ABSTRACT

HODGES, RACHEL NICOLE. Evaluation of a Novel Feed Attractant and Ultra-High Radio-Frequency Identification Technology for Improving Weaned Pig Management (Under the direction of Drs. Suzanne Leonard and Eric van Heugten).

Weaning is a stressful phase of production for the pig, requiring intensive management as the pigs are transported and undergo many environmental and social changes. This thesis explores the use of a novel feed attractant and a commercially available radio frequency identification (RFID) system aiming to improve piglet outcomes and precision pig management.

Ensuring minimal weight loss during the weaning period is crucial to both the welfare of nursery pigs as well as their productivity. This study evaluated the effects of novel feed attractant application (Nextein APF®; TechMix Global, Stewart, MN) on weight gain and nursery feed consumption. In total, 171 nursery pigs were selected for use in a 3 day pre-weaning and 28 day post-weaning trial. In farrowing, a total of 16 litters were used, with litter as the experimental unit. In nursery, a total of 43 pens (42 pens of 4, 1 pen of 3) were used, with pen as the experimental unit. Treatments were arranged in a 3 × 2 factorial with main effects of: farrowing treatment (no spray, spray a feed attractant on sow underline, or spray with the same feed attractant on the side wall of the farrowing crate), nursery treatment (spray or no spray in the feed pan of the feeder), and a bodyweight block (High or Low). Spray treatments were applied from 3 days pre-weaning through 3 days post-weaning. No differences in average daily weight gain by litter were detected pre-wean. By 3 day post-wean, nursery spray treatments tended to gain more weight than the no nursery spray treatments ($P = 0.060$). However, from day 3 to 7 the no nursery spray group had a higher average daily gain than the nursery spray group ($P = 0.005$). There was no difference in average daily gain between nursery treatments from day 0 to 7 overall. No differences in average daily feed intake by treatment for any time periods were

detected, though there was a tendency for an interaction between nursery treatment and bodyweight block from day 1 to 2 (P = 0.074). Bodyweight block had the greatest influence on performance, with Low BW pigs demonstrating greater ADG (P = 0.005) and a trend of greater ADFI (P = 0.088) in day 0 to 3. After day 7, the High bodyweight block showed greater average daily gain and average daily feed intake. For day 0 to 6 in the nursery, RFID systems were installed in 24 pens within the feeder to determine feeder area interest. Metrics recorded included duration and frequency of feeder area visits per pig. In Low bodyweight group, pens receiving no nursery spray treatment had numerically lower cumulative durations and frequency of visits to the feeder area compared to groups receiving the nursery spray treatment. In High BW group, pens receiving the farrowing wall and nursery spray treatment had numerically lowest cumulative durations and frequency of visits to feeder area compared to other treatment combinations. By the end of the 28 d nursery period, no differences were detected in average daily gain or average daily feed intake due to farrowing or nursery treatment. In conclusion, using Nextein APF as a feed attractant in the nursery may increase BW gain in the first three days post-weaning, but cessation of application may create an olfactory or palatability change that disrupts BW gain.

At weaning pigs are moved, transported, and counted several times, making an accurate inventory crucial to production metrics and management. For this study, a commercially available ultra-high frequency radio-frequency identification (UHF-RFID) system was tested to determine performance in counting inventory of nursery pigs moving through a hallway. Through preliminary testing, a maximum system power of 25 was determined to be the best option for tag detection. Preliminary testing also yielded three reader positions to evaluate in field testing: Low, Mid-Perp, and Mid-Angle. For field testing, 39 nursery pigs were given an

RFID ear tag in the middle of the right ear. Pigs were uniquely marked with livestock paint and sorted into four groups based on BW. Three RFID readers were fastened on the side of the nursery hallway. For video identification purposes, a RBG camera was attached to the ceiling over each reader to record movement of the groups. Each group was walked past the RFID readers a total of 10 times, 5 passes on the left and 5 passes on the right for all three reader positions. It was determined that the most influential factor in tag detection accuracy was reader location within the room. At the Mid-Angle position, the middle reader had the highest proportion of detections (0.779, SD=0.194) and the right side movements had a greater detection compared to the left side. This suggests that readers should be placed a location that allows for free-flowing pig movements as well as placed on the same side the ear tag is on to result in the greatest detection proportions. The off-the-shelf RFID systems demonstrates potential to be used in swine counting applications with further improvements.

Evaluation of a Novel Feed Attractant and Ultra-High Radio-Frequency Identification Technology for Improving Weaned Pig Management

by
Rachel Nicole Hodges

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Animal Science and Nutrition

Raleigh, North Carolina
2023

APPROVED BY:

Dr. Suzanne Leonard
Committee Co-Chair

Dr. Eric van Heugten
Committee Co-Chair

Dr. Jack Odle

DEDICATION

I dedicate this thesis to my friends and family who supported me. Thank you.

BIOGRAPHY

Rachel Hodges was born and raised in Dunn, North Carolina by parents Johnny and Leasa Hodges. During her undergraduate degree at N.C. State, she began working as an undergraduate lab member in swine nutrition research. This is what solidified her love for swine research and interest in both improving swine nutrition as well as studying animal behavior. She obtained her B.S. in Nutritional Science from NC State in 2021 and immediately began her M.S. in Animal Science the following semester. Under the direction of Dr. Suzanne Leonard, she conducted research in the nursery, focusing both on feed attractants as well as RFID technology. Exposure to the world of precision technology during her Masters excited her for the possibilities of using such technology in collaboration with nutritional efforts to maximize production. Upon completion of her M.S, Rachel plans to use her knowledge of precision technology and nutrition to pursue a career in the North Carolina swine industry.

ACKNOWLEDGMENTS

I have many people to credit, as the support and guidance from my peers, friends, and family are what guided me through my degree. I would like to thank my committee members Dr. Leonard, Dr. van Heugten, and Dr. Odle for your support and guidance throughout the past two years. From help on papers to life advice, I received nothing but support from my committee and I am forever grateful for their patience and willingness to teach. I would also like to thank the staff of the SEU, Clay and Ivan, as well as all undergraduates working there. Thank you for the support and assistance you provided during my trials. To Austin at Tidewater, thank you for your willingness to stay later and help me during my trials. Without the employees at these research facilities, my work could not have been completed.

To the graduate students, so many of you have helped me and I am forever grateful for you. Whether it was helping on the farm or with data, so many of you are to credit for my accomplishments. Zack Peppmeier, Olivia Kittle, Tim Boston, Lauren Anderson, and Izadora Kuneff, thank you for the words of encouragement, help with coding and writing, and most importantly the support you provided me. I would also like to thank former graduate students, Madeline Newsome and Alyx Fisk who, although graduated and out of state, both answer every text and call to support and help me.

To my family and friends, I could not have done this without you. A special thanks to Miss Kitty, Fitzgerald, Mosely, Faye, and Doobie (and honorary mention Oswald) for the support. Lastly, I’d like to thank the pork stick that I ate during my last edits of my thesis as I probably could not have finished without it. Thank you Iowa Pork Producers Association.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: LITERATURE REVIEW

This review will address the swine weaning period, focusing on the weight loss and reduced feed intake that occurs during this period. Stressors that contribute to reduced feed intake and weight loss will be identified as well as methods of mitigating these issues. Furthermore, RFID technologies will be described and considered as a method of tracking feeder interest as well as serving as an automated counting system.

1.1 Post-Weaning Stressors and Importance

In United States commercial swine facilities, piglets are typically weaned between 19 and 22 d of age (Holman et al., 2021). The weaning period is arguably one of the most important periods in the life of a pig as it undergoes significant changes during this time that can induce stress (Ramirez et al., 2022). The weaning process consists of abrupt removal from the sow and direct placement into either a barn specifically for post-weaned pigs called the nursery or into a wean-finish facility where pigs will reside until reaching market weight. Average post-weaning mortality in the industry ranges from four to eight percent for the nursery stage (Gebhardt et al., 2020). These mortalities can be greatly contributed to the multiple stress factors that young pigs experience during the weaning period. Despite free access to feed, newly weaned pigs make very infrequent visits to the feeder, averaging one visit each day in the period shortly after weaning (Samuel, 2022). This is significantly fewer feeding events compared to the pre-weaned piglet, who nurses an average of 16 to 20 times each day (Samuel, 2022). Pigs can lose 100-250 g of bodyweight (BW) on the first day in the nursery alone, taking up to 4 d to regain this weight loss (Le Dividich and Sève, 2000). This short-term weight loss can have lasting impacts on productivity and weight gain throughout the rest of the production cycle (Campbell et al., 2013).

Studies show that weight gain within the first week of weaning impacts the total days to market weight (110 kg; Kats et al., 1992). It was found that when pigs gained more than 227 g d^{-1} during the first week post-weaning, the days to market weight were reduced by about 6-10 d compared to those gaining 0-150 g d^{-1} during this first week (Kats et al., 1992). This reduction in days to market has significant impacts on profits for producers, revealing the importance of minimizing weight loss during the post-weaning period caused by various stress factors. The primary stressors that contribute to decreased feeding activity observed post-weaning include transport stress, social stress, and nutritional stress.

1.1.1 Transport Stress

In commercial swine production systems pigs are transported at minimum two times throughout their life, with transportation events including at weaning, being moved from the nursery to a finishing barn, and to market or harvesting facilities (Lay et al., 2017). Transportation stress consists of multiple components which may contribute to negative health impacts (Garcia et al., 2016). Being a multifactorial stressor, some of these components include loading stress, mixing stress from being placed in a trailer with pigs from other pens, and stress from feed and water withdrawal (Lewis, 2008). The transportation process can be a long journey for the pigs, as the pre- and post-wean facilities are typically located on different sites. Although withdrawal from feed and water does not necessarily occur during every bout of travel, it is oftentimes not provided to livestock during transport (Lewis, 2008). This period of restricted access to food and water can have negative effects on the health of the pigs, even if for just a few hours. A study using behavior, performance, and physiology as markers for transportation stress found that weaned pigs transported with no access to feed or water lost more weight compared to weaned pigs with access to both feed and water (Garcia et al., 2016). More specifically, it was found that weaned pigs transported during a 32 h period with no water access lost more weight than those with water access (Garcia et al., 2016). These results highlight how significant food and water are to the growth and development of young pigs, and how detrimental limiting access to these resources can be. Regardless of access to feed and water during transportation, pigs weaned and immediately transported lost significantly more BW after 8 h of transportation compared to pigs that were not weaned and had access to both feed and water (Garcia et al., 2016). It is important to note that other factors such as mode of transportation as well as outside temperature may contribute to the transport stress experienced by weaned pigs (Garcia et al., 2016). Transportation is a process that, despite being a stressful event, is necessary in US swine production as most sites are single-phase production for enhanced biosecurity. Combating the negative effects of the transportation process is a step that can help piglets limit harsh health effects and recover from the losses during this period.

1.1.2 Social Stress

During the weaning process, the young pig experiences many different social changes that must be adjusted for, often resulting in some negative impacts. Social stress occurs when the piglet is removed from the sow and original litter and placed with new pen-mates (Hötzel et al., 2010). Removal from the maternal sow and original litter is a significant change in the pig's life, which oftentimes leads to decreased feeding behavior during the first 3 d post-weaning (Wensley et al., 2021). Immediate introduction to a new pen further leads to a stressful environment, as the hierarchy must be established among unfamiliar pigs. This hierarchy establishment consists of fighting to establish dominance, which greatly increases the physical activity performed by the pigs. This increase in physical activity can contribute to both decreased weight gain as well as dehydration during the first few days post-weaning. Furthermore, the hierarchy establishment can prevent pigs from accessing the feed easily as the pigs at the bottom of the hierarchy will oftentimes be pushed away from of the feeder. Feeding also induces social stress as during lactation all pigs are able to eat simultaneously but must now learn to take turns at the feeder.

1.1.3 Nutritional Stress

Nutritional stress is experienced due to the abrupt change from milk to a grain-based diet, which can lead to diarrhea and decreased feed intake (Holman et al., 2021). The sow's milk is an easily digestible energy source for the pre-weaned piglet, whereas the grain-based diet is more difficult to digest, leading to diarrhea and decreased feed intake at weaning (Campbell et al., 2013). Around the time of weaning, the digestive system as well as digestive enzyme production are rapidly developing within the young pig (Samuel, 2022). At 4 weeks of age, enzymes protease, maltase, amylase, and sucrase production begin to increase while lactase production decreases, helping the young pigs transition from a milk diet to a grain-based diet (Samuel, 2022). Furthermore, the commercial industry addresses the negative impacts of the diet change by incorporating feed ingredients that are highly digestible for the pig. Furthermore, a source of lactose is included in the solid diet, which is gradually decreased to aid in transitioning pigs from a soy-based diet to a grain-based diet. Despite the digestive changes happening to help the pig better adapt to the nursery setting as well as industry adjustments to the feed, young pigs still struggle during this period. Physical factors can also contribute to decreased feed intake during the weaning period, as the pig's premolars can emerge as late as 3 months of age, making solid feed consumption difficult at first in the nursery (Miller, 2011). It is suggested that social stressors as well as transport stressors may add to nutritional issues as these factors contribute to the decreased feeding behavior that is observed within the first few days post-weaning (Hötzel et al., 2010).

1.1.4 Conclusion

The weaning period is one of the most important times in the production cycle, as the young pig undergoes many changes simultaneously and must quickly adapt to flourish and survive. Weaning at roughly 19-22 d of age (Holman et al., 2021), the young pig must learn to adjust to the new environment. Despite undergoing physiological changes such as digestive enzymes changes which help weaned pigs adapt to the grain diet provided, feeding events are found to significantly decrease compared to nursing events when moved from farrowing to the nursery (Samuel, 2022). The transportation process has been shown to increase stress, which is exacerbated by the restriction of feed and water intake during the transportation process (Garcia et al., 2016). Furthermore, removal from the sow and litter and placement into a new group of pigs largely contributes to decreased feeding behaviors during the first 3 d post-weaning (Wensley et al., 2021). With a new hierarchy being established, aggression levels are higher during this time period, preventing lower BW pigs from eating as much as higher BW pigs. The social, transportation, and nutritional stressors endured by the young pig during the weaning process can be deadly if not recovered from in a timely manner. To mitigate these issues, methods of increasing feed intake during the post-weaning period should be considered.

1.2 Methods of Increasing Feed Intake

This section will discuss feed intake for swine, highlighting the importance of palatability and how to improve the palatability of the feed with feed additives. Feed additives not only benefit the health of the pig, but also increase feed intake through the use of feed attractants. One attractant in particular, Nextein APF®, shows potential to be used as an attractant for newly-weaned pigs to increase feed intake. This could combat weight loss often experienced post-weaning, which can have lasting impacts on production.

1.2.1 Importance of Feed Palatability

In swine production, proper nutrient intake is crucial for optimal growth and performance. The amount of feed consumed is largely dependent on the pig's voluntary feed intake, which can be influenced by olfaction and taste through the palatability of the feed (Jacela et al., 2010). Palatability refers to the preference an animal has for feed based on certain characteristics such as the smell, taste, and texture. Ensuring feed has a high palatability is especially important during the days post-weaning in which multiple stress factors contribute to decreased appetite (Jacela et al., 2010).

1.2.2 Feed Additives

Feed additives are one method of increasing the production of pigs, with some additives also encouraging feed intake. Feed additives are ingredients added to the diet that do not cause nutritional deficiencies when limited or restricted but rather serve as a supplement to potentially improve production (Richert, 2006). In the United States, feed additives are regulated by the Food and Drug Administration (FDA) and usage information is typically provided on the feed tag (Richert, 2006). There are various types of feed additives available to maximize productivity and improve the health of the pig. These additives include antibiotics, anthelmintics, probiotics, prebiotics, flavors, and enzymes, among others (Sundman et al., 2022). To ensure feed has high palatability, feed additives called attractants can be incorporated into the feed or feeder to encourage curiosity and attraction to the feed via sight, smell, and taste. Flavor additives or feed attractants are a type of feed additive that is added to the diet to enhance the aroma or flavor of the feed. With many different aromas, flavors, and additive sources tested to determine the highest preference among both pre-weaned and post-weaned piglets, feed attractants show promising results in increasing feeding behavior.

1.2.3 Products of Maternal Sow

It has been observed that piglets are attracted to various scents of the maternal sow. This attraction to maternal scents can be useful in attracting piglets to feed during low intake periods induced by stress, as well as decrease behaviors that are a product of stressful environments. Aviles-Rosa et al. (2020) extracted the fecal semiochemicals skatole and myristic acid from the feces of sows, which was formed into a solution that was sprayed on the feeders of each sow's specific litter (Aviles-Rosa et al., 2020). The fecal semiochemical solution decreased piglet aggression by 30% and increased feeding behavior by 35% within 24 h of post-weaning (Aviles-Rosa et al., 2020). Figueroa et al. (2013) tested the effectiveness of supplementing feed with an additive that smelled like the amniotic fluid of the sow. When compared to feed supplemented with an attractant from the amniotic fluid of the non-maternal sow, the piglets preferred feed with their maternal sow's amniotic fluid smell (Figueroa et al., 2013). Both studies strongly suggest that maternal smells can significantly influence a litter's preferences and potentially serve as an attractant.

The main limitation of these studies is that both fecal matter and amniotic fluid must come from the maternal mother in order to show the highest success rate (Aviles-Rosa et al., 2020; Figueroa et al., 2013). Pigs from multiple litters are typically mixed at weaning, further complicating the use of maternal sow products. Collecting samples from each sow and applying it individually to each pen is both time-consuming and inefficient. Instead, a more versatile product that can be used within the entire barn would be a more practical alternative.

