MORTALITY RATE OF WEANED AND FEEDER PIGS AS AFFECTED BY GROUND TRANSPORT CONDITIONS

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ABSTRACT. *Ground transport of pigs at early ages may result in profit-stripping incidences of mortality and compromised animal welfare due to stress stemming from unfavorable transport conditions. The objective of this study was to examine possible causative relationships of mortality rate of weaned and feeder pigs to ground transport conditions. A total of 7056 transportation records of weaned pigs (3174 records) and feeder pigs (3882 records) for the period from April 2012 to January 2014 were provided by a U.S. swine company. Effects of pig type (weaned vs. feeder pigs), ambient temperature (<15°C or cool/cold, 15°C to 25°C or mild, and >25°C or warm/hot), travel distance (<600 km, 600 to 900 km, 900 to 1200 km, 1200 to 1500 km, and >1500 km), and the interactive effects on dead-on-arrival (DOA) rate (DOA per head loaded, %) were evaluated. The effects of the same variables on post-transport mortality of weaned pigs were also evaluated. Results show that DOA rate was affected by pig type, ambient temperature, and travel distance interactively. Weaned pig DOA rates (mean ±SE of 0.0333% ±0.0150%) tended to be higher than feeder pig DOA rates (0.0243% ±0.0110%) (p = 0.0004), and weaned pigs were more vulnerable to transport stress in warm/hot conditions. For weaned pigs, DOA rates were higher with >900 km travel distance (0.0543% ±0.0389%) than with <900 km travel distance (0.0118% ±0.0078%) in cool/cold conditions, and DOA rates significantly increased as travel distance increased in warm/hot conditions. For feeder pigs, DOA rates were not affected by travel distance in cool/cold or mild conditions; however, higher mortality rates were found with >1200 km travel distance (0.2717% ±0.1326%) than with <1200 km travel distance (0.0315% ±0.0151%) in warm/hot conditions. Statistical analysis showed that post-transport mortality rate of weaned pigs was affected by ambient temperature during transport and travel distance interactively for the first one or two weeks after transport. However, it should be noted that the relationship between post-transport mortality and transport conditions could have been confounded by other factors, such as management at the finishing farm. Outcomes of this study are expected to offer insight into improving the ground transport of pigs.*

Keywords. *Animal welfare, Dead on arrival (DOA), Feeder pig, Pig transportation, Weaned pig.*

The current trend in the U.S. swine industry is to separate the farrow-to-finish process into several production phases and isolate these phases at different sites that may be hundreds of kilometers apart. According to a USDA report (USDA, 2006), overall 41% of farrowing operations (75% of operations with more than 5000 head) shipped to a separate nursery site, and 48% of nursery operations (58% of operations with more than 5000 head) shipped to a separate grower/finisher site. This approach helps prevent disease transmission from older finisher pigs to younger and breeding pigs; however, it requires transport of pigs at early ages. Transport of young pigs occurs simultaneously with weaning or after nursery, when their physiology has not fully developed, thereby exacerbating the total transport stress on the animals. Proper transport of young pigs in favorable conditions is thus critical to reduce transport stress and the associated profit-stripping mortality and to improve the well-being and grow-finish performance.

The impact of transport on market-weight pigs has been a particular research interest (Gosálvez et al., 2006; Haley et al., 2008; Mota-Rojas et al., 2012; Ritter et al., 2008; Vecerek et al., 2006). Effects such as weather, loading density, pen position, transport duration, truck type, driver influences, and time of day on pig mortality, behavior, physiological response, and meat quality have been extensively investigated (Abbott et al., 1995; Gade and Christensen, 1998; Gajana et al., 2013; Kim et al., 2004; Torrey et al., 2013). These investigations have shown that unfavorable temperature conditions (too hot or cold) and long journeys downgrade animal welfare and increase transport loss. Compared to market-weight pigs, knowledge of transport conditions affecting early-age pigs (<9 weeks of age), including weaned (2.5 to 5 weeks of age) and feeder pigs (6 to 9 weeks of age), are much less established. A few studies have looked at early-age pig transport. Lewis (2008) expressed concerns about the effects on early feed consumption, dehydration, and additive fatigue of weaned pigs (17 days of age) transported during the transition to different feed. Sutherland et

