The impact of feed additives to improve growth performance in nursery pigs and meat goats

by

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Abstract

Four studies were conducted to evaluate methods to nutritionally improve nursery pig or meat goat growth and efficiency. In Exp. 1, a total of 360 weanling pigs (DNA 200 x 400; 5.4 ± 0.07 kg BW) were fed for 35 days, with 6 pigs/pen and 10 replicate pens/treatment. Pigs were allotted based on BW in a completely randomized design to treatment diets: 1) Negative control; 2) Control + 3,000 ppm ZnO in phase 1 and 2,000 ppm ZnO in phase 2; 3) Control + 50 g/ton carbadox; 4) Control + C6:C8:C10 MCFA blend; 5) Control + Proprietary Oil Blend (Feed Energy Corp.); 6) Control + monolaurate blend (FORMI GML from ADDCON). Treatments were fed through two dietary phases and a common diet fed through phase three. Pigs and feeders were individually weighed on a weekly basis to determine average daily gain (**ADG**) and average daily feed intake (**ADFI**). From d 0 to 19, pigs being fed the ZnO or Carbadox diets had the greatest ADG. These pigs had significantly higher ($P < 0.05$) ADG than pigs fed the control or Feed Energy Proprietary Oil Blend, while pigs fed the C6:C8:C10 blend or FORMI GML diets had similar ($P > 0.05$) ADG compared to those fed carbadox. Overall, these results show that ZnO and carbadox are valuable additives to help maximize growth performance in early stages of the nursery. Some MCFA products may result in similar performance while others restrict it.

Next, a total of 360 weanling pigs (DNA 200 x 400; initially 9.7 ± 0.23 kg BW) were used in a 21-d experiment with 6 pigs/pen and 10 replicate pens/treatment. Pigs were allotted to pens based on BW in a completely randomized block design to one of 6 diets: 1) Negative control (no organic acids or antibiotics); 2) Control + 0.25% Commercial Acidifier A) Control + 0.3% Commercial Acidifier B; 4) Control + 0.5% Commercial Acidifier C); 5) Control + 50 g/ton Carbadox; 6) Control + 400 g/ton Chlortetracycline). Dietary treatment had a significant

impact ($P < 0.05$) on ADG, ADFI and G:F for the entire experiment. Carbadox negatively impacted ADG and ADFI ($P < 0.0001$), while pigs fed CTC had improved ($P < 0.0001$) ADG compared to all other treatments. In summary, CTC continues to be a valuable additive to enhance piglet health and subsequent performance in the nursery. Further investigation surrounding the efficacy of dietary acidifiers is warranted given inconclusive evidence in this study.

Finally, 2 experiments were conducted to: 1) evaluate corn dried distiller's grains with solubles (DDGS) vs. corn gluten feed (CGF) as alternatives for soybean meal (SBM); and 2) evaluate feeding DDGS and an ionophore on Boer goat growth performance and carcass characteristics. In Exp. 1, a total of 75 Boer-goat kids (26.9 ± 0.2 kg) were allotted to one of 5 dietary treatments: 1) Negative control (100% SBM, 0% DDGS and 0% CGF; 100SBM); 2) Positive control (100% DDGS, 0% CGF and 0% SBM 100DDGS); 3) 66% DDGS, 33% CGF and 0% SBM (66DDGS/33CGF); 4) 66% CGF, 33% DDGS and 0% SBM (33DDGS/66 CGF); and 5) 100% CGF, 0% DDGS and 0% SBM (0DDGS/100CGF). Dietary treatment did not impact ($P \le 0.21$) any of the measured growth response criteria. In Exp. 2, a total of 72 Boer-goat kids (21.7 ± 0.8 kg) were allotted in a completely randomized design. Dietary treatments were: 1) SBM/No Ionophore (SBM-NI); 2) SBM with Ionophore (SBM-I); 3) DDGS/No Ionophore (DDGS-NI); and 4) DDGS with Ionophore (DDGS-I). There were no significant protein source × ionophore interactions ($P = 0.15$) for any growth criteria. Goats fed the SBM-I diet had significantly increased ($P = 0.04$) ADG compared to goats fed DDGS-NI. Dietary treatments did not impact ($P > 0.05$) carcass characteristics. In both experiments, ingredient prices for tested ingredients dictated changes in diet cost, but no differences were observed across treatments for feed cost per goat and cost/kg of gain ($P > 0.10$). In summary, these data

suggest that corn co-products can be economically included in Boer-goat diets, however their impact on growth performance is variable compared to that of soybean meal. Further research to evaluate the efficacy of both corn co-products and ionophores in goat diets is needed.

