Graduate Theses and Dissertations

Iowa State University Capstones, Theses and Dissertations

2013

Bedding and sprinkling recommendations when transporting market weight pigs in warm weather to improve well-being

Rebecca K. Kephart
Iowa State University

Follow this and additional works at: https://lib.dr.iastate.edu/etd

Part of the Agriculture Commons, and the Behavior and Ethology Commons

Recommended Citation
Kephart, Rebecca K., "Bedding and sprinkling recommendations when transporting market weight pigs in warm weather to improve well-being" (2013). Graduate Theses and Dissertations. 13579.
https://lib.dr.iastate.edu/etd/13579

This Thesis is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Graduate Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
Bedding and sprinkling recommendations when transporting market weight pigs in warm weather to improve well-being

by

Rebecca K. Kephart

A thesis submitted to graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Animal Physiology (Ethology)

Program of Study Committee
Anna Johnson, Major Professor
       Kenneth Stalder
       Ted Huiatt
       Howard Tyler

Iowa State University
Ames, Iowa
2013

Copyright © Rebecca K. Kephart, 2013. All rights reserved.
# TABLE OF CONTENTS

## CHAPTER 1: GENERAL INTRODUCTION ................................................................. 1
- Oversight of livestock transportation .................................................................. 2
- Thesis organization ............................................................................................. 3
- Completed outcomes and expected outcomes .................................................... 4
  - Completed Outcomes ...................................................................................... 4
  - Expected outcomes ......................................................................................... 4
- Practical implications ........................................................................................... 5
- Tables ................................................................................................................... 5

## CHAPTER 2: LITERATURE REVIEW ...................................................................... 10
- Handling factors that could influence transport losses ........................................ 10
  - Handling and loading ....................................................................................... 10
  - Handling tools and intensity ............................................................................. 14
- Event times that could influence transport losses ................................................ 20
  - Duration of loading ......................................................................................... 20
  - Wait time at the farm ...................................................................................... 20
  - Duration of transport ....................................................................................... 21
  - Wait time at the plant ...................................................................................... 23
  - Duration of unloading ...................................................................................... 24
- Trailer factors that could influence transport losses .............................................. 24
  - Mixing pigs ..................................................................................................... 24
  - Density of pigs ................................................................................................ 26
  - Micro-climate inside the trailer ........................................................................ 30
  - Temperature, relative humidity, and their indices outside the trailer ............... 37
- Literature cited .................................................................................................... 40

## CHAPTER 3: ESTABLISHING BEDDING REQUIREMENTS ON TRAILERS
TRANSPORTING MARKET WEIGHT PIGS IN WARM WEATHER ................................. 49
- Simple Summary: ............................................................................................... 49
- Abstract: ............................................................................................................. 49
- 1. Introduction ..................................................................................................... 50
- 2. Experimental Section ...................................................................................... 51
  - 2.1. General procedures .................................................................................... 51
  - 2.2. Experiment 1: Effects of trailer bedding levels on market weight pig measures and bedding moisture during warm weather ..................................... 52
  - 2.3. Experiment 2: Effects of trailer bedding levels on market weight pig transport losses during warm weather .............................................................. 54
  - 2.4. Statistical analysis ...................................................................................... 55
- 3. Results and Discussion .................................................................................... 56
  - 3.1. Experiment 1: Effects of trailer bedding levels on market weight pig measures and bedding moisture during warm weather ..................................... 56
  - 3.2. Experiment 2: Effects of trailer bedding levels on market weight pig transport losses during warm weather .............................................................. 63
- 4. Conclusions ..................................................................................................... 66
- References and Notes ......................................................................................... 67
CHAPTER 1: GENERAL INTRODUCTION

In the U.S., 113 million (NASS, 2013) pigs are transported annually to market, primarily by road in a tractor trailer (also referred to as truck or trailer). Transport losses have been defined as the sum of dead on arrival and non-ambulatory (sum of fatigued and injured; Johnson et al., 2013). In the U.S., pigs are found dead upon arrival at the plant at a rate of 0.15% (Ritter, 2012). Injured and fatigued pigs resulting from transport have been estimated at 0.44% (Ritter et al., 2009). Although the incidence of dead pigs has declined over the last several years (2001 to 2011), they still represent an important issue for the U.S. swine industry (Ritter, 2012). Transport losses represent 3 challenges for the U.S. swine industry: 1) Animal well-being concerns; non-ambulatory pigs may be stepped on by contemporaries thereby becoming further stressed and injured. 2) The potential for increased government oversight (e.g., the Downed Animal and Food Safety Protection Act—Bill H. R. 661 (U.S. House of Representatives, 2007) and Bill S. 394 (U.S. Senate, 2007; govtrack.us, 2007). If this act had passed, any “animal” that became non-ambulatory would have been immediately euthanized and would not have been allowed into the food chain. 3) Financial losses; Transport losses represent substantial costs to producers and processors (Ellis et al., 2003; Ritter et al., 2009). Ritter and colleagues (2009) reviewed over 6 million mixed sex loads of market weight pigs to determine the financial impact of transport losses on the U.S. swine industry. Transport losses were calculated at ~$125/head for dead on arrival and ~$37/head for non-ambulatory pigs, together summing to $46 million yearly loss due to transport losses.
The National Pork Board has recently funded research to improve pig well-being during handling and transport. In addition, the pork industry has made attempts to reduce transportation losses during the marketing process, through handling and training materials and updating educational materials like the Pork Quality Assurance Plus (NPB, 2013a) and Transport Quality Assurance Program (TQA; NPB, 2008).

**Oversight of livestock transportation**

Regions of the world regulate live animal transportation in a variety of ways. Each method of regulation has its own unique advantages and disadvantages. Education is entirely voluntary; however, it can be used to show the consumers that those involved with the industry are working to solve issues of concern. Guidelines are the industry’s way of self-regulating. The primary advantage of guidelines is that they can be updated more quickly as new research emerges (NPB, 2013b). The primary downside to guidelines is that their implementation is up to the discretion of the producer. Laws, set forth by the government, may take varying degrees of time to pass and can be challenging to amend if new research emerges. The primary advantage of laws is that all companies and farms in that country must follow them. Additionally, laws, allow more severe punishment than guidelines for those that violate them (differencebetween.net, 2013). Immediate punishment for violation can include facility shutdown, followed by fines and in some incidences imprisonment of individuals (FSIS, 2013; Hodges, 2010).

The European Union has a single law to regulate live animal transportation (Table 1). In the U.S. and Canada educational programs (Table 2) and guidelines are in place
(Table 3) in addition to laws. The U.S. follows guidelines set forth by the American Meat Institute known as the Livestock Handling Guide (Table 1). In Canada, the transportation code is a set of guidelines followed by the industry (Table 1). The TQA program was developed by the NPB in the U.S. It is an educational program that was originally deployed in the U.S. and later was adopted by Canada (Table 2). The TQA program focuses on handling and transport of swine. Canada also has the Certified Livestock Transport program which is customized for each species and focuses on loading, handling, and biosecurity (Table 2). In Canada, there is a single law (Health of animals regulations part XII; Table 3) that covers what animals may be transported, how different ages or species of animals may be transported together, and the amount of time a species may be transported before allowing for feed water and rest. In the U.S., there are two laws regulating animal transport (Table 3). The 28 hour law regulates amount of time animals may be transported before allowing for rest and water. The humane methods of slaughter act (9 C.F.R. 313.1 - 90) defines non-ambulatory animals and specific practices for handling them.

**Thesis organization**

This thesis is organized into 5 chapters. The first chapter is a general introduction to the well-being of market weight pigs in the U.S. during transport. The second chapter is a literature review of factors that affect the well-being during transport and incidence of transport losses in market weight pigs. The third chapter is titled “Establishing bedding requirements on trailers transporting market weight pigs in warm weather” The fourth
chapter is titled “Establishing sprinkling method on trailers transporting market weight pigs in warm weather.” The fifth chapter is a general summary of both research studies. Both research studies were prepared according to Animals guidelines and include a simple summary, abstract, keywords, introduction, experimental section, results and discussion, conclusions, acknowledgements, conflicts of interest, and references and notes.

**Completed outcomes and expected outcomes**

**Completed Outcomes.**

Three peer reviewed abstracts (2 at Midwest and 1 at National American Society of Animal Science), 2 National Hog Farmer research reports, a book chapter in the new edition of “Livestock Handling and Transport,” edited by Dr. T. Grandin, and 1 paper from the Allen D. Leman Swine Conference have been submitted and accepted from this thesis.

**Expected outcomes.**

Three animal industry reports will be submitted for 2014 publication, 2 peer reviewed manuscripts will be submitted to Animals, and 1 invited proceeding paper and presentation has been accepted for the 2014 American Association of Swine Veterinarians meeting from this thesis.
Practical implications

The results from this research are expected to aid the U.S. swine industry in identifying bedding and sprinkling factors that affect well-being during transport and the incidence of transport losses in market weight pigs during the summer months in the Midwest. The National Pork Board has indicated that data collected from this research will be used to refine recommendations for bedding and sprinkling in the next version of the Transport Quality Assurance program.

Tables

Table 1.1. Livestock transport guidelines in the United States, European Union, and Canada

<table>
<thead>
<tr>
<th>Country</th>
<th>Program</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>Livestock handling guide</td>
<td>This guide helps handlers and producers learn how to better handle their animals. It is written for producers and educates them that improper handling will directly result in losses due to bruising and lower meat quality.</td>
</tr>
</tbody>
</table>
Table 1.1 cont’d. Livestock transport guidelines in the United States, European Union, and Canada

<table>
<thead>
<tr>
<th>Country</th>
<th>Program</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>Recommended code of practice for the care and handling of farm animals: Transportation</td>
<td>A nationally developed guideline which provides information on duration of transport, feed and water restriction, vehicle specifications, loading and unloading including density, care during transport, and species specific recommendations.</td>
</tr>
</tbody>
</table>

Table 1.2. Livestock transport education in the United States, European Union, and Canada

<table>
<thead>
<tr>
<th>Country</th>
<th>Program</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>Transport quality assurance (TQA)</td>
<td>The National Pork Board developed the TQA program to educate transporters, producers, and handlers of swine on how to humanely handle, move, and transport swine. This program also focuses on how different handling techniques may impact the well-being of the animals as well as the final meat quality.</td>
</tr>
<tr>
<td>Country</td>
<td>Transport quality assurance</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Canada</td>
<td>The U.S. TQA program which has also been adopted by the Canadian swine industry.</td>
<td>CLT was developed by the Alberta Farm Animal Care Association using input from industry advisors. It is customizable to specific species and trains on loading, handling, and biosecurity. CLT aims to educate livestock handlers in animal behavior, the logistics of trucking, impacts on quality, laws, how to handle accidents, and recommended management practices.</td>
</tr>
</tbody>
</table>
## Table 1.3: Livestock transport laws in the United States, European Union, and Canada

<table>
<thead>
<tr>
<th>Country</th>
<th>Law</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>The 28 hour law</td>
<td>Animals may not be confined during transport by vehicle or vessel for more than 28 h without being unloaded for feed, water, and rest. Vehicles that provide areas for feed, water, and rest during transport are exempt.</td>
</tr>
<tr>
<td></td>
<td>49 U.S.C. Section 80502</td>
<td>Handling of livestock 9 C.F.R. 3131 - 90 Slaughter act dictates that animals which are “disabled” (ie those which cannot move; non-ambulatory) should only be moved with appropriate equipment while conscious.</td>
</tr>
<tr>
<td>European Union</td>
<td>Animal welfare during transport 91/628/EEC</td>
<td>This is applicable to the transport of poultry, bovine, ovine, caprine, and porcine species. Animals may not be transported if the animals are ill or injured in such a way that transport would cause unnecessary suffering. Animals must be allowed water, feed, and rest if the journey is longer than 24 h.</td>
</tr>
</tbody>
</table>
Table 1.3 cont’d: Livestock transport laws in the United States, European Union, and Canada

| Canada | Health of animals regulations part XII C.R.C. c. 296 | No animal may be loaded that may be caused undue suffering due to illness, injury, fatigue, or other cause. At most, animals may be deprived of feed and water for 5 h. Animals may not be transported that are likely to give birth during the duration of the transport. If an animal becomes ill during transport that animal may not be transported beyond the nearest suitable care facility. Vehicles used to transport animals must be fitted with safe and secure footholds and be suitable for transporting livestock. Animals may only be loaded that are of a different species or a substantially different weight or age if those animals are segregated. All animals must be able to stand naturally without contacting the roof. Provision must be made for urine absorption or drainage from all levels. Swine may not be transported for longer than 36 h without the animals being unloaded, rested, fed, watered, and re-loaded for at least 5 h. |
CHAPTER 2: LITERATURE REVIEW

Handling factors that could influence transport losses

Marketing has been defined as the movement from finishing facilities to stunning at the processing plant (Ritter et al., 2009). Prior to marketing, pigs that have reached market weight are identified. Some facility designs provide the capability to pre-sort pigs prior to loading, which, while providing water ad libitum, can allow feed to be removed for a defined period of time from the pigs to be loaded. On the day of transport, pigs are sorted and moved from their home pen (or moved from pre-sorted pens), along the alley, through a loading chute, and onto a trailer for transport to the processing plant. By identifying pig, management, facility design, and human-pig interaction factors the incidence of transport losses at the time of marketing may be reduced. Quality of meat and well-being of pigs are decreased with negative handling before and after transportation (D’Souza et al., 1998; Stephens and Perry, 1990; Brundige et al., 1998; Benjamin et al., 2001).

Handling and loading

Unfamiliarity of the marketing process. The marketing process exposes pigs to a barrage of unfamiliar stimuli that represent an important stressor (Grandin, 1997). Examples of these stimuli include unfamiliar sights and smells, close contact with humans, and being handled. Because of the barren environment of modern finishing facilities pigs may have a decreased ability to adapt to novelty (Puppe et al., 2008). Curtis
and colleagues (2001) completed an in depth review of the pig senses. Pigs have a very acute sense of smell, are relatively sensitive to a thermal environment, and have a relatively wide peripheral vision area of approximately 310 degrees. Heffner and Heffner (1990) studied hearing in 3 gilts, 4 mo of age (~19 to 43 kg), of 3 different breeds: Duroc, Hampshire, and Yorkshire. After the pigs were trained to place their mouths on a water spout to receive a continuous stream of water when thirsty, their hearing was tested by playing a tone which was shortly followed by an electric shock from the spout. Pigs were found have a sound frequency of reasonable detection ranging from 42 Hz to 40.5 kHz with the greatest sensitivity being between 250 Hz to 16 kHz. Talling and others (1996) observed the effects of sound on 10 Duroc X large white gilt piglets 4 wks of age (15 kg). The objective of this study was to determine effects of uniform and intermediate sounds at the farm and processing plant and during transport on pig behavior and physiology. The effects of white noise were also tested. The first experiment of this study examined the responses to 15 min of sound during 1 h at 85 or 95dB and 500 or 8000 Hz. The piglet was placed in a familiar room with another “companion” piglet. The second experiment of this study exposed pigs to 20 min of 4 unique sound recordings: farm recording (80dB), transport recording (83 dB), processing plant recording (84 dB), and white noise (89dB). Both experiments found increased \((P < 0.05)\) heart rate upon sound exposure. Pigs tended to move more \((P < 0.05)\) during sound exposure. In the first experiment, increases were greater \((P < 0.05)\) as frequency and intensity increased. The second study found that transportation noise resulted in a higher \((P < 0.05)\) increase in heart rate, but a decrease \((P < 0.05)\) in movement. Although sounds may activate defense mechanisms in piglets, they may become habituated to the sound if no immediate threat
is identified. A follow up study by Talling and colleagues (1998) sought to understand whether pigs may become habituated to novel, loud, and predicable sounds, and if different types of sound were more or less aversive. In this study, 24 five wk old duroc X landrace gilt piglets weighing 25 kg were tested for reaction to uniform and intermittent sounds. Pigs did not avoid the uniform sound, but active behavior increased when the sound was first introduced \( (P < 0.01) \). Pigs avoided the intermittent sound \( (P < 0.05) \). These pigs also showed an increase in active behavior during the first sound \( (P < 0.01) \). Results from these studies show that pigs can habituate to loud unfamiliar mechanical sounds. Additionally, pigs will avoid and take longer to habituate to an intermittent sound than a uniform sound. There was also individual variation. Stephens and Perry (1990) studied the effects of the combination of noise and vibration on pig behavior. Pigs were trained to press a switch to stop vibration and noise to the pen. Pigs were tested at both high and low vibration levels. It was determined that pigs turned off the vibration more at high levels \( (P < 0.01) \) than at low level. Pigs also turned off the switch more at low levels than when the vibration and noise were off. There was also no evidence that pigs habituated to the vibration.