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al. (2009) examined space allowance (0.05 to 0.07 m^2 pig^{-1}) and found no significant impact on the physiology and behavior of weaned pigs (18 days of age) during short transport (112 min). Jesse et al. (1990) reported that the shrinkage of feeder pigs (9 weeks of age) provided with feed and water was less than that of pigs that fasted during 563 km transport. While these simulation experiments involving limited numbers of early-age pigs looked at several transport stressors to pig performance and behavior, identifying major factors for profit-associated responses, e.g., mortality, requires large amounts of commercial data. An analysis involving commercial data would provide a more representative estimation, and a large sample size would yield much greater power for statistical tests.

The objective of this study was to examine possible causative relationships between ground transport conditions and the mortality rates of weaned and feeder pigs using three years of transportation records provided by a large swine production company. Analysis of mortality during transport (dead on arrival, or DOA) was performed for both weaned and feeder pigs; analysis of post-transport mortality (death in the first one or two weeks after transport) was performed only for weaned pigs due to a lack of data for feeder pigs. The factors of interest include pig type, ambient temperature, and transport distance.

Materials and Methods

Raw Data and QA/QC

Raw data were collected from a large swine company in the U.S. The dataset included a total of 13,344 pig transportation records over three years (2012-2014). Each record was identified by date of transport, farm/city of origin (FO), farm/city of destination (FD), type of pig, number of head loaded, end body weight, distance traveled, number DOA, trucker ID, etc. (a total of 30 parameters). In total, 15 FO, 235 FD, and 21 truckers were involved. For records of weaned pigs, mortalities in the first one and two weeks after transport were also obtained. The raw data underwent strict quality assurance and quality control (QA/QC) to ensure soundness of the data analysis. The QA/QC procedures included screening and flagging suspicious records, deleting duplicate and false records, and combining records of the same trip. After QA/QC, the dataset was double-checked by representatives of the company, and 7056 transportation records (or 52.88% of the raw data records) were identified as valid data and used for analysis in this study.

Data Grouping and Statistics

The data were grouped by type of pig transported, ambient temperature, and travel distance. Two pig types, i.e., weaned pigs (mean body weight ± standard deviation or SD of 6.5 ±0.7 kg) and feeder pigs (mean body weight ±SD of 24.3 ±4.1 kg), were involved. The ambient temperature was estimated by averaging the local daily mean temperatures of the origin and destination farms/cities and was classified into three categories, i.e., cool/cold (<15°C), mild (15°C to 25°C), and warm/hot (>25°C). These three categories are most suitable for delineating the relationship between mortality and ambient temperature according to our preliminary data observation (mortality against temperature). The travel distance covered a wide range (from 8 to 2525 km) and was divided into five consecutive bins: <600 km, 600 to 900 km, 900 to 1200 km, 1200 to 1500 km, and >1500 km. The reason for dividing travel distance in this way was to ensure convergence of the parameter estimates for each distance bin in the model. The number of transportation records by temperature and distance are listed in table 1. All 3174 records of weaned pigs were used for DOA rate analysis, while 3012 records were used for post-transport mortality analysis, as 162 records did not pass QA/QC.

