Effects of yeast, essential oils, increased zinc oxide and copper sulfate, or their combination in nursery diets on pig performance

by

Austin James Langemeier

B.S., Texas Tech University, 2015

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences & Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2017

Approved by:

Major Professor
Jim L. Nelssen

Copyright

Abstract

Two experiments evaluated the effects of feeding growth promoting alternatives, alone or in combination, on nursery pig performance in comparison to a common feed additive, carbadox. In Exp.1, 288 weaned pigs (Line 600 × 241; DNA, 5.36 kg) were used in a 42-d study. Pigs were allotted to 1 of 9 dietary treatments in pens of 4 at weaning in a randomized complete block design with 8 replications per treatment. Dietary treatments were arranged with a negative control diet with no dietary feed additive, a positive control with added carbadox or 7 treatments including added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu) and added zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 28), essential oils from XTRACT 6930 at 0.91 kg/ton, Safman (yeast cell walls) at 0.23 kg/ton , Biosaf HR (yeast cells) at 0.68 kg/ton. These supplements were fed alone or in combination. From d 0 to 7 experimental diets were a pelleted diet and fed in a meal form from d 7 to 28, followed by a common corn-soybean meal-based diet from d 28 to 42. Essential oil blend (cinnamaldehyde) and yeast had no ($P > 0.05$) effect on ADG. Feeding carbadox or added trace minerals (Cu and Zn) improved ADG ($P < 0.05$) of nursery pigs compared to the control. Carryover effects from any of these dietary treatments on subsequent growth performance were not ($P > 0.05$) different. The use of added trace minerals Cu and Zn alone or in conjunction with either yeast or essential oil blend (cinnamaldehyde) results in ADG and G/F comparable to carbadox. In Exp. 2, 280 weaned pigs (Line 600 × 241; DNA, 5.18 kg) were used in a 35-d study. Pigs were allotted to 1 of 7 dietary treatments in pens of 5 at weaning in a randomized complete block design with 8 replications per treatment. Dietary treatments were arranged with a negative control diet with no dietary feed additive, a positive control with added carbadox or 5 treatments including added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu) and added zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 0 to 7 and

2,000 ppm Zn from d 7 to 35), and Victus® LIV (145 or 435 ppm). These supplements were fed alone or in combination (Cu/Zn and 145 ppm Victus® LIV or Cu/Zn and 435 ppm Victus® LIV. Diets were fed in meal form. Feeding carbadox, 145 ppm Victus® LIV or added trace minerals (Cu and Zn) improved ADG ($P < 0.05$) of nursery pigs compared to the control. In summary, under the conditions of these experiments, pigs fed zinc/copper, 145 ppm Victus® LIV or a combination of these had similar ($P > 0.05$) growth performance to pigs fed carbadox.

Key Words: Alternative, Carbadox, Copper, Essential Oil, Nursery Pig, Added Trace Minerals, Yeast, Zinc

Table of Contents

List of Tables

Acknowledgements

I would like to thank my major professor, Dr. Jim Nelssen, for all of his guidance and assistance in this enduring process. I have grown and learned a tremendous amount due to his leadership and wisdom. Additionally, I would like to thank the remainder of my committee, Dr. Travis O'Quinn and Dr. Duane Davis, for their aid in helping me along the way to get to this point near completion.

Most importantly, I thank God for this incredible experience and blessing with me the greatest peers and faculty to work with. Also, I would not be here today without the guidance and support of my family. My parents, Jeff and Ellen Langemeier, for always pushing me to do my absolute best and strive for more than I even believed I was capable of at times. My three sisters, Mackenzie, Madison and Reagan for always being there for me and giving me an unbelievable amount of support throughout this process. Last but certainly not least, Julianna for always encouraging me and being a quick phone call away to get me back on the straight and narrow. I love you all.

Thank you to Kansas State University for the opportunity to serve as a Graduate Teaching Assistant and getting the opportunity to work with Dr. Scott Schaake and Mr. Chris Mullinix in the classroom. Also, allowing me to assistant coach back-to-back National Champion Meat Animal Evaluation teams with Chris Mullinix and Dr. Travis O'Quinn was truly a dream come true. Finally, my roommates, fellow graduate students and friends that assisted with this process in one way or another. I have been beyond blessed over the past two years, and I know I have not mentioned everyone that has helped me along the way. But, thank you to everyone who has helped me in this venture.

Dedication

Although there could be many I could attribute this to, Miss Berkeley, the best dog I could have ever asked for, this one is for you.

Chapter 1 - General Review of Literature

Antimicrobial agents have played a vital role within the swine industry over the last half century, as growth promotants. New regulations restrict the use of antibiotics for growth promotion and swine producers have had to transition to antimicrobial alternatives to compensate. Pig care and pig health has always been a major priority to producers, however, the path to achieve optimal health and proper care has shifted away from depending on antibiotics. Even though producers are still able to use antibiotics for treatment, prevention and control of health issues, antibiotics have been known to not only ensure healthy pigs but to also aid in growth performance, especially in the nursery phase. With this lag of performance, there has been a major push to source other feed additives that would assist in pig health and potentially reduce losses in production within the early stages, post-weaning. Producers have consistently used antibiotics since the mid-1950s, thus making this transition significant to everyone involved in the swine nutrition industry. Consumers, retailers, and packers have shown considerable interest in pork products with little to no antibiotic usage over the span of the pig's life (Pork Checkoff, 2009). Consequently, pork producers' needs are acute and time-sensitive to seek alternatives that will enable them to recapture the pig performance lost in the absence of sub-therapeutic antibiotics (Schweer et al., 2016). There are numerous antibiotic alternatives available for use. Those evaluated within this literature review were acidifiers, copper, phytogenic feed additives, probiotics, yeast derivatives, and zinc. This list was formulated based upon recent popularity and consistent data suggesting successful usage.

Growth Promoting Alternatives

Transitioning piglets into the nursery while maintaining an appropriate rate of gain is of absolute importance. Research suggests weaning is one of the most stressful events in the pig's life and can contribute to intestinal and immune system dysfunctions that result in reduced pig health, growth, and feed intake, particularly during the first week after weaning (Campbell et al., 2013). A newborn piglet's intestinal immune system undergoes a rapid period of expansion and specialization that is not achieved before early weaning (Lalles et al., 2007). Consequently, pigs are highly susceptible to pathogenic enteric conditions such as post-weaning diarrhea (Pluske et al., 2013). Therefore, an immense amount of focus is placed upon formulating diets that provide weanling pigs with a defense toward enteric pathogens. Ultimately to enhance immune response, reduce the pathogen load within a piglet's gut, aid in establishing beneficial gut microbes, and stimulate digestive function (De Lange et al., 2010). A weaned pig with developing immune function may ultimately compromise digestibility efficiency and response to enteric diseases (Heo et al., 2013). As antibiotics typically play a role in the transition postweaning, formulating diets that provide health-promoting aspects is an ongoing necessity. Within the first 48 hours postweaning, piglets experience a high incidence of intestinal disturbances with diarrhea and depression of growth performance (Heo et. al., 2013). As weaned pigs transition from a sow's milk to a plant based diet, feed intake levels have been seen to reduce. Anti-nutritional factors within starter diets play a major role, as well as, the dietary protein source and level. Common nursery diets include formulation of leguminous plant proteins (soybean meal), that are known to have negative impacts on growth and health immediately following weaning (Heo et. al., 2013). The use of specialty proteins, such as, animal protein sources and milk powder, are commonly supplemented to bridge the gap and avoid production losses. Furthermore, increased levels of dietary protein has shown concern with increased levels of undigested protein undergoing microbial fermentation by nitrogen utilizing bacteria and ultimately increasing the occurrence of postweaning diarrhea episodes. Although, weaned piglets fed lower dietary crude protein levels still show a reduction in growth performance. Consequently, the anti-nutritional factors that coexist within a common nursery diet immediately after weaning results in a dire need for growth promoting alternatives to reduce postweaning growth lag and diarrheal episodes following the stress of weaning. With sub-therapeutic antibiotic use for growth promotion no longer being a viable option, the primary focus of considering feed additives may need to cover a few criteria: reduced content of protein that is fermented in the pigs gut, minimal buffering capacity, minimal anti-nutritional factors, and a supply of beneficial compounds (De Lange et al., 2010). With a primary focus on identifying feed additives to achieve this criteria, ongoing research continues to better understand their effectiveness and potential interactions with other dietary components (Trudeau et al., 2017). The following sections evaluate a few of the primary potential feed additives that have shown promising technology in reducing the overall stress of weaning and allowing pigs to maintain adequate growth performance and reduced experience of enteric diseases i.e. postweaning diarrhea.

Acidifiers

Postweaning growth lag is a major deficit within performance in young pigs. As pigs make the transition to the nursery, additives like an acidifier are often used to improve intake and overall performance. Acidifiers are commonly sourced from a blend of organic and inorganic acids, such as, formic, propionic, acetic, etc. Acidifiers are often seen to be effective whether they are administered through feed or water with a primary mode of action including reducing pH in feed, working as an antimicrobial and/or improving digestibility (Mathew, 2002). Research suggests that these novel dietary organic acid blends can reduce *E. coli*, stimulate immune system and improve growth performance or feed efficiency (Wang et al., 2009, Walsh et al., 2014). Furthermore, Walsh et al., (2014) found that an organic acid blend in water alone or feed alone is useful, however, including an organic acid blend in the water along with a dietary inclusion reduces feed intake. Additionally, Walsh found that an acidifier in conjunction with Tiamulin and CTC is effective to improve growth performance, yet when combined with carbadox there was not the same improvement as carbadox as an acidifier simply functions differently. Ultimately, research suggests that a dietary acid blend proves more beneficial due to a greater level of activity. Although, an acidifiers seem as a positive benefactor to implement in nursery pig diets, there is a wide variety of acidifiers available and consistency is minimal across the industry. Further evaluation of acidifiers is highly suggested as research suggests that environmental factors, such as, stress, genetics, and disease exposure often impacts the outcome.