1.2.4 Flavors Tested in Attractants

It is important to note that preference for certain smells and tastes may be influenced by previous exposure to the ingredient or lack thereof as well as ingredient levels within previous feed (Solà-Oriol et al., 2009). One study introduced anise and milky cheese flavorings to the sow's diet in late gestation to determine if consumption while pregnant influenced the litter's preference (Figueroa et al., 2013). The pre-weaned piglets displayed a preference for feed supplemented with the same flavoring as the sow's feed compared to other flavorings, suggesting that flavor introduction during late gestation may influence taste preferences in piglets (Figueroa et al., 2013). However, the piglets did not display a preference for the anise and milky cheese flavoring when compared to a non-supplemented feed, suggesting that feed supplemented with an anise or milky cheese attractant may not be beneficial for feed intake (Figueroa et al., 2013). Yan et al. (2011) tested both the milky cheese flavoring and vanilla flavoring in creep feed and found that both supplements were preferred over non-supplemented creep feed by piglets, with administration of either flavor increasing pre-weaning intake ($p<0.05$; Yan et al., 2011). Furthermore, post-weaning average daily gain (ADG) increased in both supplement groups when compared to the non-supplement group (Yan et al., 2011). The milky cheese flavoring has also been tested for other applications such as on rope for enrichment purposes. Sundman et al. (2022) determined a milky cheese attractant showed the highest preference rate compared to a sunflower oil attractant and a semiochemical attractant.

Other studies have found sweet flavors to be the most preferred through the inclusion of sweeteners such as saccharin (Jacela et al., 2010). However, including sweeteners can contribute to pest issues within the barn, as many insects and flies are also attracted to sweet smells and flavors. Feed attractants with either a sweet or umami taste show the most preference and potential with pigs when compared to other tastes.

Taste, attractant application, pig age, and previous exposure all seem to play important roles in how successful an attractant is. Though studies show mixed results, there is undeniable potential for feed attractants to be useful tools for both pre-weaned and post-weaned pigs. Ultimately, there are multiple components necessary for a feed attractant to be successful. A successful feed attractant should not only attract pigs towards the feed, but also encourage consumption of the feed while being cost-effective and versatile in the facility. The ability for a product to be used in multiple applications such as different production stages and serving multiple benefits can increase the versatility of a product, making it much more valuable within the production system.

1.2.3 Nextein APF®

Nextein APF® (Animal Protein Free) by TechMix is a liquid supplement developed to provide hydration and energy to pigs (Nextein APF). Consisting of electrolytes, functional proteins, amino acids, and energy, Nextein has multiple nutritional applications that can decrease the number of supplemental products needed in a facility (Nextein APF). Furthermore, Nextein consists of a sweet flavoring that has the potential to attract pigs to the feed when applied. Compared to previously stated feed attractants, no customization per pen is necessary when using Nextein, making the product far more efficient. Nextein is a versatile product that can be used on both pre-weaned and post-weaned pigs in both water and feed. More specifically, Techmix highlights that Nextein can be used for pigs of all ages and in different scenarios in which pigs undergo stress. These scenarios include at weaning, during off-feed events, recently transported pigs, and during dehydration periods (Nextein APF). Because of the product's versatile application methods, Nextein shows potential for improving a pig's voluntary feed intake, which in turn could minimize weight loss in the pigs and maximize productivity within the facility. As a relatively newly developed product with positive anecdotal results in commercial settings, further research was needed to determine the effectiveness of Nextein.

1.3 Importance of Swine Inventory

Accurate recordkeeping is an imperative part of successful swine production management. Moving pigs into facilities, transporting pigs, and loading on and off trucks are all points in production in which an inventory needs to be taken. Pig inventory is most often obtained manually by workers, a practice which leaves room for errors such as double counting or missing pigs. This can often be a more prevalent issue with younger pigs, as their size allows for them to move more quickly, making them harder to count compared to larger pigs. Manually counting pigs is also a time-consuming process, with a 2,000 head commercial sow farm weaning up to 1,000 pigs in a single day (MetaFarms Inc, 2020). Miscounting pigs may potentially result in monetary losses as the producer or integrator does not have accurate production records. To mitigate mistakes due to human error, an automated counting method should be considered. More rapid inventory collection provided by an automated system could save producers money through potentially decreasing labor costs (Bouazza et al., 2017).

1.3.1 Available Automated Counting Systems

There are several automated counting technologies both available on the market as well as in research. Many of these automated systems' form of counting relies on cameras and associated software. PigCounter, an automated counting system powered by PigBrother, is an example of a system that uses cameras and software to provide real time counting of moving pigs. PigBrother promotes that the system can differentiate between pigs and other objects, and that the system provides a seamless counting experience, resulting in a rapid return on investment. Ro-Main SmaRt Counting is another example of an automated counting system on the market. This system uses a camera to identify and count pigs moving within an area, and has a minimum accuracy guarantee of 99.9% (Conception Ro-Main Inc). Like PigBrother, the system is capable of using imaging to distinguish between humans and pigs. PigCounter Portable is another automated counting system that uses a camera system to count pigs during a sale or relocation process (Big Dutchman International). With a system accuracy of 99.8%, PigCounter Portable ensures that the system's real time results and high accuracy can end time-consuming counting, although the system is not yet available in the US or Canada (Big Dutchman International). Despite the high accuracy of these systems and claims for quick return on investment, there are typically expensive initial investments and infrastructure required by camera systems such as PigCounter, Ro-Main, and PigCounter Portable, making a more affordable system a better option for the average producer.

One automated counting system developed as a research tool, EmbeddedPigCount, had a counting accuracy of 99.44% with an estimated cost of less than $500 USD (Figure 1; Kim et al., 2022). Although EmbeddedPigCount exhibited high accuracy during testing with comparatively lower equipment costs, the study was limited as different lighting and flooring conditions were not tested (Kim et al., 2022). Because lighting and flooring both can vary from barn to barn as well as depending on the time of day, automated counting systems using cameras can be limited.

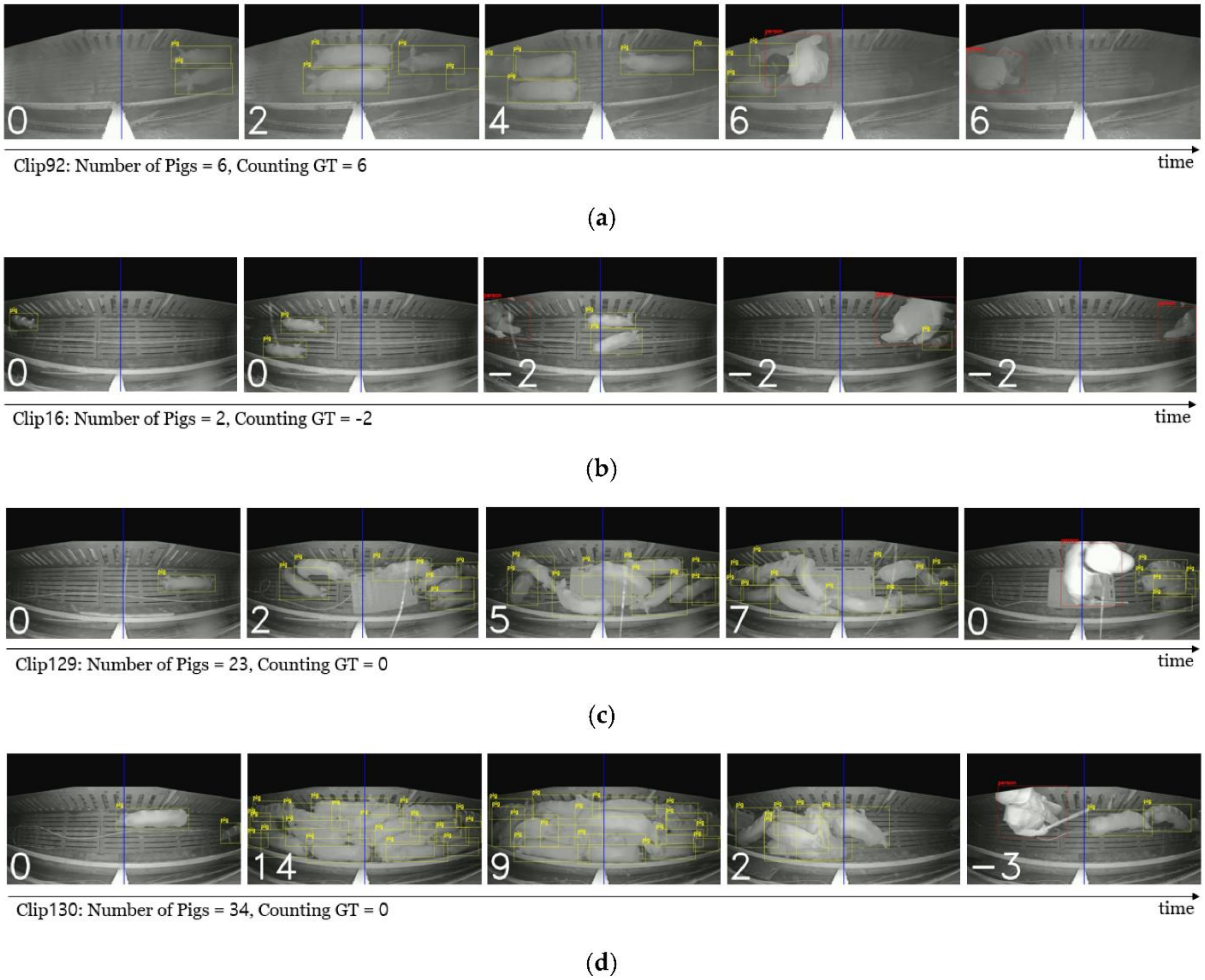

Figure 1.1. Qualitative Results of EmbeddedPigCount, with (a): common situations of counting, (b): counting opposite direction, (c): counting during dense scenarios, and (d): incorrect counting (Kim et al., 2022).

Camera systems are also greatly impacted by dirt and dust, both of which are common in swine barns and may cloud lenses, preventing accurate detection if not regularly cleaned. This not only poses a limitation to the long-term use of camera systems, but also increases labor on the farm. Another limitation of camera systems such as Ro-Main and EmbeddedPigCount is that despite a high count accuracy, the systems fail to provide unique pig identification. While caretakers can accurately count the number of pigs, these systems fail to provide caretakers with individual animal data. Because of this limitation, radio-frequency identification (RFID) technology could serve as an alternative to manual counting and automated systems based on images.

1.3.2 Radio-Frequency Identification

RFID is a technology that automatically identifies RFID tags when in range of the corresponding reader. The RFID tags can be attached to objects of interest to identify their locations relative to the readers. The three frequency ranges that are most commonly used in RFID systems are low frequency (LF; 125 kHz or 134.2 kHz), high frequency (HF; 13.56 MHz) and ultra-high frequency (UHF; 860-960 MHz; Kapun et al., 2020).

Table 1.1. RFID systems and their associated frequency and read ranges (Kapun el al., 2020; GAO RFID).

RFID type	**Frequency**	**Approximate Range**
Low Frequency	125 kHz or 134.2 kHz	10 cm
High Frequency	13.56 MHz	1 m
Ultra-High Frequency	860-960 MHz	10 m

High frequency and UHF RFID readers have a greater reading capacity compared to LF readers, meaning that tags at greater distances can be registered at a faster rate (HID, 2014).

Furthermore, HF and UHF RFID readers can register multiple tags at once while LF readers can only register one tag at a time (HID, 2014). Of the three frequency ranges, UHF RFID readers have the highest reading range capacity and can read hundreds of tags simultaneously (HID, 2014). However, it is important to note that UHF readers are also highly sensitive to reflection and dampening (HID, 2014). This can potentially limit the locations that UHF systems are used in as the surrounding environment may decrease system detection rates.

1.3.3 RFID Applications

RFID systems can be beneficial in many different settings where tracking of inventory is necessary to maintain productivity. RFID systems are often used by stores to locate and track items such as merchandise (Wu et al., 2019). Many manufacturing facilities also benefit from RFID, using the system to find equipment that would otherwise be cumbersome to find manually in a large warehouse (Wu et al., 2019). RFID technology can also be useful when applied to healthcare settings, as hospitals can use the technology to track medical equipment (Fry & Lenert, 2005). Some hospitals have taken this a step further and used RFID technology to track both staff and patients while in the hospital, improving patient care as well as hospital efficiency (Fry & Lenert, 2005). The success of using RFID to track not only items but also humans within a facility shows the potential for this equipment to be used in livestock production as a tool for identifying animal movement and location in a barn.

1.3.4 RFID in Livestock and Swine Production

Though RFID systems have proven to be successful in tracking both equipment and inventory in multiple settings, using the technology to track animal movement itself in livestock production is not a popular practice. More commonly, use of RFID technology in production is through monitoring behaviors such as feeding, watering, and nesting, which may be difficult to identify through observation (Matthews et al., 2016). One study using RFID technology to determine the nesting behavior of laying hens attached an RFID tag to the leg of each hen, which then was monitored by an RFID antenna when in the nesting box area (Oliveira et al., 2019). Another study using RFID technology applied the system to cattle in order to track waterer activity (Tang et al., 2021). In conjunction with other technology, cattle waterer visits and water consumed was collected (Tang et al., 2021). It is important to note that while RFID technology cannot itself quantify intake of feed and water, it can be used in collaboration with other technologies that can obtain these metrics.

RFID technology in swine production has been used to look at feeder trough visits in growing-finishing pigs (Brown-Brandl et al., 2013). In a study by Brown-Brandl et al. (2013), feeding behavior collected on growing-finishing pigs revealed trends in behavior associated with a pneumonia outbreak within the barn, suggesting that RFID technology can also be used to track behaviors that indicate illness (Brown-Brandl et al., 2013).

In swine production, RFID systems are commonly used by attaching the RFID tag to ears on pigs and identifying movement and location within the barn relative to an RFID reader. One-time use RFID ear tags cost approximately $2 each, making these tags more expensive compared to standard tags used in swine production. However, RFID systems are relatively simple to install and the pigs can be ear tagged during piglet processing. This means that the system does not require significantly more infrastructure or time to install compared to standard production procedures.

The RFID system helps to quantify behavior by recording pigs individually (Andretta et al., 2016). Furthermore, the system better represents commercial facilities by monitoring all pigs at once rather than observing pigs one at a time (Brown-Brandl et al., 2013). LF readers are often suggested to be used in swine barns, as these facilities have water and metal which can lead to radio wave interference, especially with readers that have higher frequencies (GAO RFID). However, LF readers have a limited read range up to 10 cm (GAO RFID) as well as a slower reader speed (HID, 2014). Furthermore, LF readers have difficulty registering multiple tags simultaneously, making the LF range a poor option to monitor multiple pigs (HID, 2014).

One study by Adrion et al. (2018) testing a custom UHF RFID technology to look at trough visits in grow-finish pigs had a highest average sensitivity of 79.7% and R^2 value of 0.78 (Adrion et al., 2018). This reveals the true potential of UHF-RFID systems to detect feeding behavior as well as complete animal behavior, though it was suggested that ear tissue negatively affected the performance of the system's detection capabilities (Adrion et al., 2018).

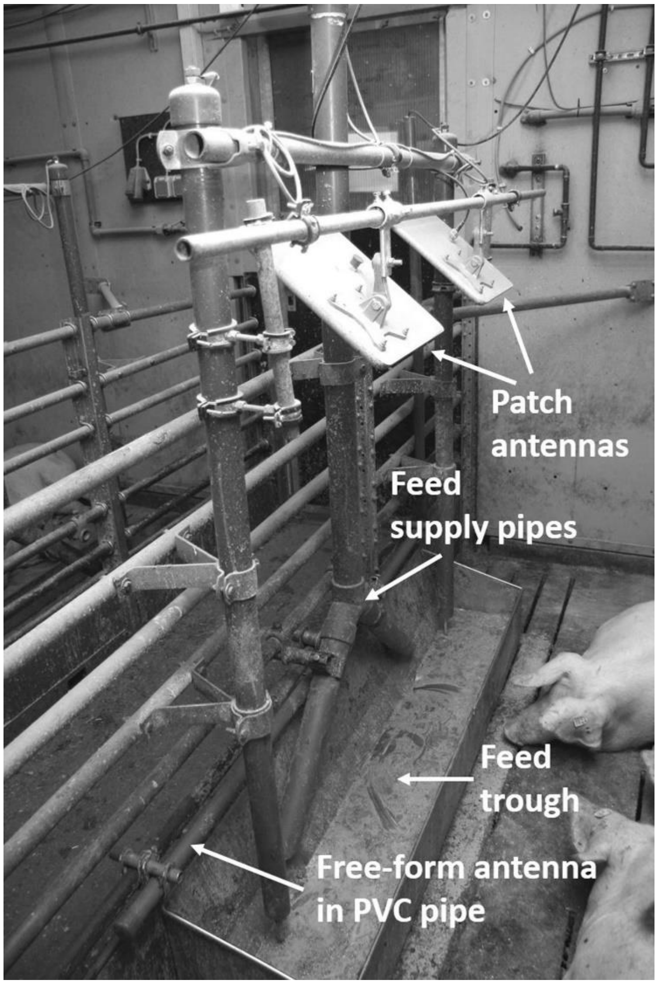

Figure 1.2. Set-up of the custom UHF-RFID system tested by Adrion et al. (2018) to detect feed trough visits in grow-finish pigs (Adrion et al., 2018).

Outside of research, RFID systems are used in conjunction with many other technologies for the monitoring and tracking of feeding as well as a source of record keeping. FIRE (Feed Intake Recording Equipment) feeders are one example of field implementation of RFID technology (Osborne Livestock Equipment). Through RFID tag identification, antennas inside each FIRE feeder identify which animal is at the feeder (Osborne Livestock Equipment). Total feed intake as well as body weight are recorded with each visit to the feeder for real-time data on the animal (Osborne Livestock Equipment). RFID technology can also be used to identify pigs eating at electronic sow feeders, a system used to control feed intake on an individual level for group-housed sows (Vargovic et al., 2021). FIRE feeders and electronic sow feeders are two examples of RFID applications to make farms both more productive as well as efficient.