Pigs are sensitive to environmental temperature and olfactory cues (Curtis et al., 2001). The pig has a wide range of hearing may activate the fight or flight response (Heffner and Heffner, 1990; Talling et al., 1996). Pigs may habituate to environmental sounds, but may have difficulties habituating to intermittent sounds (Talling et al., 1996, 1998). Vibrations may be unpleasant for pigs and the pig may be unable to habituate to the sensation (Stephens and Perry, 1990).
**Previous handling.** In most commercial settings in the U. S., pigs are placed in finishing facilities at weaning where they do not leave their home pens until marketing and have little to no direct contact with humans. As a result, several studies have recommended that caretakers routinely walk the home pens and/or handle pigs to minimize stress responses during loading (Grandin, 1997, Grandin and Schultz-Kaster, 2006; Geverink et al., 1998). Abbott and others (1997) studied the effects of routine handling on time for pigs to leave their home pen during loading. Using 720 boars and gilts, 10 to 20 wk of age, they tested for differences between moving pigs once a wk for 3 wk (moved), and not moving pigs (no moved). For the group of pigs that were moved, more pigs left the pen within 2 min during the second movement (26 - vs 42%; \( P < 0.01 \)). From first to second movement, for pigs in the moved group, time for 50% of pigs to leave the pen decreased from 79 to 39 s (\( P < 0.05 \)). At loading, fewer pigs remained in their pens 1 min after opening the pen door in the group that received the movement treatment than pigs that were not moved (\( P < 0.01 \)). Likewise, Geverink and colleagues (1998) used 144 Great Yorkshire X (Great Yorkshire X Dutch Landrace) crossbred gilts and barrows 10 wk of age (average 28 kg) that were evenly divided into 3 treatments groups. The environment treatment pens were open to a small portion of the alley for 8 min and the pigs were then moved into a transport box which was moved through the building for 2 min before the pigs were returned to their pens. The handling treatment involved a researcher squatting in the pen for 3 min and stroking any pigs that contacted the researcher behind the ears or on the snout after the 3 min the researcher walked around the pen for 1 min stroking then holding any pigs that contacted the researcher for 5 s. Lastly, the pigs in the control treatment only received human contact during routine
husbandry. This study reported the pigs in the environment group required 50% less time 
\((P < 0.05)\) during loading than control pigs and pigs that were routinely handled within the pen. Pigs in the environment group had lower pH in the semimembranosus muscle after slaughter than the control pigs. Lower muscle pH is indicative of anaerobic metabolism, which occurs when oxygen cannot be transport quickly enough to the muscle. Low pH can cause poor meat quality by causing breakdown of muscle post mortem. Stewart and others (2008) used 32 trailer loads \((n = 5,884\) pigs\) of market weight \((\sim 117\) kg\) barrows and gilts to study the effects of prior handling on stress response and transport losses. The loads were split into two treatments: control (no previous handling) and previous handling (pigs being moved from their pens to the loading area and back to their pens the day before loading). These authors reported that previous handling tended \((P = 0.08)\) to reduce total transport losses \((0.07\% - 0.38\%)\) compared to control group pigs. Additionally, previous handling also reduced \((P < 0.01)\) open mouth breathing and skin discoloration \((30\% - 19.1\%\) and \(5\% - 2\%,\) respectively).

_Handling tools and intensity_

**Handling tools.** Handling tools recommended by TQA to move finisher pigs include sort boards, flags, rattles, witch’s cape, or paddles (NPB, 2008). The use of electric prods also called goads and “hot shots” is controversial within and across the pork production chain. Grandin (2011) suggested that prods should not be used to move finisher pigs onto the trailer. If regular use of an electric prod is needed, the adequacy of the handling facilities should be examined (Grandin, 2003). Studies have shown that different types of handling
tools affect pigs differently (Brundige et al., 1998; Correa et al., 2010; McGlone et al.,
2004); specific effects of handling tools will be discussed below. Use of electric prods
has been shown to increase stress in pigs (Brundige et al., 1998; Correa et al., 2010). The
board may be the most efficient tool for moving pigs (McGlone et al., 2004). The TQA
program states that the use of electric prods is a stressful event and should be avoided or
minimized (NPB, 2008). Furthermore, it defines that pigs must never be prodded in
sensitive areas such as the eyes, nose, anus, or testicles. Some research shows that prods
should never be used (McGlone, 2004).

Brundige and others (1998) looked at the differences between loading pigs with a
prod (P) versus a sort board (B) on 48 halothane gene free, market weight pigs. Pigs in
the P group had higher \( P < 0.01 \) activity levels after loading than pigs in the B group.
Pigs in the P group also had higher \( P < 0.01 \) heart rates and rectal temperatures after
loading than B pigs. However, salivary cortisol was not different between the two
treatments. Correa and colleagues (2010) studied effects of moving devices on 360
crossbred pigs (120 kg) in Canada. Three treatment groups were used: moved with an
electric prod and a sort board; moved with a sort board and a rattle; and moved with a
paddle and compressed air prod. Pigs loaded using the electric prod and sorting board 3%
fatigued pigs at the processing plant, compared to 0% in the group moved using the
paddle and sorting board. Those pigs moved with an electric prod moved faster \( P <
0.01 \) than those in the other treatment groups with the pigs moved with the compressed
air prod moving the slowest. The authors attributed the slow movement of the pigs
moved with compress air prod to the noise made by the air compressor for the
compressed air prod and the handlers’ inexperience with the compressed air prod. Pigs
moved with the compressed air prod also turned around more often \((P = 0.01)\) than pigs in the other treatments. Additionally, pigs moved with the electric prod slipped and fell more \((P = 0.03)\) and vocalized more \((P = 0.02)\) with longer vocalization duration \((P < 0.01)\) than those pigs moved with other devices. Physiologically, the pigs handled with the electric prod had a higher heart rate during loading \((P < 0.01)\), before departure \((P < 0.01)\), and in lairage \((P = 0.02)\) than the pigs moved by different tools. In agreement, Ritter and others (2008) examined differences between when market weight pigs (131 kg) moved through a 50 m course that received 0, 2, or 4 shocks. The study found that rectal temperature and blood lactate increased \((P < 0.01)\). McGlone and others (2004) compared the efficacy of the electric prod, board, paddle, and flag. 99 barrows and gilts that weighed > 70 kg were used. Efficacy was measured in seconds to move through the course, vocalizations (assumed negative), and times the pigs turned around. The pigs moved with the board took less time \((P < 0.05)\) to complete the course than those moved with either the prod or the paddle. It was also found that pigs turned around more \((P < 0.01)\) when moved with the paddle. Vocalizations were greatest \((P < 0.01)\) when pigs were moved with the paddle or prod. There was no difference \((P > 0.10)\) found between the board and the flag. D’Souza and others (1998) looked at the effects of minimal and negative handling on pigs prior to slaughter on pork quality using 48 male Large White X Landrace pigs (95 kg). Pigs in the minimal handling treatment were moved with gentle coaxing without prods. Pigs in the negative handling treatment were give 15 shocks from a prod. Both treatments occurred after 15 h rest period at the processing facility immediately before stunning with \(\text{CO}_2\). Negative handling resulted in an increased \((P = 0.05)\) frequency of pale soft exudative pork over minimal handling.
Electric prods have negative effects on pig well-being including adverse behavior, increased activity levels, heart rate, and rectal temperature (Brundgie et al., 1998; Correa et al., 2010) and may negatively affect meat quality (D’souza et al., 1998). Furthermore, when handlers are experienced, pigs move more quickly with the use of a board than when a prod was used (McGlone et al., 2004).

**Handling intensity.** Currently, the industry does not use a scale to rate animal handling; however, the AMI animal handling guidelines (historically used by the Food Safety and Inspection Service; FSIS) use the number of falls during unloading to evaluate handling intensity and pig well-being (AMI, 2012). The other measures of the AMI audit primarily revolve around the process of stunning of the pigs. Benjamin and others (2001) evaluated handling intensity effects by moving 180 barrows and gilts (120 kg) either “aggressively” or “gently” through a course. Moving pigs “aggressively” meant that handlers moved pigs through a 300 m handling course and up a high ramp with frequent use of an electric prod. Moving pigs “gently” was defined as moving pigs through the course with a lower ramp, at a moderate pace, and with plastic cane instead of an electric prod. Pigs moved aggressively had a higher ($P < 0.01$) percentage of open-mouth breathing, skin discoloration, vocalizations, and fatigued pigs (10.0- vs. 0%). Additionally, a relationship was found between aggressively handled pigs and skin temperature, rectal temperature, and heart rate ($P$ - values and data were not provided for this interaction). Serum lactate and glucose were higher ($P < 0.05$) in aggressively moved pigs. Within the aggressively handled pigs, pig that became non-ambulatory were found to have higher ammonia levels and got wedged more during handling. Hamilton and colleagues (2004)
looked at the effects of high and low handling intensity on 40 barrows and 40 gilts (104 - or 128 kg; progeny of Line 337 sires mated to C22 dams PIC U.S.). Pigs were moved 8 laps through a 12.2 m course individually. High handling intensity involved moving pigs with an electric prod and a board; pigs were shocked twice per lap. Low handling intensity was defined as moving pigs with a paddle and board; the pig was only touched with the paddle if it stopped moving. Pigs subjected to high handling intensity had higher ($P < 0.01$) blood lactate and $\text{PO}_2$ than those subjected to low handling intensity. Pigs subjected to high handling intensity tended ($P = 0.06$) to have higher rectal temperature than those subjected to low handling intensity. Furthermore, pigs moved with electric prods may require more time to recover than pigs moved with livestock paddles, as pigs moved with electric prods had higher blood lactate and lower blood bicarbonate and base-excess values 2 h after handling (Hamilton et al., 2004). Bertol and colleagues (2005) tested the effects of high and low handling intensity on 60 market weight barrows and gilts (~108 kg; progeny of line 337 sires mated to C22 dams PIC U.S.A). Pigs were moved individually for 8 laps through a 12 m course. Pigs subjected to high handling intensity were shocked twice per lap. Pigs subjected to low handling intensity were moved with a paddle and board; they were touched with the paddle when they stopped. Pigs handled at high intensity had higher ($P < 0.01$) blood lactate and lower ($P < 0.01$) pH, bicarbonate, base excess, and $\text{tCO}_2$. An increase ($P < 0.05$) in blood $\text{pCO}_2$ was observed in pigs subjected to high handling intensity but not those subjected to low handling intensity. Anderson and colleagues (2002) used 108 barrows and gilts (~120 kg) to determine the differences between their responses to aggressive handling and gentle handling. Aggressive handling was defined as moving pigs through a 300 m course up a
high ramp frequently using the electric prod. Gentle handling pigs were moved through the same course and up a low ramp with the use of a cane in replacement of the prod.

Pigs handled aggressively had a increased red-blotchy skin, open mouth breathing, and vocalizations ($P < 0.01$). Additionally, aggressively handled pigs had higher skin temperature, rectal temperature, and heart rate than gently handled pigs. Furthermore, no pigs became non-ambulatory non-injured in the gently handled group whereas 11 pigs were non-ambulatory non-injured in the aggressively handled group. A study by Carr and colleagues (2008) looked at physiological effects of 2 handling treatments on 336 crossbred (HT 2000 × Fertilis 10 GenetiPorc U.S.) market weight (122 kg) barrows and gilts. The study defined passive handling as pigs being loaded at a moderate to slow speed where the handlers remained relatively quiet and only boards and paddles were used to load the pigs. Conventional handling was defined as pigs being rapidly loaded where the handlers were relatively loud, and pigs were handled with a prod, board, and paddle. In the conventional handling pigs were each prodded once and were extensively handled whereas the passive handling had no use of prods and pigs were handled minimally. They found handling had no effect on digestive tract temperature during load out. However, when transported at lower stocking density (0.38 m$^2$/100 kg) the passive handling pigs trended towards lower temperature than conventionally handled pigs ($P < 0.09$).

These studies show that aggressive handling may have detrimental effects on pork quality (Benjamin et al., 2001; Hamilton et al., 2004; Carr et al., 2008). Furthermore, aggressive handling could result in quicker acidosis development resulting in more
fatigued pigs (Bertol et al., 2005; Anderson et al., 2002). This may indicate that handling intensity is an important factor for pork quality and pig well-being.

**Event times that could influence transport losses**

*Duration of loading.*

Loading has been defined as the time from when the first pig stepped out of the barn until the last trailer compartment was closed (Gesing et al., 2010). Ritter and others (2006) used 74 trailers carrying 12,511 barrows and gilts (average: 129 kg; progeny of PIC 337 sires mated to C22 dams PIC U.S.A.) to determine the effects of loading time on transport losses. The study did not observe any effects of loading time on non-ambulatory (NA), dead on arrival (DOA), or total transport losses.

*Wait time at the farm.*

Waiting time at the farm has been defined as the time from when the last trailer compartment was closed until the trailer left the farm (Gesing et al., 2010). Ritter and others (2006) used 74 trailers carrying 12,511 barrows and gilts (average: 129 kg; progeny of PIC 337 sires mated to C22 dams PIC U.S.A.) to determine the effects of wait time at the farm on transport losses. Increased wait time at the farm increased the number of fatigued pigs \( P < 0.05 \).
**Duration of transport.**

Transport has been defined as the time from when the trailer left the farm until the trailer arrived at the processing facility (Gesing et al., 2010). Warriss and others (1990) studied 239 boars and gilts (63 kg) in the United Kingdom (U.K.) to determine the effects of transport time on meat quality. Transport was reported to have no major effects on meat quality. However, Pérez and others (2002) conducted a study using 144 pigs (Landrace X Large White) market weight (~115 kg) barrows and gilts in Spain. Half of the pigs were subjected to a short transport time (15 min) and the other half were given the long transport time (3 h). The pigs were slaughtered immediately upon arrival at the plant. Pigs transported for a short time had higher \( P < 0.05 \) white blood cell, neutrophil, and eosinophil count, higher blood lactate, and blood cortisol than those in the long transport treatment. Additionally, pigs transported for 15 min had lower \( P < 0.05 \) pH in longissimus thoracis and semimembranosus muscles. Kephart and colleagues (2010) studied 41,744 market weight pigs and looked at the effects of transport times on transport losses. They found that short transport times (< 2.5 h) were associated with increased lameness \( P < 0.05 \) at higher densities. Dewey and others (2005) collected data on 4,760,213 market weight pigs to describe losses in Canada. No effects were reported of transport distance on transport losses. Vecerek and others (2006) conducted a retrospective study on 33,912,125 pigs to determine the effects of 8 transport distances (<50 km, 51 to 100 km, 101 to 200 km, 201 to 300 km, >300 km) in the Czech Republic. This study reported that average of DOA increased from 0.06 to 0.34% as transport distances increased from < 50 km to > 300 km. Gosálvez and others (2006) collected
information on 90,366 crossbred market weight pigs (~100 kg) in Spain to determine effects of distance transported (<50 km, 50 to 100 km, and >100 km). This study found that distance transported affected ($P < 0.01$) mortality, live weight loss, and transport yield as well as killing out percentage ($P < 0.05$). Mortality and live weight loss increased as transport distance increased from 50 km. Gade and others (2007) studied 17,882,622 market weigh pigs at 16 processing facilities in Denmark to determine the effects of transport distances on mortality (< 100 km, 100 to 200 km, and > 200 km). Transport losses increased ($P < 0.01$) as transport distance increased. Rademacher and Davies (2005) reviewed records from 1,303,148 market weight hogs on 7,396 loads to determine the effects of transport time on transport losses. When transport time was 30 to 90 min transport losses were 0.7% whereas for transport times 90 to 160 min transport losses were only 0.25%. Werner and colleagues (2007) used 319,005 market weigh pigs to determine effects of 4 transport times (1 h, 4 h, 6 h, or 8 h) on transport losses in Germany. This study found that loads transported for short times (< 1 h) had a higher ($P < 0.05$) higher transport deaths than those transported for median times (4 h). Sutherland and others (2009) looked at 2,730,754 market weight (~125 kg) barrows and gilts. Percent DOA increased ($P < 0.01$) with transport times from 30 to 240 min. Percentages of pigs that were injured on the trailer increased ($P < 0.01$) as transit time increases. Percentages of NANI pigs increased ($P < 0.01$) when transit was 31 min to 5 h. NANI decreased ($P < 0.01$) when transit was between 5 and 11 h.

These studies are somewhat conflicting as some show that short transport times (< 2.5 h) may be detrimental to pig well-being (Pérez et al., 2002; Kephart et al., 2010; Rademacher and Davies, 2005; Werner et al., 2007) in terms of transport losses and
increased immune cell count. And others show that transport losses can increase with increasing transport time > 30 min may increase transport losses (Vecerek et al., 2006; Gosálvez et al., 2006; Gade et al., 2007; and Sutherland et al., 2009).

**Wait time at the plant.**

Wait time at the plant has been defined as the time from when the trailer arrives at the plant until the trailer begins unloading (Gesing et al., 2010). When a trailer carrying pigs is stopped and waiting to unload the temperature inside the trailer goes up continually (Ellis et al., 2008). Some facilities provide banks of fans that trailers can park near to allow continued air flow over the pigs. Other facilities require sprinkling with water during wait time. Some facilities have hot weather action plans that generally consist of a short route truckers are to drive when they have a wait time of > 1 h during hot weather.

Sutherland and others (2009) used 2,730,754 market weight (~125 kg) barrows and gilts to determine the effects of wait time at the plant. This study found that loads with wait time 2 to 3 h and > 4 h had the greater percent dead (~0.28%; P < 0.05) than those with < 3 h wait time. Kephart and others (2010) studied 41,744 market weight pigs and looked at the effects of transport times on transport losses. This study found no effect of wait time on transport losses (P > 0.10). Ritter and colleagues (2006) used 12,511 market weight (227 sire X C22 dam breed PIC U.S.; ~129 kg) barrows and gilts to determine the effects of wait time on transport losses. The study found that as waiting time increased so did the number of total transport losses (P < 0.05). Sunstrum and others
(2007) observed 46,331 market weight pigs in Canada to determine the effects of wait time. It was determined that increased wait time increased dead and fatigued pigs ($P < 0.01$; 2.2 and 2.3 times, respectively).

These studies agree that increasing wait time at the plant can be detrimental to pig well-being in terms of transport losses.

**Duration of unloading.**

Unloading has been defined as the time from when the the driver started unloading the trailer until the last pig exited the trailer (Gesing et al., 2010). Ritter and others (2006) used 74 trailers carrying 12,511 barrows and gilts (average: 129 kg; progeny of PIC 337 sires mated to C22 dams PIC U.S.A.) to determine the effects of wait time at the farm on transport losses. Unloading time was reported to increase the number of fatigued pigs also increased ($P < 0.05$). Additionally, as duration of unloading increased the sum of fatigued and injured pigs also increased.

**Trailer factors that could influence transport losses**

**Mixing pigs**

Mixing pigs most often refers to putting pigs from different pens together which often causes fighting (NPB, 2008). Social hierarchies are developed when pigs are raised together in groups (Landsberg, 2012). Pigs from different pens are often mixed during
loading and transport to obtain pigs of a similar weight or adjust the number of pigs per trailer compartment (Faucitano, 2001). Mixing can occur on the farm prior (pre-sorting) to loading or within the trailer compartment.