Data Analysis

Analysis of Mortality of Weaned and Feeder Pigs during Transport

Effects of pig type, ambient temperature, and travel distance on pig DOA rate were analyzed using a general linear mixed model (GLIMMIX, eq. 1) with binomial random components in SAS (ver. 9.3, SAS Institute, Inc., Cary, N.C.). Because DOA rate may be influenced by the environment in which the pigs were raised and the way they were transported, original farm and trucker were included as two random factors in the model. The analysis was first performed by excluding the >1500 km distance data (for both weaned and feeder pigs) because there were no transportation records in the >1500 km bin for feeder pigs, which may result in inestimable parameters. The effect of travel distance (and the interaction with temperature condition) was then examined for each pig type with all distance bins included. Multiple comparisons were adjusted using the Tukey method. In this article, we report mortality rates using values predicted by the SAS program because these values account for the tested factors and unequal sample sizes within factors and are thus unbiased estimations:

$$MR_t = \frac{DOA}{HL} = P + T + D + P \times T + T \times D + P \times D + P \times T \times D \quad (1)$$

where

MR_t = mortality rate during transport (%)

Table 1. Number of pig transportation records involved in the analysis in this study.[a]

Travel Distance (km)	Weaned Pigs				Feeder Pigs			
	Cool/Cold	Mild	Warm/Hot	Total	Cool/Cold	Mild	Warm/Hot	Total
<600	174	114	72	360	401	279	243	923
600 to 900	278	312	205	795	869	860	502	2231
900 to 1200	435	382	387	1204	240	176	149	565
1200 to 1500	156	166	111	433	61	51	51	163
>1500	129	136	117	382	0	0	0	0
Total	1172	1110	892	3174	1571	1366	945	3882

[a] Ambient temperatures: <15°C = cool/cold, 15°C to 25°C = mild, and >25°C = warm/hot.

DOA = number of pigs dead on arrival
HL = number head loaded onto truck
P = type of pig transported, i.e., weaned or feeder
T = ambient temperature during transport, i.e., cool/cold (<15°C), mild (15°C to 25°C), and warm/hot (>25°C)
D = distance traveled, i.e., <600 km, 600-900 km, 900-1200 km, 1200-1500 km, and >1500 km.

Analysis of Mortality of Weaned Pigs One or Two Weeks after Transport

Effects of ambient temperature during transport and travel distance on the post-transport mortality rate of weaned pigs were analyzed using a GLIMMIX model (eq. 2) in SAS 9.3. Original farm, trucker, and finishing farm were considered as random factors. The NEWRAP optimization method was used for convergence. Multiple comparisons were adjusted using the Tukey method:

$$MR_p = \frac{D_p}{HP} = T + D + T \times D \quad (2)$$

where
MR_p = post-transport mortality rate of weaned pigs (%)
D_p = number of dead weaned pigs during the first one or two weeks after transport
HP = head placed in finishing barn, i.e., number of weaned pigs
T = ambient temperature during transport, i.e., cool/cold (<15°C), mild (15°C to 25°C), and warm/hot (>25°C)
D = distance traveled, i.e., <600 km, 600-900 km, 900-1200 km, 1200-1500 km, and >1500 km.

Results and Discussion

Mortality of Weaned and Feeder Pigs during Transport

The DOA rate was affected by all the fixed factors tested (pig type, ambient temperature, and travel distance), and there were significant interaction effects (table 2). The predicted DOA rates (mean ±SE) were 0.0333% ±0.0150% for weaned pigs and 0.0243% ±0.0110% for feeder pigs (fig. 1). There are no publicly available DOA data for weaned and feeder pigs that could be used as a comparison to demonstrate the quality of the company's transportation records. However, the company included many different drivers, and they were all trained in the Transportation Quality Assurance (TQA) program, which is required by the swine industry, so they should be representative of the entire industry. Compared to feeder pigs, weaned pigs had a higher mortality rate (p = 0.0004). The higher mortality rate for weaned pigs was presumably due to the combined stress on the piglets brought about by simultaneous weaning and transport. Furthermore, weaned pigs are younger than feeder pigs, and their immunological and physiological functions may not be as developed as those of feeder pigs (Potočnjak et al., 2012; Whary et al., 1995), which would increase their vulnerability to transport stress. For a normal distribution, two means do not significantly differ if their error bars (95% confident interval) overlap. However, the pig mortality data in this study follow a binomial distribution. The standard error of a binomial distribution is a function of the estimated probability and does not necessarily correspond to the errors derived by the model that was used for comparing two means. This is why the comparison of means shows a significant difference even though their error bars overlap.