Both research and commercial settings have utilized RFID technology to identify animals for the purpose of customizing animal nutrition as well as to obtain individual animal observations and production-related metrics. Because of the ability for RFID technology to identify animals, tracking and counting can be an application in which this technology is utilized. However, with tracking of animals it is crucial to select a RFID system that has a large enough range to accurately read tags within the area animals are moving past. As most commercial swine hallways are at least 60 cm wide, a larger detection range is needed to accurately track animals moving along hallways and through doorways. Although HF systems have a marketed read range of 1 m, many systems have been found to inconsistently detect tags beyond the 10 cm range (Wallace et al., 2020). Therefore, a UHF RFID system is most likely the best option for greater distance detection capabilities.

1.3.5 RFID Limitations

RFID technology does pose certain limitations, depending on the setting and metrics which it is observing. When used to investigate intake of food or water, these systems prove to be highly accurate in tag detection within the desired range. However, these technologies cannot directly quantify feed intake or water consumption. For measurements like feed intake, other technologies such as scales would need to be used, as is used for FIRE feeders (Osborne Livestock Equipment). Most swine tracking systems are specially designed technologies that are not yet commercially available. The particular design as well as lack of availability limit the abilities of researchers and producers to use such technologies within their facilities. A customizable system that requires simple installation and is user-friendly should be considered for the average end-user. Furthermore, this system should be commercially available, providing producers with easy access to the automated counting system and replacement components as needed.

1.3.6 Conclusions

Camera systems have been tested and are also available for purchase to monitor pig behavior as well as to serve as a counting system. Though some of these systems produce high accuracies, the cost is prohibitive for the average producer. A more affordable and flexible alternative should be considered for automated counting. RFID could serve as this alternative, proving to be both affordable as well as capable of pig detection. Used in other applications such as FIRE feeders and electronic sow feeders, RFID technology has been proven to accurately detect and identify pigs based on their corresponding ear tag. This suggests potential to be used as an automated counting system to identify movement past the reader within a designated area. Research should be conducted to explore customizable, commercially available RFID technologies that are both affordable and user-friendly for the average producer.

1.4 Summary

The impacts of weaning stressors can greatly impact pig performance both in the nursery as well as throughout the rest of the production cycle (Campbell et al., 2013). All the stressors encountered by newly-weaned pigs most often lead to weight loss (Campbell et al., 2013). Thus, efforts to mitigate weight loss in the nursery phase are necessary. Identifying the challenges of low feed intake during weaning as well as identifying its performance impacts enhance our understanding of how ingredients, feed additives, and other products can be used to manage weight loss in the nursery (Campbell et al., 2013). Studies show that the additions of feed attractants to feed can be beneficial at different production stages. Nextein is a liquid product that, along with providing electrolytes and increasing hydration, may be used as an attractant to increase feed intake (Nextein APF®).

Proper tracking of swine inventory is crucial for a successful production system, as incorrect counts may lead to loss of profits and inefficient management. However, counting is often done manually, a tedious task that can lead to human error such as double counting or missing a pig. An automated counting system should be considered to not only decrease labor costs, but also increase farm productivity (Bouazza et al., 2017). Automated counting systems such as Ro-Main SmaRt Counting use cameras to identify pig movement with extremely high accuracy rates (Conception Ro-Main Inc). Despite this, other research investigating automated counting systems report that a major limitation to these camera systems can be poor lighting (Kim et al., 2022) as well as dirt and dust collecting on the camera lens. RFID technology may produce better results compared to these systems as a camera is not necessary to count pigs. Using individual ear tags, RFID readers are able to detect tags within a given range and record the duration of time a tag is within a certain area, suggesting that this technology can be used to look at both pig movement as well as behavior.

This thesis explores these areas of young pig management with the aim of testing feed attractant usage to mitigate the weight loss and reduced feed intake that is often experienced in the post-weaning period. Furthermore, this thesis investigates the use of RFID technology to quantify young pig behavior as well as to track pig movement within a facility. The purpose of this technology is to better understand and track animal movement and behaviors with the goal of improving productivity and management within the facility. Overall, this thesis contributes understanding of implementation methods to increase feed intake and count pigs to improve both swine health and production.

REFERENCES

Adrion, F., Kapun, A., Eckert, F., Holland, E.-M., Staiger, M., Götz, S., & Gallmann, E. (2018). Monitoring Trough visits of growing-finishing pigs with UHF-RFID. *Computers and Electronics in Agriculture,* vol. 144, 2018, pp. 144–153, https://doi.org/10.1016/j.compag.2017.11.036

Andretta, I., Pomar, C., Kipper, M., Hauschild, L., & Rivest, J. (2016). Feeding behavior of growing–finishing pigs reared under precision feeding strategies. *Journal of Animal Science*, *94*(7), 3042–3050. https://doi.org/10.2527/jas.2016-0392

Aviles-Rosa, E. O., Surowiec, K., & McGlone, J. (2020). Identification of faecal maternal semiochemicals in swine (sus scrofa) and their effects on weaned piglets. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-62280-9

Big Dutchman International. Pigcounter Portable: A Revolution in Pig Counting. *Big Dutchman*, 10 Nov. 2022, www.bigdutchman.com/en/pig-production/news/detail/pigcounter-revolutioniert-schweinezaehlung/

Brown-Brandl, T.M., Rohrer, G. A., & Eigenberg, R. A. (2013). Analysis of feeding behavior of group housed growing–finishing pigs. *Computers and Electronics in Agriculture*, vol. 96, 2013, pp. 246–252, https://doi.org/10.1016/j.compag.2013.06.002

Campbell, J. M., Crenshaw, J. D., & Polo, J. (2013). The biological stress of early weaned piglets. *Journal of Animal Science and Biotechnology*, vol. 4, no. 1, 2013, https://doi.org/10.1186/2049-1891-4-19

Cross, A. J., Brown-Brandl, T. M., Keel, B. N., Cassady, J. P., & Rohrer, G. A. (2020). Feeding behavior of grow-finish swine and the impacts of heat stress. *Translational Animal Science*, *4*(2), 986–992. https://doi.org/10.1093/tas/txaa023

Figueroa, J., Solà-Oriol, D., Vinokurovas, L., Manteca, X., & Pérez, J. F. (2013). Prenatal flavour exposure through maternal diets influences flavour preference in piglets before and after weaning. *Animal Feed Science and Technology*, *183*(3-4), 160–167. https://doi.org/10.1016/j.anifeedsci.2013.04.023

Osborne Livestock Equipment. FIRE: Feed Intake Recording Equipment. Osborne Livestock Equipment. 31 May 2023, osbornelivestockequipment.com/products/performance-testing/fire/.

Garcia, A., Sutherland, M., Pirner, G., Picinin, G., May, M., Backus, B., McGlone, J. (2016). Impact of providing feed and/or water on performance, physiology, and behavior of weaned pigs during a 32-H transport. *Animals,* vol. 6, no. 5, 2016, p. 31, https://doi.org/10.3390/ani6050031

Gebhardt, J. T., Tokach, M. D., Dritz, S. S., DeRouchey, J. M., Woodworth, J. C., Goodband, R. D., & Henry, S. C. (2020). Postweaning mortality in commercial swine production. I: Review of non-infectious contributing factors. *Translational Animal Science,* vol. 4, no. 2, 2020, pp. 462–484, https://doi.org/10.1093/tas/txaa068

HID Global Corporation. (2014). Top 7 considerations to choose the right RFID Tag. White paper, HID Global Corporation/ASSA ABLOY AB

Holman, D. B., Gzyl, K. E., Mou, K. T., & Allen, H. K. (2021). Weaning age and its effect on the development of the Swine Gut Microbiome and resistome. *mSystems, 6(*6), e00682-21. https://doi.org/10.1101/2021.05.20.444551

Hötzel, M. J., Machado Filho, L. C. P., Irgang, R., & Alexandre Filho, L. (2010). Short-term behavioural effects of weaning age in outdoor-reared piglets. *Animal*, *4*(1), 102–107. https://doi.org/10.1017/s1751731109990875

Jacela, J. Y., DeRouchey, J. M., Tokach, M. D., Goodband, R. D., Nelssen, J. L., Renter, D. G., & Dritz, S. S. (2017). Feed additives for swine: Fact sheets – flavors and mold inhibitors, mycotoxin binders, and antioxidants. *Kansas Agricultural Experiment Station Research Reports*, no. 10, 2010, pp. 27–32, https://doi.org/10.4148/2378-5977.7069

Kapun, A., Adrion, F., & Gallmann, E. (2020). Case study on recording pigs' daily activity patterns with a UHF-RFID system. *Agriculture*, *10*(11), 542. https://doi.org/10.3390/agriculture10110542

Kats, L. J., Tokach, M. D., Goodband, R. D., & Nelssen, J. L. (2017). Influence of weaning weight and growth during the first week postweaning on subsequent pig performance. *Kansas Agricultural Experiment Station Research Reports*, no. 10, 1992, pp. 15–17, https://doi.org/10.4148/2378-5977.6731

Lewis, Nora J. (2008). Transport of early weaned piglets. *Applied Animal Behaviour Science*, vol. 110, no. 1–2, 2008, pp. 128–135, https://doi.org/10.1016/j.applanim.2007.03.027

Oliveira, J. L., Xin, H., Wang, K., & Zhao, Y. (2019). Evaluation of nesting behavior of individual laying hens in an enriched colony housing by using RFID technology. *International Journal of Agricultural and Biological Engineering*, vol. 12, no. 6, 2019, pp. 7–15, https://doi.org/10.25165/j.ijabe.20191206.5129

Maselyne, J., Saeys, W., De Ketelaere, B., Mertens, K., Vangeyte, J., Hessel, E. F., Millet, S., & Van Nuffel, A. (2014). Validation of a high frequency radio frequency identification (HF RFID) system for registering feeding patterns of growing-finishing pigs. *Computers and Electronics in Agriculture*, *102*, 10–18. https://doi.org/10.1016/j.compag.2013.12.015

Matthews, S. G., Miller, A. L., Clapp, J., Plötz, T., & Kyriazakis, I. (2016). Early detection of health and welfare compromises through automated detection of behavioural changes in pigs. *The Veterinary Journal*, *217*, 43–51. https://doi.org/10.1016/j.tvjl.2016.09.005

Miller, D. (2011). *Sow dentistry 101*. National Hog Farmer. Published Nov 14, 2011. Retrieved July 26, 2022, from https://www.nationalhogfarmer.com/mag/farming_sow_dentistry

Nextein APF®. *TechMix Global*, www.techmixglobal.com/product/nextein-apf/. Accessed 28 Sept. 2023.

"Pig Counting Camera and Software Solution by PigBrother: Pig Counting Automation." *PigBrother*, pigbrother.hu/en/our-solutions/pigcounter.html. Accessed 5 Oct. 2023.

Ramirez, B. C., Hayes, M. D., Condotta, I. C. F. S., Leonard, S. M. (2022). Impact of housing environment and management on pre-/post-weaning piglet productivity. *Journal of Animal Science*, vol. 100, no. 6, 2022, https://doi.org/10.1093/jas/skac142

Reiners, K., Hegger, A., Hessel, E. F., Böck, S., Wendl, G., & Van den Weghe, H. F. A. (2009). Application of RFID technology using passive HF transponders for the individual identification of weaned piglets at the Feed Trough. *Computers and Electronics in Agriculture*, *68*(2), 178–184. https://doi.org/10.1016/j.compag.2009.05.010

Richert, B.T. (2006). Feed additives for swine. *Pork Information Gateway*. PIG 07-03-03

Samuel, R. (2022). Nursery Pig Management. *SDSU Extension*, 28 July 2022, https://extension.sdstate.edu/nursery-pig-management.

Solà-Oriol, D., Roura, E., & Torrallardona, D. (2009). Use of double-choice feeding to quantify feed ingredient preferences in pigs. *Livestock Science*, *123*(2-3), 129–137. https://doi.org/10.1016/j.livsci.2008.10.015

Sundman, E. R., Gabler, N. K., Millman, S. T., Stalder, K.J., Karriker, L.A., & Johnson, A.K. (2022). The use of attractants to stimulate neonatal piglet interest in rope enrichment. *Animals, 12*(2):211. https://doi.org/10.3390/ani12020211

Tang, W., Biglari, A., Ebarb, R., Pickett, T., Smallidge, S., & Ward, M. (2021). A smart sensing system of water quality and intake monitoring for livestock and wild animals. *Sensors*, vol. 21, no. 8, 2021, p. 2885, https://doi.org/10.3390/s21082885

Vargovic, L., Hermesch, S., Athorn, R. Z., & Bunter, K. L. (2020). Feed intake and feeding behavior traits for gestating sows recorded using electronic sow feeders. *Journal of Animal Science*, *99*(1). https://doi.org/10.1093/jas/skaa395

Wensley, M. R., Tokach, M. D., Woodworth, J. C., Goodband, R. D., Gebhardt, J. T., DeRouchey, J. M., & McKilligan, D. (2021). Maintaining continuity of nutrient intake after weaning. II. review of post-weaning strategies. *Translational Animal Science*, *5*(1). https://doi.org/10.1093/tas/txab022

Yan, L., Jang, H. D., & Kim, I. H. (2011). Creep feed: Effects of feed flavor supplementation on pre- and post-weaning performance and behavior of piglet and sow. *Asian-Australasian Journal of Animal Sciences*, *24*(6), 851–856. https://doi.org/10.5713/ajas.2011.11011

CHAPTER TWO: EFFECTS OF A NOVEL FEED ATTRACTANT ON NURSERY PIG WEIGHT GAIN, FEED INTAKE, AND FEEDER INTEREST

Rachel Hodges[1], Suzanne Leonard[1], Eric van Heugten[1], Denny McKilligan[2]
[1]Department of Animal Science, North Carolina State University, Raleigh, NC
[2]TechMix Inc., Stewart, MN

2.1 Abstract

A total of 16 litters and 171 nursery pigs were used in a 3 d pre-weaning and 28 d post-weaning trial to determine the effects of spraying a novel feed attractant (Nextein APF®; TechMix Global, Stewart, MN) on weight gain, nursery feed intake, and feeder interest. The treatments in this study were arranged in a 3 × 2 factorial with main effects of: farrowing treatment (no spray, spray on sow underline, or spray on wall), nursery treatment (spray or no spray), and a bodyweight block (High or Low). Spray treatments were applied according to experimental design from 3 d prior to weaning through 3 d post-wean. No differences in average daily weight gain by litter were detected pre-weaning. In the first three days after weaning, nursery spray treatments tended to gain more weight than the no nursery spray group ($P = 0.060$); however, in D3-D7 the no nursery spray group had a greater average daily gain than the nursery spray group ($P = 0.005$). This suggests the spray was successful at encouraging weight gain during the first 3 d when it was used, but piglets did not adjust as well when the spray was stopped. There was no difference in average daily gain between nursery treatments from day 0-day 7 overall. No differences were detected in average daily feed intake due to treatment for any of the time periods investigated, though there was a weak interaction between nursery treatment and BW block from day 1- day 2 ($P = 0.074$). Overall, bodyweight block had the greatest influence on performance, with Low bodyweight pigs presenting greater average daily gain ($P = 0.005$) and a trend of greater average daily feed intake ($P = 0.088$) in day 0-day 3. After day 7 the

High bodyweight block demonstrated greater average daily gain and average daily feed intake. For the first 6 d in the nursery, RFID systems were installed feeders in select pens to investigate feeder area interest to record duration and frequency of feeder area visits. For Low bodyweight pens, those receiving no nursery spray treatment had numerically lower cumulative durations as well as lower frequency of visits in the feeder area compared to those receiving the nursery spray treatment. For High bodyweight pens, those receiving the farrowing wall and nursery spray treatment had numerically lower cumulative durations as well as lower frequency of visits in the feeder area compared to other treatment combinations. Over the 28 d nursery period, no differences were detected in piglet average daily gain or average daily feed intake due to farrowing or nursery treatment. In conclusion, using a feed attractant spray in the nursery may improve bodyweight gain in the first three days after weaning, but the cessation of spraying may create an olfactory or palatability change that limits bodyweight gain.

2.2 Introduction

Commercial swine facilities in the United States wean pigs between 19 to 22 d of age (Holman et al., 2021). The weaning process is one of the most stressful periods of a pig's life, filled with many changes within a short period of time. Stress factors experienced by newly weaned pigs include nutritional stress, transportation stress, and social stress (Holman et al., 2021; Garcia et al., 2016; Hötzel et al., 2010). Nutritional stress is caused by removal from the sow, leading to a direct change from a milk diet to a grain diet. The sow's milk is an easily digestible energy source for the pre-weaned piglet, whereas the grain diet requires more complex digestion. This removal from the sow may also cause social stress by separating the pig from its original litter and placing it with new pen mates in the nursery (Wensley et al., 2021).

Transportation stress may also occur from transferring pigs into new facilities or barns during the weaning period. Just one hour of transportation has been shown to have negative impacts on physiometabolic imbalances in recently weaned pigs such as higher percentage levels of blood hematocrit (Roldan-Santiago et al., 2014). Social stress as well as transport stress may add to the nutritional issues of newly weaned pigs as these factors contribute to decreased feeding behavior and diarrhea often seen in the first few days after weaning (Hötzel et al., 2010).

Newly weaned pigs can lose 100-250 g of bodyweight after the first day of weaning, requiring up to 4 d to recover (Le Dividich and Sève, 2000). These negative impacts have the potential to have long lasting effects on pig productivity and weight gain. Minimizing weight loss and increasing feed intake during the first few days post–weaning may have positive effects on pig productivity and efficiency.

Feed attractants are a product used to help combat weight loss and decreased feed intake associated with weaning. Feed attractants are added to the diet to enhance the flavor or aroma of the feed. The objective of this study was to test the effectiveness of Nextein APF® (TechMix Global; Stewart, MN) as a feed attractant for influencing pig bodyweight (BW), average daily weight gain (ADG), and average daily feed intake (ADFI) in farrowing in nursery phases. Nextein APF® is a nutrient-dense liquid that serves as a hydration and energy supplement for pigs of all ages and was selected for use in this study due to its high palatability and potential to support newly weaned pigs.