It is often assumed fighting occurs to establish dominance, but one article suggests that it may be due to unfamiliarity (Gonyou, 2003). Fighting may also occur amongst familiar pigs during transport due to other stressors such as space limitations, fatigue, group size, or hunger (Warriss, 1998b). Fighting is problematic because it can result in skin damage and carcass blemishes (reviewed by Faucitano, 2001). Warriss and Brown (1985) used 80 commercial hybrid boars and barrows (55 kg) to determine the physiological effects of fighting. It was determined that increased carcass damage increased cortisol, glucose, and lactate ($P < 0.01$). Guise and others (1996) looked at the effects of mixing pigs (~98 kg) on five loads of pigs each from a different farm. Each pen contained 10 to 16 barrows and gilts from the same farm. No aggressive behaviors were observed using time lapse video recordings in any of the pens of pigs from the departure to arrival at the processing plant. Bradshaw and others (1996a) used 12 groups of four 90 kg gilts and barrows (Landrace X Large White) that were transport for 1.5 h. Half of the pigs were transported in their social groups and half were mixed. Pigs were far more active when mixed. Sains (1980) reviewed 2 surveys taken in Britain including 723,510 market weight pigs. Two thirds of all dead pigs at the processing plant were involved in fights. The other third had signs of heart failure and bruising. Perhaps mixing of unfamiliar pigs during transport and lairage may be related to the number of dead and non-ambulatory pigs. A commercial study (Ritter, 2007) utilized 4,027 market weight (128 kg) barrows and gilts (PIC 337 sires X C22 dams PIC U.S.) to determine the
effects of mixing unfamiliar pigs during transport. Mixed trailer compartments were filled with approximately equal numbers of pigs taken from two different barn pens, while unmixed trailer compartments were filled with pigs from the same barn pen. Mixed and unmixed compartments did not show differences in open mouth breathing, skin discoloration, or muscle tremors \( (P \geq 0.17) \). No differences in DOA, NA, or total losses were reported between mixed and unmixed compartments \( (P \geq 0.34) \). Finally, no differences were reported between mixed and unmixed for total carcass trim loss percent \( (P = 0.29) \). Gesing and others (2010) used 5,802 market weight barrows and gilts (192 d of age; 120 kg) of standard commercial genetics (halothane gene free) to determine the effects of pre-sorting. Pre-sorting was reported to reduce loading time \( (P < 0.01; \text{21 - vs 17 min per deck}) \). Pre-sorting pigs reduced \( (P < 0.01) \) open mouth breathing and skin discoloration during loading over pigs that were not pre-sorted. This study also found no differences in fatigued or injured pigs between the treatments \( (P > 0.05) \).

Fighting may be determinental to pig well-being in terms of blood stress measures (glucose, lactate, and cortisol) as well as transport related deaths (Warriss et al., 1985; Sains, 1980). However whether mixing pigs causes fighting or affects pig well-being is unclear (Guise et al., 1996; Ritter et al 2007; Gesing et al, 2010).

\textit{Density of pigs}

The TQA program recommends market weight pigs (~91 to 136 kg) should be transported at a density between 0.32- and 0.45 m\(^2\)/pig (NPB, 2008). Additionally, TQA recommends fewer pigs should be loaded as temperature increases to help reduce stress
on the pigs. Density also known as floor space or stocking/loading density of pigs on a trailer has been studied in several papers. These different terms have slightly different meanings. For example, increasing floor space means pigs have more room whereas increasing density means they have less room. Some look at m²/100 kg (Gade and Christensen, 1998) whereas others look at kg/m² (Fitzgerald et al., 2009; Lambooy et al., 1985, Warriss, 1998a). Warriss (1998a) conducted a review to determine the appropriate density when transporting market weight pigs in the U.K. This review found that most studies report that pigs prefer to lie down during transport. Therefore, when transporting pigs, enough space should be allowed so that all pigs can lie down simultaneously. For the market weight pig (90-100 kg), this means about 253 kg/m².

Fitzgerald and colleagues (2009) studied more than 2 million market weight barrows and gilts to determine the effects of density. Pigs were transported between 34 and 160 km from farm to plant. This study found that the density of the pigs on the trailer accounted for a majority of the variation in transport losses between loads (P < 0.01). By increasing density by 50 kg/m² and 100 kg/m² transport losses increased from 0.53 to 0.74%. Gade and Christensen (1998) used 774 market weight (101 kg) barrows and gilts (3 to 4 crossbreeds of Landrace, Large White, Duroc and Hampshire) to measure the effects of density (m²/100 kg) in Denmark. Four stocking densities (0.35, 0.39, 0.42 and 0.50 m²/100 kg) were used for this study and pigs were transported for ~2.5 h. This study observed pig behavior in transport, measured creatine phosphokinase, meat quality, and blood profile. When density was 0.35 m²/100 kg the pigs stood close together and the primary behavior was one pig pushing another with their head. Around 40% of the pigs were lying after 20 min of transport. When density was 0.39 m²/100 kg more exploratory
behaviors were observed in the first 30 min of transport and later fewer pigs were lying than in the 0.35 m²/100 kg treatment. Pigs were continuously changing position between standing, sitting, and lying. When density was 0.42 m²/100 kg the primary activity observed was changing positions between standing, lying, and sitting. Pigs seemed to have difficulty keeping their balance and no group of pigs was simultaneously lying as with the previous treatments. The last stocking density, 0.50 m²/100 kg, found that pigs primarily changed position between lying, standing, and sitting and displayed exploratory behavior. Most pigs remained standing or sitting. Creatine kinase was observed to be lower ($P < 0.01$) at 0.50 m²/100 kg than for the other densities tested. When density was 0.42 m² more pigs showed unacceptable skin damage. Lambooy and colleagues (1985) studied the effects of 3 different densities (0.66, 0.44, and 0.33 m²/pig) during 2 days of simulated travel in the Netherlands on 316 crossbred market weight (~103 kg) barrows and gilts. Pigs transported at the lowest density, 0.66 m²/pig, sat or lied down within the first 2 h of transport. Pigs transported at 0.44 m²/pig sat or lied down about 2.5 to 2.75 h after the start of transport. Pigs transported at 0.33 m²/pig could not all lie down simultaneously, so the pigs were changing positions throughout transport. The pH of the semimembranosus muscle and temperature of the longissimus dorsi muscle were found to increase with increased density. Lambooy and Engel (1991) looked at the effects of 3 densities (186, 232, and 278 kg/m²) on 60 market weight (~110 kg) gilts and barrows transported 25 h in the Netherlands. Pigs hauled at 186 kg/m² laid down sooner after transport started and remained lying longer. Pigs transported at 278 kg/m² took longer to lie down. Because not all the pigs could lie down when transported at 278 kg/m², the pigs changed positions frequently. The pH of semimembranosus and longissimus dorsi
muscles as well as rigor level increased ($P < 0.05$) as density increased. Pilcher and others (2011) studied the effects of density on the trailer on 17,652 market weight (125 kg) barrows and gilts of standard commercial genotype. Six different density treatments were used: 0.396, 0.415, 0.437, 0.462, 0.489, and 0.520 m$^2$/pig. Although the study found no effects of density on transport losses ($P > 0.05$), the study did find that skin discoloration (a sign of stress in pigs), was greater ($P < 0.01$) when pigs were transported on the two smallest treatments (0.317 and 0.332 m$^2$/100 kg or 0.396 and 0.415 m$^2$/ pig).

Ritter and others (2006) used 74 loads of market weight barrows and gilts (129 kg; 337 sires X C22 dams, PIC U.S.) to determine the effects of 2 densities (0.39 and 0.48 m$^2$/pig) on transport losses. Two densities were achieved on the same trailer by loading 2 similar compartments with different numbers of pigs. Decreasing density from 0.39 to 0.48 m$^2$/pig reduced total losses (0.88 vs. 0.36 ± 0.16%; $P < 0.05$), non-ambulatory (0.62 vs. 0.27 ± 0.13%, respectively; $P < 0.05$) and fatigued (0.52 vs. 0.15 ± 0.11%, $P < 0.01$). Decreasing density also tended to reduce the incidence of dead pigs (0.27 vs. 0.08 ± 0.08; $P = 0.06$).

Overall, these studies show that increasing density increases transport losses (Fitzgerald et al., 2009; Ritter et al., 2006). Furthermore, when there was not enough space for pigs to lie down simultaneously (> 253 kg/m$^2$) skin discoloration was greater, but pH was higher (Gade and Christensen, 1998; Lambooy et al., 1985; Lambooy and Engel, 1991; and Pilcher et al., 2011).
**Micro-climate inside the trailer**

Trailers that move swine in the U.S. rely on passive ventilation, meaning air flow is dependent upon thermal buoyancy, movement of the vehicle itself, and wind speed. Therefore, in certain geographical regions and seasons, the trailers’ passive ventilation must be supplemented with bedding or water sprinkling to control the micro-environment within the trailer (NPB, 2008). The U.S. swine industry has one program that specifically focuses on transportation: TQA (NPB, 2008). The TQA program suggests light bedding (2 bags/trailer) when the temperature exceeds 10 °C. Bedding is defined as straw, wood shavings, sand, or corn stover. Additionally, it notes that when > 15 °C bedding can be wetted if it is not too humid (no specific break on what too humid is). The TQA program also says pigs should be sprinkled with a large droplet size after loading but prior to departure at the farm when > 27 °C. The program lacks further details on sprinkling (duration, water pressure, etc.). The trailer micro-environment includes the temperature, humidity, how or if sprinkling is used, and the amount and condition of bedding (Ellis et al., 2008; Sutherland et al., 2009).

Ellis and others (2008) took measurements inside 20 loads of market weight (132 kg) pigs transported 5.5 h to determine micro-environment inside the trailer. As pigs were loaded onto the trailer temperature was found to increase in all compartments (~4 °C). Relative humidity declined steadily from loading to unloading ~7% averaged between compartments. This study found that when the trailer is stopped and airflow is minimal (< 1 m/s) the pigs are at the greatest risk for thermal stress.
Thermal stress in pigs results in several physiological reactions, some of which can be observed. Pigs do not sweat effectively (Ingram 1967; Ingram, 1977). Instead, pigs pant to produce evaporative cooling through the respiratory system (observed as open mouth breathing). Furthermore, blood flow to the skin and limbs will be increased to allow heat from blood to be released through the skin (observed as red or purple blotchy skin).

**Sprinkling.** In the summer months it is a common practice to mist, water, or sprinkle swine during loading or immediately after they are loaded. Merriam Webster defines misting as “a stream of liquid in the form of small very small drops (Merriam-Webster.com, 2013a).” Water is defined as “to moisten, sprinkle, or soak with water (Merriam-webster.com, 2013c).” Sprinkling is defined as “to put small drops of liquid on something (Merriam-webster.com 2013b).” Some processing plants require drivers to sprinkle pigs before unloading. TQA recommends that pigs are sprinkled with water in temperatures $> 27 \, ^\circ C$. The TQA program notes a larger droplet size should be used. No studies have occurred to determine at what temperature sprinkling becomes effective for market weight pigs on trailers.

Some work that may provide some guidance has been conducted using bovine as the experimental model. Gaughan and colleagues (2008) looked at the effects sprinkling to reduce heat stress in cattle using 6 Murray Grey X Hereford yearling steers in a climate controlled facility in Australia. Cattle were exposed to 2 d of thermoneutral control portion where the ambient temperature ranged from 20 to 24 $^\circ C$ and the temperature humidity index (THI) ranged from 65 to 72. The steers were then exposed to 4 d of the
hot treatment where the ambient temperature and THI were cycled with temperatures increasing starting at 0600 in 1.8 °C intervals to a maximum temperature halfway through the day; thereafter decreasing in 1.2 °C increments until 2100 h. Sprinklers (droplet size = 150 µm, range = 180 °) positioned 1.7 m above the steers' heads were used at 2.84 L/min. Sprinklers were turned on for 5 min on then off for 20 min when > 20 °C. Fans at 2 m/s were run continuously when > 28 °C from the front of the stalls. Half were cooled during the day and half cooled at night. This study found that watering using large droplet size combined with air flow from fans can decrease rectal temperature (~39 - to 38 °C) and respiration rates (120 - to 95 breaths per minute). A more recent review by Worley (2012) looked at heat stress in dairy cows. It is reported that fans and sprinklers should be used together for maximum efficacy. Additionally, it reports cows should be wetted in 15 min cycles for 0.5 - to 3 min where 0.13 cm of water is applied per cycle. It noted that research has shown a 10% increase in milk production when sprinkling was used in addition to fans.

McGlone and colleagues (1988) used 120 mixed parity, lactating mixed breed (Yorkshire, Landrace, Hampshire, Duroc) sows to determine the efficacy of drip cooling sows. The study maintained air temperature ≥ 29 °C with relative humidity at 44.9%. It used a water drip on the sows' neck/shoulders at 2 L/h which cycled on for 3 min every 10 min. Researchers measured various factors of performance in both the sow and piglets. In addition, 30 sows had respiratory rate measured. Use of the drip coolers was correlated with increased feed intake ($P < 0.01$) and thus less weight loss during lactation ($P < 0.01$). Additionally, the drip cooler reduced the respiratory rates of the sows ($P < 0.05$). Another study by Huynh and colleagues (2006) used 120 grow finish (Duroc X Pietrain)
X Large White pigs (~57 kg start weight) to determine the effects of sprinkling in Vietnam. Sprinklers were 1.2 m over the floor with sprinkler heads placed every 30 m. The foggers, installed toward one end of the pen, were run for 2 min every 30 min from 1000 to 1600 (100 – 500 µm). Pigs were observed using the sprinklers 4.7 times of 12 sprinkling periods. Three randomly selected pigs from each pen were randomly chosen 2 times/day for skin temperature, respiration rate, and rectal temperature. Skin temperature was taken using a radiant thermometer and rectal temperature was taken with a standard thermometer. Respiration rate was taken by counted flank movements. Rectal temperature was not observed to did not differ between treatments. It was observed that sprinkling reduced respiration rate by 5.2/min and skin temperature by 0.4 °C (P < 0.01 and P < 0.05 respectively) over pigs that were not sprinkled. Additionally, average daily gain was increased by 50 g/day with sprinkling (P < 0.05). Fox (2013) studied the effects of sprinkling on 4,992 york X landrace maternal and duroc sire lines market weight pigs (average: 115 kg) being transported to slaughter. Pigs were sprinkled 5 min prior to departure after loading and 5 min before unloading. When temperature > 24°C, gastrointestinal tract temperature tended to decrease more (P = 0.08) on sprinkled trailers than non-sprinkled trailers.

Overall, these studies show that sprinklers combined with airflow are effective at reducing heat stress on pigs as measured by internal and skin temperatures as well as respiration rate (McGlone et al., 1988; Huyhn et al., 2006; Fox, 2013).

Bedding. The AMI guidelines/audit requires bedding for all pigs being transported regardless of temperature and relative humidity (AMI, 2012). Historically, FSIS
inspectors use the AMI guidelines as part of their humane handling inspections at the plant (FSIS, 2012). There has been little to no research published for the effects of bedding on trailers transporting market weight pigs. The TQA program and others have noted that pigs should never be transported without bedding due to footing and temperature control issues. Additionally, the TQA program recommends that when temperature > 10 °C, 2 bags of bedding/trailer should be provided. However, there is little scientific data to back up these claims. Sutherland and others (2009) used 2 million market weight (~129 kg) barrows and gilts to determine the effects of wet, dry, and no bedding on trailers on the number of transport losses. The results of this showed that when transport time was 4.5 - to 5 h, DOA occurred less frequently in trailers with dry bedding versus those that had wet bedding ($P < 0.05; 0.20 \text{ vs } 0.36 \%$, respectively). Also, when the transport time was between 8 and 9 h the occurrence of injured pigs at the plant was lower in those trailers with dry bedding ($P < 0.01; 0.07 \text{ vs } 0.16\%$). When transport lasted between 8 and 9 h number of pigs injured on trailer increased ($P < 0.01$) when the bedding was wet than when bedding was dry. Additionally, the study reported that when temperature was 0 - to 5 °C fatigued pigs occurred more often on trailers with no bedding over those with dry bedding ($P < 0.05; 0.43 \text{ vs } 0.22\%$ respectively). Finally, DOA and injured on trailer were 69.8% lower ($P < 0.05$) when bedding was dry than when there was no bedding.

Bedding that has previously had pigs on it may contain pheromones released in the urine of those previously hauled pigs. Fear and alarm pheromones may cause adverse reactions, but it is believed that “good” pheromones such as those expressed by a sow may have a calming effect. A study by Lewis and others (2010) used market weight
barrows and gilts (PIC commercial lines and PIC crossbred lines) to determine the effects of maternal pheromone during transport. In Experiment 1, used 31 trailers of market weight pigs to determine the effects synthetic maternal pheromone or water sprayed on trailer. In experiment 2, 41 trailers of market weight pigs were used to determine the effects of synthetic maternal pheromone or water sprayed in the pens as well as on the trailer. Meat quality (muscle pH and Japanese color score) was not observed to differ between treatments (P > 0.05). The first experiment of this study found that pigs on trailers with the control treatment vocalized more at the plant (P < 0.05; 13.9 - vs 9.0%). However, experiment 2 showed that pigs exposed to the pheromone vocalized more than those given the control treatment (P < 0.05; 1.36 - vs 0.20%). It was also reported that pigs in the second experiment in the pheromone treatment had 39% fewer fatigued pigs than those given the control (P < 0.05). However, a power test was performed and found that 249 loads of pigs were needed to find a 50% difference due to the low rate of fatigued pigs. Guy and others (2009) used 52 pens of 20 Large White X Landrace wean pigs (~28 d of age) to determine if there was a difference in fighting when a sow pheromone was applied rather than a control in the U.K. Pheromones were applied to the pens one hour prior to pigs being added. The control treatment consisted of nothing being applied. Video observation revealed that general activity (feeding, standing, walking, lying, and active.) levels did not differ between control and pheromone treated groups. Live observation revealed that control treated pens tended to have more fighting and biting, biting, and chase behaviors than those in pheromone treated pens (P = 0.06). However, mounting behavior increased in pheromone group over control group (P = 0.02). No differences were found between treatments on number of skin lesions (P >
36

0.05). Treatment did not affect live weight, growth rate, or feed conversion, but feed intake was lower for pheromone treated pigs ($P = 0.02$). Mcglone and Anderson (2002) used 148, three to four wk old, weaned pigs to determine the effects of maternal pheromone on behavior and performance of wean pigs (3-4 wk old). Either a pheromone or control, pheromone free placebo, was applied to the snouts of pigs or feeder and waterer in each pen (3 pigs/pen). Pigs in the pheromone treatment group spent 1.7% more time feeding and 3.2% more time standing/walking than those pigs given the control ($P < 0.03$). Pigs in the pheromone treatment spent more time lying in the first 4 h after weaning than the control group ($P < 0.05$). Piglets given the control treatment were ~1 kg lighter than pigs given either pheromone treatment at the end of the nursery period. Additionally, pigs in pheromone group had better average daily gain, and better feed:gain ratio than control pigs 28 d post weaning ($P < 0.01$). Driessen and others (2008) used 90 pigs (22 kg) to test the effects of pheromones on stress signs during simulated transport in the U.K. Treatments were control of nothing applied, two levels of synthetic maternal pheromones (2- and 5 ml), and a placebo of a non-relevant odor (a spray used to inhibit feather pecking in birds and tail biting in pigs). Treatments were applied with a paint brush to the snouts of the pigs. Pigs were anesthetized the day before so that a device could be attached to monitor heart rate. Transport simulation occurred by placing 3 pigs in a crate for 1 h, the engine noise was turned on for 1 h, then the treatments were applied, and the vibration began and lasted for 2 h. During the first hour of simulated transport, pigs treated with pheromones had a minimum heart rate ~11 beats per minute lower than those treated with control ($P < 0.02$). During the second hour of simulated transport, pigs given the higher concentration of pheromone had a minimum heart rate 10
beats per minute lower than those given the control. In the first hour of simulated transport, pigs treated with the non-relevant odor had a minimum heart rate ~13 beats per minute higher than pigs treated with either pheromone. In the second hour of transport pigs treated with the non-relevant odor had a minimum heart rate ~15 beats per minute higher than pigs treated with either pheromone level.