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Additionally, I owe a thank you to Chris Mullinix and the 2019 and 2020 K-State Livestock Judging Teams. The opportunity to coach has been extremely gratifying and I have thoroughly enjoyed getting to know so many awesome livestock minds from all over the country. To my fellow graduate students and the undergraduate researchers in our department – thank you for your assistance and friendship. I appreciate each of you and the role you have played in my program.

Finally, to my biggest support system of all, my family. Mom and dad, thank you for teaching me to set goals, work hard and never stop trying to be better than you were the day before. Your support of my endeavors has never faded, and I will never be able to repay you. Paxton and Payge, I can't wait to see what you will accomplish in the future – thank you both for being part of the best "team" around. Whitney, thank you for the consistent motivation, always being there to listen and reminding me to never take life too seriously.

There are many other people who are deserving of thanks for their contributions to my academic career. The faculty at Kansas State University are second to none and have truly enriched my experience as a graduate student. As always, EMAW!

Dedication

This thesis is dedicated to my grandmother, Peggy. Since the day I was born she has always been my biggest fan. Whether it was a livestock show, FFA activity or graduation – she has been there for them all. I am so grateful to share this milestone in my life with her as well.

Chapter 1 - KSU Show Lamb Guide[1]

Selection

First...

- To help select the right lamb, you should ask yourself a few questions: What is your end goal?

    - Participate at the county, state, or national level?

    - How well are you aiming to do at that level?

- Determine the date of your "target show" or the show in which you want your lamb to be in optimal condition/appearance

- Also, start thinking about things like:

    - What breed of lamb do I want to exhibit?

    - Where am I going to get it?

    - What are the ownership requirements for the exhibitions?

        - Most shows require that you own your project by a certain deadline, typically a few months before the show

        - This information can be found in the rules/regulations of the show

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[1]This work is currently in the publication process by *Kansas State Research Exchange (K-REx)*: Dahmer, P.L., A.R. Crane, J.M. DeRouchey and C.K. Jones. 2020. Kansas State University Show Lamb Guide.

Next...

For some, selection of a good project comes easy with a natural ability to evaluate livestock. If you are less experienced or do not know how to select the right lamb, it is important that you reach out to someone who has that expertise. Agriculture teachers, FFA advisors, 4-H leaders, extension agents and breeders are all knowledgeable sources when it comes to finding the right project for you and are always willing to help you in the process.

- Finding the appropriate age and weight of lamb is important for your long-term goals and success
  - You want to avoid finding a project that is too old and will be hard to maintain at the correct weight, but still find one big enough to meet the minimum weight requirement for most shows

Table 1.1. Ideal age of lamb according to target show date

Target Show Date	Ideal Age of Lamb to Select
July-August (most Kansas county fairs fall in this time frame)	Typically, lambs born in January or early February work best
September-November (this time frame encompasses shows like the Kansas State Fair, Kansas Junior Livestock Show, and most national livestock shows)	Lambs born in February to early March are ideal

- An important thing to keep in mind when selecting your lamb is maturity; indicating the point in time that the lamb will reach optimal condition or the peak of lean muscle to optimal fat ratios, or finished weight

- Some lambs are later maturing, meaning they will need to be fed to heavier

    weights (140-160 lbs.) to reach the optimal muscle to fat ratio

    - Later maturing lambs are usually longer through their head (nose to poll),

        neck, body, and cannon bone while having less fat over the fore rib

- Others are earlier maturing, meaning they will be finished (or reach optimal fat

    levels) at lighter weights (120-130 lbs.)