In conjunction with physiological measures, animal behavior can provide further information about an animal’s health status, as sickness within an animal can be identified through the behavioral changes that develop during infection (Dantzer, 2004). Moreover, behavior can also indicate improvements in animal health through monitoring changes in movement, feeding, and drinking behavior. Thus, this study also aimed to monitor feeder area behavior utilizing a Radio Frequency Identification (RFID) system. RFID is an automated technology that identifies RFID tags when located in the desired range of the RFID reader. These tags are typically attached to objects to identify their location within an area. The frequency ranges typically used in RFID systems are low frequency (LF; 125 kHz or 134.2 kHz), high frequency (HF; 13.56 MHz) and ultra-high frequency (UHF; 860-960 MHz; Kapun et al., 2020). In animal production systems, RFID technology is used to individually monitor the behaviors of animals (Andretta et al., 2016). These behaviors include feeding, watering, and nesting, which can be difficult to manually observe (Matthews et al., 2016). RFID technology has proven to be a promising tool in the world of automated behavior tracking. One study using UHF RFID technology to observe trough visits in a grow-finish facility was able to achieve an average sensitivity of 79.7% and R2 value of 0.78 (Adrion et al., 2018). While not adequate for everyday use, these numbers highlight the potential for UHF-RFID to serve as a feeding behavior monitoring system.

The UHF-RFID system by GAO RFID (GAO RFID Inc. Toronto, Canada) was selected for automated feeding behavior tracking for this study. The GAO RFID system is commercially available and extremely versatile, with lightweight equipment and easy to operate software that can be customized to optimize the system for specific applications. With user-friendly software and hardware, the GAO RFID system shows potential to be used as a successful automated feeding behavior monitoring system. Therefore, the overall goal of this study was to compare the physiological and behavioral impacts of farrowing and nursery applications of Nextein APF®.

2.3 Materials and Methods

The protocol for this experiment was approved by the North Carolina State University Institutional Animal Care and Use Committee.

2.3.1 Feed Attractant

A total of 16 litters were selected for use at the North Carolina State University Swine Education Unit in Raleigh, NC. Three days prior to weaning (DM3) a total of 171 pigs from 16 litters were individually weighed and litters were randomly assigned a farrowing treatment, balanced by average litter BW. Treatments included a control of receiving no spray (FarrNo), receiving spray on the underline of the sow (FarrUnderline), or receiving spray on the side divider walls of the farrowing stall (FarrWall). The guaranteed analysis for the attractant was: Crude Protein minimum 11.00%, Lysine minimum 0.40%, Crude Fat minimum 0.50%, Crude Fiber maximum 0.25%, Salt minimum 11.00%, Salt maximum 13.2%, and Potassium minimum 2.60%. The spray treatment was applied using a handheld pump sprayer. The pump was fully pressurized and spray function activated for approximately 5 s to uniformly apply 60 mL of spray to the prescribed area with the nozzle approximately 10 cm from the surface of the sow or wall. Each farrowing spray treatment was applied PM on DM3, and then twice daily (AM and PM) until weaning (D0; 5 spray applications total). All piglet BW from DM3 were averaged to obtain the weight criteria for BW block (High or Low) for nursery pen assignments.

At weaning (D0), a total of 171 pigs were blocked based on BW within farrowing treatment and placed in nursery pens. The BW block categories were High and Low, which were developed based on the mean weight of all 171 pigs. Pens were balanced by sex, with two gilts and two barrows in each pen. Each pen was randomized to a treatment of spray (NursSpray) or no spray (NursNo), with 42 pens of four pigs and one pen of three pigs (one pig in the FarrNo group was removed from the study on D0 due to lameness). The spray treatment was applied on top of exposed feed located in the bottom of each feed pan with a handheld pump sprayer. Each spray event was for 5 s and dispersed approximately 60 mL of spray product. Nursery treatments were applied starting PM of D0 and continued twice daily (AM and PM) until D3 (7 spray applications total). Each treatment had 7 pen replicates, with the exception of FarrWall×NursNo having 8 pen replicates.

Each nursery pen was equipped with two nipple waterers and one dry self-feeder for ad libitum access to water and feed. Pigs were fed a standard commercial nursery diet. Individual pig weights were collected on DM3, D0, D3, D7, D14, D21, and D28. Nursery pen-level feed intake was measured on D1, D2, D3, D7, D14, and D28.

2.3.2 Feeding Behavior Data Collection

At weaning, each pig received an RFID tag in the left ear. Each tag was labeled with a unique identification number to both identify pigs in the barn as well as to identify movement through the RFID technology. In total, 24 pens had an Ultra High Frequency (UHF) Radio-Frequency Identification (RFID) reader (Model #216030, GAO RFID Inc., Manhattan, NY) installed. The pens selected to receive an RFID reader were chosen with the aim of balancing by treatment while also considering room layout limitations within the barn. RFID readers were fastened to the feeder approximately 30 cm from the bottom of the feed pan and angled 30 degrees inward towards the bottom of the feeder. RFID readers collected time-series data of feeding behavior which was managed by the RFID software on the connected computer. RFID data were downloaded daily to the computer and all equipment was checked for malfunctions. The RFID data were collected for the first 6 d after placement in the nursery, and then all RFID readers were removed.

2.3.3 Cameras

Video recordings of select pens were collected to validate the RFID system. Two pens were chosen to serve as these validation pens, pen 28 (NursSpray, FarrWall, High BW) and pen 29 (NursNo, FarrUnderline, Low BW). One video camera (AKASO Brave 7) with a frame rate of 1 FPS and 3840 × 2160 resolution was securely fastened to the ceiling in between each set of pens such that it could record the pen areas. In order to identify pigs in each pen when watching recordings, each pig was marked with a different color of livestock paint uniquely corresponding to its RFID tag number. The livestock paint was reapplied each morning, as the markings faded throughout the day. On D6, the RFID equipment and the cameras were removed from the pens.

Ground-truth feeding behavior was established through human labeling. One video segment lasting roughly 6 h was randomly selected from each day of available video footage. Trained human observers manually recorded the timestamps when each pig's head was in the feeder, noting pig livestock paint color for matching with its RFID tag number. The RFID data and camera video recordings were compared to evaluate RFID system performance.

2.3.4 Analysis

Feed intake and bodyweight data

Pre-weaning data were analyzed using a randomized complete block design with litter as the experimental unit. Farrowing treatment was considered a fixed effect and room was considered a random effect. Post-weaning data were analyzed as a 3 × 2 factorial with three farrowing treatments of FarrNo, FarrUnderline, and FarrWall, two nursery treatments of NursSpray and NursNo, and a BW block of High vs Low. The experimental unit for post-weaning data was pen. Nursery treatment and farrowing treatment were considered fixed effects.

Room was considered a random effect. All data were analyzed in RStudio using the lmerTest package to investigate linear mixed effects models. Results were considered a trend at $p \leq 0.1$ and significant at $p \leq 0.05$. One mortality occurred in the FarrNo × NursNo group on D17 due to unknown causes. Feed intake was evaluated on a daily basis as ADFI and BW was used to calculate ADG. The percentage of pigs within each pen that lost BW from D0-D3 and D0-D7 was analyzed using a binomial model.

Feeding interest data

Pig feeding bout occurrence and duration were compared between the RFID system and human labels from the video. A confusion matrix was developed to determine system accuracy, specificity, and sensitivity when compared to human labeling. Analysis determined the overall system accuracy was 96.7% with a specificity of 99.9%; however, the RFID system had a sensitivity of 3.2%, indicating the system produced a significant amount of false negative readings. Upon further inspection, it was determined that the RFID readers were recognizing pigs in close proximity (approximately 0.3 m) to the feeder in addition to misidentifying when the pig’s head was actually in the feeder, resulting in elevated false negatives. The human observers could not re-label the data to capture this accurately, as the camera was positioned between two pens and the feeder itself blocked the view of the pen floor area on the far side of the feeder. Thus, RFID data were unfiltered and analyzed as collected. Metrics of interest included daily frequency and cumulative duration of feeder area interest. Data were visually and numerically explored for trends but no statistical analysis was conducted due to small sample size and limited inferencing.

2.4 Results and Discussion

2.4.1 Average Daily Feed Intake

Mean ADFI values are presented in Table 2.1. There were no significant differences in ADFI attributed to farrowing or nursery treatments in any of the time periods evaluated (Table 2.2). Low BW pigs tended to have a greater ADFI than High BW pigs from D0-D1 (P = 0.052; Low = 0.063 kg, High = 0.036 kg), but by D7 the trend had reversed and the High BW group ADFI was greater than the Low group. Overall for D0-D28, the High BW ADFI was 0.06 kg greater than the Low BW group (P = 0.029). The greater feed intake by Low BW pigs in the first day after weaning was unexpected and not fully understood. This result could possibly be attributed to compensatory gain, as perhaps the small piglets were from litters with extreme competition. This could also be due to aggression based on BW. One study investigating nursery housing based on BW found that pigs that were classified in the Light and Medium BW groups not only had earlier onset feeding behavior, but also significantly less aggression compared to High BW groups (Faccin et al., 2020). More specifically, High BW groups had a greater number of fights within the first 24 h post-weaning compared to Medium and Low BW groups (Faccin et al., 2020). The later onset of feeding behavior is thought to potentially be a result of the aggression exhibited by pigs in the high BW groups.

Table 2.1. Average daily feed intake (ADFI) by treatment. Treatments were arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low). Values are in kg.

	FarrNo		FarrUnderline		FarrWall		
Period, d	NursNo	NursSpray	NursNo	NursSpray	NursNo	NursSpray	SEM
0-1	0.049	0.050	0.067	0.062	0.035	0.048	0.007
1-2	0.17	0.17	0.18	0.18	0.19	0.16	0.008
2-3	0.18	0.19	0.16	0.18	0.18	0.16	0.006
3-7	0.16	0.15	0.15	0.15	0.16	0.15	0.004
7-14	0.35	0.37	0.36	0.37	0.34	0.36	0.008
14-28	0.80	0.81	0.74	0.77	0.71	0.73	0.011
0-3	0.13	0.13	0.14	0.14	0.14	0.12	0.004
0-7	0.15	0.14	0.14	0.15	0.15	0.14	0.003
0-28	0.52	0.53	0.50	0.51	0.48	0.49	0.011

Table 2.2. Factor p-values for average daily feed intake. Treatments were arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low). P ≤ 0.05 are in bold. P > 0.1 are shown as ns (not significant). Interactions are indicated with a dimension sign (×).

Period, d	Farr Trt	Nurs Trt	BWBlock	FarrTrt× NursTrt	FarrTrt×BW Block	NursTrt× BWBlock	FarrTrt×Nurs Trt×BWBlock
0-1	ns	ns	0.052	ns	ns	ns	ns
1-2	ns	ns	ns	ns	ns	0.074	ns
2-3	ns	ns	ns	ns	ns	ns	ns
3-7	ns	ns	ns	ns	ns	ns	ns
7-14	ns	ns	0.079	ns	ns	ns	ns
14-28	ns	ns	**0.020**	ns	ns	ns	ns
0-3	ns	ns	0.088	ns	ns	ns	ns
0-7	ns	ns	ns	ns	ns	ns	ns
0-28	ns	ns	**0.029**	ns	ns	ns	ns

There was weak evidence for an interaction between nursery treatment and BW block from D1-D2 (P = 0.074), with the NursSpray increasing ADFI for Low BW pigs and decreasing ADFI for High BW pigs.

As there were no statistical differences due to farrowing treatments, the FarrWall and FarrUnderline groups were combined into a single group to test exposure to the spray in farrowing (FarrExposure) compared to the control of no spray (FarrNo; Table 2.3). Statistical analysis was performed as above. Similar results were seen from the influence of BW block, with Low BW pigs tending to consume more feed in D0-1 (P = 0.088; Table 2.4) but High BW pigs having greater ADFI overall (P = 0.058).

Table 2.3. Average daily feed intake (ADFI). Farrowing treatments were grouped by farrowing exposure (FarrExposure includes FarrUnderline and FarrWall). Treatments were arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

	FarrNo		FarrExposure		
Period, d	NursNo	NursSpray	NursNo	NursSpray	SEM
0-1	0.05	0.05	0.05	0.05	0.007
1-2	0.17	0.17	0.18	0.17	0.008
2-3	0.18	0.19	0.17	0.17	0.006
3-7	0.16	0.15	0.15	0.15	0.004
7-14	0.35	0.37	0.35	0.36	0.008
14-28	0.80	0.81	0.73	0.75	0.018
0-3	0.13	0.13	0.14	0.13	0.004
0-7	0.15	0.14	0.15	0.14	0.003
0-28	0.52	0.53	0.49	0.50	0.011

Table 2.4. Factor p-values for average daily feed intake with farrowing treatments grouped by farrowing exposure (FarrExposure includes FarrUnderline and FarrWall). Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low). $P \leq 0.05$ are in bold. $P > 0.1$ are shown as ns (not significant). Interactions are indicated with a dimension sign (×).

Period, d	FarrExp	NursTrt	BWBlock	FarrExp× NursTrt	FarrExp× BWBlock	NursTrt× BWBlock	FarrExp× NursTrt× BWBlock
0-1	ns	ns	0.088	ns	ns	ns	ns
1-2	ns	ns	ns	ns	0.062	ns	ns
2-3	ns	ns	ns	ns	ns	ns	ns
3-7	ns	ns	ns	ns	ns	ns	ns
8-14	ns	ns	ns	ns	ns	ns	ns
15-28	ns	ns	**0.019**	ns	ns	ns	ns
0-3	ns	ns	**0.044**	ns	0.062	ns	ns
0-7	ns	ns	ns	ns	ns	ns	ns
0-28	ns	ns	0.058	ns	ns	ns	ns

Combining FarrWall and FarrUnderline into the FarrExposure group resulted in an interaction trend in farrowing exposure and BW block. From D1-D2 farrowing exposure to the spray increased ADFI for High BW pigs, but lowered ADFI for Low BW pigs (P = 0.062; Figure 2.2).

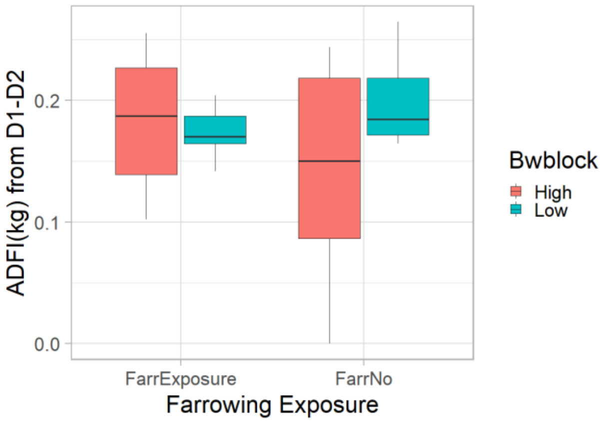

Figure 2.1. When FarrUnderline and FarrWall were grouped together as FarrExposure, there was a trend (P = 0.062) for an interaction between body weight block and nursery treatment in average daily feed intake (ADFI) from D1-D2. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

Overall, there were no clear trends in ADFI associated with the farrowing or nursery spray treatments. BW block had the greatest influence on nursery feed intake (Figure 2.2).

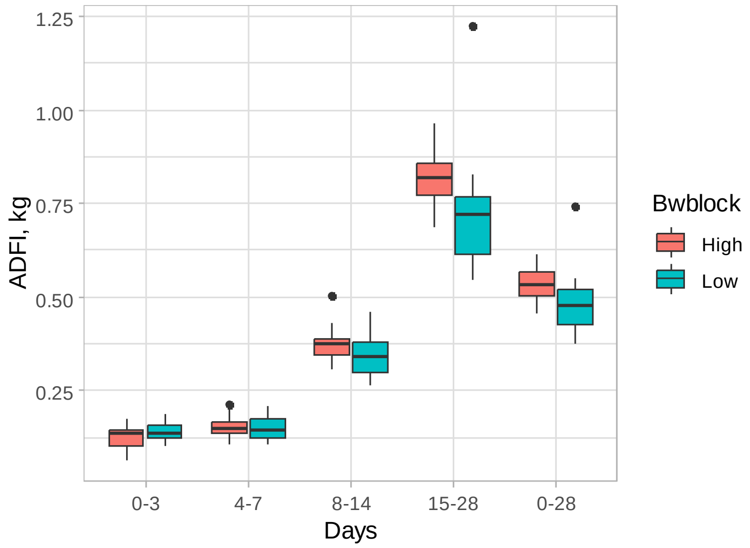

Figure 2.2. Average daily feed intake by bodyweight block. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

2.4.2 Average Daily Gain

Mean ADG values are presented in Table 2.5. No significant impacts of farrowing treatment on ADG pre- or post-weaning were detected, with the exception of an interaction with nursery treatment and BW block from D14-21 (Table 2.6).

Table 2.5. Average daily weight gain (ADG) by treatment. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low). Values are in kg.

	FarrNo		FarrUnderline		FarrWall		
Period, d	NursNo	NursSpray	NursNo	NursSpray	NursNo	NursSpray	SEM
(-3)-0	0.24	0.22	0.24	0.26	0.24	0.25	0.010
0-3	0.13	0.17	0.12	0.19	0.15	0.15	0.009
3-7	0.08	0.02	0.10	0.06	0.11	0.03	0.010
7-14	0.37	0.37	0.35	0.38	0.36	0.38	0.009
14-21	0.38	0.35	0.39	0.40	0.36	0.36	0.016
21-28	0.53	0.46	0.55	0.52	0.46	0.53	0.005
0-7	0.10	0.08	0.11	0.12	0.13	0.08	0.007
0-28	0.29	0.26	0.30	0.30	0.28	0.28	0.010

Table 2.6. Factor p-values for average weight gain (ADG). Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low). P ≤ 0.05 are in bold. P > 0.1 are shown as ns (not significant). Interactions are indicated with a dimension sign (×).