Overall, pheromones may be effective at increasing pig well-being assisting pigs in coping with the stress of transport, mixing, and weaning (Guy et al., 2009; McGlone and Anderson, 2002; and Driessan et al., 2008).

**Temperature, relative humidity, and their indices outside the trailer**

Heat stress is an important factor in finisher pig well-being and has been reported to result in 1.1 deaths/1000 head/yr in Iowa when no steps are implemented to reduce heat stress (St. Pierre et al., 2003). A finisher pig’s thermo-neutral zone ranges between 10 to 21 °C (Fox, 2013). Temperature in addition to humidity becomes more dangerous for swine much faster than it does for cattle (The Pig Site, 2002b). Cattle reach emergency status on the heat stress index at 33.3 °C and 55%; however, at the same temperature, swine reach emergency status when RH is only 10% (ABE, 2002). This is due to the pig’s inability to regulate their body temperature effectively by sweating (Ingram 1967; Ingram, 1977). Instead, pigs will pant to regulate heat stress, which becomes ineffective when humidity is high.

Marple and colleagues (1974) subjected four Chester White gilts (~68 kg) to temperatures of 27 °C with 5 °C increases in temperature each hour, and reported that all
of the pigs died after ~160 min of heat stress. Rectal temperature increased from ~39 °C  to
43 °C during heat stress \((P < 0.01)\). Heart rate also increased from ~130 to 270 beats per
minute during heat stress \((P < 0.01)\). Respiratory rate increased \((P < 0.01)\) from ~30 to
190 breaths per minute until 40 min before death when it began to decrease. During the
last 40 min preceding death, rectal temperature increased by ~1.5 °C and plasma lactate
values increased \((P < 0.01)\) from ~15 to 55 mg/100 ml. Blood pH remained constant at
~7.5 for ~140 min, but dropped to ~7.15 in the last 20 min preceding death \((P < 0.01)\). At
death all of the pigs had rectal temperatures of ~43 °C, blood pH of ~7.15, and plasma
lactate values of 55 mg/100 mL. Allen and colleagues (1974) observed 400,000 market
weight barrows and gilts in the U.K. to determine the relationship between transport
losses and temperature. Transport and lairage deaths were very low at ambient
temperatures < 10 °C, but increased linearly as the temperature increased from 10 to 18
°C. Similarly, Warriss and Brown (1994) observed 2,907,707 market weight pigs
transported over 2 years to determine the descriptive relationship between temperature
and transport losses. The relationship between deaths and temperature is curvilinear when
temperature > 15 °C. Dewey and colleagues (2005) conducted a retrospective study on
4,760,213 market weight pigs to determine the descriptive relationship of temperature on
transport losses in Canada. Transport deaths were lower at < 15 °C (0.14%), but the
percentage of deaths increased as ambient temperature increased to 31 °C (0.72%).
Likewise, numerous studies have reported marked seasonal effects for transport and
lairage mortality where death loss is highest in the summer months (Allen et al., 1974;
Smith and Allen, 1976; Warriss and Brown, 1994). Kephart and others (2010) studied
41,744 market weight pigs during unloading to determine the effects of temperature on
pig measures and transport losses. Pigs transported at $< 17 \, ^\circ C$ had 1.8% less open mouth breathing and 2.38% less skin discoloration than those transported at $\geq 17 \, ^\circ C$ ($P < 0.01$). Sutherland and others (2009) used 2 million market weight (~129 kg) barrows and gilts to determine the effects of temperature on transport losses. Number of DOA pigs increased as the temperature increased $> 20 \, ^\circ C$ ($P < 0.01$) with the highest DOA numbers at temperatures $> 25 \, ^\circ C$ ($P < 0.05$). In addition, percent non-ambulatory increased as the temperature decreased $< 5 \, ^\circ C$. The percentage of fatigued pigs decreased as temperatures increased above 0 °C with more than 50% fewer fatigued pigs at temperatures above 5 °C. This study speculated that pigs that are NANI at lower temperatures would have been dead on arrival at temperatures above 20 °C. Haley and colleagues (2008) conducted an observational study in Canada on 4,760,213 market weigh pigs to determine how the temperature affected transport loss. When relative humidity was 60%, this study saw transport losses were 5.9 times higher at 26 to 31 °C than at 16 to 18 °C.

It is clear that higher temperatures correlate to more transport losses and increased pig stress (Marple et al., 1974; Allen et al., 1974; Warriss and Brown 1994; Dewey et al., 2005; Kephart et al., 2010; Sutherland et al., 2009). The research in this subject is clear and fairly complete. The industry already works to schedule transport times at cooler times of the day in the warmer months of the year. The industry also works to reduce heat stress on the pigs by sprinkling water over the pigs during or after loading.

Although, the effects of ambient temperature on transport losses are well established, but the effects of relative humidity on transport losses are not fully understood as shown by conflicting literature. Allen and colleagues (1974) observed 400,000 market weight barrows and gilts in the U.K to determine cause of transport
losses. However, no effects of dew point were observed. Smith and Allen (1976) studied the effects of weather conditions on market weight pigs after transport in England. Days with wet cold (higher dew point) seemed to have more deaths than dry cold (lower dew point). A low number of DOA pigs prevented statistical analysis of the effects of dew point. Fitzgerald and others (2009) looked at the effects of relative humidity in 2,053,945 market weight swine. The final model in this study used THI developed by the National Oceanic and Atmospheric Association (NOAA, 1976):

\[
\text{THI} = T - \{[0.55 - (0.0055 \times RH)] \times (T - 14.5)\}
\]

“The log of total losses (%) per load increased by 0.0102x + 0.000541x^2 per unit of THI and 0.0191 kg/m^2 of density (Fitzgerald et al., 2009; no P-value reported).” Additionally, THI accounted for variation in percent of transport losses (no P-value reported). The conflicting results between these studies may be due to differences in climatic conditions.

Literature cited


https://www.govtrack.us/congress/bills/110/s394.


CHAPTER 3: ESTABLISHING BEDDING REQUIREMENTS ON TRAILERS TRANSPORTING MARKET WEIGHT PIGS IN WARM WEATHER

A paper to be submitted to Animals.

Rebecca K. Kephart 1,2, Anna Johnson 1,*, Avi Sapkota 3, Kenneth Stalder1, and John McGlone3

1 Graduate student, associate professor, and statistician, respectively. Iowa State University, Ames, IA 50011; E-Mails: r.kephart8@gmail.com (R.K.K.); johnsona@iastate.edu (A.J.); stalder@iastate.edu (K.S.)
2 Primary researcher and author.
3 Professor and graduate student, respectively. Texas Tech University, Lubbock TX 79409; E-Mails: asapkota@purdue.edu (A.S.); john.mcglone@ttu.edu (J.M.)

*Author to whom correspondence should be addressed; E-Mail: johnsona@iastate.edu (A.J.);
Tel.: +1-515-294-2098; Fax: +1-515-294-4471.

Simple Summary: Transport is an inevitable process in the U.S swine industry. Trailers transporting pigs are bedded with straw, wood shavings, corn stover, or sand; however, too much bedding may detrimentally affect the micro-environment inside the trailer during warm weather and in turn negatively affect animal based measures and transport losses. These experiments aim to determine the amount of bedding that is ideal for market weight pig transport during warm weather.

Abstract: During warm weather, incorrect bedding levels on a trailer transporting market weight swine may result in heat stress, fatigue, and death. Two experiments were conducted in June and July 2011; Experiment 1 used 80 loads (n = 13,887 pigs) to determine the effects of two bedding levels (3- or six 22.7 kg, 0.2 m\textsuperscript{3} bags of wood shavings/trailer) on pig measures (surface temperature, vocalizations, slips and falls, and stress signs). Experiment 2 used 131 loads (n = 22,917 pigs) to determine the effects of bedding on transport losses (dead, sum of dead- and euthanized- on arrival; non-ambulatory, sum of fatigued and injured; total transport losses sum of dead and non-ambulatory). Bedding did not affect surface temperature, vocalizations, or slips and falls (\(P = 0.58\), \(P = 0.50\), and \(P = 0.28\), respectively). However, pigs transported on 6 bags/trailer had 1.5 % more stress signs than pigs transported on 3 bags/trailer (\(P < 0.01\)). The relationship was weak (\(R^2 = 0.26\)). No differences were observed between bedding levels for non-ambulatory, dead, or total transport losses (\(P = 0.10\), \(P = 0.67\), and \(P = \))
Within the context of these experiments there was no evidence of deleterious effects on pig measures or transport losses. However, using more bedding would cost the industry more. Therefore, 3 bags of bedding/trailer may be used when transporting market weight pigs during warm weather in the Midwestern U.S.

**Keywords:** bedding; market-weight pig; transport losses; well-being

### 1. Introduction

In 2011, ~110 million pigs were marketed in the U.S. [1]. Transporting pigs is essential to multi-site pork production. For pigs, the marketing process is a combination of potentially novel (defined as the first exposure), unfamiliar (defined as infrequent exposures), and physically exerting experiences that could be perceived as stressful [2]. If the pig is unable to cope with these stressors, increased transport losses and decreased meat quality may result [3-5]. The term “transport losses” refers to pigs that become non-ambulatory (pigs that are unable to keep up with the group and may be injured) or are classified as dead on arrival at the plant [2].

The conditions under which pigs are handled and transported can have a direct impact on their well-being, which may result in increased transport losses. In the U.S., pigs are transported in trailers which rely on passive ventilation where air flow is dependent upon thermal buoyancy, movement of the vehicle itself, and wind speed. To control the environment inside the trailer, truckers provide bedding to help absorb urine and fecal matter, reduce slips and falls, and to help maintain the pigs’ thermo-neutral zone [6-8]. The U.S. industry’s Transport Quality Assurance (TQA) program defines appropriate bedding as straw, corn stover, wood shavings or sand and provides recommendations for bedding levels. However, these recommendations are based on experiential information rather than scientific data [7]. Therefore, the objectives of these experiments were to compare the effects of 2 bedding levels on the (1) pig measures at the time of unloading and (2) transport losses during warm weather for market weight pigs.
2. Experimental Section

2.1. General procedures

2.1.1. Treatments and Experimental Design

Both experiments compared two bedding levels on trailers transporting market weight pigs: 3- and 6 bags (0.2 m$^3$; 22.7 kg) of wood shavings/trailer. Treatments were randomly assigned to trailers by the trucking companies. The data was collected during two-1 wk periods during June and July 2011.

2.1.2. Animals, Farms, and Pig Handling

The protocol for these experiments was approved by the Iowa State University Institutional Animal Care and Use Committee. The company’s loading crew identified market weight barrows and gilts and moved them from the home pens to the loading ramp entrance. The trucker moved these pigs up the loading ramp and onto the trailer. During loading, the loading crew and the trucker used a combination of sort boards, rattles, paddles, and electric prods (the number of times these devices were used was not recorded). On average, 7 pigs were moved from the home pens to the trailer. Following the TQA recommendations, any pig unable to keep up with the group during loading was returned to the home pen, and therefore was not included in either experiment. The pigs were transported from commercial finishing facilities to a commercial processing plant. All finishing facilities and the processing plant were located in Iowa. Transport occurred throughout the day and night. Upon arrival at the plant, the trucker unloaded the pigs from the truck and plant personnel moved the pigs from the bottom of the unloading ramp to the lariage pens. During unloading, plant personnel and the trucker used paddles, rattles, and boards.

2.1.3. Transport Trailers and Density

All pigs were transported on aluminum drop deck (pot belly) trailers ~17 m in length with diamond plate flooring. These were owned and operated by the trucking companies contracted through the plant. All compartments in the trailer were stocked according to the industry’s current standard operating procedure of 0.41 m$^2$/pig or ~173 pigs/load. The plant provided data on the number of pigs/trailer and the average weight of pigs on a trailer. For these experiments a density value was calculated and added to the
statistical model because previous work has found density is an important variable in affecting animal based measures and transport losses [9-12].

Density [9] = (average pig weight per trailer) * (pigs per trailer)/(floor space in trailer)

2.1.4. Environmental Measures at Loading and Unloading

At loading, relative humidity and ambient air temperature (temperature) were measured either with a mini thermo-anemometer with humidity (n = 77; model 45158, Extech Instruments Nashua, NH USA; accurate ± 0.4 % for relative humidity and ± 1 °C for temperature) or by a weather station closest to the farm (n = 54; ≤ 32.8 km from the farm). The Citizen Weather Observer Program (CWOP) dictates these weather stations are accurate to ± 1.1 °C [13]. The National Oceanic and Atmospheric Association (NOAA) which oversees CWOP, only uses dew point for accuracy. Therefore, CWOP dictates dew point should be accurate to ± 2.2 °C. During loading, temperature and relative humidity ranged from 10.6 to 38.3 °C and 33.2 to 98.0 %, respectively.

During unloading, temperature and dew point were measured at an airport 16.9 km from the plant (1088 hygrothermometer Technical Service Laboratory Fort Walton Beach, FL 32548). Relative humidity was then calculated from dew point and temperature measurements by the outputting computer (accurate ± 0.003 °C). Temperature and relative humidity during unloading ranged from 16.1 to 43.4 °C and 43.0 to 97.4 %, respectively. Temperature (T) and relative humidity (RH) were used to calculate a Temperature Humidity Index (THI) using the following equation provided by the NOAA [14] and was included in the statistical model [9]:

\[
THI = T - \{[0.55 - (0.0055 \times RH_{\text{decimal}})](T - 14.5)\}
\]

2.2. Experiment 1: Effects of trailer bedding levels on market weight pig measures and bedding moisture during warm weather

This experiment used 80 loads; 48 loads had 3 bags/trailer and 32 loads had 6 bags/trailer.

2.2.1. Transport events

Transport events in this experiment were loading, transport, wait time, and unloading. Loading was defined as the time interval from the first pig’s first foot stepping
onto the trailer until the last pig’s last foot stepped onto the trailer. Transport was defined as the time interval from when the last pig’s last foot stepped onto the trailer until the trailer arrived at the plant. Wait time was defined as the time interval from when the trailer arrived at the plant until the first pig’s first foot stepped off the truck. Unloading was defined as the time interval from when the first pig’s first foot stepped off the truck until the last pig’s last foot stepped off the truck. Total transport time was the time from when the first pig’s first foot stepped onto the trailer (start of loading) until the last pig’s last foot stepped off the trailer (end of unloading).

2.2.3. Bedding Moisture

A total of 19 fresh bedding samples and 99 used bedding samples were collected from the trailers. Fresh samples (0 loads) were defined as bedding that had not been previously used for transporting pigs being placed in a clean trailer. A fresh bedding sample ~45 g was collected. After each trailer had unloaded at the plant, a used bedding sample, defined as bedding which had transported ≥ 1 trailer loads of pigs was collected. Half of the used bedding was collected from the bottom trailer deck and the remainder was collected from the top deck. Each used bedding sample collected was ~410 g. Bedding samples were stored at room temperature (~21 °C) for no longer than 1 wk after trial completion.

Bedding moisture was determined following standard operating procedure for drying samples. A tin measuring 7.6 cm wide by 2.2 cm deep (model A90, Wilkinson Industries Inc., Fort Calhoun, NE 68023 USA) was weighed. Each bedding sample was kneaded by hand inside the closed storage bag for ~30 s. Two, 3 to 6 g subsamples (subsample A and B) were removed from the bag using a spoon. Subsample A was placed in one tin and subsample B was placed in a second. The bedding subsample in its respective tin was weighed (accurate ± 0.03 mg; model AT261 DeltaRange, Metler-Toledo GmBh Laboratory & Weighing Technologies, Greifensee, Switzerland) to determine wet weight. Bedding subsamples were dried for ~20 to 24 h at 100 °C in a convection oven (model DKN810, Yamato Scientific America Inc., Santa Clara, CA 95050). After drying, subsamples were re-weighed; this was defined as the dry weight. Moisture percent for each subsample was calculated using the following equation [15]:

\[
\text{Moisture percent} = \left[ \frac{(\text{dry weight})}{(\text{wet weight})} \right] \times 100
\]

A standard deviation of moisture percentage between subsample A and subsample B and an average of the moisture percent of subsample A and subsample B were
calculated. Between subsample A and subsample B, the coefficient of variation (CV) was calculated using the following equation:

\[ \text{CV} = \frac{\text{Standard deviation}}{\text{average}} \times 100 \]

If the CV ≥ 10 the sample was re-subsampled and dried a second time (n = 14). If the sample was still found to be too variable on the second drying, that samples were removed from the data set (n = 0). The data from bedding moisture will be presented descriptively separated by the number of loads on the bedding, ranging from 0 to ≥ 4 loads.