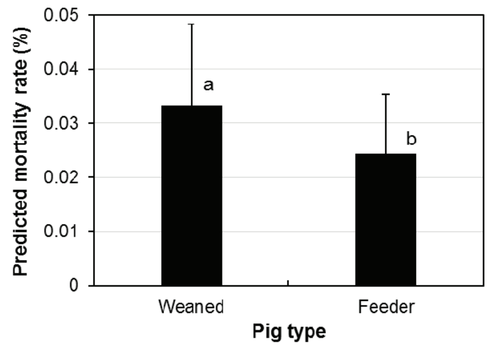

Figure 1. Predicted pig mortality rate (%) during ground transport. Vertical bars are predicted standard errors. Different letters indicate significant difference (p < 0.05).

Figure 2 shows the predicted DOA rates of weaned and feeder pigs for the three temperature categories. The mortality rates (mean ±SE) for the weaned and feeder pigs during transport were, respectively, 0.0257% ±0.0116% and 0.0237% ±0.0108% in cool/cold conditions, 0.0159% ±0.0073% and 0.0130% ±0.0060% in mild conditions, and 0.0907% ±0.0413% and 0.0470% ±0.0213% in warm/hot conditions. Mortality rates were highest in warm/hot conditions and lowest in mild conditions for both pig types (fig. 2). A similar temperature effect on market-size pigs was reported by Warriss and Brown (1994). There was no signif-

Table 2. Tests of effects of pig type, ambient temperature, and travel distance on pig mortality during ground transport.

Effect	Num DF[a]	Den DF[b]	F Value	p Value
Pig type	1	6617	12.76	0.0004
Ambient temperature	2	6617	162.62	<0.0001
Travel distance	3	6617	13.02	<0.0001
Type × Temperature	2	6617	8.47	0.0002
Temperature × Distance	6	6617	26.61	<0.0001
Type × Distance	3	6617	33.23	<0.0001
Type × Temperature × Distance	6	6617	20.31	<0.0001

[a] Numerator's degrees of freedom.
[b] Denominator's degrees of freedom.

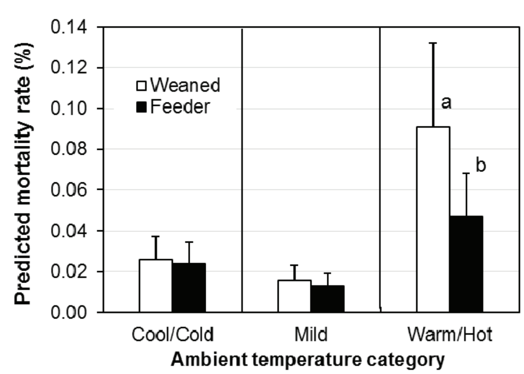

Figure 2. Predicted pig mortality rate (%) during ground transport in cool/cold (<15°C), mild (15°C to 25°C), and warm/hot (>25°C) conditions. Vertical bars are predicted standard errors. Different letters indicate significant difference (p < 0.05) within a subgroup.

cant difference in mortality between pig types for the cool/cold and mild categories, but the mortality rate of weaned pigs was about twice that of feeder pigs in the warm/hot category (fig. 2). This result indicates that the weaned pigs were more susceptible to heat stress during transport than the feeder pigs. In commercial production, younger pigs typically need warmer temperatures than older pigs; however, this does not hold true for ground transport when hot weather is encountered. The higher mortality of weaned pigs might also be attributed to greater loading density (National Pork Board, 2015) as compared to feeder pigs (Roldan-Santiago et al., 2013).