Period, d	FarrTrt	NursTrt	BWBlock	FarrTrt× NursTrt	FarrTrt× BWBlock	NursTrt× BWBlock	FarrTrt× NursTrt× BWlock
(-3)-0	ns	-	-	-	-	-	-
0-3	ns	0.068	**0.011**	ns	ns	ns	ns
3-7	ns	**0.004**	ns	ns	ns	ns	ns
7-14	ns	ns	**0.001**	ns	ns	ns	ns
14-21	ns	ns	0.055	ns	ns	ns	**0.049**
21-28	ns	ns	0.003	ns	ns	ns	ns
0-7	ns	ns	ns	ns	ns	ns	ns
0-28	ns	ns	0.001	ns	ns	ns	ns

From D0-D3 NursSpray ADG was 0.033 kg greater than NursNo (P = 0.068; Figure 2.4). However, from D3-D7 NursSpray average ADG was 0.054 kg less than NursNo (P = 0.004). This suggests that the attractant encouraged intake during the first three days when it was applied, but when application was stopped on D3 the change depressed intake. This decrease in feed consumption could be due to a decreased feed palatability, as the smell and taste provided by the attractant were no longer present within the feed. With a lack of olfaction influence, the pigs' voluntary feed intake tends to decrease (Jacela et al., 2010). There was no difference between nursery treatment groups from D0-D7 overall, suggesting that the early gains and subsequent lag of the NursSpray group offset making it equivocal with the NursNo group performance. It is notable that all treatment groups demonstrated greater ADG from D0-D3 compared to D3-D7, an unexpected result with no clear causation. There were no differences between nursery treatment ADG for the remainder of the nursery period.

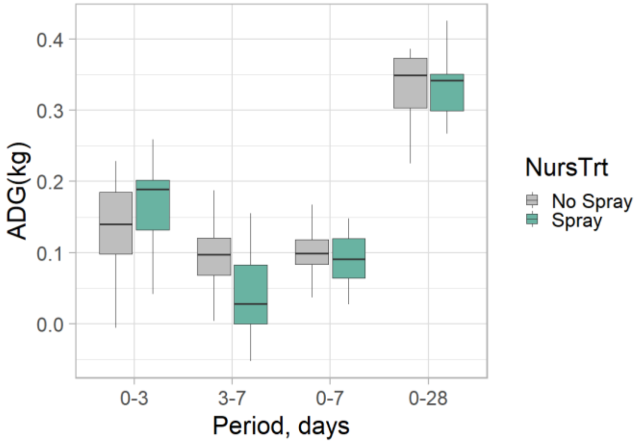

Figure 2.3. Average daily gain by time period and nursery treatment. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursS pray: spray, NursNo: no spray), and a bodyweight block (High or Low).

ADG was strongly impacted by BW block, with similar relationships as reported with ADFI (Figure 2.5). From D0-D3 Low BW pigs ADG was greater than High BW (P = 0.011; Low = 0.17 kg, High = 0.13 kg). There were no BW differences D3-D7, but by D7-D14 High BW group ADG was greater than Low (P = 0.0008). From D0-D28 overall, High BW pigs had greater ADG than Low BW pigs (P = 0.001).

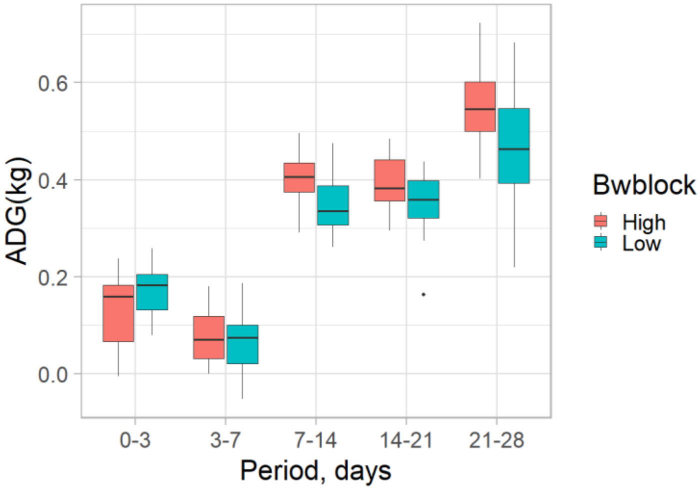

Figure 2.4. Average daily weight gain by bodyweight block. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

The only significant three-way interaction of farrowing treatment, nursery treatment, and BW block occurred from D14-D21 (P = 0.049). However, the final spray was applied on D3, making it unlikely that the spray treatments were still creating an impact on performance two weeks later. We hypothesize this interaction is an artifact of the relatively small sample size.

As there was no statistical difference due to farrowing treatments, the FarrWall and FarrUnderline groups were combined into a single group to test exposure to the spray in farrowing (FarrExposure) compared to the control of no spray (FarrNo; Table 2.7). Statistical analysis was performed as above for ADG (Table 2.8). Influence of nursery treatment and BW block remained the same as described above. From D0-D3 there was a trend for an interaction between BW block and farrowing exposure (P = 0.058), with a BW block difference within the FarrNo group (Figure 2.7). However, the two-way interaction trend from D7-D14 suggested the inverse, with a BW block difference within the FarrExposure group.

Table 2.7. Average daily weight gain (ADG) with farrowing treatments grouped by farrowing exposure (FarrExposure includes FarrUnderline and FarrWall). Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

	FarrNo		FarrExposure		
Period, d	NursNo	NursSpray	NursNo	NursSpray	SEM
(-3)-0	0.24	0.22	0.24	0.26	0.010
0-3	0.13	0.17	0.13	0.17	0.009
3-7	0.08	0.02	0.10	0.05	0.010
7-14	0.37	0.37	0.36	0.38	0.009
14-21	0.38	0.35	0.37	0.38	0.016
21-28	0.53	0.46	0.50	0.53	0.005
0-7	0.09	0.08	0.10	0.09	0.007
0-28	0.34	0.32	0.33	0.35	0.010

Table 2.8. Factor p-values for average weight gain (ADG) with farrowing treatments grouped by farrowing exposure (FarrExposure includes FarrUnderline and FarrWall). $P \leq 0.05$ are in bold. $P > 0.1$ are shown as ns (not significant). Interactions are indicated with a dimension sign (×). Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

Period, d	FarrExp	NursTrt	BWBlock	FarrExp× NursTrt	FarrExp× BWBlock	NursTrt× BWBlock	FarrExp× NursTrt× BWlock
(-3)-0	ns	-	-	-	-	-	-
0-3	ns	0.060	**0.005**	ns	0.058	ns	ns
3-7	ns	**0.005**	ns	ns	ns	ns	ns
7-14	ns	ns	**0.006**	ns	0.063	ns	ns
14-21	ns	ns	**0.030**	ns	ns	ns	0.058
21-28	ns	ns	**0.003**	ns	ns	ns	ns
0-7	ns	ns	ns	ns	ns	ns	ns
0-28	ns	ns	**0.002**	ns	ns	ns	ns

These trends suggest that in the first three days post weaning, pigs not exposed to the spray in farrowing (FarrNo) had a higher ADG when in the Low BW category compared to the High BW pigs. However, moving on to week 2 in the nursery (D7-D14), High BW pigs had a greater ADG when exposed to spray in farrowing (FarrExposure) vs Low BW pigs also exposed to spray. Farrowing treatment did not seem to have a significant impact on ADG, as well as general farrowing exposure did not have significant impacts on ADG. This indicates that regardless of spray location in farrowing or spray presence in general, applying a spray treatment in farrowing did not seem to impact ADG in the nursery. A limitation of this argument, however, is that both FarrExposure and FarrNo groups were housed in the same farrowing rooms. Though not directly receiving and consuming spray, FarrNo groups could have smelled the treatment coming from other stalls, potentially influencing study outcomes.

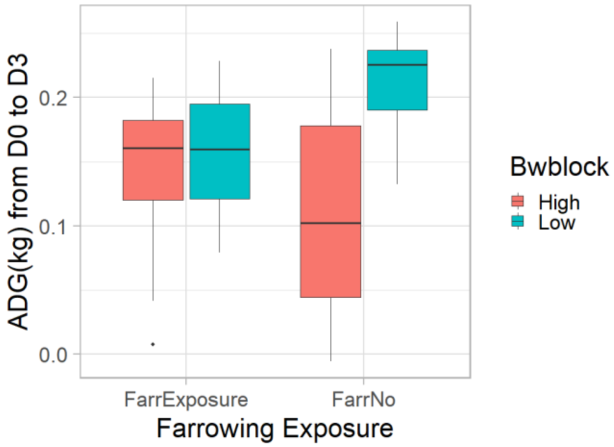

Figure 2.5. Average daily weight gain (kg) from D0 to D3 by farrowing exposure and bodyweight block. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

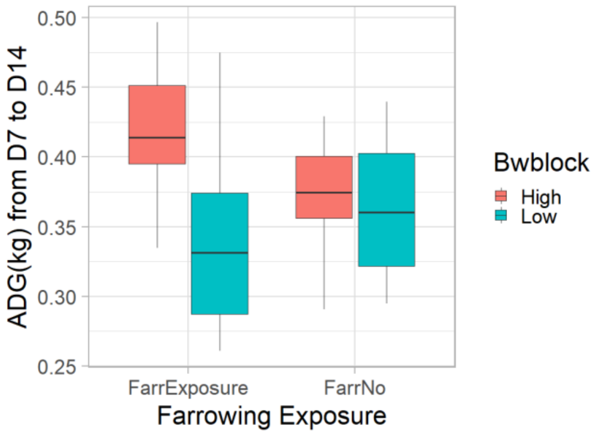

Figure 2.6. Average daily weight gain (kg) from D7 to D14 by farrowing exposure and bodyweight block. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

Overall, BW block had the greatest influence on ADG. This was expected as it was hypothesized that High BW groups would consume more than Low BW groups. The NursSpray treatment tended to improve ADG in the first three days after weaning when the attractant was being sprayed, but these early gains were offset by a decreased ADG for the first few days after the spray application ceased. This suggests that groups receiving NursSpray were no longer as interested in the feed once the treatment application ended, whereas NoSpray groups were not affected by a change in palatability.

After grouping the farrowing treatments based on exposure, FarrExposure does not seem to have an impact on nursery ADG. It was hypothesized that previous exposure to the spray attractant would improve nursery productivity. However, in the present study, previous exposure did not impact piglet ADFI or ADG. A similar study using a liquid feed attractant in farrowing and nursery to determine pre- and post-wean exposure effects on ADG and ADFI found that no statistical differences were observed for the pre-weaning application, and that no differences for the post-weaning application were observed (Wensley et al., 2022). However, Wensley et al. (2022) did observe treatment differences for the main effect of BW, with pigs in the heavy BW groups having an increased ADG as well as increased ADFI compared to pigs in the light BW groups. These findings agree with the results from the present trial, as by D28 High BW pigs had a higher ADG compared to Low BW pigs. One study by Figueroa et al. (2013) introducing anise and milky cheese flavorings to the sow's diet in the late stages of gestation found that pre-weaned piglets exposed to these flavorings preferred the flavor that was given to the maternal sow compared to other flavorings (Figueroa et al., 2013). Although the flavor additive was given initially to the sow and then to the piglets, it does suggest that flavor introduction during late gestation may impact piglet taste preferences (Figueroa et al., 2013). While our results did not definitively determine a significant impact of pre-wean exposure on nursery gain, other research indicates early exposure may influence taste preferences, which in turn could impact feed intake.

The salinity of the attractant could have potentially impacted ADG during the first three days when treatments were applied. Since each application of spray was roughly 60 mL twice a day for a pen of four pigs, each pig consumed 30 mL of spray each day. With the salt concentration in Nextein varying from 11-13%, each pig consumed approximately 3.96 grams to 4.68 grams of salt each day. For D0-D3, the mean ADFI for Low BW pigs was 139.7 grams of feed and 126.9 grams for High BW pigs. This means that for Low BW pigs, the addition of Nextein provided anywhere from 2.8% to 3.4% more salt than the original diet, and for High BW pigs provided 3.1% to 3.7% more salt. With the nursery diet including anywhere from 5-6% salt alone, this addition of salt is significant and could impact weight gain due to increased water intake.

2.4.3 Percentage of Pigs which Lost Bodyweight

The percentage of pigs within each pen that lost body weight from D0-D3 and D0-D7 was analyzed by treatment (Table 2.9). No statistical difference was associated with any of the factors or their interactions, including when farrowing treatments were grouped as FarrExposure (FarrWall+FarrUnderline). A small proportion of the pigs lost weight during these time periods, with the highest percentage of weight lost from D0-D7 being 17.9% by the FarrWall and NursSpray treatment. One study found that 28.7% of pigs weaned at 22 d of age and 35.1% of pigs weaned at 19 d lost weight within the first week of weaning (Faccin et al., 2019). Comparatively, the present study had a lower percentage of piglets (5.8% overall) that lost bodyweight. This is potentially due to production system differences, as the present study housed pigs in groups of four compared to 18 by Faccin et al. (2019). An additional potential cause is transportation, as our study transported pigs at weaning by handcart into the adjacent nursery building while the Faccin et al. (2019) did not describe their weaning transportation procedures.

Table 2.9. Average percentage of pigs that lost bodyweight after weaning. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

Period, d		FarrNo		FarrUnderline		FarrWall	
		NursNo	NursSpray	NursNo	NursSpray	NursNo	NursSpray
D0-D3	Avg, %	14.3	7.1	7.1	3.6	0.0	17.9
	SE	10.7	7.1	7.1	3.6	0.0	7.1
D0-7	Avg, %	7.1	7.1	7.1	3.6	0.0	10.7
	SE	7.1	7.1	4.6	3.6	0.0	7.4

2.4.4 Feeder Area Behavior

For Low BW pigs, groups receiving NursNo seem to have spent less time in the feeder area (average cumulative duration = 4278 s, SE = 152) compared to NursSpray pens (average cumulative duration = 467 s, SE = 134). Similar findings were observed with ADG, in which the NursSpray average ADG was 0.033 kg more than NursNo for D0-D3 (P = 0.068; Figure 2.4). Similarly, groups receiving NursNo also had a lower frequency of feeder area visits compared to the NursSpray group (Figure 10). For High BW pigs, it is notable that groups receiving FarrWall and NursSpray treatment had some of the lowest feeder area durations from all of the groups (Figure 2.9). This correlates with the weight loss data, as the greatest percentage of weight lost occurred in this same treatment group (loss of 17.9% from D0 to D7). The High BW pigs for the FarrWall and NursSpray treatment also had less frequency in the feeder area compared to other treatments (Figure 2.9).

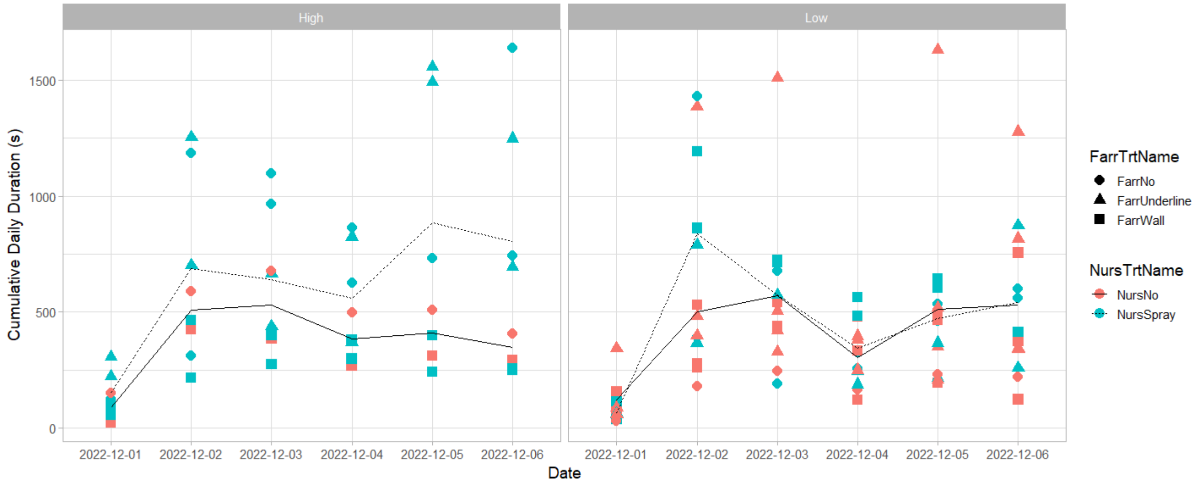

Figure 2.6. Cumulative daily duration (s) of visits to feeder area for pigs from D0 to D5 by bodyweight block, farrowing treatment, and nursery treatment. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

Figure 2.7. Frequency of visits to feeder area for pigs from D0 to D5 by farrowing treatment and nursery treatment. Treatments are arranged in a 3 × 2 factorial with main effects of: farrowing treatment (FarrNo: no spray, FarrUnderline: spray on sow underline, FarrWall: spray on wall), nursery treatment (NursSpray: spray, NursNo: no spray), and a bodyweight block (High or Low).

Overall, there was great variation in numerical feeder area behavior between individual pigs and between treatment groups. Pigs had lower frequency of feeder area visits and a lower cumulative duration of feeder area visits on D0, due in part to only having 15 h of observational data as pigs were placed in the nursery at approximately 09:00 on D0. However, the average frequency and duration of visits on D0 were 24.7% and 68.2% of the values on D1, suggesting that the lower feeder activity was not entirely explained by the shortened observation window.

2.5 Conclusions

Overall, there were no clear differences in ADFI associated with the farrowing or nursery spray treatments. BW block had the greatest influence on nursery feed intake and ADG. The NursSpray treatment tended to improve ADG in the first three days after weaning when the attractant was being sprayed, but these early gains were offset by a decreased ADG for the first few days after the spray application ceased. By D28 there were no differences between treatment groups. For Low BW pens, those receiving the NursNo treatment had both lower cumulative durations as well as lower frequency of visits in the feeder area. For High BW pens, those receiving the FarrWall and NursSpray treatments had both lower cumulative durations as well as lower frequency of visits in the feeder area. Nextein APF® may help Low BW pigs within the first few days post-weaning, but a more gradual cessation of spray application may be needed to limit the negative impacts of abruptly ending application demonstrated in this study. Future studies should investigate more gradual ending of spray applications of Nextein APF® in the nursery.