2.2.4. Pig measures

Vocalizations, slips and falls, and stress signs were collected on a random sample of pigs at unloading using live observation. A random sample was defined as ignoring ~10 pigs at the beginning of unloading, counting measures for 50 pigs (group A), ignoring a further ~10 pigs, and counting measures for another 50 pigs (group B). This provided 100 pigs/load. Vocalizations were defined as an extended sound of high amplitude and frequency produced with an open mouth [2]. Slips were defined as a knee or hock touching the ground; falls were defined as a pig’s body touching the ground [6]. Slips and falls were tallied as a single measure. Stress signs were defined as open mouth breathing, muscle tremors, and red-blotchy skin [16]. Surface temperature was measured on 5 random pigs in group A and 5 random pigs in group B (total of 10 pigs/load) laterally near the midline. Surface temperature was measured with a dual laser infrared thermometer laterally near the midline (model 42570, Extech Instruments Nashua, NH 03063 US; accurate ± 1 °C).

2.3. Experiment 2: Effects of trailer bedding levels on market weight pig transport losses during warm weather

This experiment used 131 loads; 88 loads had 3 bags/trailer and 43 loads had 6 bags/trailer.
2.3.1. Transport losses at the plant

Processing facility employees identified dead (sum of euthanized- and dead on arrival) and non-ambulatory pigs (sum of fatigued and injured) [2]. Total transport losses, were defined as the summation of dead and non-ambulatory pigs.

2.4. Statistical analysis

For both experiments, data were evaluated for missing and erroneous values by using the filter feature in Excel (Microsoft Office 2010, Microsoft Redmond, WA, US). Using the means and sort procedures (SAS Institute Inc., Cary, North Carolina) data was checked for erroneous and potential outlier data points. Data that was identified as a potential outlier was checked against the original data. If correct it was simply highlighted in the excel data, if incorrect that value was substituted per the original data. A $P$ - value $\leq 0.05$ was considered significant for both experiments. A $P$ - value $\leq 0.10$ was considered trending for both experiments.

Each variable collected was evaluated on whether it should be present in the model. Variables that might have affected the response variable were attempted in the model. Those variables that were dictated by previous research to affect the response were retained for the final model as well as any other variables found to be significant during model development.

2.4.1. Experiment 1. Effects of trailer bedding levels on market weight pig measures and bedding moisture during warm weather

Because researchers sometimes counted more or less than, 50 pigs/group, data for vocalizations, slips and falls, and stress signs were analyzed as a percent of the pigs counted:

\[
\text{Percent pig measure} = \frac{\text{(number of times a measure was counted)}}{\text{(number pigs counted in that group)}} \times 100
\]

Furthermore, the SAS program (SAS 9.3, SAS Institute Inc., Cary, North Carolina) was used to create a new variable from the percent of vocalizations, slips and falls, and stress signs from group A and group B of 50 (eg [percent stress signs group A + percent stress signs group B]/2). Surface temperature was analyzed as an average of the 5 pigs measured/group (10 pigs measured/load).
Data were analyzed using a mixed model (PROC MIXED, SAS 9.3 SAS Institute Inc., Cary, North Carolina) where the response variables, surface temperature, vocalizations, slips and falls, and stress signs, were analyzed using bedding level as a fixed effect, THI at unloading and density as linear covariates, and farm as a random effect.

2.4.2. Experiment 2: Effects of trailer bedding levels on market weight pig transport losses during warm weather

Analysis of non-ambulatory-, dead-, and total transport losses per trailer was performed using a generalized mixed model (GLIMMIX procedure, SAS 9.3, SAS Institute Inc., Cary, North Carolina.). The data approximated a Poisson distribution and was log transformed by the GLIMMIX procedure (SAS 9.3, SAS Institute Inc., Cary, North Carolina) prior to statistical analysis. The model used bedding level as a fixed effect, THI at unloading and density as linear covariates, and farm as a random effect. The ILINK option (SAS 9.3, SAS Institute Inc., Cary, North Carolina) was used to back-transform least squares means into their original unit of measure for ease of interpretation.

3. Results and Discussion

3.1. Experiment 1: Effects of trailer bedding levels on market weight pig measures and bedding moisture during warm weather

3.1.7. Bedding

No differences were observed between 3- and 6 bags/trailer for surface temperature, vocalizations, or slips and falls ($P \geq 0.17$; Table 3.1). The TQA program defines appropriate bedding as straw, corn stover, wood shavings, or sand [7]. A temperature what is considered hot weather is not given. However, other sources [17-19] suggest straw bedding may be too warm when temperatures exceed 15.6 °C because it may insulate the trailer holding heat in. Bedding is used in trailers transporting market weight pigs to reduce slips and falls [20]. However, in the current study, slips and falls were collected after the pigs were off the trailer and away from the bedding source. Thus it cannot be concluded that more bedding did not aid in reducing the number of slips and falls experienced by the pig during transit or while still on the trailer during unloading. Studies collecting slips and falls during transit on the trailer should be conducted.
Pig vocalizations are a non-invasive measure and which may indicate the distress level in pigs [21,22]. Different frequencies and amplitudes mean very different things in terms of why the pig is vocalizing [23]. For example, Kiley [21] describes 13 different types of pig vocalizations being expressed by pigs of different ages within a variety of situations (e.g. social-greeting; non-social-startle etc). Studies have found that squeal type vocalizations are associated with unpleasant situations [21,22]. Therefore, it is vital to define what is meant by vocalization. However, there does seem to be an inherent understanding by persons not experienced with pigs when pigs expressed distressed vocalizations [24]. In the current study, only squeals were recorded.

**Table 3.1.** Experiment 1. Effects of bedding level on trailers and handling intensity for pig measures\(^1\) during unloading for market weight pigs\(^2\)

<table>
<thead>
<tr>
<th>Pig Measure</th>
<th>Bags of bedding(^4)</th>
<th>(P) - value</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 (n = 48)</td>
<td>6 (n = 32)</td>
<td></td>
</tr>
<tr>
<td>Surface temperature</td>
<td>32.9 ± 0.3</td>
<td>33.1 ± 0.3</td>
<td>0.58</td>
</tr>
<tr>
<td>Vocalizations, °c</td>
<td>1.8 ± 0.4</td>
<td>2.2 ± 0.5</td>
<td>0.50</td>
</tr>
<tr>
<td>Slips and falls, % of pigs counted</td>
<td>2.2 ± 0.8</td>
<td>3.0 ± 0.8</td>
<td>0.28</td>
</tr>
<tr>
<td>Stress signs, % of pigs counted</td>
<td>0.1 ± 0.3</td>
<td>1.6 ± 0.4</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

\(^1\) Pig measures were surface temperature (ST), vocalizations, slips and falls, and stress signs. ST was measure on 10 pigs/load with a dual laser infrared thermometer laterally midline. Vocalizations, slips and falls, and stress signs were tallied for 100 pigs/load.

\(^2\) Based on 79 trailer loads of market weight pigs.

\(^3\) 0.2 m\(^2\) bags of wood shavings.

\(^4\) Handling intensity ranged from 1 (very good handling) to 5 (very poor handling).

Stress signs observed on the pigs at the time of unloading were 1.5 % higher when 6 bags/trailer were used instead of 3 bags/trailer during transit \((P < 0.01; \text{Table 3.1})\). It is interesting that TQA notes that bedding is provided in the trailer for insulation [7]. Therefore, it follows that increased bedding in warm weather, may have insulated pigs trapping their body heat in the trailer causing increased heat stress, and thereby increasing stress signs.

### 3.1.1. Transport Events

The mean loading and unloading times for the current study is similar to previous studies 38 min [16], 45 min [25] and 18 min [16] respectively (Table 3.2). The mean
transport time in the current study (138 min) was more than double compared to previously reported studies at 59 min \cite{16} and at 107.1 min \cite{26}. A possible explanation for this increased transport time in this study was the distance between the farms and the plant. The shortest distance from farm to plant in the current study was 23.2 km, the furthest was 284.9 km, and the average was 189.4 km. Gesing noted the finishing sites used in their study were only 85 km or ~1-h from the plant \cite{16}. The wait time observed in the current study (20 min) was longer than that reported in Gesing’s 2011 study (9 min) \cite{16}. However, Pilcher reported mean wait time of 21 min \cite{26} and Gesing in 2010 reported a mean wait time of 22 min \cite{27}. Wait time can be affected by a variety of factors such as time of arrival and labor availability at the plant.

**Table 3.2.** Experiment 1. Descriptive statistics for transport events\(^1\) for market weight pigs\(^2\)

<table>
<thead>
<tr>
<th>Event, min</th>
<th>Mean</th>
<th>SD(^3)</th>
<th>Min(^4)</th>
<th>Max(^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading</td>
<td>35</td>
<td>12</td>
<td>15</td>
<td>84</td>
</tr>
<tr>
<td>Transport</td>
<td>158</td>
<td>40</td>
<td>32</td>
<td>222</td>
</tr>
<tr>
<td>Wait time</td>
<td>20</td>
<td>13</td>
<td>2</td>
<td>66</td>
</tr>
<tr>
<td>Unloading</td>
<td>16</td>
<td>5</td>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>Total Time</td>
<td>228</td>
<td>44</td>
<td>77</td>
<td>298</td>
</tr>
</tbody>
</table>

\(^1\)Transport events were loading, transport, wait time, unloading, and total time. Loading was the time from when the first pig stepped on to the trailer until the last pig stepped onto the trailer. Transport was as the time from when the last compartment on the trailer was closed until the truck arrived at the plant. Wait time was defined as the time from when the truck arrived at the plant until the first pig stepped off. Unloading was as the time from the first pig stepped off the trailer until the last pig stepped off the trailer the trailer. Total time is the time from when the first pig steps onto the trailer until the last pig steps off the trailer.

\(^2\) Based on 77 trailers of pigs.

\(^3\) SD abbreviation for standard deviation.

\(^4\) Min abbreviation for minimum.

\(^5\) Max abbreviation for maximum.

Transportation event times will need to be carefully monitored by trucking companies, processing facilities, and the truckers due to changes made by the U.S. Department of Transportation (DOT). As of July 1\(^{st}\), 2013, the DOT hours-of-service
safety regulation states that after 8 h of driving the trucker must take a 30 min break away from the truck [28]. For transportation of non-animal related goods this will likely not be a challenge. However, if live animals are being transported several challenges to their well-being are recognized including a build-up of heat and humidity in the warm months [29].

3.1.3. Bedding moisture

Fresh bedding (0 loads) had ~9% moisture, which increased 7-fold once pigs had been transported once. Six bags/trailer resulted in 14% less moisture than 3 bags/trailer after one load had been transported. However, as number of loads increased, more bedding did not provide additional moisture absorption (Table 3.3).

Table 3.3. Experiment 1. Descriptive statistics for bedding moisture (%) between 3 and 6 bags of bedding/trailer transporting market weight pigs in warm weather

<table>
<thead>
<tr>
<th>Bedding levels (bags / trailer)</th>
<th>3</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Loads 0</td>
<td>8.5</td>
<td>2.1</td>
</tr>
<tr>
<td>1</td>
<td>69.1</td>
<td>8.1</td>
</tr>
<tr>
<td>2</td>
<td>71.0</td>
<td>6.9</td>
</tr>
<tr>
<td>3</td>
<td>69.1</td>
<td>3.3</td>
</tr>
<tr>
<td>≥4</td>
<td>70.0</td>
<td>9.9</td>
</tr>
</tbody>
</table>

1 There were 77 bedding samples taken from trailers with 3 bags/trailer: 0 loads, n = 13; 1 load, n = 20; 2 loads, n = 15; 3 loads, n = 9, and ≥ 4, n = 20. There were 41 samples taken from trailers with 6 bags/trailer: 0 loads, n = 6; 1 load, n = 8; 2 loads, n = 12; 3 loads, n = 5; ≥ 4 loads, n = 10.
2 ~0.2m³ bags of wood shavings/trailer.
3 SD abbreviation for standard deviation.
4 Min abbreviation for minimum.
5 Max abbreviation for maximum.
6 Zero loads indicate samples were bedding not previously used being placed onto the clean trailer floor prior to loading. One load or more indicates those samples which have been on the trailer when pigs were transported from farm to plant.
Lack of increasing moisture with subsequent loads suggests that only fresh bedding is effective at absorbing pig waste. This study only observed trailers using wood shavings. Wood shavings are less absorbent than straw or corn stover (1.15 vs. 1.97 vs. 2.70 mean absorbency factor, respectively) [30]. However, straw and corn stover compared to wood shavings during warm weather may provide more insulation [7,31]. This may result in the internal trailer temperature increasing from heat trapped inside the trailer which may result in increased transport losses. This data supports the TQA guidelines, suggesting trailers should be washed out and fresh bedding applied after every load [7] because used and/or saturated bedding may result in some challenges for the pig. Saturated bedding in the trailer could increase relative humidity inside the trailer, which may cause additional heat stress in warmer months. Wet bedding may cause pigs to slip or fall more during transport that could in turn increase bruising and injury. Sutherland and others found that trailers with wet bedding had a greater number of pigs injured on the trailer than those with dry bedding [32]. Third, although bacterial load in the bedding does not directly threaten the pigs being transported, bedding could fall out of the trailer as it passes other farms, raising a potential biosecurity concern [33]. Finally, fear pheromones released in pig urine may increase stress for the pigs currently being loaded and transported [34-36].

Currently, individual company protocols vary in the frequency of complete trailer washout, and application of fresh bedding. These guidelines reflect numerous considerations based on cost, effects to the environment, and animal well-being. For example, trailer wash out trailers costs $15 to $190 [37]. Annually, washing out trailers between each load and re-bedding the trailer could cost between ~$8 – and $108 million annually [38]. However, this estimate does not include potential lost income to the driver while washing the trailer or environmental implications for water usage and bedding disposal. A cost benefit analysis for using fresh bedding after every load, in relation to overall swine well-being improvements is suggested.

3.1.4. Temperature humidity index at unloading

It was observed that as THI decreased from ~20 to 15 slips and falls at the time of unloading tended to increase ~22 % ($P = 0.09; R^2 = 0.13; $ data not presented). One possible explanation for this is that pigs are more active when THI is closer to their thermo-neutral zone and therefore move off the trailer more quickly thus creating the potential for more slips and falls.

As THI increased from ~13 to 23 surface temperature increased ~14 °C ($P < 0.01; $ figure 3.1). As THI increased from ~19 to 24 vocalizations increased ~18 % and stress
signs increased ~13 % (*P* < 0.01 and *P* = 0.04, respectively; Figure 3.2). The relationship between THI and surface temperature was moderate (*R*² = 0.47). The relationship between THI- and vocalizations and stress signs was weak (*R*² = 0.10 and *R*² = 0.20, respectively). A pig’s thermo-neutral zone ranges from 10 to 21 °C [39] and their normal core temperature ranges from ~39 to 40 °C [40]. Although surface temperature has been shown to be reflective of core temperature [41] it is slower to reflect changes in core temperature than rectal measurement [42]. When pigs become heat stressed they will pant and increase blood flow to skin and limbs [42,43]. Increasing blood flow to the skin can cause discolored skin. It follows that this could also cause increased skin temperature. Although surface temperature ranges seen in this study are not reflective of heat stressed pigs this may simply mean that their physiological mechanisms for coping with heat were acting effectively.

**Figure 3.1.** Experiment 1. Effects of temperature humidity index (THI) at unloading on surface temperature of pigs at unloading (*P* < 0.01; *R*² = 0.47)
Figure 3.2. Experiment 1. Effects of temperature humidity index (THI) at unloading on vocalizations (◆) and stress signs (■) at unloading including linear trend lines (respectively; \( P < 0.01, R^2 = 0.10; P = 0.04, R^2 = 0.20 \)).

3.1.5. Density

In the current experiment, there was no observed density effects on pig surface temperature, vocalizations, or slips and falls \((P = 0.31, R^2 = 0.47; P = 0.19, R^2 = 0.10;\) and \( P = 0.55, R^2 = 0.13 \) data not presented). Direct comparisons for changes in pig surface temperature based on density have not been published. Ritter and others found that density did not affect rectal temperature between 0.39 and 0.49 m\(^2\)/pig (~333 - and 265 kg/m\(^2\) respectively) [11] and Chung and others [41] noted that as rectal temperature increased surface temperature increased in a linear manner.

However, as density increased in the current work from ~295 to 305 kg/m\(^2\) stress signs increased ~13 % \((P = 0.03, \text{Figure 3.3})\). Pigs in the current study study were transported at an average density of 296 m\(^2\)/pig, but the density equation used factored in weight- and number of pigs on the trailer and was presented as a continuous variable. This may be why the stress results in the current work disagree with Ritter and others [9] who reported that pigs transported at 0.52 m\(^2\)/pig (~252 kg/m\(^2\)) had a higher incidence of skin discoloration than pigs transported at 0.39-, 0.42-, or 0.46 m\(^2\)/pig (~336-, 312-, and 285 kg/m\(^2\) respectively). This raises an interesting statistical discussion in regards to fixed effects and covariates, the use of both density and THI equations and in turn results, making comparison of these data sets challenging. Fixed effects allow comparison of discrete categories, but, unlike continuous effects, it is not possible to determine what is
happening in the space between categories. Even with more or heavier pigs on the trailer, slips and falls may not increase if pigs are not rushed off the trailer and the floor is dry [20].

Figure 3.3. Experiment 1. Effects of density on stress signs \((P = 0.03; R^2 = 0.20)\).