Copper

Copper is a mineral commonly added at pharmacological levels to serve as a growth promoter within nursery pig diets. Typically, Cu is a derivative of multiple enzymes and hemoglobin synthesis that has been shown to be effective as an antimicrobial to improve growth performance and feed efficiency postweaning (Zhao et al., 2007). Dietary copper is observed as a trace mineral due to a pig's nutritional requirement of 5-10 ppm (Jacela et al., 2010). Even still, pharmacological levels of copper have been suggested between 125 and 250 ppm through nursery phase (Cromwell et al., 1989, Davis et al., 2002, Armstrong et al., 2004, Zhao et al., 2007, Jacela et al., 2010). Although the understanding of copper's mechanism is not quite clear as to why copper works as an antimicrobial, research suggests that feeding copper to weaned pigs during the nursery phase has an additive effect to growth performance and feed efficiency (Jacela et al., 2010). Furthermore, numerous studies have been conducted to confirm that copper improves growth performance (Zhao et al., 2007) and feed efficiency in weanling pigs (Armstrong et al., 2004). Although there is conflicting data in regards to length of implementation and appropriate level used within nursery diets. Most recent conclusions suggest that dietary inclusion is best suited in phase 2 and 3 nursery diets containing copper resulting in improved performance (Davis et al., 2002). Although there have been some reports of toxicity (Edmonds et al., 1986) when fed at pharmacological levels, the concluding evidence suggests that feeding copper to nursery pigs in the later phases has shown to be very effective as an alternative to antimicrobials in nursery pig diets

Phytogenic feed additives

Phytogenic feed additives have been ever increasing in popularity for use in swine diets and further research. Phytogenic feed additives (**PFA**) are plant-derived products that are sourced from herbs, spices, products derived thereof, and are mainly essential oils, or oleoresins (Windisch et al., 2008). They are typically mixtures of secondary plant metabolites and may contain phenolic compounds (i.e. thymol, carvacrol and eugenol), terpenes (i.e. citric and pinapple extracts), alkaloids (capsaicine, capsicum oleoresin), lectins, aldehydes (i.e. cinnamaldehyde), polypeptides or polyacetylenes (Gatnau, 2009). The mode of action and activity of PFAs is still quite limited, however, researchers suggest that PFAs serve as an antimicrobial through the modulation of immune function or improvement of digestibility (Windisch et al., 2008). Windisch et al., (2008) also mentioned that, research suggests that phytogenic feed additives have potential for improvement of palatability, and antioxidative or antimicrobial efficacy in vitro. With the new and rising interest for alternatives to antibiotics, phytogenics like essential oils have shown an immense amount of research in the last 20 years. Along with some initial inclinations of use and effectiveness, further improvements have been made to understand their purpose in swine diets. For instance, phytogenic feed additives, menthol or cinnamaldehyde, consistently improved feed efficiency in weaned piglets, and it was associated with improved ileal protein and amino acid digestibility (Maenner et al., 2011). However, Maenner et al., (2011) further stated that the effectiveness differs considerably depending on the constituents of the phytogenic feed additives being used. Also, that phytogenics positively affect growth performance of weaning pigs, indicating that their use as an alternative in the diets of weaning pigs can significantly improve ADG, under challenge with *E. coli* K88. Although there is promising data to support the use of phytogenic feed additives within swine diets, there still is a fair amount of conflicting data suggesting the inconsistency of phytogenics as they, vary widely due to botanical origin, processing method, and overall composition (Windisch et al., 2008). Further research also mentions that weaned pigs did not significantly respond to the phytogenic feed additive supplementation in diets (Muhl et al., 2007). In conclusion, Zeng (2015) found that, in the future, the detailed constituents of essential oils are needed to assess their different biological effects. In this way, it may be possible to compare different essential oil products and formulate mixtures that optimize their efficacy.

Currently research is being done to observe the effects of essential oils that have been found to be effective in various species. Limonene, for example, is an essential oil that has shown to work as an antimicrobial against fusobacterium necrophorum and to potentially reduce liver abscesses in cattle (Samii et al., 2014). Citrus byproducts may have a positive immunomodulatory role. Citrus contains several essential oils, including limonene, linalool, and citrulline, which are known to have an antimicrobial effect (Callaway et al. 2008). With new essential oils and other phytogenic compounds being discovered as beneficial, further research may be needed to fully understand the proper use and effectiveness of these products in swine.

Probiotics

Probiotics are simply known as live bacteria or yeast that provide potential digestive health benefits. A probiotic's mode of action suggests that probiotics work as an antimicrobial or modulation of immune function. Also, probiotics are broken into two classifications, as live cultures of defined microorganisms from either *Bacillus* spp. or *Lactobacillus* spp. (Giang et al., 2011). Probiotic preparations have shown promising results in a variety of animal production areas (Whitley et al., 2009). Supplementing weaned pigs with *Lactobacillus* brevis increased growth rates by the end of the nursery period compared with control pigs (Davis et al., 2007). Current trends focus on finding alternatives to antimicrobial agents that assist in overall health in nursery pigs, and attempt to generate additional performance for nursery pigs when diets are fed without an antibiotic. The balance of young pig's intestinal flora is crucial for effective digestion and maximal absorption of nutrients, as well as for adequate body's resistance against infectious diseases (Morrison et al., 2003). When pigs experience stress, such as weaning, there is an absence on *Lactobacilli* in the gut allowing for the multiplication of microorganisms such as enterotoxigenic *E. coli* to induce postweaning diarrhea syndrome. Ultimately, this allows for the onset of reduced performance or a consequent increase in mortality. However, within recent studies evaluating probiotics and their effectiveness in nursery pigs there is inconsistency in response. Although some studies provide convincing data justifying the use of probiotics within nursery pig diets. Probiotics had a beneficial effect on piglet growth performance and resulted in a reduction of diarrhea and increased microbial diversity in the gut (Krause et al., 2010) and probiotic protected against *E. coli* K88+ by enhancing immune responses, improved performance, and nutrient digestibility (Pan et al., 2016). Yet, considerable research provides valid information stating, probiotics provide no consistent benefits (Williams et al., 2017, Choi et al., 2009, Khafipour et al., 2013). Ultimately, further research is needed to further evaluate the appropriate use and level of probiotics fed to nursery pigs as an antibiotic alternative.

Yeast derivatives

Yeasts are classified as unicellular fungi. The three main types of yeast that are commonly used to produce feed and food grade yeast-based products are *Phaffia rhodozyma*, *Candida utilis*, and *Saccharomyces cerevisiae* with the last type being by far the most studied type (Mateo, 2006). A new generation of products have been derived from specific yeast cell components such as the cell wall, cell membrane and cell extract (Mateo, 2006). Yeast cell wall plays a vital role in regulation, transport, defense, and life cycle of yeast (Hildabrand et al., 2004). Yeast plasma membrane serves a purpose of transporting molecules, signal transduction and anchoring of the cytoskeleton (Hildabrand et al., 2004). Lastly, yeast cell extracts is the remaining part after the cell wall is removed and is a source of yeast-based amino acids, enzymes, vitamins, and minerals (Hildabrand et al., 2004). However, the added expense for preparation reduces its commercial availability. Yeasts are hypothesized to alter the intestinal microbiota in the pig by interacting with potential pathogens in the gut (Hildabrand et al., 2004). Certain classes of bacteria adhere to yeast cell walls and, in doing so, decrease the likelihood of pathogen binding and colonization of the gut wall (Hildabrand et al., 2004). The current pursuit of using a product like yeast to promote gut health and function within young pigs has pushed yeast derivatives to be considered as an alternative for antibiotics for growth promotion and overall improvement in gut function. Research suggests there is a considerable upside and benefit in utilizing such products postweaning. The comparable effect of yeast culture supplementation and antibiotic growth promoters on the growth performance of nursery pigs indicates that yeast culture may be a good candidate as an antibiotic alternative (Shen et al., 2009). Additionally, results indicate that live yeast supplementation had a positive effect on nursery pig performance when diets contained growth-promoting antimicrobials (Shen et al., 2009). Nonetheless, the response was variable, and the conditions under which a response might be expected need to be further defined (van Heugten et al., 2003). However, upon findings of research within this field, there is a fair amount of inconsistency in the benefits that yeast derivatives may provide within a dietary inclusion of the nursery phase. As other authors mention, Mannan oligosaccharides improved pig performance in some instance when fed in combination with an antibiotic, but it had no effect or negative effects in the absence of an antibiotic (LeMieux et al., 2003). Without the option to include an antibiotic in nursery diets for growth promotion, there is still further research needed to specify the appropriate level and type to best fit a given scenario to confirm yeast derivatives purpose to be more heavily considered throughout the industry.

Zinc

Zinc, like copper, is a commonly added mineral to swine diets at pharmacological levels to promote growth performance, especially during the early nursery phases. Zinc is recognized as a trace mineral as pigs require 50 to 125 ppm (Jacela et al., 2010) to meet daily nutritional requirements. Although there is a great variety of source of zinc that has been researched, the general consensus suggests that Zn is effective in promoting growth and feed efficiency in nursery pigs by working as an antimicrobial. Although the mechanism of zinc functioning as an antimicrobial is still unclear, some research suggests zinc works by disruption of cell membrane and oxidative stress (Xie et al., 2011) on bacteria. Furthermore, Carlson et. al., (1999) suggests pharmacological concentrations of zinc stimulate metallothionein synthesis in mucosal cells, which regulate zinc uptake into the body, perhaps resulting in the improved growth observed in weanling pigs. The majority of research analyzing different zinc sources, either organic or inorganic, concludes zinc oxide (ZnO) to be a primary source with experiments. Despite conflicting discussion, the benefits of dietary inclusion of pharmacological levels of zinc in nursery pig diets are beneficial to pigs only during the early phases of the nursery period and diets including pharmacological levels of zinc should be limited to approximately three weeks, somewhere between 2,000-3,000 ppm (Shelton et al., 2009). Consequently, utilizing zinc in the early phases of nursery pigs ultimately provide an improvement in growth performance and reduction in diarrhea (Smith et al., 1997, Carlson et al., 1999, Hill et al., 2000). Precautions of adding zinc at elevated levels include potential toxicity (Cromwell et al., 2001) and a more recent focus has shifted to environmental concerns relating to zinc being more caustic to flooring and generating elevated levels of zinc in the manure that may play a part in management decisions about durations and level of zinc in nursery diets (Tri-State Nutrition Guide, 1998, Kansas State Swine Nutrition Guide, 2007). In conclusion, the use of pharmacological levels of zinc within nursery diets is very effective in reducing diarrhea incidences, improving growth performance and feed efficiency. Although there are some limitations related to toxicity and fundamental management practices, zinc can play a vital role as an alternative to antimicrobials within nursery pig diets.