References

Adrion, F., Kapun, A., Eckert, F., Holland, E.-M., Staiger, M., Götz, S., & Gallmann, E. (2018). Monitoring Trough visits of growing-finishing pigs with UHF-RFID. *Computers and Electronics in Agriculture*, vol. 144, 2018, pp. 144–153, https://doi.org/10.1016/j.compag.2017.11.036

Andretta, I., Pomar, C., Kipper, M., Hauschild, L., & Rivest, J. (2016). Feeding behavior of growing–finishing pigs reared under precision feeding strategies. *Journal of Animal Science*, *94*(7), 3042–3050. https://doi.org/10.2527/jas.2016-0392

Dantzer, R. (2004). Cytokine-induced sickness behaviour: A neuroimmune response to activation of innate immunity. *European Journal of Pharmacology*, vol. 500, no. 1–3, 2004, pp. 399–411, https://doi.org/10.1016/j.ejphar.2004.07.040

Faccin, J. E. G., Laskoski, F., Quirino, M., Goncalves, M. A. D., Mallmann, A. L., Orlando, U. A. D., Mellagi, A. P. G., Bernardi, M. L., Ulguim, R. R., & Bortolozzo, F. P. (2019). Impact of housing nursery pigs according to body weight on the onset of feed intake, aggressive behavior, and growth performance. *Tropical Animal Health and Production*, vol. 52, no. 3, 2019, pp. 1073–1079, https://doi.org/10.1007/s11250-019-02096-6

Faccin, J. E., Laskoski, F., Hernig, L. F., Kummer, R., Lima, G. F. R., Orlando, U. A. D., Goncalves, M. A. D., Mellagi, A. P. G., Ulguim, R. R., & Bortolozzo, F. P. (2020). Impact of increasing weaning age on pig performance and belly nosing prevalence in a commercial multisite production system. *Journal of Animal Science*, vol. 98, no. 4, 2020, https://doi.org/10.1093/jas/skaa031

Garcia, A., Sutherland, M., Pirner, G., Picinin, G., May, M., Backus, B., McGlone, J. (2016). Impact of providing feed and/or water on performance, physiology, and behavior of weaned pigs during a 32-H transport. *Animals*, vol. 6, no. 5, 2016, p. 31, https://doi.org/10.3390/ani6050031

Holman, D. B., Gzyl, K. E., Mou, K. T., & Allen, H. K. (2021). Weaning age and its effect on the development of the Swine Gut Microbiome and resistome. *mSystems*, *6(*6), e00682-21. https://doi.org/10.1101/2021.05.20.444551

Hötzel, M. J., Machado Filho, L. C. P., Irgang, R., & Alexandre Filho, L. (2010). Short-term behavioural effects of weaning age in outdoor-reared piglets. *Animal*, *4*(1), 102–107. https://doi.org/10.1017/s1751731109990875

Kapun, A., Adrion, F., & Gallmann, E. (2020). Case study on recording pigs' daily activity patterns with a UHF-RFID system. *Agriculture*, *10*(11), 542. https://doi.org/10.3390/agriculture10110542

Le Dividich, J., and B. Sève. (2000). Effects of underfeeding during the weaning period on growth, metabolism, and hormonal adjustments in the piglet. *Domestic Animal Endocrinology*, vol. 19, no. 2, 2000, pp. 63–74, https://doi.org/10.1016/s0739-7240(00)00067-9

Matthews, S. G., Miller, A. L., Clapp, J., Plötz, T., & Kyriazakis, I. (2016). Early detection of health and welfare compromises through automated detection of behavioural changes in pigs. *The Veterinary Journal*, *217*, 43–51. https://doi.org/10.1016/j.tvjl.2016.09.005

Roldan-Santiago, P., Trujillo-Ortega, M., Borderas-Tordesillas, F., Marinez-Rodriguez, R., Mora-Medina, P., Flores-Peinado, S., Sanchez-Hernandez, M., Garcia-Herrera, R., Gonzalez-Lozano, M., Mota-Rojas, D. (2014).Physiometabolic responses to road transport in weaned piglets for a short period and the effects of straw bedding. *Animal Science Journal*, vol. 86, no. 5, 2014, pp. 563–571, https://doi.org/10.1111/asj.12324

Nextein APF®. *TechMix Global*, www.techmixglobal.com/product/nextein-apf/. Accessed 28 Sept. 2023.

Wensley, M. R., Tokach, M. D., Woodworth, J. C., Goodband, R. D., Gebhardt, J. T., DeRouchey, J. M., & McKilligan, D. (2021). Maintaining continuity of nutrient intake after weaning. II. review of post-weaning strategies. *Translational Animal Science*, vol. 5, no. 1, 2021, https://doi.org/10.1093/tas/txab022

Wensley, M. R., Tokach, M. D., Woodworth, J. C., Goodband, R. D., Gebhardt, J. T., DeRouchey, J. M., McKilligan, D., & Upah, N. (2022). Effects of providing sensory attractants to suckling pigs during lactation and after weaning on post-weaning growth performance. *Translational Animal Science*, vol. 7, no. 1, 2022, https://doi.org/10.1093/tas/txac170

CHAPTER THREE: FEASIBILITY OF UHF-RFID SYSTEM IN DETECTING NURSERY PIGS MOVING THROUGH A HALLWAY

R. Hodges, S.M. Leonard

Department of Animal Science, North Carolina State University, Raleigh, NC, USA

3.1 Abstract

Counting pigs accurately is an important part of maintaining animal inventories, reporting production metrics, and planning for downstream functions. Manual counting is time consuming and error-prone, making automated technology counting methods attractive alternatives for swine producers. This study evaluated a commercial ultra-high frequency radio-frequency identification (UHF-RFID) system's performance in counting nursery pigs moving through a hallway. Preliminary testing involved general equipment testing to ensure all tags were detectable by all readers, followed by evaluating different reader settings and positions to determine the most reliable configurations. Through preliminary testing it was determined that a maximum read power of 25 was the most suitable for this experiment. Furthermore, three reader positions achieved similar tag detection accuracies: Low (height of 0.25 m and perpendicular to floor), Mid-Perp (height of 0.64 m and perpendicular to floor), and Mid-Angle (0.64 meters and angled 30 degrees towards the floor). These three positions were selected to be used in field testing. For field testing, a total of 39 nursery pigs were given RFID ear tags and placed into four groups. Three RFID readers were mounted on the same side of the nursery hallway, all at a read power of 25. A RGB camera was secured to the ceiling over each RFID reader to record the movements of the groups in order to investigate tag non-detection events. To identify pigs in the videos, pigs were uniquely marked with livestock paint. Each group was walked past the RFID readers a total of 10 times, 5 passing on the left and 5 passing on the right. This was repeated for

all reader positions (Low, MidPerp, and MidAngle). It was found that reader location within the room influenced tag detection accuracy. The middle reader at the Mid-Angle and Mid-Perp positions had higher proportions of detection (0.777) compared to the Low position. For this position, the right side movements (i.e., eartag on the same side of the pig's body as reader) had a greater detection proportion compared to the left (0.400 and 0.377, respectively). This suggests that readers should be placed in the middle of the aisle length to allow for free-flowing pig movement, and readers should be on the same side of the pig as the ear tag while the reader is in the Mid-Angle position for the greatest detection proportions. Future work should focus on continued testing of different configurations to determine what will yield the highest accuracy and precision. With additional improvements, the commercially available RFID system shows the potential to be an affordable and easily-operated automated counting system for producers.

3.2 Introduction

Maintaining pig inventory in a facility is an important part of production management. There are multiple times in the production cycle in which a pig inventory is necessary. Inventories are required when moving pigs into a new facility, loading onto a truck to be transported, and loading off a truck when taken to harvesting facilities. Manual counting of pigs by caretakers is the most common method of obtaining inventory records when moving pigs. However, manual counting is a tedious process that leaves room for errors such as missing a pig or double-counting, leading to inaccurate production records and potential monetary losses for producers. Counting errors are especially likely with young pigs, as they are smaller, move more quickly, and can turn around more easily in alleyways than older pigs. Manual counting can also be time consuming, as a standard 2,000 head commercial batch farrow sow farm may wean upwards of 1,000 pigs in a single day (MetaFarms Inc, 2020). An automated counting method could replace human counting and provide faster, more accurate inventory data compared to manual counting. This faster inventory collection can reduce input costs through a potential decrease in labor costs (Bouazza et al., 2017).

Current commercially available automated pig counting technologies include systems such as Ro-Main SmaRt Counting, which utilizes a digital camera to identify and count pigs moving in the camera’s view. While a minimum accuracy of 99.9% is guaranteed, the system is not an affordable option for the average producer and requires permanent installation (Conception Ro-Main Inc). One automated pig counting system not yet commercially available, EmbeddedPigCount, demonstrated a counting accuracy of 99.44% (Kim et al., 2022). Though this system achieves high accuracy, testing with different flooring and lighting conditions was not conducted in this study. Automated counting systems using cameras may not work as well at night or in dim settings as the system relies on clear visuals to accurately count the pigs. Furthermore, there is no unique pig identification with EmbeddedPigCount. This limits the caretaker’s ability to collect data and track pigs on an individual basis. Since lighting can vary greatly from barn to barn, a system that can track on an individual basis without relying on video may be a better option for automatically counting pigs. Radio-Frequency Identification (RFID) could be an alternative to manual counting or video systems.

RFID is a technology that automatically detects uniquely numbered RFID tags when in the range of the corresponding reader. RFID systems are commonly used by stores, companies, and manufacturing facilities to track and locate merchandise and equipment (Wu et al., 2019). RFID technology has been used in hospitals to track not only medical equipment but also patients and staff (Fry & Lenert, 2005). The demonstrated success of RFID for tracking equipment and humans within a facility show the potential to be used in livestock production to identify animal movement and location within the barn, though this use is not widespread in industry. A more common use of RFID technology in livestock production is to monitoring feeding, drinking, nesting, and other social behaviors, which may be difficult to manually identify by visual observation alone (Matthews et al., 2016). With the ability to quantify behavior by recording animals at an individual level (Andretta et al., 2016), RFID is a suitable contender for obtaining pig inventory counts.

Commercially available RFID reader costs vary from approximately $900 - $2,000 USD and typically require the purchase of additional software licensure. One-time use RFID ear tags for swine cost $2 each. Though the reader and ear tag prices are not insignificant compared to standard ear tags, improvements in counting accuracy and labor reduction can provide additional value to production. Readers are relatively easy to install and piglets can be ear tagged during the normal piglet processing procedure, meaning this system does not drastically increase required labor to install or use. Further, RFID systems are not as sensitive to dust and dirt buildup as camera systems, meaning the RFID technology would not need to be cleaned as frequently.

The frequency ranges most commonly used in RFID systems are low frequency (LF, 125 kHz or 134.2 kHz), high frequency (HF, 13.56 MHz), and ultra-high frequency (UHF, 860-960 MHz; Kapun et al., 2020). When determining which RFID frequency to use, multiple aspects must be considered. Although LF RFID readers are suggested for use in environments with metal and water due to a decreased sensitivity to radio wave interference, these readers have a limited read range up to 10 cm (Wallace et al., 2020). As most commercial swine barn hallways are a minimum of 60 cm wide, a greater detection range is needed. Although HF systems have a standard range of 10 cm to 1 m, these tags often provide a range of 10 cm or less (Wallace et al., 2020). Thus, an UHF-RFID system with a read range of up to 1,000 cm may be the best option.

The objective of the present study was to evaluate the feasibility of a commercially available UHF RFID system to count nursery pigs moving along a hallway.

3.3 Materials and Methods

The protocol for this experiment was approved by the North Carolina State University Institutional Animal Care and Use Committee.

3.3.1 Preliminary Testing

General equipment testing

Preliminary testing began with a general equipment test to ensure all tags were detectable by all readers being evaluated. This was to prevent misleading results caused by faulty equipment and to limit tag-to-reader issues. All preliminary testing was performed in an indoor, climate controlled laboratory with excess equipment and supplies removed from the testing area. An RFID reader (Model #216030, GAO RFID Inc. Toronto, Canada) was placed on a table facing directly upwards and each tag was individually suspended over the reader at a distance of approximately 25 cm to ensure that the reader could identify the tag from a close distance. This was repeated for 42 available tags and for four readers. All tags were detected at each reader and tag combination, demonstrating that the equipment worked as expected in a simple reader orientation and small tag-to-reader distance.

Individual readers and reader positions

The preliminary testing evaluated four reader positions. The first position tested was the reader centered at a height of 0.25 m and facing perpendicular to the floor (Low; Figure 1). The

Low position was used to determine how well the reader performed at a height similar to the anticipated height of the pigs. The second position tested was the reader centered at a height of 0.64 m and facing perpendicular to the floor (Mid-Perp). Oriented in the same manner as the Low position, the Mid-Perp position was selected to determine if a greater reader height impacted detection rates. The third position evaluated was the reader centered at a height of 0.64 m and at a 30° downward angle (Mid-Angle). The fourth position tested was reader centered at a height of 0.91 m and at a 30° downward angle (High-Angle). The Mid-Angle and High-Angle positions were used to evaluate if angling the reader towards the pigs influenced detection rates, and if height was a limiting factor with these positions.

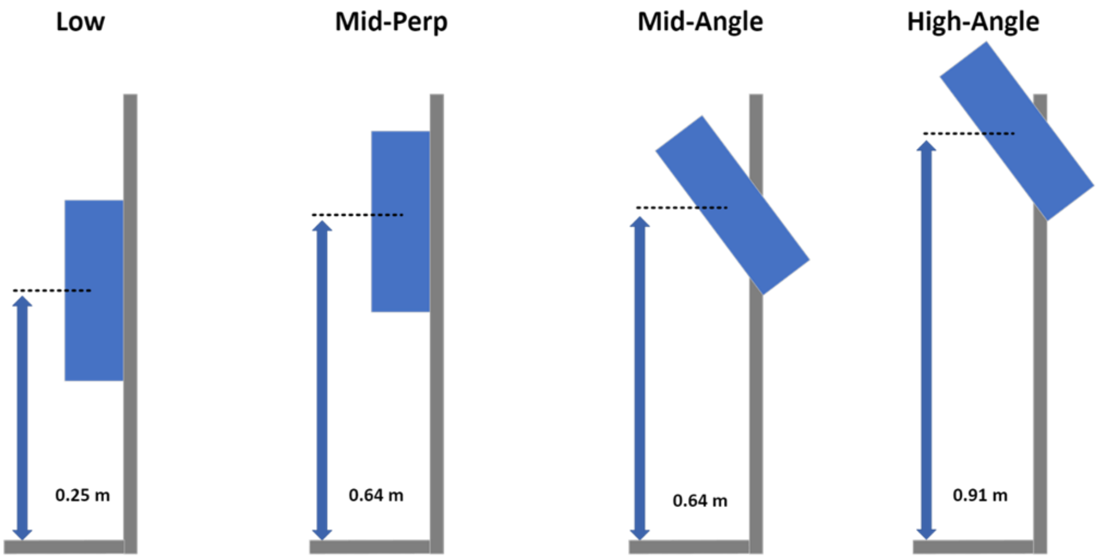

Figure 3.1. Illustration of the RFID reader (illustrated by blue rectangle) positions that were tested in the controlled laboratory environment, highlighting the distance from the ground to the middle of the reader. Both the Low and Mid-Perp positions were perpendicular to the floor, with the Low position being 0.25 m from the ground and Mid-Perp 0.64 m from the ground. The Mid-Angle position was also 0.64 m from the ground, but tilted at a 30° angle towards the floor. The High-Angle position was also angled 30° towards the floor, but at a height of 0.91 m from the ground.

Read power

The read power setting of the RFID reader was another aspect to be evaluated. With an integer range of read powers from 1 to 25, the two read power options tested were 15 and a max power of 25 to determine the optimal setting. Too low read power could limit detection of tags, while too high read power could detect pigs in surrounding pens or areas near the RFID reader that are in range but not in the targeted group.

Preliminary testing configurations

One at a time, each RFID reader was fastened to the wall in the Low position and set to a read power of 15. An RFID tag was placed approximately 2.03 m directly in front of the reader at a height of approximately 0.31 m and slowly moved forward towards the reader. The tags were held with the identification number facing the reader. A taped line on the floor allowed for the tag to be moved in a straight line directly perpendicular towards the reader. Tags were moved closer until the reader was able to detect the tag and this distance was recorded. The process was repeated five times for each tag and a total of five randomly selected tags were used. After all tags and replicates were completed, the read power was increased to 25 and the process was repeated. When the Low position testing was completed, the reader was re-positioned to the Mid-Perp position, followed by the Mid-Angle and then the High-Angle. All positions were tested for all four readers at both a read power of 15 and a read power of 25 using the same five tags for a total of 32 setup combinations (4 readers × 4 positions × 2 read power settings). The average distance of tag first detection was used to determine what read power, positions, and readers would be used in field testing. With the nursery hallway width of 0.89 m for field testing, it was critical to ensure the selected configurations could detect tags at this distance.

3.3.2 Field Testing

Pig Grouping

A total of 39 pigs were selected for use at the North Carolina State University Swine Education Unit in Raleigh, North Carolina. The original experimental design prescribed 40 pigs; however, only 39 ear tag backs were available for use at the time of testing. The experiment was conducted the day after weaning when pigs were approximately 22 d of age. Each pig was given an RFID ear tag with a unique identification number in the right ear. The ear tag was placed in the middle of the ear with the RFID transponder on top of the ear. Pigs received generic ID tags in their left ear prior to being placed in the nursery. Individual pig height and bodyweight measurements were recorded, with height being measured from the floor to the top of the shoulders. Based on bodyweight, the pigs were divided into four groups, with three groups of 10 pigs (Groups 1-3) and one group of 9 pigs (Group 4). Livestock paint was used to provide each pig with unique markings within group for video playback identification.