3.2. Experiment 2: Effects of trailer bedding levels on market weight pig transport losses during warm weather

3.2.3. Bedding

No differences were observed between bedding levels for non-ambulatory, dead, or total transport losses \((P \geq 0.10; \text{ Table 3.4)}\). The current study observed ~0.05 non-ambulatory pigs/load. Although non-ambulatory pigs are not tracked by the Food Safety and Inspection Service, Ritter and colleagues [11] used 23 previous studies and estimated that in 2006 non-ambulatory pigs occurred at a rate of 0.44 \% (~0.74 pigs/trailer). This study observed ~0.13 dead pigs/load. In 2011 in the U.S. ~0.26 dead pigs/load were observed [38]. Fitzgerald [9] found transport losses during summer were mainly as a result of dead pigs, which is reflected in the current study’s results (Table 3.4). Kephart and others [38] determined that each dead pig costs the industry $178, and in 2011, nationally, dead pigs cost the industry ~$29 million. As there are no recent numbers on
the number of non-ambulatory pigs it is not possible to calculate the total cost of non-
ambulatory pigs in 2011. In the current study using wood shavings at 3- or 6 bags/trailer
pig well-being was not determinedly affected. The current TQA program recommends 2
bags of bedding when temperature $> 4.4 \, ^\circ\text{C}$. The current study chose to compare 3- and 6
bags/trailer because it was determined that 3 bags/trailer barely covers the trailer floor.
However, future work should compare 1, 2 and 3 bags/trailer over the warm months to
decide if less bedding still offers acceptable well-being for the pigs during transit.

Table 3.4. Experiment 1. Effects of bedding level on trailers transporting market weight
pigs on transport losses$^1$.

<table>
<thead>
<tr>
<th>Bags of Bedding$^2$</th>
<th>Transport losses, pigs per trailer</th>
<th>3</th>
<th>6</th>
<th>$P$ - value</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 88</td>
<td>0.02 ± 0.02</td>
<td>0.09 ± 0.05</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>NA</td>
<td>Dead</td>
<td>0.11 ± 0.04</td>
<td>0.13 ± 0.06</td>
<td>0.67</td>
<td>0.07</td>
</tr>
<tr>
<td>Dead</td>
<td>TTL</td>
<td>0.14 ± 0.04</td>
<td>0.22 ± 0.07</td>
<td>0.24</td>
<td>0.08</td>
</tr>
</tbody>
</table>

$^1$ Pig measures were surface temperature, vocalizations, slips and falls, and stress signs. Surface temperature was measure on 10 pigs/load with a dual laser infrared thermometer laterally midline. Vocalizations, slips and falls, and stress signs were tallied for 100 pigs/load.

$^2$ Based on 131 trailer loads of market weight pigs.

$^3$ 0.2 m$^2$ bags of wood shavings.

3.2.1. Temperature humidity index at loading and density

No effects were observed for THI at loading and of the number of non-ambulatory recorded at the plant ($P = 0.51$, $R^2 = 0.03$; data not presented). However, it was observed that as THI at loading increased from ~19 to 24, dead and total transport losses increased by 3 pigs/trailer ($P = 0.01$, Figure 3.4 and 3.5, respectively).
In addition, there were no effects of density on non-ambulatory, dead, or total transport losses ($P = 0.51, R^2 = 0.03; P = 0.66, R^2 = 0.07; P = 0.68, R^2 = 0.08; $data not presented). The current study reviewed 131 loads and recorded transport losses at 0.05 non-ambulatory-, 0.17 dead-, and 0.21 total transport losses. These values are very low. This may explain why the results differ from Fitzgerald and colleagues [9] reviewed 12,333 loads and observed 0.99 non-ambulatory-, 0.42 dead-, and 1.41 total transport losses pigs/trailer. It was reported that increased total transport losses as both THI and density
increased. It is difficult to compare the results found in the current study with other studies because other studies use temperature and relative humidity separately rather than in as an index [12, 21, 32, 44].

3.2.4. Economical costs of bedding

Using 3- instead of 6 bags in warm weather (defined as temperature ranging 16.1 °C to 43.4 °C) has been estimated to save $13 million [38]. Transport Quality Assurance program, published by the National Pork Board, states that “....[the] trailer should be washed, disinfected, and completely dried after being unloaded...[and] weather appropriate bedding [should be added]” [7]. Adding the cost of washout, Kephart and others [38] found that using 3 bags/trailer and washing out after every load would cost between ~$22- and $121 million annually.

4. Conclusions

Stressors during transportation have been shown to be additive. Therefore, reducing or preventing stressors may improve pig well-being [9,27,19]. A variety of factors may influence animal based measures indicative of well-being and transport losses in the market weight pigs. The current study did not observe detrimental effects between bedding level and animal based measures or transport losses. It was interesting to note, that regardless of the bedding level, bedding moisture was not adversely affected. The authors recommend future pig transport studies to use both THI and density in the statistical model as both had effects on animal based- and transport loss measures. It is extremely important to note that the inference space of this study is relatively small (in July in Iowa), so further studies should be conducted to see if this may be applicable to other geographic regions and seasons.

Acknowledgments

Thank you to the farms and plant that participated and to the National Pork Boards Pork’s Checkoff program for funding. Thank you to Dr. Art Coquelin, Joel Cowart, Brittany Davis, Holland Doughtry, Alex Folkman, Dr. Monique Pairis-Garcia, Megan Place, Garrett Thompson, and Derek Thomison for data collection. Thank you to Dr. Robert Fitzgerald and Dr. Caitlyn Abell for their assistance in developing the statistical model. Thank you to Dr. Nicholas Gabler for use of his lab facilities and to Martha Jeffery for her assistance in using the equipment.
Conflicts of interest

The authors declare no conflict of interest.

References and Notes


CHAPTER 4: ESTABLISHING SPRINKLING REQUIREMENTS ON TRAILERS TRANSPORTING MARKET WEIGHT PIGS IN WARM WEATHER

A paper to be submitted to Animals.

Rebecca K. Kephart\textsuperscript{1,2}, Anna Johnson\textsuperscript{1,*}, Avi Sapkota\textsuperscript{3}, Kenneth Stalder\textsuperscript{1}, and John McGlone\textsuperscript{3}

\textsuperscript{1} Graduate student, associate professor, and statistician, respectively. Iowa State University, Ames, IA 50011; E-Mails: r.kephart8@gmail.com (R.K.K.); johnsona@iastate.edu (A.J.); stalder@iastate.edu (K.S.)

\textsuperscript{2} Primary researcher and author.

\textsuperscript{3} Professor and graduate student, respectively. Texas Tech University, Lubbock TX 79409; E-Mails: asapkota@purdue.edu (A.S.); john.mcglone@ttu.edu (J.M.)

*Author to whom correspondence should be addressed; E-Mail: johnsona@iastate.edu (A.J.);
Tel.: +1-515-294-2098; Fax: +1-515-294-4471.

\underline{Simple Summary}: Transport is an inevitable process in the modern, multi-site swine industry. Pigs do not have efficient physiological means (such as sweating) to cool themselves, therefore, being transported in hot weather can cause heat stress and even death. Sprinkling the pigs and/or bedding may facilitate cooling, thereby improving animal well-being and improve survivability of pigs arriving at the plant.

\underline{Abstract}: This study was conducted in July of 2012 in Iowa, in WARM\textsuperscript{\textless} 26.7 \textdegree C) and HOT (\textgeq 26.7 \textdegree C) weather. Four sprinkling methods were compared, with one treatment being randomly assigned to each load: Control (not applied in HOT weather), pigs only, bedding only, or pigs and bedding. Experiment 1 used 51 loads in WARM- and 86 loads in HOT weather to determine the effects of sprinkling method on pig measures (surface temperature, vocalizations, slips and falls, and stress signs). Experiment 2 used 82 loads in WARM- and 54 loads in HOT weather to determine the effects of sprinkling on transport losses (non-ambulatory, dead, and total transport losses). Experiment 1 found that, in WARM weather, there were no differences between sprinkling treatments for surface temperature, vocalizations, or slips and falls (\textit{P} \geq 0.18). However, stress signs were 2 \% greater for the pigs and bedding- than for the control treatment (\textit{P} = 0.03).

Experiment 2 found, that in WARM and HOT weather, sprinkling did not affect non-ambulatory, dead, or total transport losses (\textit{P} \geq 0.18). Therefore, it is only necessary to
sprinkle the pigs when transporting market weight pigs during WARM and HOT weather in the Midwestern U.S.

**Keywords:** market-weight pig; sprinkling; transport loss; well-being

---

1. **Introduction**

Transporting swine is essential to the multi-site pork production. Around 113 million pigs were marketed in 2012 in the U.S. [1]. For pigs, marketing is a combination of potentially novel (defined as the first exposure), unfamiliar (defined as more than one exposure that is infrequent), and physically exerting experiences that could be perceived as stressful [2]. The term “transport losses” refers to pigs that become non-ambulatory (pigs that are unable to keep up with the group and may have a structural injury) or are dead on arrival [2]. Increased transport losses and decreased meat quality may result if the pig is unable cope with these stressors [3-5].

The conditions under which pigs are handled and transported can have a direct impact on the pigs’ well-being. In the U.S., trailers rely on passive ventilation, meaning air flow is dependent upon thermal buoyancy, movement of the vehicle itself, and by wind speed. To control the internal trailer environment, the National Pork Board’s Transport Quality Assurance (TQA) program recommends that pigs (> 27 °C) and bedding (> 15 °C) are sprinkled to facilitate evaporative cooling with the intention of reducing heat stress [6]. However, these recommendations are based on experiential information rather than scientific data [6]. Therefore, the objectives of these experiments were to compare the effects of 4 sprinkling methods used on trailers transporting market weight pigs on (1) pig measures at the time of unloading and (2) transport losses at the plant.

2. **Experimental Section**

2.1. **General procedures for both experiments**

2.1.1. **Treatments and experimental design**

Many trailers are equipped with internal sprinkling systems. However, these systems are installed by the owner of the trailer, and are not consistent with pressure, droplet size, or flow rate. Due to concern in regards to potential variation, all treatments
were applied by the researcher. These experiments consisted of 4 treatments. The first treatment (control) was defined as not sprinkling pigs or bedding on the trailer where the bedding was dry before the start of loading. The second treatment (pigs only) was defined as pigs being sprinkled after loading was completed for 6 to 8 min where the bedding on the trailer was dry before the start of loading. The third treatment (bedding only) was defined as bedding being damp or being sprinkled 4 to 6 min before the start of loading. The fourth treatment (pigs and bedding) was defined as both pigs and bedding being sprinkled as previously described. Due to concerns about pig well-being, the control treatment was not applied when the temperature was \( \geq 26.7 \) °C. Therefore, two data sets will be presented: WARM (temperature < 26.7 °C; all 4 treatments) and HOT (\( \geq 26.7 \) °C; 3 treatments) Researchers randomly assigned sprinkling treatments to trailer. This data was collected during 3 wk in July 2012.

2.1.2. Animals, farms, and handling.

The protocol for these experiments was approved by the Iowa State University Institutional Animal Care and Use Committee. The company’s loading crew sorted and moved market weight barrows and gilts from their home pen to the entrance of the loading ramp. The trucker moved the pigs up the loading ramp and onto the trailer. Both the loading crew and the trucker used a combination of sort boards, rattle paddles, and electric prods during loading (the number of times these devices were used was not recorded for these experiments).

Following TQA recommendations, any pig that became hot or stressed during loading was not loaded onto the truck and therefore was not included in these experiments (these were not recorded for these experiments). The pigs were transported from commercial finishing facilities to a commercial processing plant, all located in Iowa. Transport occurred throughout the day and night. The trucker unloaded the pigs off the trailer and plant personnel moved the pigs from the bottom of the loading ramp to the rest pens. During unloading, plant personnel and the trucker used paddles, rattles, and boards.

2.1.3. Transport trailers and density

All pigs were transported on aluminum drop deck (pot belly) trailers \( \sim 17 \) m in length with diamond plate flooring. These were owned and operated by drivers employed by trucking companies contracted through the plant. All compartments in the trailer were
stocked according to the industry’s current standard operating procedure of 0.41 m²/pig or ~171 pigs/load [6].

The plant provided data on the number of pigs/trailer and the average weight of pigs on a trailer. For these experiments a density value was calculated and added to the statistical model because previous work has found density is an important variable in affecting animal based measures and transport losses [7-9].

\[
\text{Density} = \frac{\text{(average pig weight per trailer) \times (pigs per trailer)}}{\text{(m}^2\text{ floor space in trailer)}}.
\]

2.1.4. Temperature humidity index.

Ambient relative humidity and air temperature were measured at an airport 16.9 km from the plant. The airport data logger (1088 hygrothermometer, technical service laboratory, Fort Walton Beach, FL 32548) collected temperature and dew point. Relative humidity was then calculated from dew point and temperature measurements. The airport data logger was accurate for ambient temperature and for dew point ± 0.003 °C. Ambient temperature (T) and relative humidity (RH) were used to calculate a temperature humidity index (THI) using the following equation [10]:

\[
\text{THI} = T - \frac{14.5}{T - 14.5} \times (0.55 - 0.0055 \times \text{RH}_{\text{decimal}})
\]

This equation was found to fit the model of pig transport by Fitzgerald and others [7]. Additionally, other evidence suggests that it is important to consider both temperature and humidity when determining heat stress in pigs [11-13].

2.2. Experiment 1: Effects of sprinkling inside trailers transporting market weight pigs during WARM and HOT weather on pig measures and bedding moisture at unloading

A total of 51 loads were used in WARM- and 86 loads were used in HOT weather. In WARM weather, the treatments were control (n = 24), pigs only (n = 13), bedding only (n = 7), and pigs and bedding (n = 7). In HOT weather, the treatments were pigs only (n = 41), bedding only (n = 18), and pigs and bedding (n = 27).

2.2.4. Pig measures

Pig measures were collected on a random sample of pigs at unloading using live observation. A random sample of pigs was defined as ignoring the first ~10 pigs at the
beginning of unloading, counting 50 pigs (group A), ignoring a further ~10 pigs, and counting another 50 pigs (group B). This provided 100 pigs/load. For groups A and B, the following pig measures were tallied: vocalizations, slips and falls, and stress signs. Vocalizations were defined as an extended sound of high amplitude and frequency produced with an open mouth [2]. Slips were defined as a knee or hock touching the ground; falls were defined as a pig’s body touching the ground [14]. Slips and falls were tallied as a single measure. Stress signs were defined as open mouth breathing, muscle tremors, and red-blotchy skin [15]. Surface temperature was measured laterally near the midline on 5 randomly selected pigs from groups A and B (total of 10 pigs/load). Surface temperature was measured with a dual laser infrared thermometer (model 42570, Extech Instruments Nashua, NH 03063 USA) which was accurate to ± 1°C.

2.2.2. Bedding moisture

A total of 8 fresh bedding samples and 140 used bedding samples were collected from trailers. Fresh samples (0 loads) were defined as bedding that had not been previously used for transporting pigs being placed in a clean trailer. A fresh bedding sample was ~45 g. After each trailer had unloaded at the plant, a used bedding sample, defined as bedding which had transported ≥ 1 trailer loads of pigs was collected. Half of the used bedding was collected from the bottom trailer deck and the remainder was collected from the top deck. Each used bedding sample was ~410 g. Bedding samples were stored at room temperature (~21 °C) for no longer than 1 wk after trial completion.

Bedding moisture was determined following standard operating procedure for drying samples. A tin measuring 7.6 cm wide by 2.2 cm deep (model A90, Wilkinson Industries Inc., Fort Calhoun, NE 68023 USA) was weighed. Each bedding sample was kneaded by hand inside the closed storage bag for ~30 s. Two, 3 to 6 g subsamples (subsample A and B) were removed from the bag using a spoon. Subsample A was placed in one tin and subsample B was placed in a second. The bedding subsample in its respective tin was weighed (accurate ± 0.03 mg; model AT261 DeltaRange, Metler-Toledo GmBh Laboratory & Weighing Technologies, Greifensee, Switzerland) to determine wet weight. Bedding subsamples were dried for ~20 to 24 h at 100 °C in a convection oven (model DKN810, Yamato Scientific America Inc., Santa Clara, CA 95050). After drying, subsamples were re-weighed; this was defined as the dry weight. Moisture percent for each subsample was calculated using the following equation [16]:

$$\text{Moisture percent} = \left[\frac{\text{dry weight}}{\text{wet weight}}\right] \times 100$$
A standard deviation of moisture percentage between subsample A and subsample B and an average of the moisture percent of subsample A and subsample B were calculated. Between subsample A and subsample B, the coefficient of variation (CV) was calculated using the following equation:

\[
CV = \left( \frac{\text{Standard deviation}}{\text{average}} \right) \times 100
\]

If the CV \( \geq 10 \) the sample was re-subsampled and dried a second time (n = 14). If the sample was still found to be too variable on the second drying, that samples were removed from the data set (n = 0). The data from bedding moisture will be presented descriptively separated by the number of loads on the bedding, ranging from 0 to \( \geq 4 \) loads.

2.2.3. Transport events

Researchers recorded the time that loading started and ended, the time the trailer left the farm, and the time that unloading started and ended. Processing plant records provided the arrival time of the trailer at the plant. Loading was defined as the time interval from the first pig’s front foot stepped onto the trailer until the last pig’s hind foot stepped onto the trailer. Wait time at the farm was defined as the time from when the last pig’s hind foot stepped onto the trailer until the trailer left the farm. Transport was defined as the time interval from when trailer left the farm until the trailer arrived at the plant. Wait time at the plant was defined as the time interval from when the trailer arrived at the plant until the first pig’s front foot stepped off the truck. Unloading was defined as the time interval from when the first pig’s front foot stepped off the truck until the last pig’s hind foot stepped off the truck. Total transit time was defined as the time from when the first pig’s front foot stepped onto the trailer (start of loading) until the last pig’s hind foot stepped off the trailer (end of unloading).

2.2.4. Bedding level.

The number of 0.2 m\(^3\) (22.7 kg) bags of wood shaving bedding/trailer were recorded. Because trailers rely on passive ventilation, in the winter bedding is believed to insulate pigs from extreme cold. In the summer, less bedding is included as a means of providing traction and absorbing waste. Bedding level was included as a covariate because of its potential impact on trailer micro-environment.
2.3. Experiment 2: Effects of sprinkling inside trailers on market weight pig transport losses during WARM and HOT weather

A total of 82 loads were used in WARM- and 54 loads were used HOT weather to determine if sprinkling effected transport losses. In WARM weather, the treatments were control (n = 48), pigs only (n = 11), bedding only (n = 15), and bedding and pigs (n = 8). In HOT weather, the treatments were pigs only (n = 31), bedding only (n = 9), and bedding and pigs (n = 14).

