NANI pigs. On arrival, these pigs are conducted to the meat inspection room; therefore their carcass may be partially/fully condemned. Most of the animals identified as NANI on unloading have recovered during the lairage period, allowing them to be normally conducted until slaughter, corroborating the literature (Ritter et al., 2006). Based on our findings, it is recommended that NANI should be kept in a place where they can rest until they are recovered before handling or sacrificed if they are not recovered.

## 4.2. Factors affecting pre-slaughter losses

### 4.2.1. Ramp slope

The positive correlation between NAI, NANI and dead pigs suggests that these conditions share some common causes. Most factors responsible for pig losses are related to on-farm handling and to the own animal. For instance, ramp slope was the variable that affected the most the occurrence of NAI, NANI and dead pigs when comparing them together, and this variable is directly related to the facilities. The loading ramp with a slope higher than 20° was a risk factor for all variables related to NAI (5.75), NANI (3.48), dead (4.07) and total loss (5.97) during transport.

In fact, sloping ramps may represent physical stress for pigs that are not used to physical activities (Goumon et al., 2013) as those kept in confinement systems with restricted space. Climbing ramps is difficult for pigs, because this exercise psychologically disturbs them, what makes them refuse to climb or even turn their sides towards the ramps (Lambooij, 2014; Phillips, Thompson, & Fraser, 1988). Descending a loading ramp steeper than 20º is also difficult for all animals and should be avoided, besides they spend more time to climb. As the ramp slope increases, the heart rate also increases, especially in hot weather conditions (Garcia & McGlone, 2015). Therefore, the use of ramps with a slope lower than 20° has been recommended for bovine and pigs (Goumon & Faucitano, 2017; Lambooij, 2014). However, to our knowledge, this is the first study to show the direct connection between the ramp slope and the incidence of NAI, NANI and dead pigs at unloading. This reflects how simple improvements (inclination of $5^{o}$) can reduce pre-slaughter losses. One of the challenges that may be overcame is the ramp slope by the use of truck type with hydraulic upper deck, leading to easier and faster (un) loading, improved animal welfare and reduced labor of handlers (Dalla Costa et al., 2016).

### 4.2.2. Truck loading order

Truck's loading order affects the incidence of NANI pigs and transport total losses, probably because the loading team was stressed or fatigued because they spent 30 min on average for each loading on a truck with 96 pigs (Dalla Costa et al., 2016). The farm size and the number of loaded pigs in the truck influence the probabilities of NAI and total loss incidence. Our findings demonstrate the importance of training the loading crew and the planning of loading to avoid pre-slaughter losses. Ritter et al. (2006) observed that the number of loadings performed by the team during the day was correlated to the incidence of on-farm NANI/NAI pigs. It is recommended to handle small groups of 2 to 6 pigs at a time; this practice is beneficial to handlers and also to pigs, because heart rate and time spent to load them are decreased (Goumon & Faucitano, 2017; Lewis & McGlone, 2007; Paranhos da Costa, Huertas, Gallo, & Dalla Costa, 2012).

#### 4.2.3. Transport time

The increase in the transport time was responsible for increasing the probabilities of dead pigs, NANI pigs and total losses, what may be attributed to transport and waiting time to unload pigs at the slaughterhouse (Ritter et al., 2006). However, Haley et al. (2008) reported that dead on arrival pigs and at risk of death during transport decreased 0.81 times each 50 km travelled and with distances over 134 km, respectively. A large survey of 109 trips in different EU countries indicated that 0.07% of weaned piglets arrived dead and death losses happened on 13.8% of the trips. Longer trips with higher temperatures provided increased death losses (Lambooij, 2014). Mota-Rojas et al. (2006) investigated the effects of mid-summer transport in Mexico, on pre-and post-slaughter performance and pork quality) and recommended that optimal transport time should not take more than 16 h in order to improve carcass quality and animal welfare. Indeed, depending on stress level during pre-slaughter handling, pigs may not be able to recover during short journeys. Transport represents numerous stressors to pigs, including climates, geographies and transport equipment, especially when the experience is unfamiliar or novel (McGlone, Johnson, Sapkota, & Kephart, 2014).

#### 4.2.4. Truck speed

Truck speed did not increase transport losses. Our results showed that the longer the truck moved below 60 km/h, the greater the probability of total losses during transport. Low speeds, possibly, does not mean caution in driving the vehicle, but poor road conditions that forced the driver to move slowly (Schwartzkopf-Genswein et al., 2012). Besides, higher speeds may affect animals' balance, increasing physical effort to maintain them standing or increase impacts against the truck structures and among the animals (Dalla Costa, Lopes, & Dalla Costa, 2017; Schwartzkopf-Genswein et al., 2012).