RFID set-up

Three RFID readers (GAO RFID Inc.) were securely fastened to one side of the hallway in between two rows of nursery pens (Figure 2). The pen sides were comprised of metal gating and wire mesh and the hallway floor was solid concrete. One reader was mounted at the front of the nursery aisle (R1), one in the middle of the aisle (R2), and one at the end of the aisle (R3; Figure 1). Readers were at least 1.8 m apart and 2.4 m from each end of the hallway, though distances between readers and ends of the hallway were inconsistent due to limitations of hallway construction. All readers started in the Low position and all reps were completed for every group before changing to the Mid-Perp position, followed by the Mid-Angle position (Figure 2). To download and store the RFID data, the RFID readers were connected to a laptop with the RFID software. As two laptops were available for testing, only two readers were able to connect and record data simultaneously. After completing the passes for R2 and R3 simultaneously, one laptop was connected to R1 and the groups completed the same number of passes for this reader.

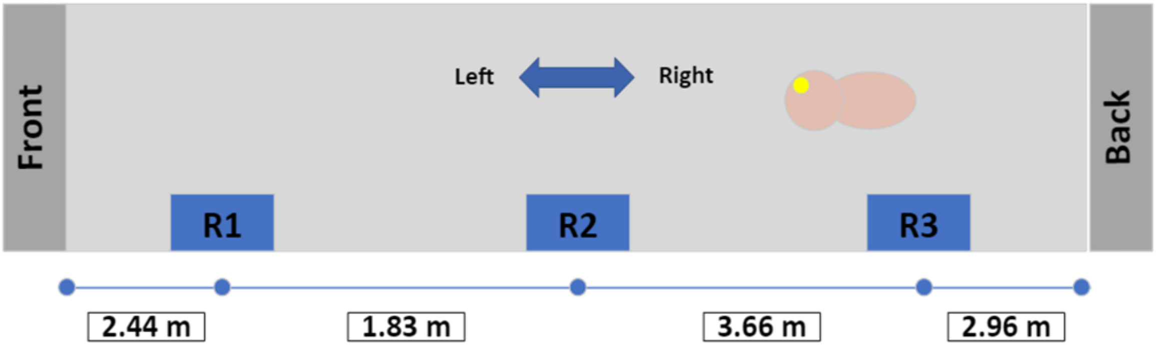

Figure 3.2. Illustration of nursery hallway layout, RFID reader locations (R1, R2, and R3), and pig movement. R1 was closest to the front of the nursery hallway, followed by R2 and then R3 which was closest to the back. Pigs were moved in groups of 9-10 to the left and to the right, with each having an RFID ear tag in the right ear.

Cameras

Three video cameras (Brave 7, AKASO Tech LLC) with a frame rate of 30 frames/second and 3840 × 2160 resolution were securely fastened to the ceiling over the hallway, one above each RFID reader. The cameras recorded video of the movements for each group. Using the livestock paint marks corresponding to a unique RFID tag number, each pig was identified in the video recordings to further investigate factors that may have contributed to tag detection failures.

Five potential tag detection failure categories were developed (Table 3.1). Proximity between tag and reader is known to influence RFID performance (Maselyne et al. 2014a), so the first category of Distance represented instances when the missed tag was more than halfway across the width of the hallway when passing in front of the reader (i.e., more than 0.445 m away from the reader). The Pig Obstruction category described instances when one or more other pigs were located in the line-of-sight between the tag and the reader. Pigs traveling at a fast rate of speed were labeled as Running, as faster movement resulted in less time the tag spent within the detectable range of the reader. Atypical movement conditions not well described by Distance, Pig Obstruction, or Running were specified in the Other category, while if the undetected tag did not meet any of the above criteria the unidentified tag occurrence was labeled as Unclear. Distance, Pig Obstruction, Other, and Running were not mutually exclusive categories, meaning that a pig which was more than halfway across the hallway and was running would be labeled as Distance and Running. Unclear was the only exclusive category.

Table 3.1. RFID tag detection failure categories and their definitions.

Category	Definition
Distance	Tag is over halfway across the middle of the hallway (0.445 m) when passing reader
Pig Obstruction	At least one pig is between the tag and the reader when passing reader
Running	Pig appears to be running when passing reader
Other	Characteristics that are not typical but could impact system performance
Unclear	No noticeable characteristics to prevent detection

Movement of Groups

Starting with Group 1 and reader position Low, the pigs were moved along the length of the hallway a total of 10 times, five passes to the left and five passes to the right. The same caretaker walked the pigs for each pass using a single sorting panel. Once the data were recorded for all readers, Group 1 was placed back in their home pen and this process was repeated for the rest of the groups. After all four groups were complete, all three RFID readers were re-positioned to the Mid-Perpendicular height and the process was repeated. Upon completion of the Mid-Perpendicular height, the readers were re-positioned to the Mid-Angle height and the same process was completed at this position.

3.4 Results and Discussion

3.4.1 Preliminary Testing

For preliminary testing, five randomly selected tags were used to evaluate performance with a combination of readers, reader positions, and read powers. To investigate tag variability, the average distance of tag detection was considered for all positions (Figure 3.3). The greatest average distance was tag #058 at 103.11 cm, and the lowest average distance was tag #085 with an average distance of 93.45 cm. Average detection distance by tag differed by less than 10 cm across all five tags, demonstrating that the tags performed similarly.

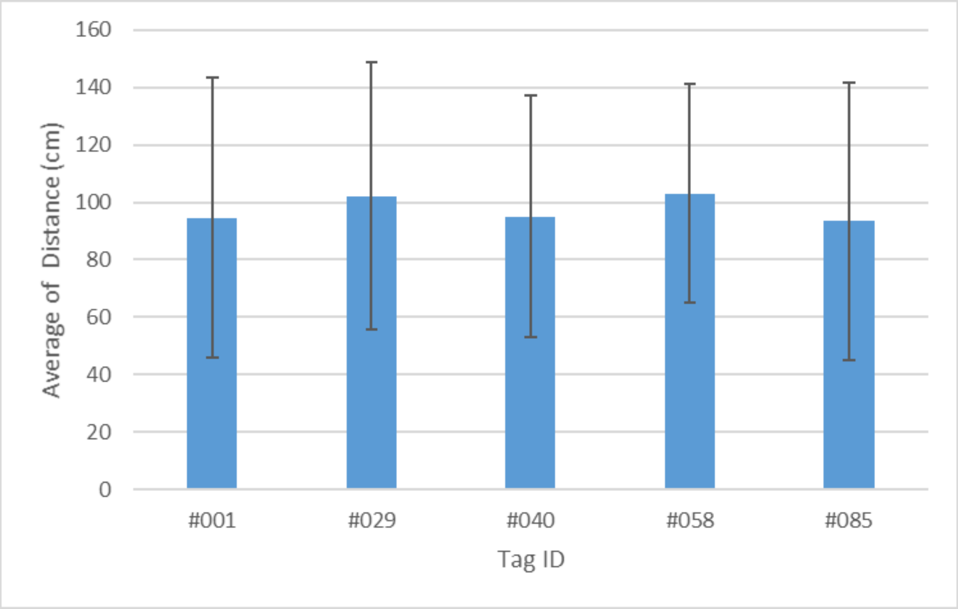

Figure 3.3. Average detection distance for each RFID tag during preliminary testing. Data are averaged over five replicate tests per tag at each of 32 setup combinations (4 RFID readers × 4 positions × 2 power settings).

All four reader positions were evaluated at read powers of 15 and 25, and the results determined what setting to utilize for field testing (Figure 3.4). As expected, the read power of 25 had greater average detection distances for each position. While the target minimum detection distance was 0.89 m, this was not achieved for any of the positions at 15 read power. To ensure the greatest detection accuracies, a power of 25 was chosen for field testing.

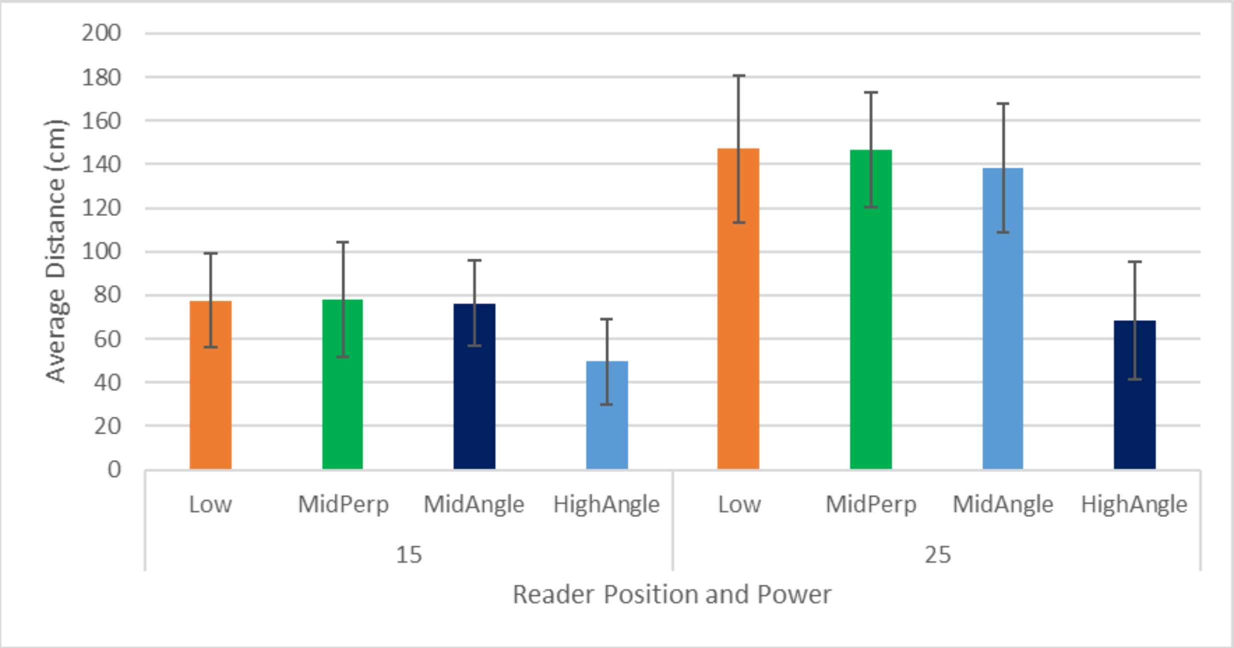

Figure 3.4. Average tag detection distance for each reader position at a read power of 15 and a read power of 25.

With the exception of the High-Angle position, all positions averaged greater than 0.89 m for their maximum distance at a power of 25. Further, the High-Angle consistently had the lowest detection distance out of all four position options during preliminary testing, while the remaining three positions performed similarly. It is hypothesized that the High-Angle position was at too great a distance from the tags for reliable detection. Thus, the Low, Mid-Perp, and Mid-Angle positions were chosen for field testing.

Four readers were used during preliminary testing and the three highest-performing readers were selected for field testing. As seen in Figure 3.5, Readers 1, 2, and 3 performed similarly with overall average detection distances of 101.75 cm, 103.25 cm, and 102.36 cm, respectively. Reader 4 had consistently lower detection distances with an average of 83.46 cm, and it is hypothesized that potential manufacturing flaws contributed to the reader's poor performance. Consequently, Readers 1, 2, and 3 were chosen for field testing to ensure the readers selected were not merely the highest performing, but also the most similar performing to reduce intra-reader variation that could skew results.

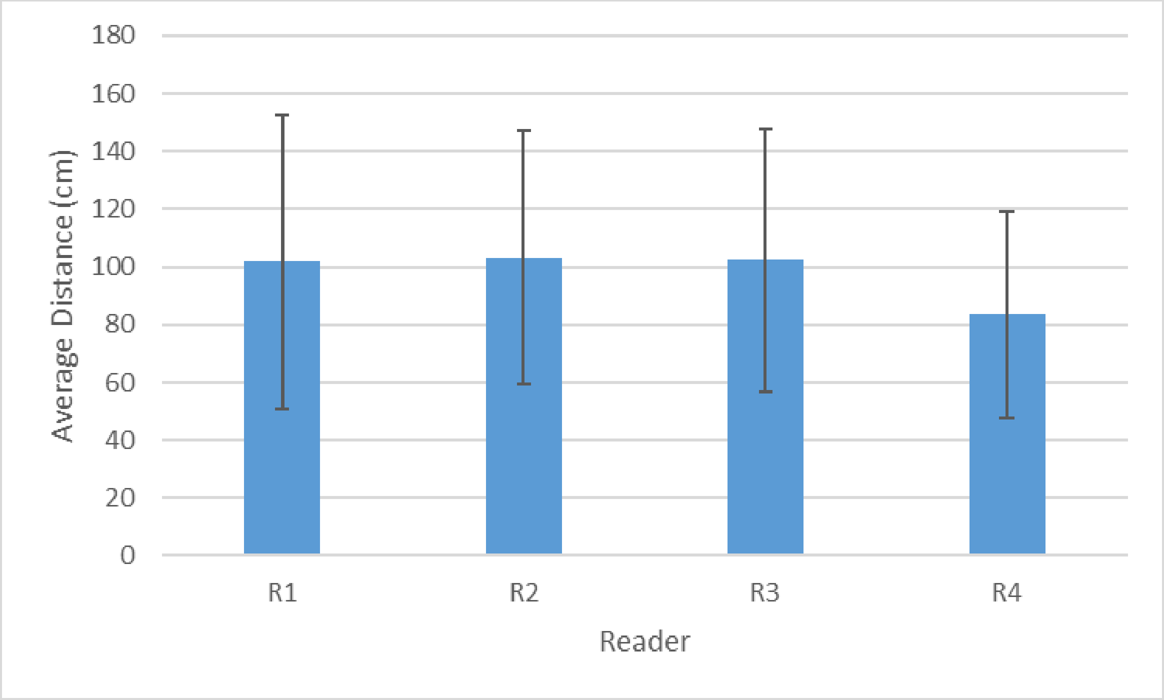

Figure 3.5. Overall average distance of maximum detection for each RFID reader. Data are averaged over 5 replicate tests at 40 setup combinations (5 RFID tags x 4 positions x 2 power settings).

3.4.2 Field Testing

Reader Comparison Results

All field test detection accuracies are reported as proportions (Table 3.2). R2 and R3 had the greatest overall proportion of detection in the Low position, with a mean proportion of 0.744 and 0.521, respectively. Since the Low position was at a height of 0.25 m compared to the Mid positions' height of 0.64 m, the Low position was closer in height to the pigs. This could have contributed to the Low position's detection rates since there was less distance from tag to reader compared to the other two positions tested. R2 had the highest overall proportion in both the Mid-Perp and the Mid-Angle positions, with mean proportions of 0.703 and 0.777 respectively.

Table 3.2. Proportion of Detection for each Reader and Position for Overall Passes, Left Passes, and Right Passes.

		Overall		Left		Right	
Reader	Position	Mean Proportion	SD	Mean Proportion	SD	Mean Proportion	SD
1	Low	0.403	0.193	0.441	0.120	0.364	0.119
	Mid-Perp	0.333	0.233	0.503	0.139	0.164	0.088
	Mid-Angle	0.333	0.151	0.344	0.110	0.323	0.144
2	Low	0.744	0.152	0.646	0.104	0.841	0.095
	Mid-Perp	0.703	0.241	0.754	0.137	0.651	0.133
	Mid-Angle	0.777	0.194	0.754	0.118	0.800	0.115
3	Low	0.521	0.221	0.436	0.141	0.605	0.137
	Mid-Perp	0.277	0.203	0.277	0.111	0.277	0.127
	Mid-Angle	0.372	0.179	0.323	0.121	0.421	0.117

It is evident that R2 had the greatest overall mean proportions for every position tested. Specifically, the greatest overall proportion recorded during this testing was R2 in position Mid-Angle with a mean proportion value of 0.779. The lowest overall proportion recorded was R3 in position Mid-Perp, with a mean proportion value of 0.277. In the field test R2 performed substantially better than R1 and R3; the lowest configuration performance by R2 (0.703) was greater than the highest performances by R1 and R3. Preliminary testing proved the three readers performed comparably in a more controlled testing environment, thus reader location within the barn hallway is likely one of the causes for the differences in overall detection proportions between readers. As seen in Figure 1, R2 was located in the middle of the hallway length, with R1 and R3 located towards the ends of the hallway. When pigs were walked, crowding most likely occurred at R1 and R3 as groups slowed down approaching the end of the hallway. R2 was in a location where pig movement was most likely most uniform, providing optimal detection conditions. Adding to this, directionality could have had an impact on performance from reader to reader. If starting at R1 and being moved towards R3, more crowding could have occurred around R3 as the pigs were led to the end of the hallway and quickly moved away from R1, potentially impacting reader results.

3.4.3 Left versus Right Passes

As ear tags were placed in the right ear for each pig, it was expected that right passes would have greater detection accuracies compared to left passes. The body of the pig itself between the tag and the reader was thought to limit tag detection of the left passes; however, mixed results were found. For R1, the left passes had higher mean proportions for all three reader positions. R2 had greater detection proportions for the left passes for the Mid-Perp position, while the Low and Mid-Angle positions had better performance on the right. R3 had greater detection proportions on the right for the Low and Mid-Angle positions, with the Mid-Perp position performing the same for both the left and the right.

3.4.4 Group Comparisons

Smaller pigs were expected to have lower detection rates compared to taller, larger pigs. However, there was little variation in tag detection performance between the four groups of pigs. Group 1 had the greatest average height and bodyweight (0.301 m and 8.57 kg) while Group 4 had the lowest average height and bodyweight (0.258 m and 4.68 kg). For overall detection, Group 4 had the greatest proportion (0.563), followed by Group 2 (0.492), Group 1 (0.484), and Group 3 (0.451). For Groups 1 and 4, higher detection was seen on the right (0.516 and 0.565, respectively) while Groups 2 and 3 had higher detection on the left (0.496 and 0.487, respectively). Group 4 had the highest detection proportion (0.563) while also having the smallest pigs regarding both height and body weight.