2.3.3. Transport losses at the plant

Plant employees identified non-ambulatory (sum of fatigued and injured) [2] and dead (sum of euthanized- and dead on arrival), Total transport losses were defined as the sum of non-ambulatory and dead.

2.4. Statistical analysis

For both experiments, Excel (Microsoft Office 2010, Microsoft Redmond, WA, U.S.) was used to check for empty cells and by using PROC SORT and PROC MEANS (SAS Institute Inc., Cary, NC, U.S.) to check for erroneous and potential outlier data points. Empty cells were either filled with data from the original data sheets or filled with a period to indicate the data was indeed missing. Data that was identified as a potential outlier was checked against the original data. If correct it was simply highlighted in the excel data, if incorrect that value was substituted per the original data. Because all 4 treatments were only present when the temperature was < 26.7 °C SAS was used to create 2 data sets from the single excel file data was originally entered (WARM and HOT data sets). \( P \leq 0.05 \) was considered significant for both experiments. \( P \leq 0.10 \) was considered tending for both experiments. For both experiments, each variable collected was evaluated on whether it should be present in the model. Variables that might have affected the pig measures were attempted in the model. Those variables that were found to be significant or were indicated by previous research to cause variation in pig transport were retained for the final model.

2.4.1. Experiment 1: Effects of sprinkling inside trailers transporting market weight pigs during WARM and HOT weather on pig measures and bedding moisture at unloading
Because researchers sometimes counted more, or less than 50 pigs/group, data for vocalizations, slips and falls, and stress signs were analyzed as a percent of the pigs counted:

\[
\text{Percent pig measure} = \left(\frac{\text{number of times a measure was counted}}{\text{number pigs counted in that group}}\right) \times 100
\]

Furthermore, the SAS program (SAS 9.3, SAS Institute Inc., Cary, North Carolina) was used to create a new variable from the percent of vocalizations, slips and falls, and stress signs from group A and group B of 50 (eg [percent stress signs group A + percent stress signs group B]/2). Surface temperature was analyzed as an average of the 10 pigs measured per load.

Data were analyzed using a mixed model (PROC MIXED, SAS 9.3 SAS, Institute Inc., Cary, North Carolina) where the response variables, surface temperature, vocalizations, slips and falls, and stress signs, were analyzed using sprinkling treatment and bedding level as fixed effects, THI at unloading and density as linear covariates, and farm, trucking company, and researcher at the plant as random effects.

2.4.2. Experiment 2: Effects of sprinkling inside trailers on market weight pig transport losses during WARM and HOT weather

Analysis of non-ambulatory-, dead-, and total transport losses per trailer was performed using a generalized linear mixed model (GLIMMIX procedure, SAS 9.3 Cary, NC.). The data approximated a Poisson distribution and was log transformed by the GLIMMIX procedure (SAS 9.3 Cary, NC) prior to statistical analysis. The model used sprinkling treatment as a fixed effect, THI at loading and density as linear covariates, and farm and trucking company as random effects. The ILINK option (SAS 9.3 Cary, NC) was used to back-transform least squares means into their original unit of measure for ease of interpretation.

3. Results and Discussion

3.1. Experiment 1: Effects of sprinkling inside trailers transporting market weight pigs during WARM and HOT weather on pig measures and bedding moisture at unloading
3.1.1. Sprinkling

In WARM weather, sprinkling treatment had no observed effect on surface temperature, vocalizations, or slips and falls \((P ≥ 0.18)\). However, stress signs were 2% greater for the bedding and pigs treatment than for the control treatment \((P = 0.03;\) Table 4.1). In HOT weather, sprinkling method had no effect on surface temperature, vocalizations, slips and falls, or stress signs \((P ≥ 0.19;\) Table 4.1).

Table 4.1. Experiment 1. Effects of sprinkling\(^1\) on pig measures\(^2\) in market weight pigs in WARM\(^3\) and HOT\(^4\) weather

<table>
<thead>
<tr>
<th>Sprinkling treatment</th>
<th>WARM weather, measure</th>
<th>Control (n = 24)</th>
<th>Pigs only (n = 13)</th>
<th>Bedding only (n = 7)</th>
<th>Bedding &amp; pigs (n = 7)</th>
<th>(P)-value</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface temperature, °C</td>
<td>32.2 ± 0.5</td>
<td>32.7 ± 0.4</td>
<td>33.1 ± 0.6</td>
<td>32.3 ± 0.6</td>
<td>0.18</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>Vocalizations, % of pigs counted</td>
<td>2.4 ± 1.8</td>
<td>2.6 ± 1.8</td>
<td>2.7 ± 1.9</td>
<td>3.4 ± 1.9</td>
<td>0.65</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Slips and falls, % of pigs counted</td>
<td>0.7 ± 0.2</td>
<td>0.5 ± 0.2</td>
<td>0.5 ± 0.3</td>
<td>0.2 ± 0.3</td>
<td>0.61</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Stress signs, % of pigs counted</td>
<td>0.6 ± 0.4(^a)</td>
<td>0.5 ± 0.4(^a,b)</td>
<td>1.5 ± 0.6(^a,b)</td>
<td>2.6 ± 0.6(^b)</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HOT weather</th>
<th>(n = 0)</th>
<th>(n = 41)</th>
<th>(n = 18)</th>
<th>(n = 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface temperature, °C</td>
<td>.</td>
<td>35.3 ± 0.3</td>
<td>34.8 ± 0.3</td>
<td>34.9 ± 0.3</td>
</tr>
<tr>
<td>Vocalizations, % of pigs counted</td>
<td>.</td>
<td>1.7 ± 1.2</td>
<td>1.7 ± 1.2</td>
<td>2.0 ± 1.2</td>
</tr>
<tr>
<td>Slips and falls, % of pigs counted</td>
<td>.</td>
<td>0.6 ± 0.4</td>
<td>0.9 ± 0.4</td>
<td>0.6 ± 0.4</td>
</tr>
<tr>
<td>Stress signs, % of pigs counted</td>
<td>.</td>
<td>7.2 ± 1.4</td>
<td>6.0 ± 1.6</td>
<td>5.7 ± 1.4</td>
</tr>
</tbody>
</table>

\(^1\) sprinkling methods, applied by researchers were: bedding only (bedding already being damp or being watered down by the researcher for 4-6 min before the start of loading), pigs only (pigs being watered after loading completed for 6 - 8 min when the bedding on the trailer was dry before loading started), pigs and bedding (both pigs and bedding being watered).
Pig vocalizations are a non-invasive measure and which may indicate the distress level in pigs [17,18]. Different frequencies and amplitudes mean very different things in terms of why the pig is vocalizing [19]. For example, Kiley [17] describes 13 different types of pig vocalizations being expressed by pigs of different ages within a variety of situations (e.g. social-greeting; non-social-startle etc). Studies have found that squeal type vocalizations are associated with unpleasant situations [17,18]. Therefore, it is vital to define what is meant by vocalization. However, there does seem to be an inherent understanding by persons not experienced with pigs when pigs expressed distressed vocalizations [20]. In the current study, only squeals were recorded.

Past research has correlated surface temperature to core temperature (such as that measured by rectal thermometry), but often surface temperature does not quickly reflect core temperature changes [21]. Past research found surface temperature for the market weight pigs ranged between 38.6 to 39.5 °C [22]. The current study observed surface temperature ranging 29.3 to 36.2 °C in WARM weather and 30.1 to 38.7 °C in HOT weather. A review by Fox [23] in Canada reported that sprinkled pigs had 10 % lower surface temperature than those pigs which were not sprinkled. Based on the surface temperatures seen in this study, it seems pigs in this study were not heat stressed to the point of changing core body temperature. This may indicate that the pigs’ physiological responses to heat were effective.

3.1.2. Bedding moisture

Fresh bedding averaged ~5 % moisture, which increased ~12 fold once a load of pigs had been transported. With 1 load, bedding only and bedding and pigs sprinkling treatments had ~5 % more moisture than pigs only or control treatments. However, when ≥ 2 loads had been transported, bedding moisture held constant at ~65 % regardless of sprinkling treatment (Table 4.3).
Table 4.3. Experiment 1. Bedding moisture\(^1\) by sprinkling method\(^2\) combined WARM\(^3\) and HOT\(^4\) weather

<table>
<thead>
<tr>
<th>Sprinkling treatment</th>
<th>Control</th>
<th>Bedding only</th>
<th>Pigs only</th>
<th>Bedding and pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>0</td>
<td>5.5</td>
<td>1.5</td>
<td>3.7</td>
<td>.</td>
</tr>
<tr>
<td>1</td>
<td>63.3</td>
<td>6.2</td>
<td>68.8</td>
<td>8.2</td>
</tr>
<tr>
<td>2</td>
<td>63.2</td>
<td>5.4</td>
<td>65.4</td>
<td>5.2</td>
</tr>
<tr>
<td>3</td>
<td>62.5</td>
<td>4.2</td>
<td>59.4</td>
<td>6.4</td>
</tr>
<tr>
<td>≥ 4</td>
<td>60.6</td>
<td>2</td>
<td>61.7</td>
<td>7.3</td>
</tr>
</tbody>
</table>

\(^1\) There were 27 samples collected from trailers given the control treatment: 0 loads, n = 2; 1 load, n = 14; 2 loads, n = 6; 3 loads, n = 2; and ≥ 4 loads, n = 3. There were 58 samples taken from trailers given the pigs only treatment: 0 loads, n = 1; 1 load, n = 26; 2 loads, n = 11; 3 loads, n = 11; and ≥ 4 loads, n = 6. There were 25 samples collected from trailers given the bedding only treatment: 0 loads, n = 1; 1 load, n = 6; 2 loads, n = 9; 3 loads, n = 5; and ≥ 4 loads, n = 4. There were 38 samples taken from trailers given the pigs and bedding treatment: 0 loads, n = 1; 1 load, n = 12; 2 loads, n = 10; 3 loads, n = 6; and ≥ 4 loads, n = 9. Bedding moisture was calculated by: [(dry bedding weight)/(wet bedding weight)] * 100.

\(^2\) Sprinkling treatments were defined as: control (no water on pigs, bedding dry), pigs only (bedding dry, pigs watered for 6 - 8 min), bedding only (bedding already wet or bedding watered for 4 – 6 min), and bedding and pigs (both pigs and bedding wetted as previously described).

\(^3\) WARM weather was defined as < 26.7 °C; based on 50 loads

\(^4\) HOT weather was defined as ≥ 26.7 °C; based on 92 loads

Lack of increasing moisture with subsequent loads suggests that only fresh bedding is effective at moisture absorbance. This study only observed trailers with wood shavings. Wood shavings are less absorbent than straw or corn stover (1.15 vs. 1.97 vs. 2.70 mean absorbency factor, respectively) [24]. However, straw and corn stover may not be appropriate bedding during warm and hot weather because of they may insulate the trailer holding heat in [6,25]. Data from this study supports the TQA guidelines, suggesting trailers should be washed out and fresh bedding applied after every load [6]. However, individual company protocols note the frequency of complete trailer washout and application of fresh bedding. However, minimal- and/or saturated bedding may result in challenges for the pig. Once bedding is saturated it cannot perform one of its essential functions: to absorb pig waste. Saturated bedding in the trailer could potentially increase
relative humidity inside the trailer, which may cause additional heat stress in the warmer months. Wet bedding may cause pigs to slip or fall more during transport that could in turn increase bruising and injury. Sutherland and colleagues [26] found that trailers with wet bedding had a greater number of pigs injured on the trailer than those with dry bedding. Another concern could be bacterial load in the bedding, which may not be an issue for the pigs being transported, but bedding could fall out of the trailer resulting in a potential biosecurity concern for other farms [27]. Finally, fear pheromones released in pig urine may increase stress for the pigs currently being loaded and transported [28-30]. Stress signs were not taken at the time of loading in this study but future work on number of loads transported with stress signs at loading maybe a useful consideration. There are several limitations to washing out trailers after each load and applying new bedding. Washing out trailers costs $15 to $190 [31]. Annually, washing out trailers between each load has been estimated to cost $8- to $108 million [32]. However, this estimate does not include potential lost income to the driver while washing the trailer or the environmental implications for the water usage and bedding disposal. A cost benefit analysis for using fresh bedding after every load, in relation to overall swine well-being improvements is suggested.

3.1.3. Transport events

The mean loading times in this study were similar (~30 min; Table 4.2) to previous studies by Gesing and others [15] and Brown and colleagues [33] at 38 min and 45 min respectively. Mean unloading time in the current study (~20 min) was also similar to Gesing and others [15] at 18 min. Transport time was about double (~162 min) for that reported by Gesing and others [15] at 59 min, but comparable to Pilcher and others [34] at 107 min. A possible explanation for this increased transport time in the current study was the distance between the farms and the plant (ranging from 74 to 296 km). The plant in the Gesing and others [15] study was 85 km or ~1 h from the farm. The wait time at the plant observed in this study was longer (~20 min) than that reported by Gesing and others (9 min [15]). However, Pilcher and colleagues [34] reported a mean wait time of 21 min and another study by Gesing and colleagues [35] reported 22 min. Wait time can be affected by a variety of factors such as whether the trailer arrived at the plant on schedule, labor availability, and the timing of other trailers’ arrival (Table 3). Because wait time at the farm is confounded with treatment it is difficult to compare to past studies. However, a wait of approximately 20 mins is still very acceptable for the U.S. swine industry and within the context of this study was not detrimental to the well-being of the pigs.
Transport event times will need to be carefully reviewed by trucking companies, processing facilities, and the truckers themselves due to changes made by the U.S. Department of Transportation (DOT). As of July 1st, 2013, the DOT hours-of-service safety regulation states that after 8 h of driving the trucker must take a 30 min break away from the truck [36]. For transportation of non-animate goods this will likely not be a challenge. However, if live animals are being transported, increased time when the trailer is stationary can result in an increased in both temperature and relative humidity [37].

Table 4.2. Experiment 1. Descriptive statistics for transport events\(^1\) for sprinkling method in market weight pigs\(^2\) for both WARM\(^3\) and HOT\(^4\) weather

<table>
<thead>
<tr>
<th>WARM weather; Event, min</th>
<th>Mean</th>
<th>SD(^5)</th>
<th>Min(^6)</th>
<th>Max(^7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading</td>
<td>32</td>
<td>12</td>
<td>14</td>
<td>65</td>
</tr>
<tr>
<td>Wait time at farm</td>
<td>7</td>
<td>6</td>
<td>2</td>
<td>42</td>
</tr>
<tr>
<td>Transport</td>
<td>156</td>
<td>43</td>
<td>63</td>
<td>280</td>
</tr>
<tr>
<td>Wait time at plant</td>
<td>15</td>
<td>13</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>Unloading</td>
<td>15</td>
<td>6</td>
<td>5</td>
<td>36</td>
</tr>
<tr>
<td>Total time</td>
<td>230</td>
<td>52</td>
<td>126</td>
<td>390</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HOT weather</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading</td>
<td>28</td>
<td>11</td>
<td>13</td>
<td>65</td>
</tr>
<tr>
<td>Wait time at farm</td>
<td>9</td>
<td>4</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Transport</td>
<td>168</td>
<td>41</td>
<td>48</td>
<td>255</td>
</tr>
<tr>
<td>Wait time at plant</td>
<td>24</td>
<td>15</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>Unloading</td>
<td>24</td>
<td>15</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>Total time</td>
<td>238</td>
<td>62</td>
<td>56</td>
<td>369</td>
</tr>
</tbody>
</table>

\(^1\)Transport events were loading (the time from when the first pig stepped on to the trailer until the last pig stepped onto the trailer), wait time at the farm (the time from when the last pig stepped onto the trailer until the trailer left the farm), transport (the time from when the trailer left the farm was closed until the truck arrived at the plant), wait time at the plant was defined as the time from when the truck arrived at the plant until the first pig stepped off), unloading (the time from the first pig stepped off the trailer until the last pig stepped off the trailer the trailer).

\(^3\) WARM weather was defined as < 26.7 °C; based on 50 loads

\(^4\) HOT weather was defined as ≥ 26.7 °C; based on 92 loads

\(^5\) SD abbreviation for standard deviation

\(^6\) Min abbreviation for minimum

\(^7\) Max abbreviation for maximum
3.1.4. Temperature humidity index

In WARM and HOT weather, with increasing THI at unloading pig surface temperature increased ($P < 0.01$; Figures 4.1 and 4.2). In WARM weather, as THI increased from ~17 to 19, surface temperature increased ~7 °C. In HOT weather, as THI increased from ~20 to 24, surface temperature increased ~9 °C.

**Figure 4.1.** Experiment 1. Effects of THI at unloading on surface temperature of market weight pigs at unloading in WARM weather (< 26.7 °C; $P < 0.01$, $R^2 = 0.41$)
Figure 4.2. Experiment 1. Effects of THI at unloading on surface temperature of market weight pigs at unloading in HOT weather (≥ 26.7 °C; \( P < 0.01, R^2 = 0.35 \))

In WARM weather, no THI effects were observed at unloading on vocalizations, slips and falls, or stress signs (\( P = 0.19, R^2 = 0.04; \ P = 0.15, R^2 = 0.10; \) and \( P = 0.44, R^2 = 0.03 \), respectively; data not presented). In HOT weather, there were no THI observed effects on vocalizations or slips and falls (\( P = 0.96, R^2 = 0.01; \ P = 0.40, R^2 = 0.05; \) data not presented).