This review offers insight on a few of the many potential alternatives to antibiotics available when considering formulation of nursery pig diets. Other alternatives were discovered upon researching this topic. However, due to limitations and availability of viable literature no further categories were covered in depth. This list includes, but is not limited to: egg yolk antibodies, antimicrobial peptides, plasmid vaccination, and quorum sensing inhibitors. With the request for an alternative to antibiotics deriving from consumers, retailers, and meat packers the continued efforts of research will be needed to fully understand the opportunity and availability of new and promising technologies in this field.

Literature Cited

Andersson, D.I. and Hughes, D., 2010. Antibiotic resistance and its cost: is it possible to reverse resistance?. Nature Rev. Microbiol., 8(4), pp.260-271.

Armstrong, T. A., D. R. Cook, M. M. Ward, C. M. Williams, and J. W. Spears. 2004. Effect of dietary copper source (cupric citrate and cupric sulfate) and concentration on growth performance and fecal copper excretion in weanling pigs. J. Anim. Sci. 82:1234-1240. doi:10.2527/2004.8241234x

Boudry G., Peron V., Le Huerou-Luron I., Lalles JP., & Seve B. 2004. Weaning induces both transient and long-lasting modifications of absorptive, secretory, and barrier properties of piglet intestine. J. Nutr. 134:2256–2562.

Callaway, T. R., J. A.Carroll, J. D.Arthington, C. Pratt, T. S.Edrington, R. C. Anderson, M. L. Galyean, S. C. Ricke, P. Crandall, and D. J. Nisbet. 2008. Citrus products decrease growth of E. coli O157:H7 and Salmonella Typhimurium in pure culture and in fermentation with mixed ruminal microorganisms in vitro. Foodborne Pathog. Dis. 5:621–627. doi:10.1089/fpd.2008.0088.

Campbell, J.M., Crenshaw, J.D. and Polo, J., 2013. The biological stress of early weaned piglets. J. Anim. Sci. Biotechnol., 4(1), p.19.

Carlson, M.S., G.M. Hill, and J.E. Link. 1999. Early- and traditionally weaned nursery pigs benefit from phase-feeding pharmacological concentrations of zinc oxide: effect on metallothionein and mineral concentrations. J. Anim. Sci. 77:1199.

Che, T. M., O. Adeola, M. J. Azain, S. D. Carter, G. L. Cromwell, G. M. Hill, D. C. Mahan, P. S. Miller, and J. E. Pettigrew. 2012. Effect of Dietary Acids on Growth Performance of Nursery Pigs: A Cooperative Study. J. Anim. Sci. 90:4408-4413. doi:10.2527/jas.2012 5110

Choi, J. Y., J. S. Kim, S. L. Ingale, K. H. Kim, P. L. Shinde, I. K. Kwon, and B. J. Chae. 2011. Effect of potential multimicrobe probiotic product processed by high drying temperature and antibiotic on performance of weanling pigs. J. Anim. Sci. 89:1795-1804. doi:10.2527/jas.2009-2794

Cribbs, J. T., B. C. Bernhard, T. R. Young, M. A. Jennings, N. C. Burdick Sanchez, J. A. Carroll, T. R. Callaway, T. B. Schmidt, B.J. Johnson, and R. J. Rathmann. 2015. Dehydrated citrus pulp alters feedlot performance of crossbred heifers during the receiving period and modulates serum metabolite concentrations before and after an endotoxin challenge. J. Anim. Sci. 93:5791-5800. doi:10.2527/jas.2015-9571

Cromwell GL. 2002. Why and how antibiotics are used in swine production. Anim. Biotechnol. 13:7–27.

Cromwell, G. L. 2001. Antimicrobial and promicrobial agents. Pages 401–426 in Swine Nutrition. 2nd ed. A. J. Lewis and L. L. Southern, ed. CRC Press, Boca Raton, FL.

Cromwell, G. L., M. D. Lindemann, H. J. Monegue, D. D. Hall, and D. E. Orr Jr.. 1998. Tribasic copper chloride and copper sulfate as copper sources for weanling pigs. J. Anim. Sci. 76:118–123.

Cromwell, G. L., T. S. Stahly, and H. J. Monegue. 1989. Effects of source and level of copper on performance and liver copper stores in weanling pigs. J. Anim. Sci. 67:2996–3002.

Davis, M. E., C. V. Maxwell, D. C. Brown, B. Z. de Rodas, Z. B. Johnson, E. B. Kegley, D. H. Hellwig, and R. A. Dvorak. 2002. Effect of dietary mannan oligosaccharides and(or) pharmacological additions of copper sulfate on growth performance and immunocompetence of weanling and growing/finishing pigs. J. Anim. Sci. 80:2887-2894. doi:10.2527/2002.80112887x

De Lange, C.F.M., Pluske, J., Gong, J. and Nyachoti, C.M., 2010. Strategic use of feed ingredients and feed additives to stimulate gut health and development in young pigs. Livest. Sci., 134(1), pp.124-134.

Edmonds, M.S. and Baker, D.H., 1986. Toxic effects of supplemental copper and roxarsone when fed alone or in combination to young pigs. J. Anim. Sci., 63(2), pp.533-537.

Gatnau R. 2009. Use of plant extracts in swine. www.pig333.com/nutrition/use-of-plant-extracts in-swine_957/

Giang, H.H., Viet, T.Q., Ogle, B. and Lindberg, J.E., 2011. Effects of supplementation of probiotics on the performance, nutrient digestibility and faecal microflora in growing-finishing pigs. Asian-Australasian J. Anim. Sci., 24(5), pp.655-661.

Heo, J.M., Opapeju, F.O., Pluske, J.R., Kim, J.C., Hampson, D.J. and Nyachoti, C.M., 2013. Gastrointestinal health and function in weaned pigs: a review of feeding strategies to control post-weaning diarrhoea without using in-feed antimicrobial compounds. J. Anim. Physiol. Anim. Nutr., 97(2), pp.207-237

Herfel, T., S. Jacobi, X. Lin, E. Van Heugten, V. Fellner, and J. Odle. 2013. Stabilized rice bran improves weaning pig performance via a prebiotic mechanism. J. Anim. Sci. 91:907 913. doi:10.2527/jas.2012-5287

Hildabrand, B.M.; Neill, C.R.; Burkey, T.E.; Johnson, B.J.; Minton, J. Ernest; Dritz, Steven S. 2004. Growth performance of nursery pigs fed BIOSAF yeast alone or in combination\ with in-feed antimicrobial. Kansas State University Swine Day Article 2004.

Jacela, J.Y., DeRouchey, J.M., Tokach, M.D., Goodband, R.D., Nelssen, J.L., Renter, D.G. and Dritz, S.S., 2010. Feed additives for swine: fact sheets–high dietary levels of copper and zinc for young pigs, and phytase. J. Swine Health Prod., 18(2), pp.87 91.

Kansas State Swine Nutrition Guide. 2007. General Nutrition Principles for Swine, MF-2298. Kansas State University.

Khafipour, E., P. M. Munyaka, C. M. Nyachoti, D. O. Krause, and J. C. Rodriguez-Lecompte. 2014. Effect of crowding stress and Escherichia coli K88+ challenge in nursery pigs supplemented with anti-Escherichia coli K88+ probiotics. J. Anim. Sci. 92:2017-2029. doi:10.2527/jas.2013-7043

Kil, D.Y., Kwon, W.B. and Kim, B.G., 2011. Dietary acidifiers in weanling pig diets: a review. Revista Colombiana de Ciencias Pecuarias, 24(3), pp.231-247.

Krause DO, Bhandari SK, House JD, Nyachoti CM. 2010. Response of nursery pigs to a synbiotic preparation of starch and an anti-Escherichia coli K88 probiotic. Appl. Environ. Microbiol. doi: 10.1128/AEM.01427-10

Lallès, J.P., Bosi, P., Smidt, H. and Stokes, C.R., 2007. Nutritional management of gut health in pigs around weaning. Proceedings of the Nutrition Society, 66(2), pp.260-268.

LeMieux, F. M., L. L. Southern, and T. D. Bidner. 2003. Effect of mannan oligosaccharides on growth performance of weanling pigs. J. Anim. Sci. 81:2482-2487. doi:10.2527/2003.81102482x

Maenner, K., W. Vahjen, and O. Simon. 2011. Studies on the effects of essential-oil-based feed additives on performance, ileal nutrient digestibility, and selected bacterial groups in the gastrointestinal tract of piglets. J. Anim. Sci. 89:2106-2112. doi:10.2527/jas.2010-2950

Mateo, C. 2006. Aspects of yeast-based products in enhancing animal production – NPB #05 134

Mathew, A., 2002. Seeking alternatives to growth promoting antibiotics. In Manitoba Swine Seminar (Vol. 16, pp. 115-128).

Mohana Devi, S., Lee, S.I. and Kim, I.H., 2015. Effect of phytogenics on growth performance, fecal score, blood profiles, fecal noxious gas emission, digestibility, and intestinal morphology of weanling pigs challenged with Escherichia coli K88. Polish J. Vet. Sci., 18(3), pp.557-564.

Morrison, R., Kritas, S. 2003. Effect of probiotics in the health and performance of nursery pigs raised in conventional or antibiotic/growth promoter free farms. NPB #02-197

Muhl, A. and Liebert, F., 2007. No impact of a phytogenic feed additive on digestion and unspecific immune reaction in piglets. J. Anim. Physiol. Anim. Nutr., 91(9-10), pp.426-431.