#### 4.2.5. Enthalpy

Both mortality reduction and NAI losses can be promoted by enthalpy increase or thermal comfort. Our results showed that average temperature increased the probability of transport total losses especially above 20 °C. Kephart et al. (2010) verified a greater incidence of panting pigs and skin discoloration on unloading above 17 °C. Similarly, at an environment temperature of 16 °C and air velocity of 0.2 m/s, the heat production is low, thus meat quality is expected to be better in slaughtered pigs (Lambooij, 2014). Previous research (Vitali et al., 2014) reported that above 5 °C, transport mortality increased, due to the difficulty of pigs in losing heat in hot temperature and high humidity. Peterson et al. (2017) established that either in hot weather conditions (29–33 °C), or minimum temperature (4–10 °C), the risk of death of finishing pigs is respectively 1.37 and 0.97 times greater than baseline temperature range (12–26 °C). In order to reduce effects of the environment during summer on animal welfare, Dalla Costa et al. (2015) studied the use of showering pigs on the truck before the transport and on arrival at the slaughterhouse. However, no effects on animal welfare variables or losses were found. Recently, Pereira et al. (2018) developed a cooling system, through water misting with forced ventilation, which appeared to be effective in improving the trailer internal thermal environment and thermal comfort of marketed pigs kept in a stationary trailer.

### 4.3. Factors influencing occurrence of fractures and bruises on carcass

Larger group size housed per finishing pen decreased the risk of bruises in the carcasses. The number of pigs per pen varied from 9 to 240 (n= 302). In this study, the farms with the greatest group size (240 pigs) per pen were also those with higher densities. Therefore, pigs are likely to move less in smaller pens, especially when splitting the groups at loading into the truck; this procedure makes them less likely to present bruises and fractures. The dimensions of the aisles, ramp and pen gates were, respectively, 0.95 ± 0.12 m, 0.92 ± 0.22 m and 2.61 ± 1.82 m. The expected percentages of bruises in this study, based on estimates of model parameters as a function of the number of animals per group are 0.44% for 10 animals, 0.25% for 20 animals, 0.15% for 30 animals and 0.08% for 40 animals. These expected values were obtained by fixing the other parameters of the model according to their mean or mode, in the case of categorical factors. During (un) loading, transport injuries and bruising may occur in all animal species by forceful contacts in passageways, in compartments and in containers, by fighting between animals and by mounting (Lambooij, 2014).

The evaluated farms had great variation of pen gates width and most of them had a feeder system which occupies the full extent of the pen front. Usually, in this system the wall/gate is suspended to allow the animal exit, which represents a challenge for animals, increasing bruises and fractures occurrence. In Brazil, animals are usually driven directly from the finishing pen to the loading ramp without accessing the waiting room. Therefore, when the loading ramp is located at the end of the facility, the animals need to walk long distances during loading, increasing the risk of fractures.

During pre-slaughter handling, bruising and fractures can occur due to fighting, shocks against animals and facilities and also contact with handling tools. The greater risk of fractures in larger herds reflects fatigue, exhaustion and stress of the handling crew in a large group of pigs (Dalla Costa et al., 2016b). An increased risk of injury in larger herds was previously reported in the literature (Harley, More, Boyle, O' Connel, & Hanlon, 2012; Mousing et al., 1990). A number of studies have already shown that more intense or aggressive handling affect pig stress, carcass damage, and meat quality (D'Souza & Leury, 1998; Goumon & Faucitano, 2017; Hambrecht et al., 2005). Despite being a common practice, handling large groups of pigs impairs the ease of handling and skin lesions (Goumon & Faucitano, 2017; Schwartzkopf-Genswein et al., 2012). Different from expected, the probability of carcass bruises were lower when the group size was increased during loading, and this variable did not represent a risk factor for fracture occurrence. This result indicates that the effect of group size probably interacts with other factors related to shipping conditions. For this effect, it is important to associate the aisle width to group size handled.

Independently of the group size handled, Goumon and Faucitano (2017) reported easier handling using loading ramps/aisles of 0.75–1.2 m compared to wider ones. Thus, wider loading ramps and aisles may difficult the handling and increase number of contacts between animals and handler and against walls due to the greater attempts of turning around and return. Larger aisles and pen gates reduced the risk of fractures due to ease of handling. However, the occurrence of bruising was greater in larger pen gates and loading ramp width. In this case, how animals are handled and driven, including group size, may influence on the results. In addition, regarding to the handling procedure, the results showed that fracture occurrence was lower when the following variables were also lower: time spent to load each pig and number of falls.