Figure 3a shows the predicted DOA rate of the weaned pigs as affected by travel distance for the three temperature categories. In the cool/cold category, the mortality rate was significantly lower for <900 km travel distance than for >900 km travel distance. In the warm/hot category, the mortality rate significantly increased as the travel distance increased. In the mild category, the mortality rate was less affected by travel distance than in the two temperature categories. Figure 3b shows the predicted mortality rate of feeder pigs as affected by travel distance for the three temperature categories. Travel distance had no significant effect on the mortality rate of feeder pigs in the cool/cold and mild categories. However, the mortality rate of feeder pigs was much higher at 1200 to 1500 km travel distance than at shorter travel distances in the warm/hot category. Based on the results shown in figure 3, there is a significant interaction effect between travel distance and temperature condition. It seems that travel distance (in the range of 8 to 2525 km) has less impact on pig mortality when the thermal conditions (and hence the microenvironment) are within the pigs' thermal comfort zone. However, special caution should be taken when transporting pigs for long distances on warm/hot days.

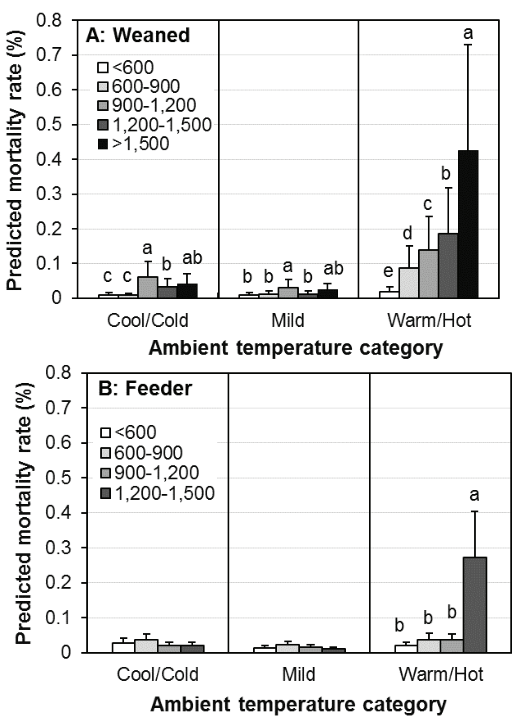

Figure 3. Predicted pig mortality rate (%) during transport as affected by travel distance in cool/cold (<15°C), mild (15°C to 25°C), and warm/hot (>25°C) conditions: (a) weaned pigs and (b) feeder pigs. Vertical bars are predicted standard errors. Different letters indicate significant difference ($p < 0.05$) within a temperature category.

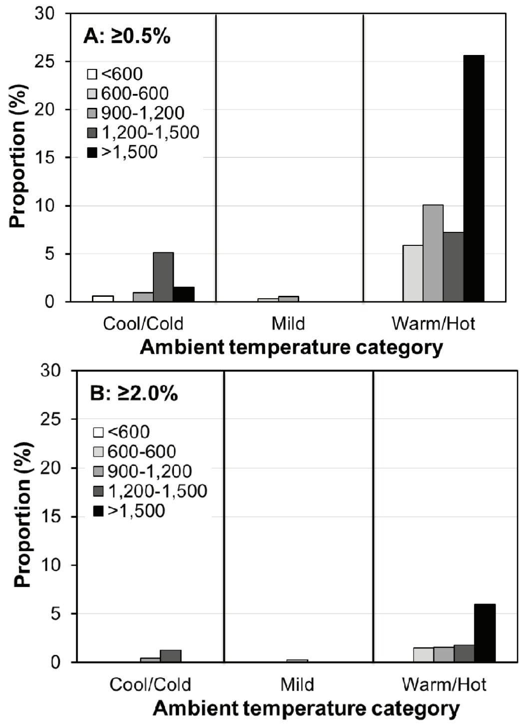

Figure 4. Proportion of total transportation records with DOA rates of (a) ≥0.5% or (b) ≥2.0% for weaned pigs transported at different ambient temperature conditions and travel distances.