Pan, L., P. F. Zhao, X. K. Ma, Q. H. Shang, Y. T. Xu, S. F. Long, Y. Wu, F. M. Yuan, and X. S. Piao. 2017. Probiotic supplementation protects weaned pigs against enterotoxigenic Escherichia coli K88 challenge and improves performance similar to antibiotics. J. Anim. Sci. 95:2627-2639. doi:10.2527/jas.2016.1243

Pluske, J.R., 2013. Feed-and feed additives-related aspects of gut health and development in weanling pigs. J. Anim. Sci. Biotechnol., 4(1), p.1.

Pork Checkoff, Facts, Q., 2009. The pork industry at a glance. Pork checkoff.

Samii, S.S., 2014. Effect of limonene on ruminal Fusobacterium necrophorum (Doctoral dissertation, Kansas State University).

Schweer, W. P., J. F. Patience, K. Schwartz, D. Linhares, C. Rademacher, H. K. Allen, C. L. Loving, A. Ramirez, and N. K. Gabler. 2017. 305 A review and evaluation of antibiotic alternatives in the literature. J. Anim. Sci. 95(Suppl2):148-148. doi:10.2527/asasmw.2017.305

Shelton, N. W., M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. M. DeRouchey, and G. M. Hill. 2011. Effects of copper sulfate, tri-basic copper chloride, and zinc oxide on weanling pig performance. J. Anim. Sci. 89:2440-2451. doi:10.2527/jas.2010-3432

Shelton NW, Jacob ME, Tokach MD, Nelssen JL, Goodband RD, Dritz SS, DeRouchey JM, Amachawadi RG, Shi X, Nagaraja TG. 2009. Effects of copper sulfate, zinc oxide, and neoterramycin on weanling pig growth and antibiotic resistance rate for fecal Escherichia coli. Kansas Agric Exp Sta Prog Rep 1020: 73–79. Available at: http://www.ksre.ksu.edu/library/lvstk2/srp1020.pdf.

Shen, Y. B., X. S. Piao, S. W. Kim, L. Wang, P. Liu, I. Yoon, and Y. G. Zhen. 2009. Effects of yeast culture supplementation on growth performance, intestinal health, and immune response of nursery pigs. J. Anim. Sci. 87:2614-2624. doi:10.2527/jas.2008-1512

Smith, J.W. II, M.D. Tokach, R.D. Goodband, J.L. Nelssen, and B.T. Richert. 1997. Effects of the interrelationship between zinc oxide and copper sulfate on growth performance of early weaned pigs. J. Anim. Sci. 75:1861-1866.

Solomons, I. A. 1978. Antibiotics in Animal Feeds—Human and Animal Safety Issues. J. Anim. Sci. 46:1360-1368. doi:10.2527/jas1978.4651360x

Tri-State Swine Nutrition Guide. 1998. Feed additives. The Ohio State University. pp74-79.

Trudeau, M., Chen, C. and Shurson, G., 2017. Metabolite changes in the gut rule antibiotic impact. Delta.

Walsh, M. C., D. M. Sholly, R. B. Hinson, K. L. Saddoris, A. L. Sutton, J. S. Radcliffe, R. Odgaard, J. Murphy, and B. T. Richert. 2007. Effects of water and diet acidification with and without antibiotics on weanling pig growth and microbial shedding. J. Anim. Sci. 85:1799-1808. doi:10.2527/jas.2006-049

Wang, J. P., J. S. Yoo, J. H. Lee, H. D. Jang, H. J. Kim, S. O. Shin, S. I. Seong, and I. H. Kim. 2009. Effects of phenyllactic acid on growth performance, nutrient digestibility, microbial shedding, and blood profile in pigs. J. Anim. Sci. 87:3235-3243. doi:10.2527/jas.2008-1555

Whitley, N. C., D. Cazac, B. J. Rude, D. Jackson-O'Brien, and S. Parveen. 2009. Use of a commercial probiotic supplement in meat goats. J. Anim. Sci. 87:723-728. doi:10.2527/jas.2008-1031

Williams, H. E., M. D. Tokach, S. S. Dritz, J. C. Woodworth, J. M. DeRouchey, R. G. Amachawadi, T. G. Nagaraja, and R. D. Goodband. 2017. 172 Effects of feeding probiotic or chlortetracycline or a combination on nursery pig growth performance.. J. Anim. Sci. 95(Suppl2):81-82. doi:10.2527/asasmw.2017.12.172

Windisch, W., K. Schedle, C. Plitzner, and A. Kroismayr. 2008. Use of phytogenic products as feed additives for swine and poultry. J. Anim. Sci. 86(Suppl14):E140-E148. doi:10.2527/jas.2007-0459

Xie, Y., He, Y., Irwin, P.L., Jin, T. and Shi, X., 2011. Antibacterial activity and mechanism of action of zinc oxide nanoparticles against Campylobacter jejuni. Appl. Environ. Microbiol., 77(7), pp.2325-2331.

Zeng, Z., Zhang, S., Wang, H. and Piao, X., 2015. Essential oil and aromatic plants as feed additives in non-ruminant nutrition: a review. J. Anim. Sci. Biotechnol., 6(1), p.7.

Zhao, J., A. F. Harper, M. J. Estienne, K. E. Webb, A. P. McElroy, and D. M. Denbow. 2007. Growth performance and intestinal morphology responses in early weaned pigs to supplementation of antibiotic-free diets with an organic copper complex and spray-dried plasma protein in sanitary and nonsanitary environments. J. Anim. Sci. 85:1302-1310. doi:10.2527/jas.2006-434

Chapter 2 - Effects of yeast, essential oils, increased zinc oxide and copper sulfate, or their combination in nursery diets on pig performance[1]

Abstract

Two experiments evaluated the effects of feeding growth promoting alternatives, alone or in combination, on nursery pig performance in comparison to a common feed additive, carbadox. In Exp.1, 288 weaned pigs (Line 600 × 241; DNA, 5.36 kg BW) were used in a 42-d study. Pigs were allotted to 1 of 9 dietary treatments in pens of 4 at weaning in a randomized complete block design with 8 replications per treatment. Dietary treatments were arranged with a negative control diet with no dietary feed additive, a positive control with added carbadox or 7 treatments including added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu) and added zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 28), essential oils from XTRACT 6930 at 0.91 kg/ton, Safman (yeast cell walls) at 0.23 kg/ton , Biosaf HR (yeast cells) at 0.68 kg/ton. These supplements were fed alone or in combination. From d 0 to 7 experimental diets were a pelleted diet and fed in a meal form from d 7 to 28, followed by a common corn-soybean meal-based diet from d 28 to 42. Essential oil blend (cinnamaldehyde) and yeast had no ($P > 0.05$) effect on ADG. Feeding carbadox or added trace minerals (Cu and Zn) improved ADG ($P < 0.05$) of nursery pigs compared to the control. Carryover effects from any of these dietary treatments on subsequent growth performance were not ($P > 0.05$) different. The use of added trace minerals Cu and Zn alone or in conjunction with either yeast or essential oil blend (cinnamaldehyde) results in ADG and G/F comparable to carbadox. In Exp. 2, 280 weaned pigs (Line 600 × 241; DNA, 5.18 kg BW) were used in a 35-d study. Pigs were allotted to 1 of 7 dietary treatments in pens of 5 at weaning in a randomized complete block design with 8 replications per treatment. Dietary treatments were arranged with a negative control diet with no dietary feed additive, a positive control with added carbadox or 5 treatments including added copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu) and added zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 35), and Victus® LIV (145 or 435 ppm). These supplements were fed alone or in combination (Cu/Zn and 145 ppm Victus® LIV or Cu/Zn and 435 ppm Victus® LIV. Diets were fed in meal form. Feeding carbadox, 145 ppm Victus® LIV or added trace minerals (Cu and Zn) improved ADG ($P < 0.05$) of nursery pigs compared to the control. In summary, under the conditions of these experiments, pigs fed zinc/copper, 145 ppm Victus® LIV or a combination of these had similar ($P > 0.05$) growth performance to pigs fed carbadox.

Key Words: Alternative, Carbadox, Copper, Essential Oil, Nursery Pig, Added Trace Minerals, Yeast, Zinc

[1]Appreciation is expressed to, Pancosma North America, Drumondville, Canada for financial support and for supplying XTRACT 6930 and DSM Nutritional Products, Parsippany, NJ, for financial support and supplying Victus® LIV.

Introduction

Within the swine industry today, the removal of antimicrobial agents for growth promotion has been a pertinent objective (Marshall et al., 2011). With increasing public concern for risks associated with antimicrobial resistance, producers removing feed-grade antibiotics have seen reductions in pig performance (CDC, 2016). Since the mid-1950s, feed-grade antibiotics have been available for use by swine producers. As research has shown, the dietary inclusion of antimicrobial agents has improved the growth rates and feed efficiency of nursery pigs. With the shift in the industry to remove antimicrobial agents for growth promotion purposes, many producers have indicated concerns about the possible production losses associated with the elimination of antimicrobial agents in nursery pig diets.

Thus, we conducted this experiment to focus on three critical points. First, as consumers have become increasingly more concerned, there has been a large push for pig raised without antibiotics in the marketplace. Secondly, other classes of feed additives have been suggested to improve nursery pig performance. Many of these have been shown to increase feed consumption during the post-weaning period, which can positively influence the growth of young pigs during such a critical time. Some of these feed additives include, but are not exclusive to the following classes of compounds; phytogenic additives (essential oils), yeast cells and yeast cell walls, increased levels of certain trace minerals, or combinations of these additives. Lastly, these trials were conducted as a follow-up study to a recent trial at KSU (Feldpausch et al., 2014), and we hypothesized that feeding a combination of these feed additives could improve feed intake and sustain growth performance comparable to feeding nursery pigs carbadox. Therefore, the objective of this experiment was to compare the growth performance of nursery pigs fed diets containing carbadox and different supplemental feed additives known to improve feed intake (added levels of Zn and Cu, yeast cells and yeast cell walls or essential oils), either alone or in combination with each other.

Materials and Methods

Experiment 1

This trial was conducted as a follow up study to Feldpausch et al., (2014) with the primary objective of evaluating the potential impact of different types of feed additives used as growth promoting alternatives in comparison to carbadox. This report describes the growth performance of nursery pigs and the effects of dietary feed additives on growth performance.

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee #3839. The study was conducted at the K-State Swine Teaching and Research farm nursery in Manhattan, KS.