The risk of condemnation due to carcass bruising was lower when farms were < 160 km to the slaughterhouse. Indeed, a long journey reduce pig welfare and meat quality (Pérez et al., 2002). However, Gosálvez et al. (2006) found no effect of transport distance on the percentage of carcases with partial or total condemnation. Nielsen, Dybkjær, & Herskin (2011) and Schwartzkopf-Genswein et al. (2012) concluded that journey quality, including road, weather and driving conditions, are factors associated to cause animal welfare problems, transport losses and meat quality defects than journey duration itself. In addition, probability of fractures occurrence increased when the truck remained more time at speeds below 60 km/h. This association between low speed and greater occurrence of fractures can be explained by farm access difficulty (not considered in this study) that forced trucks to drive slowly. The association between distance that animals are transported to the slaughterhouse and the occurrence of fractures is unclear. It has been demonstrated that the effects of transport are more related to road conditions and driving style (Dalla Costa et al., 2017, 2016b, 2007; Schwartzkopf-Genswein et al., 2012).

Higher densities impair pig accommodation in the truck. As a result, they can increase the number of disputes, trampling or the attempts of the animals to climb on top of each other (Dalla Costa et al., 2017; Gispert et al., 2000; Guise et al., 1996), resulting in greater probability of limb fracture. However, transport cost is usually calculated based on fuel costs per pig, what leads to increased density. In order to cope with low temperatures, pigs huddle and climb over the backs of other pen mates (Guise et al., 1996; Lambooij & Engel, 1991), contributing to the greater probability of fracture and bruising in low enthalpy values. In Brazil, lower carcass bruising during transport were found in the winter (Dalla Costa et al., 2007). Gosálvez et al. (2006) reported that under commercial conditions in Spain, the percentage of carcasses with partial condemnations was lower in the summer than in other seasons. A loading density for slaughter pigs of 235 $kg/m^2$ is suggested as being acceptable as a compromise between animal welfare, meat quality and economics of transport; at loading densities of > 200 $kg/m^2$, pigs showed increased body temperature, heart rate and breathing frequency after a short journey (Lambooij, 2014; McGlone et al., 2014).

Grandin (1999) suggested that in modern pig genetic lines with great proportions of muscle in the carcass, the skeleton growth and maturation cannot support the rapid muscular growth, resulting in weak bones that are more likely to have fractures during electrical stunning. However, our results also showed that the incidence of fractures was lower as the carcasses presented greater muscle thickness.

Condemnation due to limb fractures and bruises were higher in this study, compared to total condemnations previously reported in a Brazilian slaughterhouse (5 to 26%; Bueno et al., 2013) and Ireland (3.68%; Harley et al., 2012). However, these two studies evaluated data recorded by the inspection systems of the slaughterhouse, and the lack of recorded data may have been responsible for this difference.

## 5. Conclusions

Pre-slaughtering carcass losses do have multifactorial causes and they are not only related to transport factors, but also to on-farm conditions. Within the risk factors associated to pre-slaughtering losses, the conditions of lodging and on-farm loading, besides the animal itself are the main ones. Other important factors for NANI, NAI and dead pigs on-arrival are the design of the facilities, the group size housed, the handling at loading, the environmental conditions during loading and transportation, the transport logistics, the muscle thickness and animal health status. Also, the on-farm problems are responsible for increasing losses.

The occurrence of bruises, which is a welfare issue, has a large number of factors that should be worked on to be reduced. Usually, these factors could be solved with facilities and handling improvements, such as aisle width and pen gates, loading ramp location, quality of handling and transport density. Indeed, more training programs for handling crews and drivers could reduce effects of preslaughter procedures on animal welfare.

Based on our results, the recommendations to improve welfare are: ramp slope should be as minimum as possible, without exceeding 20°; aisle width, gate width and loading ramp width should all be at minimum 1 m. Despite the recommended pen size being 40 pigs or more, the handled group size should be kept smaller (2-6 pigs at a time).