However, it was observed in HOT weather that as THI increased from ~20 to 24, stress signs at unloading increased ~27 % (\( P < 0.01, \) Figure 4.3). Increased stress signs such as open mouth breathing and red blotchy skin could be explained by the pig’s natural heat coping mechanisms. Although surface temperature ranges seen in this study are not reflective of severely heat stressed pigs this may simply mean that their physiological mechanisms were acting effectively. It is difficult to speculate as to why an increase in THI would increase slips and falls. It may be that pigs are motivated to exit the trailer quicker and hence lose their footing more because of the heat in the trailer. However, this theory would need to be further evaluated in controlled heat and behavioral studies.
Figure 4.3. Experiment 1. Effects of THI at unloading on stress signs of market weight pigs at unloading in HOT weather ($\geq 26.7\, ^\circ C; P < 0.01, R^2 = 0.31$)

In WARM weather, no effects of density were observed on surface temperature, vocalizations, slips and falls, or stress signs ($P = 0.45, R^2 = 0.41$ and $P = 0.39, R^2 = 0.04$; $P = 0.15, R^2 = 0.10$; and $P = 0.98, R^2 = 0.03$, respectively; data not presented). In HOT weather, no effects of density were observed on surface temperature or vocalizations ($P = 0.74, R^2 = 0.37$; and $P = 0.36, R^2 = 0.01$, respectively; data not presented).

In HOT weather as density increased from ~275 to 300 kg/m$^2$ slips and falls tended to decrease ~5% ($P = 0.07, R^2 = 0.10$; data no presented) and stress signs tended to also decrease ~27% ($P = 0.07, R^2 = 0.03$; data no presented). Pigs in the current study were transported at an average density of 297- and 294 m$^2$/pig in WARM and HOT weather respectively, but the density equation used factored in weight and number of pigs on the trailer and was presented as a continuous variable. This may be why the stress results in the current work disagree with Ritter and others [9] who reported that pigs transported at 0.52 m$^2$/pig (~252 kg/m$^2$) had a higher incidence of skin discoloration than pigs transported at 0.39 -, 0.42 -, or 0.46 m$^2$/pig (~336 -, 312 -, and 285 kg/m$^2$ respectively). Direct comparisons for changes in pig surface temperature based on density have not been published. Ritter and others [38] reported that density on the trailer had no effect on rectal temperature between 0.39 and 0.49 m$^2$/pig (~333- and 265 kg/m$^2$).

3.1.5. Density.

In WARM weather, no effects of density were observed on surface temperature, vocalizations, slips and falls, or stress signs ($P = 0.45, R^2 = 0.41$ and $P = 0.39, R^2 = 0.04$; $P = 0.15, R^2 = 0.10$; and $P = 0.98, R^2 = 0.03$, respectively; data not presented). In HOT weather, no effects of density were observed on surface temperature or vocalizations ($P = 0.74, R^2 = 0.37$; and $P = 0.36, R^2 = 0.01$, respectively; data not presented).

In HOT weather as density increased from ~275 to 300 kg/m$^2$ slips and falls tended to decrease ~5% ($P = 0.07, R^2 = 0.10$; data no presented) and stress signs tended to also decrease ~27% ($P = 0.07, R^2 = 0.03$; data no presented). Pigs in the current study were transported at an average density of 297- and 294 m$^2$/pig in WARM and HOT weather respectively, but the density equation used factored in weight and number of pigs on the trailer and was presented as a continuous variable. This may be why the stress results in the current work disagree with Ritter and others [9] who reported that pigs transported at 0.52 m$^2$/pig (~252 kg/m$^2$) had a higher incidence of skin discoloration than pigs transported at 0.39 -, 0.42 -, or 0.46 m$^2$/pig (~336 -, 312 -, and 285 kg/m$^2$ respectively). Direct comparisons for changes in pig surface temperature based on density have not been published. Ritter and others [38] reported that density on the trailer had no effect on rectal temperature between 0.39 and 0.49 m$^2$/pig (~333- and 265 kg/m$^2$).
respectively). Chung and others noted as rectal temperature increased surface temperature increased in a linear manner [21]. This raises an interesting statistical discussion in regards to fixed effects and covariates, the use of both density and THI equations and in turn results, making comparison of these data sets challenging.

3.1.6. Bedding level.

In WARM weather, no effects of bedding were observed on surface temperature, vocalizations, slips and falls, or stress signs ($P \geq 0.12$; Table 4.5). In HOT weather, no effects of bedding were observed on vocalizations or slips and falls ($P \geq 0.28$; Table 4.4). However, in HOT weather, increasing bedding from 2 to 3 bags/trailer increased surface temperatures 0.6 °C and stress signs 2.5 % ($P \leq 0.05$; Table 4.4). This may indicate that in hot weather extra bedding may exacerbate heat stressed experienced by pigs on the trailer.

Table 4.4. Experiment 1. Effects of bedding level$^1$ on pig measures$^2$ in market weight pigs in WARM$^3$ and HOT$^4$ weather

<table>
<thead>
<tr>
<th>WARM weather; measures</th>
<th>Bedding level</th>
<th>$P$ - value</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>4</td>
<td>n = 41</td>
</tr>
<tr>
<td>Surface temperature, °C</td>
<td>32.3 ± 0.4</td>
<td>32.9 ± 0.6</td>
<td>0.12</td>
</tr>
<tr>
<td>Vocalizations, % of pigs counted</td>
<td>3.0 ± 1.7</td>
<td>2.6 ± 1.8</td>
<td>0.59</td>
</tr>
<tr>
<td>Slips and falls, % of pigs counted</td>
<td>0.5 ± 0.2</td>
<td>0.4 ± 0.3</td>
<td>0.72</td>
</tr>
<tr>
<td>Stress signs, % of pigs counted</td>
<td>1.1 ± 0.3</td>
<td>1.5 ± 0.5</td>
<td>0.42</td>
</tr>
<tr>
<td>HOT weather</td>
<td>n = 67</td>
<td>n = 19</td>
<td></td>
</tr>
<tr>
<td>Surface temperature, °C</td>
<td>34.7 ± 0.2</td>
<td>35.3 ± 0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>Vocalizations, % of pigs counted</td>
<td>1.9 ± 1.2</td>
<td>1.7 ± 1.2</td>
<td>0.56</td>
</tr>
<tr>
<td>Slips and falls, % of pigs counted</td>
<td>0.7 ± 0.4</td>
<td>0.6 ± 0.4</td>
<td>0.77</td>
</tr>
<tr>
<td>Stress signs, % of pigs counted</td>
<td>5.1 ± 1.3</td>
<td>7.6 ± 1.6</td>
<td>0.03</td>
</tr>
</tbody>
</table>

$^1$ Bedding level is the number of ~0.2m$^3$ (22.7 kg) bags of wood shavings / trailer

$^2$ Pig measures were: surface temperature (measured laterally near the midline with a dual laser infrared thermometer on 10 pigs/load), vocalizations (extended sounds of high amplitude and frequency produced with an open mouth [2]), slips and falls (a knee, hock, or body touching the ground [14]), and stress signs (open mouth breathing, muscle tremors, and red-blotchy skin [15]).

$^3$ WARM weather was defined as the temperature < 26.7 °C; based on 48 loads

$^4$ HOT weather was defined as the temperature ≥ 26.7 °C; based on 88 loads
3.2. Experiment 2: Effects of sprinkling inside trailers on market weight pig transport losses during WARM and HOT weather

3.2.1. Sprinkling

In WARM weather, the 1 non-ambulatory pig was from a trailer allocated the pigs and bedding sprinkling treatment. In WARM and HOT weather, no effect of sprinkling treatment was observed for non-ambulatory, dead, or total transport losses ($P \geq 0.18$; Table 4.5). It is important to note that total transport losses in the present study were $\sim 0.17$ pigs/trailer or $\sim 0.10\%$. Additionally, when comparing the total transport loses percentages from the present study with losses on a national level, the estimated national average for total losses was $0.69\%$ [38]. If a higher rate of losses were seen in this study there may have been bigger differences between the treatments allowing for significance.

Table 4.5. Experiment 2. Effects of sprinkling$^1$ on transport losses$^2$ in market weight pigs in WARM$^3$ and HOT$^4$ weather

| WARM weather; transport losses, pigs/trailer | Sprinkling Treatment | | | |
| --- | --- | --- | --- | --- | --- |
| | Control n = 48 | Pigs only n = 11 | Bedding only n = 15 | Pigs & bedding n = 8 | $P$ - value | $R^2$ |
| Non-ambulatory | . | . | . | . | . | . |
| Dead | $0.06 \pm 0.04$ | $0.13 \pm 0.11$ | $0.11 \pm 0.09$ | $0.00 \pm 0.00$ | 0.76 | 0.01 |
| Total transport losses | $0.06 \pm 0.04$ | $0.24 \pm 0.15$ | $0.13 \pm 0.10$ | $0.00 \pm 0.01$ | 0.33 | 0.03 |
Table 4.5 cont’d. Experiment 2. Effects of sprinkling\(^1\) on transport losses\(^2\) in market weight pigs in WARM\(^3\) and HOT\(^4\) weather

<table>
<thead>
<tr>
<th>HOT weather</th>
<th>Control n = 0</th>
<th>Pigs only n = 31</th>
<th>Bedding only n = 9</th>
<th>Pigs &amp; bedding n = 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-ambulatory</td>
<td>.</td>
<td>0.07 ± 0.04</td>
<td>0.00 ± 0.00</td>
<td>0.01 ± 0.02</td>
</tr>
<tr>
<td>Dead</td>
<td>.</td>
<td>0.37 ± 0.10</td>
<td>0.21 ± 0.14</td>
<td>0.16 ± 0.09</td>
</tr>
<tr>
<td>Total transport losses</td>
<td>.</td>
<td>0.45 ± 0.11</td>
<td>0.18 ± 0.12</td>
<td>0.19 ± 0.10</td>
</tr>
</tbody>
</table>

\(^1\) Sprinkling methods, applied by researchers were: Control (no water sprinkled and bedding dry; not applied in HOT weather), bedding only (bedding already being damp or wetted for 4 - 6 min before the start of loading), pigs only (pigs being wetted after loading completed for 6 - 8 min when the bedding was dry), pigs and bedding (both pigs and bedding being watered).

\(^2\) Transport losses were non-ambulatory (sum of fatigued and injured pigs), dead (sum of euthanized- and dead on arrival), and total transport losses (sum of non-ambulatory and dead).

\(^3\) WARM weather was defined as the temperature < 26.7 °C; based on 79 loads

\(^4\) HOT weather was defined as the temperature ≥ 26.7 °C; based on 49 loads

3.2.2. Temperature humidity index

In WARM weather, the 1 non-ambulatory pig occurred when THI was 18. In WARM weather, no THI at loading effects were observed were observed on dead or total transport losses (\(P = 0.94, R^2 = 0.01; P = 0.90, R^2 = 0.03; \) data not presented). In HOT weather, no THI effects were observed at loading on non-ambulatory, dead, or total transport losses (\(P = 0.66, R^2 = 0.32; P = 0.12, R^2 = 0.27; P = 0.19, R^2 = 0.35; \) data not presented). Pigs in the current study were only transported in the summer months. This may explain why the results differ from Fitzgerald and colleagues [7] who observed more pigs than the current study in all seasons. Fitzgerald and colleagues reported [7] that increased total transport losses as both THI and density increased. Additionally, they observed higher numbers of transport losses (1.41 total transport losses pigs/trailer) than were observed in the current study (in WARM 0.14 total transport losses pigs/load; in HOT weather 0.25 total transport losses pigs/load). It is difficult to compare the results
found in the current study with other studies because other studies use temperature and relative humidity separately rather than in as an index [8, 34, 38, 39].

3.2.3. Density

In WARM weather, the 1 non-ambulatory occurred on a trailer with a density of 291 kg/m². In WARM weather, no effects of density were observed on dead or total transport losses ($P = 0.86$, $R^2 = 0.01$; $P = 0.81$, $R^2 = 0.03$; data not presented). In HOT weather, no effects of density were observed on non-ambulatory ($P = 0.01$, $R^2 = 0.32$; Figure 4.4). In HOT weather, decreasing density from ~300 to 265 kg/m² increased dead pigs/trailer by 2 ($P = 0.01$; Figure 4.5). In HOT weather, decreasing density from ~300 to 240 kg/m² increased total transport losses by 4 pigs/trailer ($P < 0.01$; Figure 4.6). However the relationship between both dead and total transport losses and density was weak ($R^2 = 0.27$ and $R^2 = 0.35$, respectively). It is difficult to explain why dead and total transport losses increased with decreasing density. Pigs were transported at similar range of densities compared to previous studies [7,8,9].

The current study reviewed a relatively small number of loads compared to past studies [7,8] and also observed a lower rate of transport losses [7,8,9] than previous work. This may explain why the results in the current study disagree with these past studies. Pilcher and colleagues [34] found no effects of density on dead or total losses in pigs transported in November, December, May, and June. However, Pilcher and colleagues used density as a treatment and it was fixed rather than continuous. Fitzgerald and colleagues [7] predicted that total transport losses would increase constantly as density increased. Ritter and colleagues [8] found that increasing density increased non-ambulatory and total transport losses. Ritter and others [9] reported increasing density increased non-ambulatory and total transport losses.
Figure 4.4. Experiment 2. Effects of density on trailers on non-ambulatory pigs per trailer in market weight pigs at unloading in HOT weather ($\geq 26.7$ °C; $P = 0.01$, $R^2 = 0.32$)

Figure 4.5. Experiment 2. Effects of density on trailers on dead pigs per trailer in market weight pigs at unloading in HOT weather ($\geq 26.7$ °C; $P = 0.01$, $R^2 = 0.27$)
Figure 4.6. Experiment 2. Effects of density on trailers on total transport losses pigs per trailer in market weight pigs at unloading in HOT weather (≥ 26.7 °C; \( P < 0.01, R^2 = 0.36 \))

4. Conclusions

Stressors during transportation have been shown to be additive [7, 40, 41]. Therefore, reducing or preventing stressors may improve pig well-being. A variety of factors may influence animal based measures indicative of well-being and transport losses in the market weight pigs. Use of sprinklers in warm and hot weather should be considered. The current study did not find any observed effects for sprinkling on pig measures or transport losses. It was interesting to note, that regardless of the sprinkling method, bedding moisture was not adversely affected. The authors recommend future pig transport studies to calculate and use THI and density in the statistical because THI affected pig measures and density affected transport losses. It is extremely important to note that the inference space of this study is relatively small (in July in Iowa), so further studies should be conducted to see if this may be applicable to other geographic regions and seasons.

Acknowledgments

Thank you to the plant and farms that participated, to the National Pork Board’s Pork Checkoff program for funding, to Adrianne Kaiser, Dr. Avi Sapkota, David Smith, Jordann Wenzel, Dr. Kimberly Guay, and Rebecca Moest for data collection and to Dr. Nicholas Gabler for use of lab facilities and Martha Jeffery for assistance in the lab.
Conflicts of Interest

The authors declare no conflict of interest.

References and Notes


CHAPTER 5: GENERAL CONCLUSIONS

Pig well-being during transport and the rate of transport losses continue to be an important concern for the U.S. industry. The micro-environment in trailers transporting market weight pigs is an important factor for both pig well-being and transport losses. However, the current U.S. swine industry recommendations from TQA are based on experiential information rather than scientific data. The objective of Chapter 3 was to determine the effects of bedding on trailer transporting market weight pigs in the summer on pig measures and transport losses. This study observed no differences between 3- and 6 bags of wood shavings/trailer for either pig measures or transport losses. Based on these results, 3 bags of bedding/trailer could be used instead of 6 bags/trailer when transporting pigs in June and July in Iowa. Using less bedding could save both money and potentially decreasing the industry’s impact on the environment. The objective of Chapter 4 was to determine the effects of sprinkling method on trailers transporting market weight pigs in warm weather on pig measures and transport losses. In WARM weather (< 26.7 °C), stress signs increased both bedding and pigs were sprinkled prior to transport compared to control, bedding - and pigs only. However, in HOT weather (≥ 26.7 °C) stress signs did not differ between sprinkling treatments. Sprinkling method in WARM or HOT weather did not affect transport losses. The overall conclusion of this study was that the current industry practice of sprinkling only the pigs should be continued in July in Iowa. However, bedding should not be wetted.
ACKNOWLEDGEMENTS

I am truly blessed to be surrounded by such amazing people to support and usher me throughout my time as a master’s student. The nurturing supervision of Dr. Anna Johnson has taught me a great deal both scientifically and practically. Her unending patience, firm, but kind guidance, and support every step of the way has improved my critical thinking skills and attention to detail. I feel lucky to have had such a dedicated mentor.

Thank you to Dr. John McGlone, the co-primary investigator, he was always there to offer a different perspective along each step of my project.

Dr. Caitlyn Abell deserves a pile of thanks for helping with every small and big statistical problem. Her insight and knowledge of the subject helped me to understand things better than I would have ever thought. I am grateful to have had a great statistical mind in Dr. Kenneth Stalder who served on my committee. I would like to thank him in particular for the hours spent reviewing raw data and statistical models to help me understand all the steps needed to develop the proper model. Without him on my committee, I cannot imagine how it would have been completed the right way!

Thank you to Dr. Howard Tyler and Dr. Ted Huiatt for serving diligently on my committee, specifically for providing an outside view of the project. Anytime I got too bogged down in the details they were there with a bigger detail I had not thought about to get me back on track.

I would like to thank the farms and plant that participated in my study. It would not have been possible without their cooperation. Additionally, thanks are in order for the
truckers that put up with having their protocols changed for science. Thanks to Dr. Avi Sapkota for training my research assistants and myself as well as for answering my endless parade of questions about specifics in protocols. Thank you to all my research assistants Alex Folkman, Dr. Art Coquelin, Brittany Davis, David Smith, Derek Thomison, Garret Thomsen, Holland Doughtry, Joel Cowart, Jordann Wenzel, Dr. Kimberly Guay, Dr. Monique Pairis-Garcia, and Rebecca Moest for data collection. Special thanks go to Megan Place and Adrianne Kaiser, not only for their assistance in data collection, but their tireless hours in assisting with data entry and organization after each trial. Thank you to Dr. Nicholas Gabler for use of lab facilities and to Martha Jeffrey, the lab manager, for teaching me how to use the equipment and for answering all my questions.

The upbringing and constant concern for my wellness from my parents, Teresea Davis and Mike Henshaw, and Lowell Davis, has shaped me into the person I am today. More thanks than I could give go to my loving husband, Brian Kephart, for being supportive and putting up with me even when I was not pleasant. The knowledge and practicality of my committee members, my friends, and parents have helped shape me into the scientist I am today.