A total of 288 nursery pigs (Line 600 × 241; DNA, Columbus, NE; initially 5.36 kg BW) were used in a 42 d study. Pigs were allotted to 4 pigs per pen, there were 8 replications per treatment. A total of 56 pens were utilized within the north nursery at the K-State Swine Teaching and Research farm nursery. Each pen had one 4-hole self-feeder, metal tri-bar flooring, and a nipple waterer to provide ad libitum access to feed and water. Pigs were weaned at approximately 21 d of age and allotment divided pigs into a heavy and light block based off initial BW to achieve equal average pen weight, for the heavy group and light group pens, resulting in 8 blocks per treatment. Based off day 0 weights, pigs were randomly allotted to 1 of 9 dietary treatments in blocks by barn location.

The 9 dietary treatments consisted of a corn-soybean meal-based diet and were arranged with treatments of additional dietary trace minerals with added Cu from copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu) and added Zn from zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 28), essential oil blend from XTRACT 6930 (Capsicum oleoresin 2%, Carvacrol 5%, Cinnamaldehyde 3%, Pancosma North America, Drumondville, Canada) from d 0 to 28 at 0.91 kg/ton, Safman (Yeast cell walls, Lesaffre Yeast Corporation, Milwaukee, WI) from d 0 to 28 at 0.23 kg/ton , Biosaf HR (yeast cells, Lesaffre Yeast Corporation, Milwaukee, WI) from d 0 to 28 at 0.68 kg/ton and carbadox (Mecadox®, Phibro Animal Health, Teaneck, NJ) from d 0 to 28 at 50 g/ton. Equivalent amounts of corn were replaced with treatment diet to form the experimental treatments.

The experimental diets were fed from d 0 to 28. Phase 1 experimental diets were a pelleted ration fed from d 0 to 7(Table 1). Diets from all 9 treatments had an acidifier (Kem-Gest, Kemin, Des Moines, IA) at 0.18 kg/ton added to diets during the Phase 1 period. Phase 2 experimental diets were fed in meal form, from d 7 to 28 (Table 2). From d 28 to 42, a common phase 3 diet, also a meal feed, (Table 3) until the completion of the trial on d 42. No dietary feed additives, yeast, essential oils, added levels of Cu or Zn, or carbadox were fed to all pigs to evaluate any carryover effects from the treatment diets.

All diets were prepared at the K-State O.H. Kruse Feed Technology Innovation Center. Diet samples were collected periodically throughout the study and pooled samples of each diet were collected. Average daily gain (**ADG**), Average daily feed intake (**ADFI**), and feed efficiency (**G/F**) were determined by weighing pigs individually and measuring feed disappearance on d 7, 14, 21, 28, 35 and 42 by weighing each feeder on a weekly basis.

Experiment 2

The primary objective of Exp. 2 was to evaluate the potential impact of different types of feed additives for improving the feed intake and growth of nursery pigs.

The protocol for this experiment #3839 was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the K-State Swine Teaching and Research farm nursery in Manhattan, KS. Procedures were similar to Exp. 1.

A total of 280 nursery pigs (Line 600 × 241; DNA, Columbus, NE; initially 5.18 kg BW) were used in a 35-d study, with 5 pigs per pen and 8 replications per treatment. Each pen had one 4-hole self-feeder, metal tri-bar flooring, and a nipple waterer to provide ad libitum access to feed and water. Pigs were weaned at approximately 21 d of age, weighed, and blocked by initial BW to achieve equal average pen weights, within each block. Within each block, the pens of pigs were randomly allotted to 1 of 7 dietary treatments. The 7 dietary treatments consisted of a corn-soybean meal-based diet and were arranged with treatments of added trace minerals with added Cu from copper sulfate ($CuSO_4$; 0 vs. 125 ppm Cu) and added Zn from zinc oxide (ZnO; 0 vs. 3,000 ppm Zn from d 0 to 7 and 2,000 ppm Zn from d 7 to 35), an essential oils blend from Victus® LIV (DSM Nutritional Products, Parsippany, NJ) from d 0 to 35 at either 0.13 kg/ton (145ppm) or 0.39 kg/ton (435 ppm), and carbadox (Mecadox®, Phibro Animal Health, Teaneck, NJ) from d 0 to 35 at 50 g/ton. Equivalent amounts of corn were replaced with the chosen levels of additives to form the experimental dietary treatments.

The experimental diets were fed from d 0 to 35. Phase 1 experimental diets were meal rations fed from d 0 to 7 (Table 6). All diets had an acidifier (Kem-Gest, Kemin, Des Moines, IA) added at 0.18 kg/ton during the Phase 1 period. Phase 2 experimental diets were fed in meal form from d 7 to 21 (Table 7). Phase 3 experimental diets were fed in meal form from d 21 until the completion of the trial on d 35 (Table 8).

All diets were prepared at the K-State O.H. Kruse Feed Technology Innovation Center. Diet samples were collected periodically throughout the study and pooled samples of each treatment diet were stored for later potential analysis. ADG, ADFI, and G/F were determined by weighing pigs and measuring feed disappearance on d 7, 14, 21, 28 and 35.

Statistical Analyses

Growth data were analyzed as a randomized complete block design using PROC GLIMMIX in SAS with pen as the experimental unit. The model included the main effect of treatment and weight block as a random effect. The Kenward-Roger adjustment was used for denominator degrees of freedom. Differences between treatments were determined by using the p-diff option least squares means were considered significantly different at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results

Experiment 1

During phase 1 and 2 of the experiment (d 0 to 7 and 7 to 28), pigs fed carbadox proved to have increased ADG ($P < 0.05$) compared to pigs fed a negative control diet. When carbadox was removed at the conclusion of Phase 2 and pigs were fed a common diet from d 28 to 42 there was no significant difference in ADG ($P > 0.05$) compared to pigs fed a negative control diet, ending in no effect overall from d 0 to 42 by carbadox. Ultimately, showing improvement ($P < 0.05$) in overall growth performance when compared to pigs fed the negative control diet (Table 5).

During the experimental treatment period, yeast alone or essential oils alone did not improve ($P > 0.05$) growth performance compared to those fed a negative control diet. However, pigs fed added trace minerals (Cu and Zn) alone had similar growth performance to those fed carbadox during d 0 to 28 ($P > 0.05$). Additionally, pigs fed added levels of trace minerals in combination with yeast, essential oils or in combination with both yeast and essential oils also showed comparable ($P > 0.05$) growth performance to those pigs fed carbadox during phase 1 and 2. Throughout the common diet phase from d 28 to 42, there were no differences in ADG, ADFI and G/F for any dietary treatments. Overall, d 0 to 42, ADG, ADFI and G/F of pigs fed added trace minerals alone had similar ($P > 0.05$) growth performance with those pigs fed carbadox. Additionally, pigs fed added levels of Zn and Cu outperformed control pigs during this period. These trace minerals (Cu and Zn) alone increased ($P < 0.05$) d 42 weights (22.5 kg) when compared to pigs fed the negative control, and similar ($P > 0.05$) d 42 weights when compared to carbadox fed pigs with d 42 weights (21.4 kg; Table 4). The overall positive effects of combining Zn and Cu resulted in an average of a 2.1 kg per pig increase in weight at d-42 post-weaning compared to pigs fed the negative control diet.

Experiment 2

During phase 1 and 2 of the experiment (d 0 to 21), pigs fed carbadox had increased ADG ($P < 0.05$) compared to pigs fed the negative control. During phase 3, feeding pigs carbadox resulted in increased ($P < 0.05$) ADG compared to pigs fed the control, and overall (d 0 to 35) ADG was increased ($P < 0.05$) by feeding pigs carbadox. Carbadox also improved ($P < 0.05$) the overall feed efficiency during the experiment when compared to pigs fed the negative control diet.

During the experiment, feeding 435 ppm Victus® LIV alone did not improve ($P > 0.05$) growth performance compared to pigs fed the negative control. However, pigs fed added trace minerals (Cu and Zn) alone, or 145 ppm Victus® LIV alone, had growth performance similar ($P > 0.05$) to that of pigs fed carbadox from d 0 to 35. Additionally, pigs fed added levels of trace minerals in combination with Victus® LIV at either 145 ppm or 435 ppm showed comparable ($P > 0.05$) growth performance to pigs fed carbadox during the entire experiment (d 0 to 35). Overall (d 0 to 35) ADG, ADFI and G/F of pigs fed either added trace minerals or 145 ppm Victus® LIV had similar ($P > 0.05$) growth performance with those pigs fed carbadox (Table 10). Additionally, pigs fed added levels of either, Zn and Cu or 145 ppm Victus® LIV outperformed pigs fed the negative control during this period. Pigs fed added trace minerals alone increased ($P < 0.05$) d-35 weights (16.4 kg), as pigs fed Victus® LIV alone at 145 ppm increased ($P < 0.05$, 16.2 kg) when compared to pigs fed the negative control (14.9 kg; Table 9). The positive effects of feeding pigs the combination of added Zn and Cu and 145 ppm Victus®

LIV resulted in an average of a 1.8+ kg per pig increase in weight at d-35 post-weaning when compared to pigs fed the negative control diet.

Discussion

Typically, nursery pigs are fed a diet containing an antimicrobial agent, such as, carbadox. We fed carbadox to nursery pigs and found a consistent improvement in growth performance compared to pigs fed a negative control diet. However, feeding antibiotics to pigs is under increased scrutiny. Thus, future research is needed to source potential growth promoting alternatives to reduce production losses in the nursery phase. With a variety of feed additives that are commercially available, conducting studies to understand source, mode of action, and level of inclusion are important to appropriately formulate diets with these growth promoting alternatives.

When used at low, sub-therapeutic, levels in feeds, antibiotics improve growth rate and efficiency of feed utilization, reduce mortality and morbidity, and improve reproductive performance (Cromwell, 2002). Cromwell (2002) also suggests, antibiotics are also used at intermediate levels to prevent disease and at high, therapeutic, levels to treat diseases in animals. Thus, carbadox was utilized to compare the effectiveness of these potential growth promoting alternatives.