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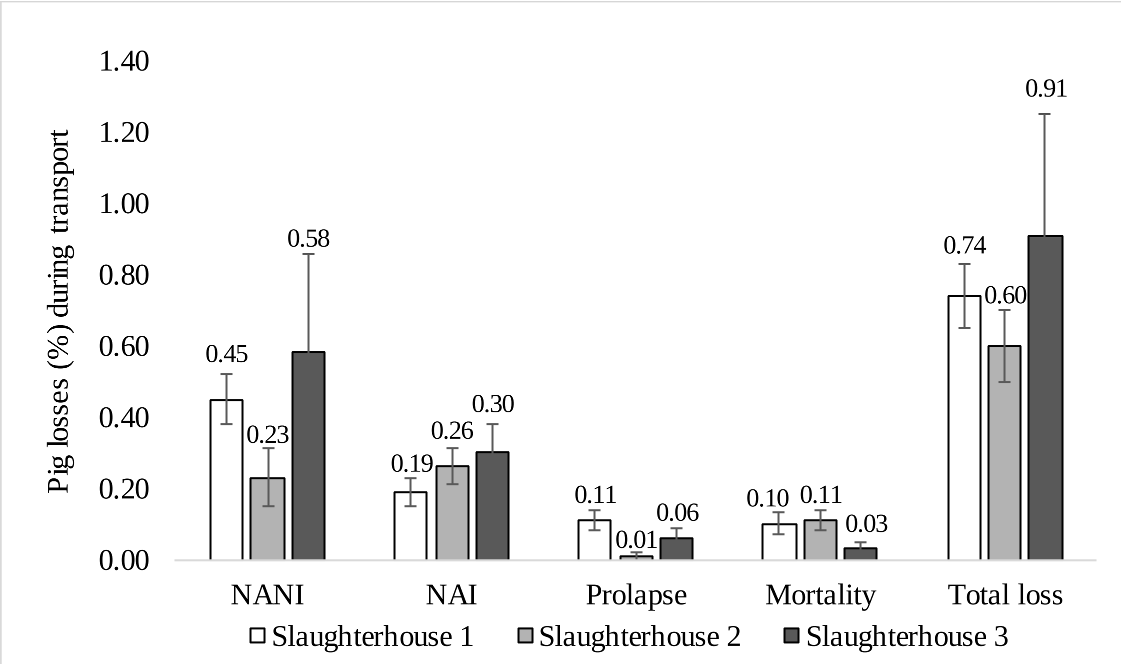
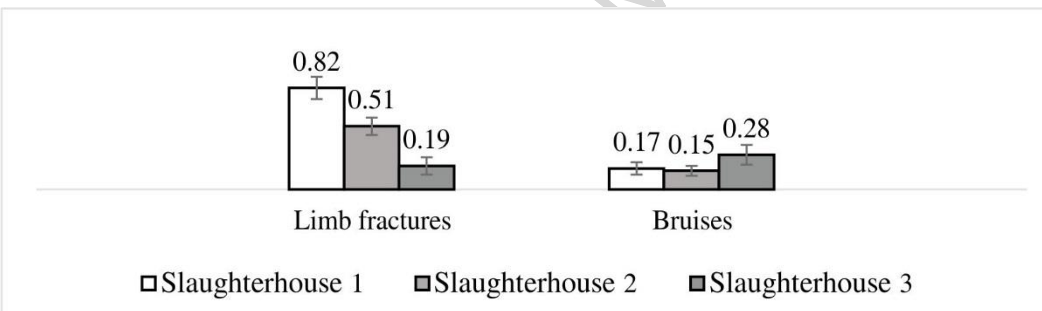


Pig losses (%) during transport
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.45
0.23
0.58
0.19
0.26
0.30
0.11
0.01
0.06
0.10
0.11
0.03
0.74
0.60
0.91
NANI
NAI
Prolapse
Mortality
Total loss
Slaughterhouse 1
Slaughterhouse 2
Slaughterhouse 3


**Fig. 1**



0.82
0.51
0.19
0.17
0.15
0.28
Limb fractures
Bruises
Slaughterhouse 1
Slaughterhouse 2
Slaughterhouse 3


**Fig. 2.**

**Table 1.**

Distribution of farms according to the number of animals housed and the distance from the slaughterhouse.

| Distance/animals | 0–400 | 400–800 | ≥ 800 | Total |
|---|---|---|---|---|
| 0–80 km | 5 | 11 | 16 | 32 |
| 80–160 km | 7 | 9 | 4 | 20 |
| ≥ 160 km | 1 | 3 | 4 | 8 |
| Total | 13 | 23 | 24 | 60 |

**Table 2.**

Classifications of losses identified during the pre-slaughter period of pigs in three Brazilian slaughterhouses.