Low percentages (<0.5%) of DOA were associated with most of the transport of weaned and feeder pigs (96.6% for weaned pigs and 98.7% for feeder pigs). Figure 4 shows the proportion of total transportation records with DOA rates of ≥0.5% or ≥2.0% for weaned pigs transported at different temperature conditions and travel distances. This proportion, particularly the occurrence of high mortality, reflects the chance of undesirable high mortality during transport in different temperature conditions. Among the different temperature conditions, the occurrence of high mortality of weaned pigs was lowest in mild conditions and highest in warm/hot conditions for both DOA levels. The combination of high temperature and long travel distance yielded the most occurrence of high mortality. Similar extrapolation on the occurrence of high mortality of feeder pigs was made, as shown in figure 5. In cool/cold and mild conditions, none of the transportation records had ≥2% mortality (fig. 5). Overall, the occurrence of high mortality was lower for feeder pigs than for weaned pigs.

Mortality of Weaned Pigs One or Two Weeks after Transport

Statistical analysis showed that ambient temperature during transport was not a significant factor on weaned pig mortality during the first week of post-transport growth; however, travel distance and the interaction were significant factors (table 3). The one-week post-transport mortality rates were, respectively, 0.050%, 0.050%, and 0.045% for cool/cold, mild, and warm/hot conditions. For cold to mild

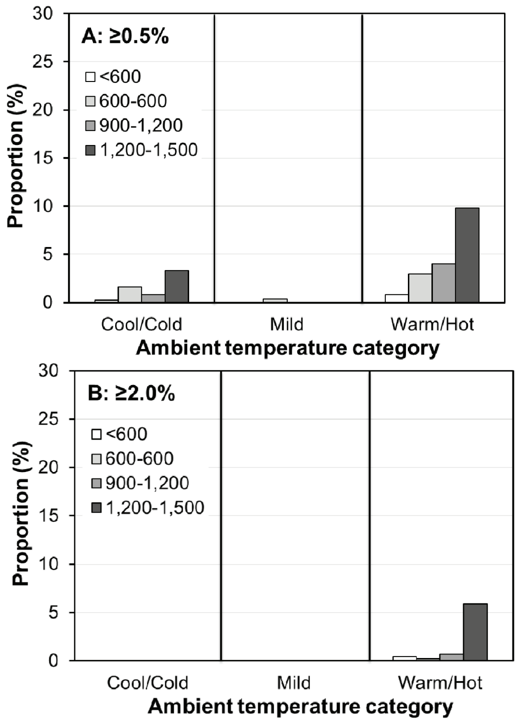

Figure 5. Proportion of total transportation records with DOA rates of (a) ≥0.5% or (b) ≥2.0% for feeder pigs transported at different ambient temperature conditions and travel distances.

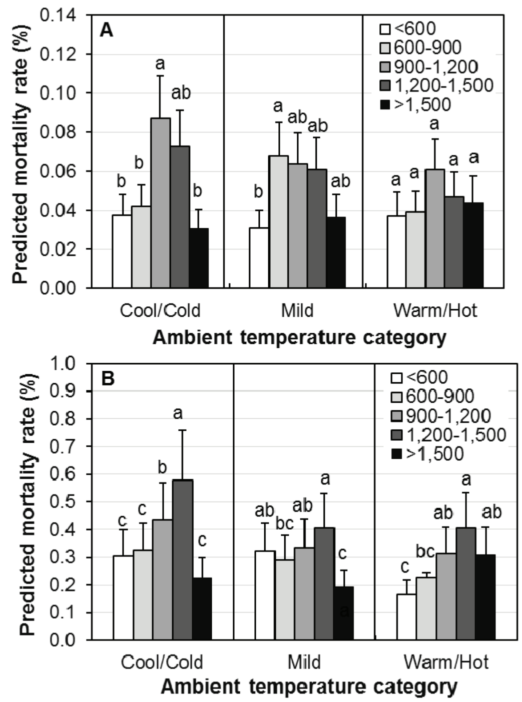

Figure 6. Predicted weaned pig mortality rate (%) during the (a) first week and (b) first two weeks after transport. Vertical bars are predicted standard errors. Letters indicate significant difference ($p < 0.05$) within a temperature category.

conditions, the one-week mortality rates tended to be higher for mid-range transport distances (fig. 6a). No significant difference in mortality was found for all distance groups in warm/hot conditions (fig. 6a). It is interesting to note that mortality during transport in the worst conditions (warm/hot weather and >1500 km distance) was highest; however, the corresponding post-transport mortality for the worst conditions was similar to or even lower than that for other transport conditions. A possible reason could be that the weakest weaned pigs had been singled out by the most unfavorable transport conditions, and those that survived recovered in the grower-finisher facility.