Increased levels of Zn and Cu in nursery pig diets has been evaluated immensely. Recent studies suggest, feeding 3,000 ppm the first, two weeks after weaning increases ADG (Carlson et al., 1999, Shelton et al., 2011). Furthermore, Shelton et al., (2011) mentions performance was numerically greater when mineral regimens were switched from feeding added Zn (3,000 ppm) for first 14 d and moderate Cu (125 ppm) levels in later nursery phases than when both minerals were fed for the entire 42-d period. Ultimately, the inclusion of increased dietary trace minerals, Zn and Cu, has been seen to be very effective in benefitting nursery pig performance.

Zinc oxide (ZnO) is the most common form of added dietary Zn, while Cu most commonly comes from copper sulfate ($CuSO_4$). In our experiment, we added zinc oxide and copper sulfate in combination within diets for nursery pigs. Pigs fed the added Zn and Cu combination had similar to or even greater performance to pigs fed carbadox. In Exp. 1, pigs fed the added zinc oxide and copper sulfate combination were over 2.1 kilograms heavier at the end of the nursery phase (d 42) compared to pigs fed a negative control diet.

Phytogenic feed additives were also evaluated during the course of these experiments. Today, there is an immense amount of phytogenic compounds available for dietary inclusion. In regards to this study, essential oils have become of primary interest with new research suggesting the ability to improve nursery pig growth performance (Li et al., 2012). Although mode of action and the ideal source and level is still not fully understood. Li et al., (2012) suggests that a combination of thymol and cinnamaldehyde improved daily gain and feed intake in nursery pigs. Also, the essential oil compound of carvacrol, cinnamaldehyde and capsicum also improved daily gain and intake (Manzanilla et al., 2006). However, there is conflicting research that provides data using a dietary inclusion of cinnamon, thyme, oregano and a carrier that decreases daily gain and intake, yet increases feed conversion (Namkung et al., 2004). The use of phytogenic feed additives, such as cinnamaldehyde, have been found to be effective in improving nursery pig growth performance. However, with the understanding of proper source and level to maintain consistent results still in question, further research is needed.

Additionally, through these experiments we investigated the effects of several potential alternatives that have been postulated to enhance nursery pig growth performance, as possible growth promoting alternatives. XTRACT 6930 was sourced for Exp. 1, as several classes of secondary plant metabolites constitute as ingredients (Capsicum oleoresin, carvacrol, and cinnamaldehyde). Additionally, the yeast products from Biosaf HR and Safman are commonly used within recent research and allowed us to utilize yeast cells and yeast cell walls. During Exp. 1, when feeding yeast from Biosaf HR/Safman or an essential oil blend from XTRACT 6930 alone or in combination, we found no consistent effects on nursery pig growth performance. Additionally, we fed pigs a dietary feed additives of yeast from Biosaf HR/Safman and/or an essential oil blend from XTRACT 6930 in combination with the mineral supplemented treatment (CuSO4 and ZnO). No further benefit in growth performance was seen, beyond the benefits of adding supplemental Cu and Zn together, was found by adding yeast or an essential oil blend. The benefits in growth performance was due to Zn and Cu being supplemented together during the nursery experiments.

During Exp. 2, we investigated the effects of an essential oils product that has been postulated to enhance nursery pig growth performance. Samii et al., (2014) suggests limonene, an essential oil deriving from the rind of a lemon, is useful against fusobacterium necrophorum and potential use with reducing liver abscesses. With ongoing research in attempting to source essential oils that are effective on improving nursery pig performance, Victus® LIV was sourced as a commercially available essential oil with a high (34%) concentration of limonene. Therefore, Exp. 2 is a pilot-study using Victus® LIV in nursery pig diets. When feeding Victus® LIV at 435 ppm either alone or in combination, we found no consistent effects on nursery pig growth performance. However, pigs fed 145 ppm Victus® LIV, either alone or in combination with added Cu and Zn, had growth performance comparable to pigs fed carbadox or the added trace minerals, Cu and Zn, alone. This suggests that feeding 145 ppm Victus® LIV could improve feed intake and overall growth performance when compared to pigs fed the negative control diet.

Finally, we evaluated yeast cells and yeast cell walls. These yeast derivatives have a multitude of conflicting data with mixed results as it relates to dietary inclusion of yeast on nursery pig performance. Davis et al., (2002) suggests that mannan oligosaccharides improve growth performance in nursery pigs. While Van Heugten et al., (2003) provides evidence that the, performance of pigs was not affected by yeast supplementation, as results were not consistent. Although there are numerous varieties of yeast derivatives, further research is needed to better understand the proper source and level to effectively influence growth performance in nursery pigs.

In summary, we are optimistic that under the conditions of this experiment that the mineral combination of zinc oxide and copper sulfate being fed together for at least four weeks or 145 ppm Victus® LIV could be effective as a growth promoting alternative to improve growth performance in nursery pigs.

Literature Cited

Carlson, M.S., G.M. Hill, and J.E. Link. 1999. Early- and traditionally weaned nursery pigs benefit from phase-feeding pharmacological concentrations of zinc oxide: effect on metallothionein and mineral concentrations. J. Anim. Sci. 77:1199.

CDC., 2016. National Antimicrobial Resistance Monitoring System for Enteric Bacteria (NARMS) https://www.cdc.gov/narms/faq.html

Cromwell GL. 2002. Why and how antibiotics are used in swine production. Anim. Biotechnol. 13:7–27.

Davis, M. E., C. V. Maxwell, D. C. Brown, B. Z. de Rodas, Z. B. Johnson, E. B. Kegley, D. H. Hellwig, and R. A. Dvorak. 2002. Effect of dietary mannan oligosaccharides and(or) pharmacological additions of copper sulfate on growth performance and immunocompetence of weanling and growing/finishing pigs. J. Anim. Sci. 80:2887-2894. doi:10.2527/2002.80112887x

Feldpausch, J.A., DeJong, J.A., Tokach, M.D., Dritz, S.S., Woodworth, J.C., Amachawadi, R.G., Scott, H.M., Nelssen, J.L. and Goodband, R.D., 2014. Comparative effects of dietary copper, zinc, essential oils, and chlortetracycline on nursery pig growth performance. Kansas State University Swine Day Article, 2014.

Li SY, Ru YJ, Liu M, Xu B, Péron A, Shi XG. 2012. The effect of essential oils on performance, immunity and gut microbial population in weaner pigs. Livest. Sci. 145:119–23.

Manzanilla EG, Nofrarias M, Anguita M, Castillo M, Perez JF, Martin-Orue SM. 2006. Effects of butyrate, avilamycin, and a plant extract combination on the intestinal equilibrium of early-weaned pigs. J Anim Sci. 84:2743–51.

Marshall, B.M. and Levy, S.B., 2011. Food animals and antimicrobials: impacts on human health. Clin. Microbiol. Rev., 24(4), pp.718-733.

Namkung H, Li J, Gong M, Yu H, Cottrill M, de Lange CFM. 2004. Impact of feeding blends of organic acids and herbal extracts on growth performance, gut microbiota and digestive function in newly weaned pigs. Can J Anim Sci. 84:697–704.

Samii, S.S., 2014. Effect of limonene on ruminal Fusobacterium necrophorum (Doctoral dissertation, Kansas State University).

Shelton NW, Jacob ME, Tokach MD, Nelssen JL, Goodband RD, Dritz SS, DeRouchey JM, Amachawadi RG, Shi X, Nagaraja TG. 2009. Effects of copper sulfate, zinc oxide, and neoterramycin on weanling pig growth and antibiotic resistance rate for fecal Escherichia coli. Kansas Agric Exp Sta Prog Rep 1020: 73–79. Available at: http://www.ksre.ksu.edu/library/lvstk2/srp1020.pdf.

van Heugten, E., D. W. Funderburke, and K. L. Dorton. 2003. Growth performance, nutrient digestibility, and fecal microflora in weanling pigs fed live yeast. J. Anim. Sci. 81:1004 1012. doi:10.2527/2003.8141004x

Tables

Table 1. Composition of Phase 1 Diets[1] (Exp. 1)

Ingredient, %	A[2]	B[3]	C[4]	D[5]	E[6]	F[7]	G[8]	H[9]	I[10]
Corn	37.35	36.35	37.25	36.90	37.30	36.80	36.85	37.20	36.75
Soybean meal	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85
Blood meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Blood plasma	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Corn DDGs, > 6 & < 9% Oil	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Fish meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Milk, whey powder	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Limestone, ground	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Lys-HCL	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
DL-Met	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Thr	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Trace mineral premix[11]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[12]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride 60%	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Kemgest	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Mecadox	---	1.00	---	---	---	---	---	---	---
Biosaf-HR	---	---	0.08	---	---	0.08	---	0.08	0.08
Safman	---	---	0.03	---	---	0.03	---	0.03	0.03
Copper sulfate	---	---	---	0.05	---	0.05	0.05	---	0.05
Zinc oxide	---	---	---	0.42	---	0.42	0.42	---	0.42
XTRACT 6930	---	---	---	---	0.05	---	0.05	0.05	0.05
Calculated Analysis, %									
Lysine	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
Ca	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
P	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72

[1]All Phase I diets were pelleted.

[2]Negative Control-common corn-soybean meal diet.

[3]Positive Control-Mecadox 50 g/ton.

[4]N.C. + Yeast (0.68 kg/ton Biosaf-HR; 0.23 kg/ton Safman).

[5]N.C. + Zinc Oxide (Phase I; 3,000 ppm d 0 to 7; Phase II; 2,000 ppm d 7 to 28) and Copper Sulfate (125 ppm).

[6]N.C. + XTRACT 6930 (0.91 kg/ton).

[7]N.C. + ZnO and $CuSO_4$ + Yeast.

[8]N.C. + ZnO and $CuSO_4$ + XTRACT 6930.

[9]N.C. + Yeast + XTRACT 6930.

[10]N.C. + ZnO and $CuSO_4$ + Yeast + XTRACT 6930.

[11]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[12]Provided per kg premix: 4,409,171 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 15 mg vitamin B12; 1,764 mg menadione; 3,307 mg riboflavin; 11,023 mg pantothenic acid, 19,841 mg niacin.