    - Earlier maturing lambs are usually shorter about their head (nose to poll),

        body and cannon bone and often times already have more fat deposition

        over the fore-rib, even at a younger age

Parts of a Sheep

While it may seem elementary to some, it is important that you understand the parts of a sheep

prior to learning about selection. A great diagram showing the primary parts of a market lamb is

shown below.
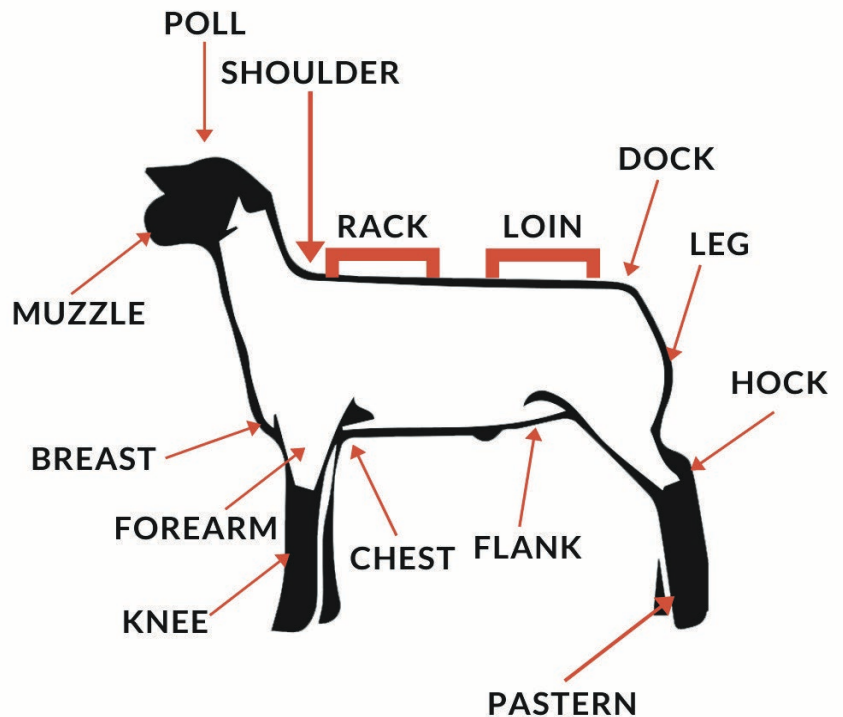
Figure 1. Parts of a show lamb

Selection Criteria

When selecting your project, keep the following criteria in mind to help find the ideal show lamb: muscle, leanness, structural correctness, balance, pattern, and growth.

Muscle

- Muscularity stems from a wide base
    - Width through the chest floor, width of base from hock to ground
- Muscle in market lambs is evaluated down their top and from behind
    - Shape of rack, width/squareness of loin, width of pins, shape/width to lower leg
- Market lambs are handled by the judge, so freshness and handling quality of the muscle is important:
    - Hard, square and upstanding shape to rack muscle
    - Length of hind saddle (measured from the last rib back)
    - Wide, square loin edge
    - Firm, bulging shape to leg and depth to the twist
    - Thin, fresh touch to the hide
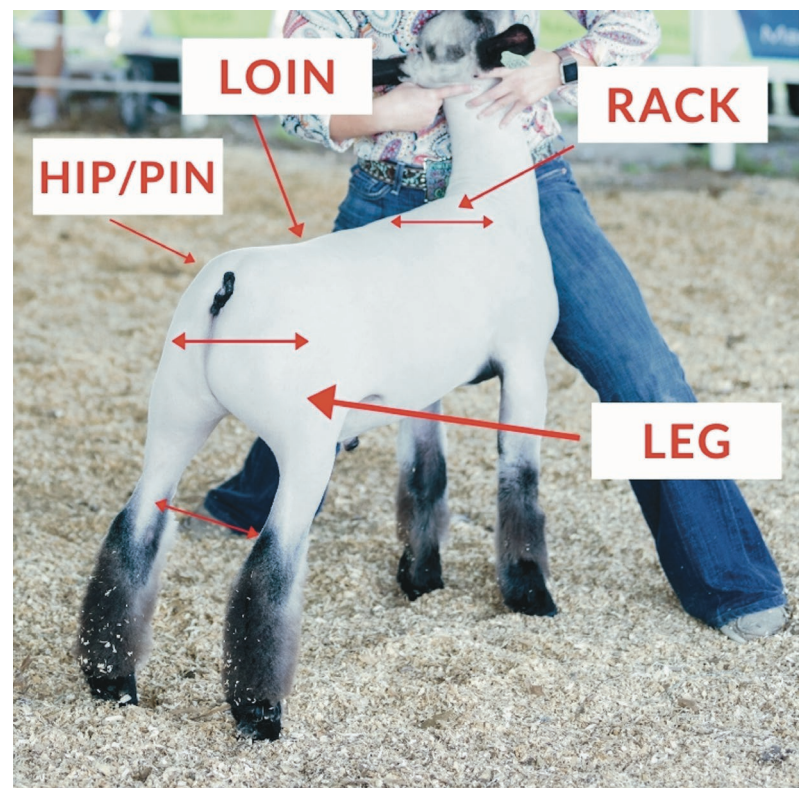
Figure 2. Areas to evaluate muscle