| Losses | Transport | | Slaughterhouse | | Total | |
|---|---|---|---|---|---|---|
| | N | %* | N | %* | N | %* |
| NAI[1] | 79 | 0.21 | 69 | 0.18 | 148 | 0.39 |
| NANI[1] | 140 | 0.37 | 1 | 0.00 | 141 | 0.37 |
| Death | 32 | 0.08 | 3 | 0.01 | 35 | 0.09 |
| Prolapse | 21 | 0.06 | 3 | 0.01 | 24 | 0.07 |
| Caudophagia | - | - | 37 | 0.10 | 37 | 0.10 |
| Arthritis | - | - | 10 | 0.03 | 10 | 0.03 |
| Rickets | - | - | 4 | 0.01 | 4 | 0.01 |
| Hernia | - | - | 37 | 0.10 | 37 | 0.10 |
| Others | - | - | 7 | 0.02 | 7 | 0.02 |
| **Total** | **272** | **0.72** | **171** | **0.46** | **443** | **1.18** |

*Total evaluated pigs: 37,962.

[1]NANI = *non-ambulatory non-injured*; NAI = *non-ambulatory injured*.

**Table 3.**

Odds ratio estimates of *non-ambulatory non-injured* (NANI) pigs, non-ambulatory injured (NAI) pigs, dead pigs, and all of them grouped together occurring during pre-slaughter procedures according to each risk factor included in the final logistic regression model.

| | NANI pigs | | | NAI pigs | | | Dead pigs | | | NAI, NANI and dead pigs | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Odds ratio[1] | Confidence interval (95%) | $P^2$ | Odds ratio[1] | Confidence interval (95%) | $P^2$ | Odds ratio[1] | Confidence interval (95%) | $P^2$ | Odds ratio[1] | Confidence interval (95%) | $P^2$ |
| *Farm size (n)* | | | | | | 0.022 | | | | | | |
| > 800 vs 0-400 | | | | 2.569 | 0.809–8.158 | 0.110 | | | | 2.496 | 0.974 – 6.398 | 0.057 |
| > 800 vs 400-800 | | | | 2.175 | 1.188–3.978 | 0.012 | | | | 1.638 | 0.988 – 2.716 | 0.056 |
| Group size in each pen (n) | | | | 1.017 | 1.010–1.024 | <.0001 | | | | | | |
| Pigs with on-farm problems (%) | | | | 1.306 | 1.118–1.525 | <0.001 | 1.318 | 1.031–1.686 | 0.028 | 1.224 | 1.046–1.433 | 0.012 |
| Supervise vs. did not supervise pig loading | 41.459 | 1.824–942.089 | 0.003 | 0.842 | 0.339–2.093 | 0.171 | 2.300 | 0.436–12.127 | 0.051 | 3.764 | 0.297–47.656 | 0.070 |
| Enthalpy at loading (KJ/mol) | 1.046 | 1.007–1.087 | 0.020 | | | | | | | 0.944 | 0.881–1.010 | 0.096 |
| Loading ramp slope >20° vs. ≤20° | 5.750 | 2.302–14.361 | <0.001 | 3.481 | 1.482–8.177 | 0.004 | 4.070 | 1.692–9.791 | 0.002 | 5.968 | 3.153–11.295 | <0.001 |
| Truck loading order | 1.148 | 1.035–1.274 | 0.009 | | | | | | | 1.073 | 0.994–1.158 | 0.072 |
| Transport time (h) | 1.631 | 1.289–2.064 | <0.001 | | | | 1.564 | 1.181–2.071 | 0.002 | 1.249 | 1.044–1.494 | 0.015 |
| Temperature during transport (ºC) | | | | | | | | | | 1.257 | 1.056–1.497 | 0.010 |
| Time truck moved below 60 km/h | 1.042 | 1.019–1.066 | <0.001 | 1.022 | 1.002–1.042 | 0.029 | | | | 1.028 | 1.013–1.043 | <0.001 |
| Hot carcass weight (kg) | | | | 1.061 | 0.995–1.132 | 0.073 | | | | | | |
| Muscle thickness (mm) | 1.120 | 1.022–1.228 | 0.016 | | | | | | | 1.066 | 1.004–1.132 | 0.036 |

[1]Estimated on 302 journeys to 60 farms and three slaughterhouses.

[2]Descriptive level of probability by Pearson test.