Table 2. Composition of Phase 2 Diets[1] (Exp. 1)

Ingredient, %	A[2]	B[3]	C[4]	D[5]	E[6]	F[7]	G[8]	H[9]	I[10]
Corn	54.71	53.71	54.61	54.38	54.66	54.28	54.33	54.56	54.23
Soybean meal	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55
Blood meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Fish meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Milk, whey powder	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Monocalcium	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Limestone, ground	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Lys-HCL	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-Met	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
L-Thr	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[11]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[12]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
HiPhos 2700	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mecadox	---	1.00	---	---	---	---	---	---	---
Biosaf-HR	---	---	0.08	---	---	0.08	---	0.08	0.08
Safman	---	---	0.03	---	---	0.03	---	0.03	0.03
Copper sulfate	---	---	---	0.05	---	0.05	0.05	---	0.05
Zinc oxide	---	---	---	0.28	---	0.28	0.28	---	0.28
XTRACT 6930	---	---	---	---	0.05	---	0.05	0.05	0.05
Calculated Analysis, %									
Lysine	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
Ca	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
P	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63

[1]All Phase II rations were meal diets.
[2]Negative Control-common corn-soybean meal diet.
[3]Positive Control-Mecadox 50 g/ton.
[4]N.C. + Yeast (0.68 kg/ton Biosaf-HR; 0.23 kg/ton Safman).
[5]N.C. + Zinc Oxide (Phase I; 3,000 ppm d 0 to 7; Phase II; 2,000 ppm d 7 to 28) and Copper Sulfate (125 ppm).
[6]N.C. + XTRACT 6930 (0.91 kg/ton).
[7]N.C. + ZnO and $CuSO_4$ + Yeast.
[8]N.C. + ZnO and $CuSO_4$ + XTRACT 6930.
[9]N.C. + Yeast + XTRACT 6930.
[10]N.C. + ZnO and $CuSO_4$ + Yeast + XTRACT 6930.
[11]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.
[12]Provided per kg premix: 4,409,171 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 15 mg vitamin B12; 1,764 mg menadione; 3,307 mg riboflavin; 11,023 mg pantothenic acid, 19,841 mg niacin.

Table 3. Composition of Phase 3 Diets (Exp. 1)

Phase 3[1], Day 28-42	
Ingredient, %	
Corn	63.83
Soybean meal	32.85
Monocalcium	1.00
Limestone, ground	1.03
Sodium chloride	0.35
L-Lys-HCL	0.30
DL-Met	0.12
L-Thr	0.12
Trace mineral premix[2]	0.15
Vitamin premix[3]	0.25
HiPhos 2700	0.02
Calculated Analysis, %	
Lysine	1.22
Ca	0.69
P	0.61

[1]All treatments were fed a common corn-soybean meal, meal feed from d 28 to 42.
[2]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.
[3]Provided per kg premix: 4,409,171 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 15 mg vitamin B12; 1,764 mg menadione; 3,307 mg riboflavin; 11,023 mg pantothenic acid, 19,841 mg niacin.

Table 4. Effects of added trace minerals, essential oils, yeast, and carbadox on nursery pig growth performance[1,2] (Exp. 1)

Yeast/Yeast Cell Walls[3]	-	-	-	+	-	+	+	-	+		
Added Cu/Zn[4]	-	-	+	-	-	-	+	+	+		
Essential oil blend[5]	-	-	-	-	+	+	-	+	+		
Carbadox[6]	-	+	-	-	-	-	-	-	-	**SEM**	***P*-value**
BW, kg											
d 0	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36	0.27	0.32
d 7	5.82[b]	6.18[a]	6.27[a]	5.86[b]	5.91[b]	6.00[ab]	6.36[a]	6.23[a]	6.14[a]	0.31	0.01
d 14	6.73[c]	7.59[a]	7.68[a]	6.64[c]	6.91[b]	7.09[b]	7.68[a]	7.73[a]	7.41[ab]	0.38	0.01
d 28	12.55[c]	13.86[ab]	14.77[a]	12.55[c]	12.77[c]	13.09[b]	14.00[ab]	14.09[ab]	13.77[ab]	0.59	0.01
d 42	20.14[c]	21.41[ab]	22.45[a]	20.91[bc]	21.18[b]	20.82[bc]	22.23[a]	22.18[a]	21.77[ab]	0.92	0.02

[1]A total of 288 nursery pigs (DNA, initially 5.36 kg BW) were used in a 42-day study with 4 pigs per pen and 8 replications per treatment.

[2]Experimental treatment diets were fed from d 0 to d 28. All treatments were fed a common diet from d 28 to d 42.

[3]Yeast cells (Biosaf HR) added at 0.68 kg/ton and Yeast cell walls (Safman) were added at 0.23 kg/ton.

[4]Added trace minerals Cu ($CuSO_4$) at 125 ppm from d 0 to 28 and Zn (ZnO) at 3,000 ppm from d 0 to 7 and 2,000 ppm from d 7 to 28.

[5]Essential oils blend from XTRACT 6930 at 0.91 kg/ton (Capsicum oleoresin 2%, Carvacrol 5%, Cinnamaldehyde 3%, Hydrogenated rapeseed oil 90%) from d 0 to 28.

[6]Mecadox®was added at either 0 or 50 g/ton from d 0 to 28.

[abc]Least squares means in the same row were considered significantly different at $P < 0.05$, with superscripts designating significant differences.

Table 5. Effects of added trace minerals, essential oils, yeast, and carbadox on nursery pig growth performance[1,2] (Exp. 1)

Yeast/Yeast Cell Walls[3]	-	-	-	+	-	+	+	-	+		
Added Cu/Zn[4]	-	-	+	-	-	-	+	+	+		
Essential oil blend[5]	-	-	-	-	+	+	-	+	+		
Carbadox[6]	-	+	-	-	-	-	-	-	-	**SEM**	***P*-value**
d 0 to 7											
ADG, kg	0.07[d]	0.12[b]	0.12[b]	0.07[d]	0.07[d]	0.10[c]	0.15[a]	0.12[b]	0.11[bc]	0.01	0.01
ADFI, kg	0.12[a]	0.13[a]	0.14[a]	0.11[a]	0.12[a]	0.14[a]	0.15[a]	0.13[a]	0.14[a]	0.11	0.05
G/F	0.55[b]	0.88[a]	0.87[a]	0.65[b]	0.64[b]	0.68[ab]	0.97[a]	0.97[a]	0.83[a]	0.16	0.02
d 7 to 28											
ADG, kg	0.32[b]	0.37[a]	0.38[a]	0.32[b]	0.33[b]	0.34[ab]	0.36[a]	0.37[a]	0.36[a]	0.02	0.01
ADFI, kg	0.57[c]	0.64[a]	0.65[a]	0.54[d]	0.54[d]	0.57[c]	0.64[a]	0.61[b]	0.63[a]	0.02	0.01
G/F	0.56	0.58	0.59	0.59	0.61	0.59	0.57	0.61	0.58	0.03	0.79
d 0 to 42											
ADG, kg	0.35[c]	0.38[ab]	0.40[a]	0.37[b]	0.38[ab]	0.37[b]	0.40[a]	0.40[a]	0.39[a]	0.02	0.04
ADFI, kg	0.62	0.66	0.66	0.62	0.60	0.62	0.65	0.65	0.65	0.02	0.39
G/F	0.56	0.58	0.61	0.60	0.62	0.59	0.61	0.62	0.61	0.03	0.15

[1]A total of 288 nursery pigs (DNA, initially 5.36 kg BW) were used in a 42-day study with 4 pigs per pen and 8 replications per treatment.

[2]Experimental treatment diets were fed from d 0 to d 28. All treatments were fed a common diet from d 28 to d 42.

[3]Yeast and Yeast Cell Walls were added as (0.68 kg/ton of Biosaf-HR; 0.23 kg/ton Safmannan).

[4]Added trace minerals Cu ($CuSO_4$) was added at 125 ppm from d 0 to 28 and Zn (ZnO) at 3,000 ppm from d 0 to 7 and 2,000 ppm from d 7 to 28.

[5]Essential oils blend from XTRACT 6930 at 0.91 kg/ton (Capsicum oleoresin 2%, Carvacrol 5%, Cinnamaldehyde 3%, Hydrogenated rapeseed oil 90%) from d 0 to 28.

[6]Mecadox®was added at either 0 or 50 g/ton from d 0 to 28.

[abcd]Least squares means in the same row were considered significantly different at $P < 0.05$, with superscripts designating significant differences.

Table 6. Composition of Phase 1 Diets[1] (Exp. 2)

Ingredient, %	A[2]	B[3]	C[4]	D[5]	E[6]	F[7]	G[8]
Corn	38.75	37.75	38.28	38.74	38.71	38.27	38.24
Soybean meal	16.95	16.95	16.95	16.95	16.95	16.95	16.95
Blood meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Blood plasma	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Corn DDGS, >6 and <9% oil	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Fish meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Milk, whey powder	12.50	12.50	12.50	12.50	12.50	12.50	12.50
Milk, whey permeate, 80% lactose	11.25	11.25	11.25	11.25	11.25	11.25	11.25
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Calcium phosphate (monocalcium)	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Limestone, ground	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Lys-HCL	0.23	0.23	0.23	0.23	0.23	0.23	0.23
DL-Met	0.14	0.14	0.14	0.14	0.14	0.14	0.14
L-Thr	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[9]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[10]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride 60%	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Acidifier	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin E, 20,000 IU	0.05	0.05	0.05	0.05	0.05	0.05	0.05
HP 300 (Hamlet Protein)	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Mecadox	---	1.00	---	---	---	---	---
Zinc oxide	---	---	0.42	---	---	0.42	0.42
Copper sulfate	---	---	0.05	---	---	0.05	0.05
Victus® LIV	---	---	---	0.015	0.044	0.015	0.044
Calculated Analysis, %							
Lysine	1.32	1.32	1.32	1.32	1.32	1.32	1.32
Ca	0.70	0.70	0.70	0.70	0.70	0.70	0.70
P	0.65	0.65	0.65	0.65	0.65	0.65	0.65

[1] All Phase I diets were meal form.
[2] Negative Control-common corn-soybean meal diet.
[3] Positive Control-Mecadox 50 g/ton.
[4] N.C. + Zinc Oxide (Phase I; 3,000 ppm d 0 to 7; Phase II; 2,000 ppm d 7 to 35) and Copper Sulfate (125 ppm).
[5] N.C. + Victus® LIV (145 ppm).
[6] N.C. + Victus® LIV (435 ppm).
[7] N.C. + $CuSO_4$ and ZnO (3,000 ppm) + Victus® LIV (145 ppm).
[8] N.C. + $CuSO_4$ and ZnO (3,000 ppm) + Victus® LIV (435 ppm).
[9]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.
[10]Provided per kg premix: 4,409,171 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 15 mg vitamin B12; 1,764 mg menadione; 3,307 mg riboflavin; 11,023 mg pantothenic acid, 19,841 mg niacin.