Leanness

- Young lambs should read lean over their forerib so they can mature into the correct degree of cover at their market weight

- Judges evaluate finish in market lambs by the amount of fat cover laid over the lambs forerib

- Ideal fat cover for market lambs depends on their weight

- You can also evaluate fat cover by looking for indentation from the lambs' shoulder into its forerib

- A great resource to learn more about market lamb carcass evaluation can be found at https://workspaces.ndsu.edu/fileadmin/4h/Animals/GBJ09.pdf
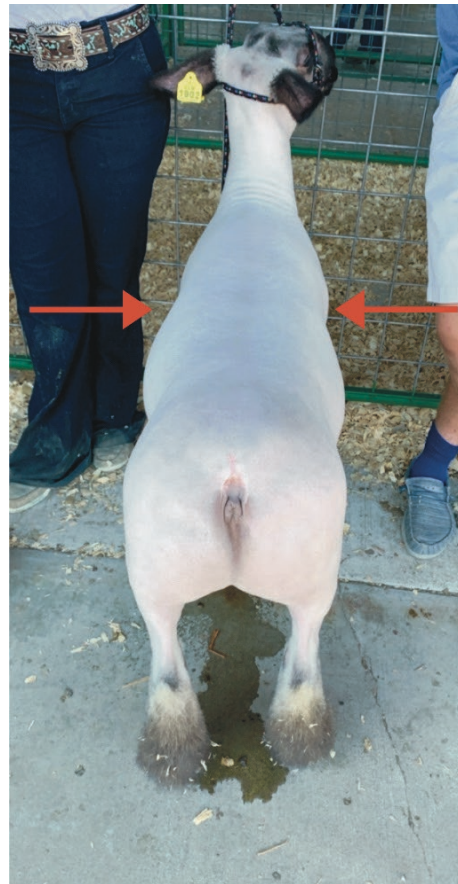
Figure 3. Areas to evaluate leanness

Structural Correctness

- Structural correctness refers to how a lamb's skeleton is put together

- Evaluate structure from the ground up, front to rear and in motion

    - Lambs should naturally carry their head high

    - Neck should project high out of their shoulder

    - Shoulder blade should have an angle similar to 45º

    - The knee should have some angle to it with a correct angle to the pastern

    - Front feet should plant wide and point straight ahead, feet should be big with toes even in size

    - Spine should be level all the way out through the lambs' hip/dock

    - Hind leg should have some angularity from the side with a correct set to the pastern