**Table 4.**

Causes of carcasses losses identified by meat inspection service in three Brazilian slaughterhouses.

| Causes | Deviated to meat inspection room | | | Partial condemnation | | | Total condemnation | | |
|---|---|---|---|---|---|---|---|---|---|
| | N of carcasses | Absolut % | Relative % | N of carcasses | Absolut % | Relative % | N of carcasses | Absolut % | Relative % |
| Pre-slaughter | 959 | 2.53 | 25.22 | 926 | 2.44 | 65.63 | 30 | 0.08 | 9.35 |
| Sanitary | 787 | 2.08 | 20.68 | 243 | 0.64 | 17.23 | 122 | 0.31 | 37.88 |
| Operational | 248 | 0.65 | 6.52 | 242 | 0.63 | 17.15 | 2 | 0.01 | 0.62 |
| PPPP[1] | 1,800 | 4.75 | 47.28 | - | - | - | 167 | 0.43 | 51.86 |
| Total | 3,794 | 10.01 | 100 | 1,411 | 3.71 | 100 | 321 | 0.83 | 100 |
| | Pre-slaughter | | | | | | | | |
| Bruise | 60 | 0.16 | 1.58 | 55 | 0.14 | 3.9 | 5 | 0.01 | 1.56 |
| Limbs Fracture | 205 | 0.54 | 5.39 | 179 | 0.47 | 12.69 | 25 | 0.07 | 7.79 |

[1]PPPP = Peritonitis, pneumonia, pleurisy and pleuritis.

**Table 5.**

Odds ratio estimates of carcass condemnation due to limb fractures and bruises according to each risk factor included in the final logistic regression model.

| | Limb fractures | | | Bruises | | |
|---|---|---|---|---|---|---|
| | Odds ratio[1] | Confidence interval (95%) | P[3] | Odds ratio[1] | Confidence interval (95%) | P[3] |
| Supervise vs. did not supervise pig loading | 0.133 | 0.022–0.812 | 0.029 | 0.003 | $2.346E10^{-6}$–4.967 | 0.126 |
| *Herd size (N)* | | | 0.012 | | | |
| >800 vs 0–400 | 3.259 | 1.263–8.409 | 0.015 | | | |
| >800 vs 400–800 | 1.967 | 1.145–3.378 | 0.014 | | | |
| *Distance (km)* | | | | | | <0.001 |
| 0–80 vs >160 | | | | 0.128 | 0.054–0.301 | <0.001 |
| 80–160 vs >160 | | | | 0.244 | 0.086–0.689 | 0.008 |
| Temperature during transport[3] (°C) | 0.907 | 0.850–0.968 | 0.003 | | | |
| Time truck moved below 60 km/h | 1.019 | 1.003–1.035 | 0.022 | | | |
| Density at farm (pigs/$m^2$) | 0.035 | 0.002–0.569 | 0.019 | | | |
| Group size of pigs during loading | | | | 0.604 | 0.398–0.915 | 0.017 |
| Falls at loading[2] (%) | 1.053 | 1.011–1.097 | 0.014 | | | |
| Width of aisle at farm (m) | 0.121 | 0.017–0.872 | 0.036 | 12.332 | 2.025–75.087 | 0.006 |
| Position of loading ramp: extremity vs middle | 3.188 | 1.490–6.819 | 0.003 | | | |
| Distance - Pen to loading ramp (m) | 0.988 | 0.976–1.001 | 0.066 | | | |
| Muscle thickness (mm) | 0.935 | 0.876–0.999 | 0.047 | 0.764 | 0.646–0.904 | 0.002 |
| Width of pen gate (m) | 0.921 | 0.835–1.016 | 0.102 | 1.306 | 0.953–1.792 | 0.097 |
| Density at transport (pig/$m^2$) | 4.372 | 0.653–29.293 | 0.129 | | | |
| Time spent for loading[3] (s/pig) | 0.933 | 0.866–1.006 | 0.070 | | | |

| | | | |
|---|---|---|---|
| Lairage period (h) | 1.079 | 0.983–1.184 | 0.112 |

[1]Estimated on 302 journeys to 60 farms and three slaughterhouses.
[2]Inside the facility, considering animals which proceeded directly to loading ramp.
[3]Descriptive level of probability by Pearson test.

## HIGHLIGHTS

- Total losses during transport of pigs were 1.18%.
- The incidence of NAI and NANI pigs were 0.39 and 0.37%, respectively.
- The NAI and NANI pigs were the causes that contributed mostly to transport losses.
- Most of risk factors occurred either on the farm or during transport.