Ambient temperature, distance, and their interactions were all significant factors for two-week post-transport mortality of weaned pigs (table 3). The mortality rates were 0.354%, 0.300%, and 0.272% for cool/cold, mild, and warm/hot conditions, respectively. The second-week mortality was notably higher than the first-week mortality, possibly a result of adjusting to the new feed and environment. Young pigs may struggle in starting to eat feed when introduced to the finishing facility after weaning. It could be that they have enough reserves to survive the first week but not the second week. These are commonly referred to as "starve outs" on farms and may be euthanized when it becomes evident that they are doing poorly. The second-week mortality rates for 1200 to 1500 km travel distance were significantly or numerically higher than those for other distance ranges for all temperature conditions (fig. 6b). However, the longest travel distance did not yield the highest post-transport mortality rate.

The effect of transport conditions on post-transport pig mortality gradually diminishes, and many other confounding factors may become dominant as pigs are raised at the finishing farm. This is the reason mortality was analyzed only for the first two weeks following transport. However, confounding factors might still have played some roles in these two weeks, which was not discernable through analyzing the current data. Therefore, the post-transport pig mortality data should be interpreted with caution, and more controlled research is needed to validate the results.

SUMMARY AND CONCLUSIONS

In this study, effects of pig type (weaned vs. feeder pigs), ambient temperature condition (cool/cold or <15°C, mild or 15°C to 25°C, and warm/hot or >25°C), and travel distance (<600 km, 600 to 900 km, 900 to 1200 km, 1200 to 1500 km,

Table 3. Tests of effects of temperature condition (during transport) and travel distance on weaned pig mortality during the first and second weeks after transport.

Effect	Num DF[a]	Den DF[b]	First Week F-Value	First Week p-Value	Second Week F-Value	Second Week p-Value
Temperature condition	2	2984	1.22	0.2944	63.80	<0.0001
Travel distance	4	2984	8.41	<0.0001	40.51	<0.0001
Temperature × Distance	8	2984	9.82	<0.0001	28.47	<0.0001

[a] Numerator's degrees of freedom.
[b] Denominator's degrees of freedom.

and >1500 km) on pig mortality rate during ground transport were examined by statistical analysis of 7056 pig transportation records (out of a total of 13,344 raw records) collected from a swine company. The effects of travel distance and temperature condition during transport on post-transport mortality rate of weaned pigs were also analyzed. The following conclusions were drawn:

- There were strong interactive effects among pig type, ambient temperature, and travel distance on pig mortality during transport.
- Overall, weaned pigs had higher mortality than feeder pigs during transport.
- Pig transport in unfavorable weather conditions (i.e., cool/cold and warm/hot) may result in higher mortality. Weaned pigs showed higher mortality than feeder pigs during transport in warm/hot conditions.
- In mild conditions (15°C to 25°C), travel distance (up to 2525 km) showed little adverse effect on the mortality rates of weaned and feeder pigs. In cool/cold conditions (<15°C), >900 km travel distance increased the mortality rate of weaned pigs but not feeder pigs. In warm/hot conditions (>25°C), longer travel distance resulted in higher mortality rate of weaned pigs. Caution should also be taken when transporting feeder pigs farther than 1200 km.
- Post-transport mortality of weaned pigs may be affected by ambient temperature during transport (only for the second week) and travel distance, although the cause-effect relationship is uncertain due to the impact of potential confounding factors associated with management of the pigs at the finishing farms.

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