    - From behind, hind leg should plant wide and square from the hock to the ground

Correct   Too much angle   Too straight
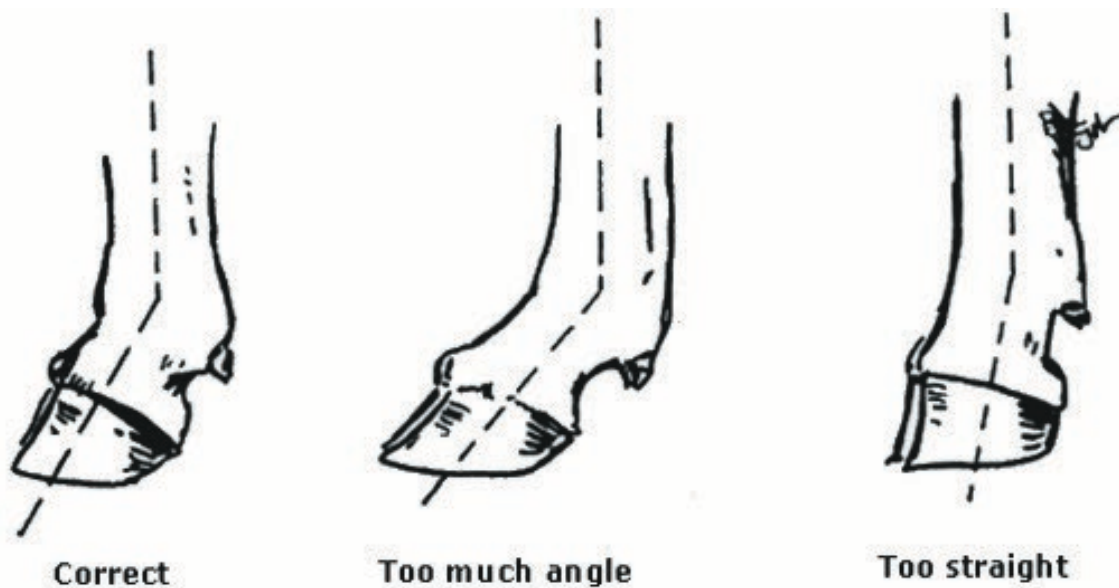
Figure 4. Illustration of correct pastern (provided by NSW Department of Primary Industries)

Balance

- Balance is **<u>NOT</u>** the same thing as attractiveness

- Balance directly means *proportional*

    - A lamb's' length of front, body, and hind quarter should all match

    - Lambs should be clean through the base of their chest (*circled area on picture to the right)* and get progressively deeper back to their flank

Figure 5. Evaluation of balance in sheep

- The amount of foot/bone a lamb has should match the amount of muscle and mass it possesses

    - An extremely heavy muscled lamb with small feet and thin/frail bone is not balanced

    - A light muscled lamb with big feet and stout bone is also not balanced

Pattern

- Pattern refers to *attractiveness*

- An attractive lamb with correct pattern is:

    - Tall at the top of the shoulder

    - Projects a long neck out of its shoulder

    - Stays smooth down its topline and is smooth from the last rib, into the loin, and back to the hip

    - Stays level and smooth down its top when set into motion

Figure 6. Evaluation of pattern in sheep

Sheep Breeds

Cheviot

- Originated in Scotland in the 1400s

- Imported to the U.S. in 1838

- Small-sized and white wool with bare head and legs

- Good maternal qualities

- Yield high amounts of medium grade wool

- http://www.cheviots.org/index.html

Figure 7. Cheviot sheep (provided by the American Cheviot Sheep Society)

Columbia

- Developed in Wyoming in 1912

- Cross of Lincoln and Rambouillet

- Large, white wool breed

- Medium wool

- Often used to sire commercial lambs

- https://columbiasheep.org/about-us/

Figure 8. Columbia sheep (provided by the Columbia Sheep Breeders Association)

Corriedale

- Developed in New Zealand/Australia in late 1800s
- Lincoln or Leicester rams with Merino females
- Imported to the US in 1914
- Medium-sized white-faced wool breed
- http://www.countrylovin.com/ACA/index.htm

Figure 9. Corriedale sheep (provided by the American Corriedale Association)

Dorper

- Developed in South Africa in the 1930s
- Cross between Horned Dorset and Black headed Persian
- Hair sheep of medium size with white bodies and a black or white colored head
- Hardy, adaptable, early maturing, yield heavy-muscled carcasses
- https://dorpersheep.org/faqs/

Figure 10. Dorper sheep (provided by the American Dorper Sheep Breeders Society)

Dorset

- Originated from Southwestern England
    - Cross between Merino and Horned Sheep of Wales
    - Imported to the US in 1860
- Medium-sized, all white wool breed
- Medium-fine wool
- Heavy milking commercial breed with fleeces free of black fibers
- Females carry "out of season" breeding characteristics with increased potential for multiple births
- Used heavily on maternal side of commercial operations
- https://dorsets.homestead.com

Figure 11. Dorset sheep (provided by Silver Smith Genetics)

Hampshire

- Hampshire County in Southern England
    - The "Hampshire Down" developed from the Southdown, Wiltshire Horn, Berkshire Knot
    - Imported to the US in the 1800's
- Blackface, practically free of wool from the eyes down, with a sufficient wool cap
- Terminal breed
    - Good growth
    - High carcass cutability
- http://www.hampshires.org