Table 3.3. Average height and bodyweight of each group and their average proportion of tag detection.

	Average Height (m)		Average Weight (kg)		Total Passes		Left Passes		Right Passes	
Group	Mean	SE	Mean	SE	Mean Proportion	SE	Mean	SE	Mean	SE
1	0.301	0.003	8.57	0.176	0.484	0.027	0.228	0.015	0.258	0.016
2	0.293	0.004	7.74	0.083	0.492	0.030	0.248	0.017	0.244	0.018
3	0.279	0.005	5.82	0.217	0.451	0.027	0.243	0.014	0.207	0.017
4	0.258	0.003	4.68	0.085	0.563	0.032	0.280	0.017	0.283	0.019

It is important to note that there was little variation in height between groups, with the difference between tallest and shortest group being only 4 cm. Additionally, Group 4 had nine pigs compared to ten pigs in the other groups, confounding the potential impacts of pig size and group size. While Group 4 had the greatest tag detection accuracy with the smallest pigs in the study, the detection performance differences were marginal and no obvious trends we observed due to pig bodyweight and height.

3.4.5 Failed Tag Detection Categories

Pigs were uniquely marked with livestock paint and group movements were video recorded to investigate individual pig positions and identify potential reasons for failed tag detection events (Figure 6). The videos were reviewed to better understand what characteristics were present during events of no detection, and the most common categories were classified (Table 3.1). The characteristics for no detection events for the overall highest performing reader and position combination (R2, Mid-Angle, right passes) are shown in Table 3.4. Due to equipment failure, no video was recorded for Group 4 and failure categories were thus unavailable. Through video analysis, it is suggested that pig interference, fast movement past the reader, and distance from the reader all limited tag detection rates.

Table 3.4. RFID tags that were not detected at the highest performing reader configuration (R2, Mid-Angle Position, right passes) were further investigated using video footage to determine potential cause.

	Group			
Category	**1**	**2**	**3**	**4[1]**
Number pigs per group	10	10	10	9
Total number non-detections	13	7	24	3
Distance[2]	5	2	14	-
Pigs Obstruction[3]	7	4	11	-
Running[4]	12	0	3	-
Unclear[5]	0	2	8	-
Other[6]	0	0	1	-

[1] Video data unavailable for category labeling

[2] Tag is over halfway across the middle of the hallway (0.445 m) when passing reader.

[3] At least one pig is between the tag and the reader when passing reader

[4] Pig appears to be running when passing reader

[5] No noticeable characteristics to prevent detection

[6] Characteristics that are not typical but could impact system performance

With five right passes per pig in the Mid-Angle position for R2 on the right side, Groups 1, 2, and 3 had 50 possible detection events while Group 4 had 45. Group 1 had a total of 13 instances of failed detection, with five of these instances being characterized by the tag being over halfway across the hallway. Furthermore, seven of the instances of failed detection occurred when at least one pig was in between the tag and the RFID reader while the pig passed. Instances of crowding can lead to more pig body interference, which is known to decrease detection rates of tags. In a related study using an RFID system monitoring feedings, a large pig density led to undetected tags and influenced system accuracy, solidifying the idea that pig interference likely impacted system performance (Adrion et al., 2018). Running was noted in 12 of the 13 failed detection events.

For Group 2, there were a total of seven instances of no detection at R2 Mid-Angle position on the right side. Distance accounted for only two of these events, while four of these events were characterized as Pig Obstruction. Two of the failed detection events were characterized as Unclear, with no obvious reason as to why the tag was not identified.

Group 3 had a total of 24 failed detection events for R2 in the Mid-Angle position on the right side. Of the 24 events, 14 were characterized as the tag being halfway across the hallway, 11 with at least one pig between the tag and the reader, and three with the pig running while passing the reader. The Unclear category was applied for eight of the 24 events, and Other for one of the events. The Other event was described as a pig moving in a zig-zag formation while passing the reader, which could have contributed to the failed detection.

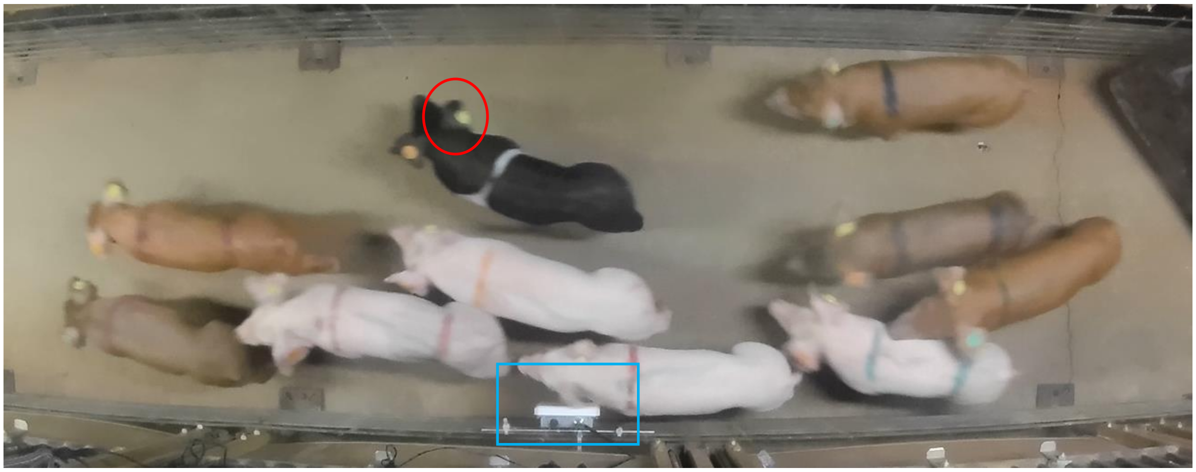

Figure 3.3. Cameras were placed over each RFID reader (blue square) to obtain aerial video of pig movements. Each pig received a unique livestock paint marking corresponding to their unique RFID tag number to identify pigs for validation purposes. Each pig had a yellow RFID tag in their right ear (red circle). These videos allowed for further analysis of pig and tag positions that may have prevented detection by the RFID system.

When comparing the RFID system used in the present study to other automated counting systems, the system reveals capabilities to compete as well as clear areas of improvement. For example, one of Ro-Main SmaRt Counting’s selling points is installation of hardware within a barn, with the ability to move the hardware into a new barn if necessary (Conception Ro-Main Inc). The RFID system requires minimal installation of equipment, with the ability to move the system from barn to barn within minutes, making this a versatile automated counting option. Another benefit of Ro-Main SmaRt Counting is the system’s ability to distinguish between humans and pigs, ensuring no humans will be counted when walking under the camera (Conception Ro-Main Inc). The RFID system also ensures that only pigs will be counted through the use of RFID tags, preventing any incorrect counting of other objects. With some automated counting systems such as Ro-Main, a subscription is necessary to have continued access to the system software (Conception Ro-Main Inc). The RFID system in the present study requires a one-time purchasing fee of the software, making this option potentially more affordable long-term. In terms of data, RFID competes with Ro-main SmaRt Counting in that both systems provide real-time data to producers through the use of technology. Lighting is another factor that can greatly impact automated counting systems, specifically those that used cameras to captures images of pigs. Using deep learning to count pigs poses challenges in achieving high accuracy, such as the impact of light variations and other light conditions such as backlight and side light (Zhou 2022). Even varying pig postures can challenge deep learning systems to detect pigs (Zhou 2022). However, with the RFID system, light is not an issue as the readers detects tags via signals rather than using imaging to identify pigs.

The RFID system for pig counting applications has notable limitations as well as areas of improvement. This system is limited in that it can only detect a tag that has been within reader range rather than the direction the pig is moving, whereas most computer vision systems can count or discount pigs passing based on the direction they are moving through the hallway (Conception Ro-Main Inc). It cannot be overlooked that Ro-Main SmaRt Counting system has a guaranteed minimum accuracy of 99% while the RFID system was only able to achieve at maximum an accuracy of 77.9% in this study. However, through identification of failure categories and continued research and modifications to the system, this off-the-shelf RFID system shows potential to improve in both accuracy and precision.

Since R2 Mid-Angle had the highest overall detection, it is suggested to have the reader away from the end of the hallway to reduce bunching and unwanted pig overlap. Furthermore, the Mid-Angle position proved to have the greatest detection rate for this reader, although the Low and Mid-Perp positions performed similarly in both laboratory and field settings. This suggests that reader position may not be as important as reader location. A maximum read power of 25 is also recommended as a lower power would have likely resulted in lower detection rates. In general, use of this UHF RFID system should be limited to distances of approximately 100 cm. It is also suggested to move pigs in a single file line to decrease instances of pig interference, while also limiting running and fast movements that may prevent tag detection. The stage of production pigs are at may impact detection, as reader height may need to be adjusted for taller pigs in later production stages (Maselyne et al., 2014a). Due to differences in height at the different production ages, readers should be adjusted accordingly to maintain system accuracy (Maselyne et al., 2014b). Furthermore, using two RFID tags instead of one may improve accuracy, though this option increases input price of the system (Maselyne et al., 2014a). Future studies should aim to improve upon the tag detection accuracy of this study by minimizing the causes of failed detection events as previously discussed.

3.5 Conclusions

Preliminary results ensured proper selection of RFID readers and tags that were similar in performance. Furthermore, preliminary testing of the Low, Mid-Perp, Mid-Angle, and High-Angle positions revealed that the RFID reader at a height of 0.91 m was inadequate to consistently detect tags within the desired range. It was also determined that for the purpose of this study, a maximum power of 25 was most suitable for tag detection. For field testing, it was found that R2 at the Mid-Angle position performed the best, with an average detection proportion of 0.779 (SD = 0.194). Mixed results were found when comparing movements to the left and to the right, suggesting that this may not be as impactful as reader position and location. The greatest impact on system performance was reader location within the barn. Based upon video evidence, placing the reader in the middle of the hallway length allowed for the system to detect more ear tags when the pigs were not as clustered, compared to the readers at the ends of the hallway. Though the greatest proportion detection was 0.779, the GAO RFID system is a customizable automated counting system that shows promise with further refinement.

References

Adrion, F., Kapun, A., Eckert, F., Holland, E.-M., Staiger, M., Götz, S., & Gallmann, E. (2018). Monitoring Trough visits of growing-finishing pigs with UHF-RFID. *Computers and Electronics in Agriculture*, *144*, 144–153. https://doi.org/10.1016/j.compag.2017.11.036

Andretta, I., Pomar, C., Kipper, M., Hauschild, L., & Rivest, J. (2016). Feeding behavior of growing finishing pigs reared under precision feeding strategies1. *Journal of Animal Science*, *94*(7), 3042–3050.

Bouazza, H., Zerzouri, O., Bouya, M., Charoub, A., & Hadjoudja, A. (2017). A novel RFID system for Monitoring Livestock Health State. *2017 International Conference on Engineering and Technology (ICET).*

Conception Ro-Main Inc. "smart Counting for farms". Accessed Dec 21, 2022. https://ro-main.com/our-products/smart-counting-for-farms/

Fry, A. E. & Lenert, A. L. (2005). MASCAL: RFID Tracking of Patients, Staff and Equipment to Enhance Hospital Response to Mass Casualty Events. *National Library of Medicine, 261-265.*

Kapun, A., Adrion, F., & Gallmann, E. (2020). Case study on recording pigs' daily activity patterns with a UHF-RFID system. *Agriculture*, *10*(11), 542.

Kim, J., Suh, Y., Lee, J., Chae, H., Ahn, H., Chung, Y., & Park, D. (2022). Embeddedpigcount: Pig counting with video object detection and tracking on an embedded board. *Sensors*, *22*(7), 2689. https://doi.org/10.3390/s22072689

Maselyne, J., Van Nuffel, A., De Ketelaere, B., Vangeyte, J., Hessel, E. F., Sonck, B., & Saeys, W. (2014a). Range measurements of a high frequency radio frequency identification (HF RFID) system for registering feeding patterns of growing–finishing pigs. *Computers and Electronics in Agriculture, 108*, 209–220.

Maselyne, J., Saeys, W., De Ketelaere, B., Mertens, K., Vangeyte, J., Hessel, E. F., Millet, S., & Van Nuffel, A. (2014b). Validation of a high frequency radio frequency identification (HF RFID) system for registering feeding patterns of growing-finishing pigs. *Computers and Electronics in Agriculture*, *102*, 10–18.

Matthews, S. G., Miller, A. L., Clapp, J., Plötz, T., & Kyriazakis, I. (2016). Early detection of health and welfare compromises through automated detection of behavioural changes in pigs. *The Veterinary Journal*, *217*, 43–51.

MetaFarms Inc, National Pork Board. (2020). Production Analysis Summary for U.S. Pork Industry: 2017-2019.

GAO RFID. (2023). *RFID hardware: RFID Systems*. GAO RFID Inc. (2023, August 11). https://gaorfid.com/

Wallace, J.W., Diamantides, L.C., Ki, K.C., Butler, M.W. (2020). Switched-antenna low-frequency (LF) radio-frequency identification (RFID) for ornithology. *IEEE Journal of Radio Frequency Identification*, vol. 4, no. 2, 2020, pp. 137–145, https://doi.org/10.1109/jrfid.2020.2971534

Wu, C., Wang, X., Chen, M., & Kim, M. J. (2019). Differential received signal strength based RFID positioning for construction equipment tracking. *Advanced Engineering Informatics*, *42*, 100960. https://doi.org/10.1016/j.aei.2019.100960

Zhou, Zishun. (2022). Detection and counting method of pigs based on YOLOV5_Plus: A combination of Yolov5 and attention mechanism. *Mathematical Problems in Engineering*, vol. 2022, 2022, pp. 1–16, https://doi.org/10.1155/2022/7078670

CHAPTER FOUR: OVERALL CONCLUSIONS AND IMPLICATIONS

This thesis describes scientific works to evaluate the use of a novel feed attractant and a commercially available RFID system, with the aims of improving piglet outcomes and precision pig management. When using Nextein APF® as a feed attractant, ADFI was not detected to be impacted by either farrowing application or nursery application. Because of farrowing findings, it is not recommended to apply this product in farrowing as pre-weaning exposure does not seem to impact feed intake or subsequent weight gain in the nursery. Investigating specifically the first three days post-wean, groups receiving spray application in the nursery had a higher ADG compared to groups not receiving nursery treatment spray. This suggests that spray application may increase feed intake and ADG during the first few days in the nursery. However, after application in the nursery stopped, a decrease in ADG occurred within these groups. While this does further suggest that application may attract pigs to consume more feed, the olfactory or palatability change that occurs when application is abruptly ended may create a significant decrease in feed intake compared to no application at all. By d 28, no significant differences in ADG between nursery groups were detected, suggesting that the 3 d nursery application may not be enough time to significantly impact long-term ADG and feed intake. BW block was the most impactful factor for ADFI and ADG, with High BW pigs consuming more feed than Low BW pigs by D28.

Furthermore, pigs in Low BW groups receiving no nursery spray had lower cumulative durations as well as lower frequency of visits compared to Low BW pigs receiving the spray, suggesting that Nextein APF® may be a useful tool to help small pigs struggling to gain weight in the nursery. With the findings presented, future studies should focus on use of Nextein APF® in the nursery for a longer period of time to see if ADG and ADFI increase during periods of longer application. A more gradual decrease in application over a period of a few days should also be investigated to see if this reduces the decrease in ADG that was experienced with the abrupt cessation of application. Because Low BW pigs receiving spray in the nursery had a greater ADG compared to High BW pigs in the first three days in the nursery, future studies should use Nextein APF® in groups where animals may be struggling to gain weight or have other health complications, as the product shows potential to help underdeveloped pigs improve weight gain.

The use of RFID technology as an automated counting system was also described and tested, highlighting the urgency for an off-the-shelf system that is both affordable and simple to use. Through testing of the UHF-RFID system developed by GAO RFID, Inc, it was determined that within this setting and at the tested configurations, this system could not detect pigs as accurately as previously mentioned systems that use cameras for detection such as PigCount and Ro-Main SmaRt Count. However, achieving a detection proportion of 0.779 at R2 and the Mid-Angle position revealed the potential for GAO RFID to serve as a reliable counting system. It was determined that the greatest factor that impacted detection rates was the location of the RFID reader. Since two of the three readers were located near the ends of the room hallways, crowding of the pigs as they approached the door most likely disrupted the function of the system. R2 was located in the middle of the hallway, where movement was free-flowing and pig back-up was minimal. As a result, detection rates were higher for this reader for all positions. When using the GAO RFID system, it is recommended to set up the RFID reader near the middle of the path the pigs will be taking, as fluent pig movement seems to allow for the greatest detection accuracies. Furthermore, reader height and location relative to the RFID tag in the pig's ear is critical to system optimization. Based on the height of the animal, it is recommended to place the RFID reader at a height that is close enough to the ear tags while also being located high enough that pig body interference does not prevent tags of other pigs passing from being detected. Animal handling and movement with RFID technology also play an important role, as animal handlers should aim to move pigs in a low-stress manner. If able, single-file movement would give each tag the opportunity to be detected by the reader without interference of other pig bodies. Furthermore, pigs should be moved in a way that limits crowding as well as running, as both were found to decrease reader detection rates.

Proper management of young pigs is crucial to production success. The nursery period is one of the most stressful and impactful periods of the production cycle, highlighted by weaning and movement to a new environment. The weaning period can be characterized by many different stressors that result in decreased feed intake and weight loss, which can negatively impact pig health as well as farm productivity. To mitigate weight loss, attractants can be used to increase feed interest during the post-weaning period. Though it was determined that application of Nextein APF for 3 d in the nursery ultimately did not impact weight gain, a longer application period or slower withdrawal period may be beneficial for weaned pigs. To understand the impacts of Nextein APF on feeder area interest, RFID technology was used. As a further application, RFID technology may also be used to improve nursery management by serving as an automated pig inventory and counting system. With continued research on tools such as feed attractants and automated counting systems, production issues within the nursery can be significantly improved.