Table 7. Composition of Phase 2 Diets[1] (Exp. 2)

Ingredient, %	A[2]	B[3]	C[4]	D[5]	E[6]	F[7]	G[8]
Corn	49.45	48.45	49.12	49.44	49.41	49.11	49.08
Soybean meal, dehull, sol extr	24.80	24.80	24.80	24.80	24.80	24.80	24.80
Blood meal	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Corn DDGS, >6 and <9% oil	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Fish meal combined	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Milk, whey powder	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Calcium phosphate (monocalcium)	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Limestone, ground	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Lys-HCL	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-Met	0.18	0.18	0.18	0.18	0.18	0.18	0.18
L-Thr	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[9]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[10]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
HiPhos 2700	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mecadox	---	1.00	---	---	---	---	---
Zinc oxide	---	---	0.28	---	---	0.28	0.28
Copper sulfate	---	---	0.05	---	---	0.05	0.05
Victus® LIV	---	---	---	0.015	0.044	0.015	0.044
Calculated Analysis, %							
Lysine	1.27	1.27	1.27	1.27	1.27	1.27	1.27
Ca	0.78	0.78	0.78	0.78	0.78	0.78	0.78
P	0.65	0.65	0.65	0.65	0.65	0.65	0.65

[1] All Phase II diets were meal form.
[2] Negative Control-common corn-soybean meal diet.
[3] Positive Control-Mecadox 50 g/ton.
[4] N.C. + Zinc Oxide (Phase I; 3,000 ppm d 0 to 7; Phase II; 2,000 ppm d 7 to 35) and Copper Sulfate (125 ppm).
[5] N.C. + Victus® LIV (145 ppm).
[6] N.C. + Victus® LIV (435 ppm).
[7] N.C. + $CuSO_4$ and ZnO (2,000 ppm) + Victus® LIV (145 ppm).
[8] N.C. + $CuSO_4$ and ZnO (2,000 ppm) + Victus® LIV (435 ppm).
[9]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.
[10]Provided per kg premix: 4,409,171 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 15 mg vitamin B12; 1,764 mg menadione; 3,307 mg riboflavin; 11,023 mg pantothenic acid, 19,841 mg niacin.

Table 8. Composition of Phase 3 Diets (Exp. 2)

Phase 3[1], Day 21-35							
Ingredient, %	A[2]	B[3]	C[4]	D[5]	E[6]	F[7]	G[8]
Corn	50.96	49.96	50.63	50.95	50.92	50.62	50.59
Soybean meal	30.70	30.70	30.70	30.70	30.70	30.70	30.70
Corn DDGS, >6 and <9% oil	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Calcium phosphate (monocalcium)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Limestone, ground	1.03	1.03	1.03	1.03	1.03	1.03	1.03
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys-HCL	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-Met	0.12	0.12	0.12	0.12	0.12	0.12	0.12
L-Thr	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Trace mineral premix[9]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[10]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
HiPhos 2700	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mecadox	---	1.00	---	---	---	---	---
Zinc oxide	---	---	0.28	---	---	0.28	0.28
Copper sulfate	---	---	0.05	---	---	0.05	0.05
Victus® LIV	---	---	---	0.015	0.044	0.015	0.044
Calculated Analysis, %							
Lysine	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Ca	0.69	0.69	0.69	0.69	0.69	0.69	0.69
P	0.66	0.66	0.66	0.66	0.66	0.66	0.66

[1] All Phase III diets were meal form.
[2] Negative Control-common corn-soybean meal diet.
[3] Positive Control-Mecadox 50 g/ton.
[4] N.C. + Zinc Oxide (Phase I; 3,000 ppm d 0 to 7; Phase II; 2,000 ppm d 7 to 35) and Copper Sulfate (125 ppm).
[5] N.C. + Victus® LIV (145 ppm).
[6] N.C. + Victus® LIV (435 ppm).
[7] N.C. + $CuSO_4$ and ZnO (2,000 ppm) + Victus® LIV (145 ppm).
[8] N.C. + $CuSO_4$ and ZnO (2,000 ppm) + Victus® LIV (435 ppm).
[9]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.
[10]Provided per kg premix: 4,409,171 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 15 mg vitamin B12; 1,764 mg menadione; 3,307 mg riboflavin; 11,023 mg pantothenic acid, 19,841 mg niacin.

Table 9. Effects of added trace minerals, Victus® LIV, and carbadox on nursery pig growth performance[1,2] (Exp. 2)

Added Cu/Zn[3]	-	-	+	-	-	+	+		
Victus® LIV (145 ppm)[4]	-	-	-	+	-	+	-		
Victus® LIV (435 ppm)[5]	-	-	-	-	+	-	+		
Carbadox[6]	-	+	-	-	-	-	-	**SEM**	***P*-value**
Weight, kg									
Day 0	5.18	5.18	5.18	5.18	5.18	5.18	5.18	0.34	1.00
Day 35	14.91[c]	17.05[a]	16.41[a]	16.18[ab]	15.23[bc]	16.86[a]	16.55[a]	0.73	0.01
d 0 to 7									
ADG, kg	-0.02[b]	0.02[a]	0.03[a]	0.03[a]	0.00[ab]	0.03[a]	0.03[a]	0.01	0.06
ADFI, kg	0.05[c]	0.08[abc]	0.09[ab]	0.08[abc]	0.07[bc]	0.10[a]	0.09[ab]	0.01	0.07
G/F	-0.36	0.29	0.32	0.35	0.07	0.33	0.35	1.28	0.37
d 7 to 21									
ADG, kg	0.22[c]	0.27[ab]	0.31[a]	0.27[ab]	0.24[bc]	0.31[a]	0.31[a]	0.02	0.01
ADFI, kg	0.39[b]	0.43[ab]	0.49[a]	0.43[ab]	0.36[b]	0.48[a]	0.50[a]	0.03	0.01
G/F	0.58[b]	0.63[ab]	0.64[ab]	0.62[ab]	0.66[a]	0.64[a]	0.62[ab]	0.03	0.13

[1]A total of 280 nursery pigs (DNA, initially 5.18 kg BW) were used in a 35-day study with 5 pigs per pen and 8 replications per treatment.

[2]Experimental treatment diets were fed from d 0 to d 35.

[3]Added trace minerals Cu ($CuSO_4$) added at 125 ppm from d 0 to 35 and Zn (ZnO) at 3,000 ppm from d 0 to 7 and 2,000 ppm from d 7 to 35.

[4,5]Essential oils were added as Victus Liv at either 145 ppm[4] or 435 ppm[5] from d 0 to 35.

[6]Mecadox®was added at either 0 or 50 g/ton from d 0 to 35.

[abc]Least squares means in the same row were considered significantly different at $P < 0.05$, with superscripts designating significant differences.

Table 10. Effects of added trace minerals, Victus® LIV, and carbadox on nursery pig growth performance[1,2] (Exp. 2)

Added Cu/Zn[3]	-	-	+	-	-	+	+		
Victus® LIV (145 ppm)[4]	-	-	-	+	-	+	-		
Victus® LIV (435 ppm)[5]	-	-	-	-	+	-	+		
Carbadox [6]	-	+	-	-	-	-	-	SEM	*P*-value
d 0 to 21									
ADG, kg	0.14[c]	0.19[ab]	0.22[a]	0.19[ab]	0.16[bc]	0.22[a]	0.22[a]	0.01	0.01
ADFI, kg	0.28[c]	0.31[ab]	0.35[a]	0.31[ab]	0.26[bc]	0.35[a]	0.36[a]	0.02	0.01
G/F	0.50[b]	0.61[a]	0.63[a]	0.61[a]	0.62[a]	0.63[a]	0.61[a]	0.03	0.01
d 21 to 35									
ADG, kg	0.47[b]	0.55[a]	0.47[b]	0.50[ab]	0.45[b]	0.50[ab]	0.48[ab]	0.02	0.10
ADFI, kg	0.65	0.71	0.66	0.67	0.64	0.68	0.69	0.03	0.47
G/F	0.73[ab]	0.77[a]	0.71[b]	0.75[ab]	0.71[b]	0.73[ab]	0.70[b]	0.02	0.15
d 0 to 35									
ADG, kg	0.23[c]	0.28[a]	0.27[a]	0.26[ab]	0.23[bc]	0.28[a]	0.28[a]	0.01	0.02
ADFI, kg	0.36[bc]	0.40[ab]	0.41[ab]	0.39[abc]	0.35[c]	0.42[a]	0.42[a]	0.02	0.04
G/F	0.63[b]	0.70[a]	0.67[ab]	0.67[ab]	0.65[ab]	0.67[ab]	0.66[ab]	0.02	0.16

[1]A total of 280 nursery pigs (DNA, initially 5.18 kg BW) were used in a 35-day study with 5 pigs per pen and 8 replications per treatment.
[2]Experimental treatment diets were fed from d 0 to d 35.
[3]Added trace minerals Cu ($CuSO_4$) added at 125 ppm from d 0 to 35 and Zn (ZnO) at 3,000 ppm from d 0 to 7 and 2,000 ppm from d 7 to 35.
[4]Essential oils were added as Victus Liv at either [4]145 ppm or [5]435 ppm from d 0 to 35.
[6]Mecadox®was added at either 0 or 50 g/ton from d 0 to 35.
[abc]Least squares means in the same row were considered significantly different at $P < 0.05$, with superscripts designating significant differences.