Figure 12. Hampshire sheep (provided by the American Hampshire Sheep Association)

Katahdin

- Maine 1958
  - Caribbean hair sheep and a variety of wool breeds
- Medium-sized hair sheep, any color, parasite tolerance, and capable of breeding out of season
- Shedding hair coat does not require shearing
- https://www.katahdins.org

Figure 13. Katahdin sheep (provided by Francis Family Farms Katahdins)

Lincoln

- Lincolnshire, England
  - Cross between Leicester and Native Lincolnshire sheep
  - Late 1700's
- The largest breed of sheep, typically have largest average weight
- White wool
- Produce a heavy fleece that is long and coarse
- http://www.lincolnsheep.com

Figure 14. Lincoln sheep (provided by the National Lincoln Sheep Breeders Association)

Merino

- Originated in Spain
- Many different types of Merino sheep developed in other countries
- Usually medium to large framed with exceptionally fine, white wool
- Fine-Wool Merino is main representative of Merino breed in Australia, where the world's finest quality wool is produced

Figure 15. Merino sheep (provided by Susan Schoenian, University of Maryland)

Oxford

- Originated in Oxford County, England (1800s)
  - Cross between Hampshire and Cotswold
- Medium to large-sized with a dark brown face
- Medium wool, terminal breed
- https://americanoxfords.org

Figure 16. Oxford sheep (provided by the American Oxford Sheep Association)

Rambouillet

- Originated in France and Germany
  - Developed from the Spanish Merino
  - Imported in the 1800s
- Large, hardy and adaptable breed
- "Dual Purpose" for their excellent wool and weight gains
- http://www.countrylovin.com/ARSBA/index.htm

Figure 17. Rambouillet sheep (provided by Benz Rambouillet)

Shropshire

- Shropshire and Staffordshire counties in England
- Developed from Longmynd, Southdown, Leicester, and Cotswolds
- Imported to the US in 1855
- Medium to large black-faced breed
- Medium wool
- Prolific with good carcass quality
- http://www.shropshires.org

Figure 18. Shropshire sheep (provided by the American Shropshire Registry Association)

Southdown

- Developed in Sussex England in the late 1700s
    o Imported to US in 1824
- Medium to small-sized breed with gray to mouse-brown nose and lower legs
- Early maturing breed, best suited for farm flock production
- Work well in cross breeding programs due to their ability to produce muscular lambs
- https://southdownsheep.org

Figure 19. Southdown sheep (provided by the American Southdown Breeders Association**)**

Suffolk

- Southeastern coast of England
- Developed from breeding Southdown rams to Norfolk Horned ewes
    o Imported to the US in 1888
- Extremely muscular, large framed sheep with a black face and legs
- Medium wool breed
- Known for their size, growth, and meat
- https://suffolks.org

Figure 20. Suffolk sheep (provided by the United Suffolk Sheep Association)

Polypay

- 1960's
- Developed with the goal of increasing prolificacy
- Created from a cross of Finnsheep, Rambouillet, Targhee and Dorsets
- Named Polypay from "poly" meaning many and "pay", meaning return on investment
- https://www.polypay.org

Figure 21. Polypay sheep (provided by the American Polypay Association)

Texel

- Originated on Isle of Texel off the coast of the Netherlands
- White faced breed with no wool on head or legs
- Superior muscling and feed efficiency
- Dominant terminal sire breed in Europe

Figure 22. Texel sheep (provided by the Texel Sheep Breeders Society)

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General Care and Management

<u>Facilities</u>

While it is not necessary to have the newest and most expensive facilities, it is still important to provide basic shelter and an optimal environment to ensure your lamb's success. Here are some key things to remember when considering the management and housing options for your lamb:

- Make sure dry, clean bedding is provided

- Can be penned individually or with others, but recommended floor space per lamb is a minimum of 20 square feet

- Fences should be at least 42 inches tall

  - If possible, use panels with vertical rather than horizonal bars to prevent injury to your lamb

- It is important to provide a comfortable area for your lamb –

  - When you first bring your lamb home in the spring, it can be chilly during the day and even cold at night, so provide a warm, draft-free area and correctly mount a heat lamp if necessary

  - Throughout the hot months of summer, if your lamb is not cool, their feed intake could decrease – so always provide fresh, cool water and shade, and utilize fans if necessary

- If penned individually, feeders should be hung at shoulder height for each lamb. If lambs are penned as a group, then individual feeding stalls may be beneficial to monitor intake of each lamb

- A variety of watering types can be used; however, it is critical that water is consistently fresh and available. If hand watering, use buckets no larger than 5 gallons and change water at least once daily
  - During hot summer months, bucket waters should be monitored and kept full throughout the day. A lower maintenance option would be automatic waterers

<u>Health</u>

Maintaining good health is a key component to your lamb's success. Proper nutrition and health are highly correlated; thus, a healthy lamb is going to gain better and have an easier time reaching its target weight. A large portion of maintaining a healthy lamb is to take preventative measures. It is very important to evaluate health **DAILY** by looking for signs of illness (ear position, coughing, not eating/drinking, lethargy, body temperature, changes in stool, etc.). Administer proper medications under the direction of your veterinarian when needed, but always stay mindful of withdrawal times. Strive to have a good working relationship with your veterinarian to ensure proper health of your animal.

Enterotoxemia
  - Also known as overeating disease, this is caused by a clostridial organism that is normally found in the intestine of most sheep. When lambs experience rapid diet changes, like consuming large amounts of grain, this causes the organism to grow and produce toxins that can result in death. Proper vaccination (against clostridials, such as types C and D) and gradual changes in your feeding program can help prevent this disease.

Internal Parasites
  - It is recommended that you deworm only when needed

- Often times, parasite problems are confirmed by a fecal test performed by your veterinarian

- Once a problem is confirmed, then follow-up deworming is only necessary if there is continued infection

- *More information regarding deworming protocols can be found at the American Consortium for Small Ruminant Parasite Control website (https://www.wormx.info/bmps)*

Coccidiosis

- One of the most common internal parasites encountered with show lambs is coccidia

- Caused by a protozoon that reproduces in the intestinal cells

- Often categorized by diarrhea (can contain mucus and blood)

  - Your veterinarian can help diagnose and develop a treatment plan

  - Many cases can be treated with medications like Corid or lasalocid

Soremouth

- This contagious disease causes scabs to form around the mouth and lips (pictured above). It is a viral infection that is transmittable to humans, so it is important to wear proper protection when handling lambs with soremouth. Application of iodine is common practice to dry out the scabs and speed up the healing process.

Figure 23. Soremouth (provided by Susan Schoenian, University of Maryland)

Show Lamb Fungus

- While there are more scientific terms for this common skin issue, it is probably the most prevalent health issue you will face throughout the show season (pictured below). This fungal infection is very contagious to both livestock and humans, otherwise known as ringworm. Red lesions typically appear on the head, neck, and back and eventually become "crusty" or "scaly" and circular.

Figure 24. Show lamb fungus (provided by CA Department of Food and Agriculture)

- While there is no specific treatment for this issue, prevention is key in order to keep your lamb free of fungus.

    - Always wash your lamb immediately after a show with an antifungal shampoo prior to getting it home

    - Keep facilities and equipment clean and disinfect frequently

    - Keep infected lambs isolated from healthy lambs and clean equipment between use animals

    - Wear proper protection when handling infected animals, as it is easy to pass to healthy sheep or even to yourself

    - Keep a close eye on your lambs hide in the days following a show to notice if any lesions start to appear

Halter Breaking

It is important to remember that halter breaking your lamb is a process. Do not try to rush into this as soon as you get your lamb home. A week of down time between getting your lamb home and starting the process is suggested; this allows enough time to get the lamb started on feed and used to their new surroundings.

- Before you can begin exercising the lamb, you must first train them to walk on a halter. Start by tying your lamb up to the fence and be sure to give it enough slack to be comfortable. The lamb is more than likely going to fight this hard. It is CRITICAL that you stay with the lamb during this time so that they do not injure themselves. Once they stop fighting the halter, release them and repeat this step daily until they are comfortable being tied.

Once your lamb is broke to tie, it is time to teach them to lead. Again, this is a process! Rather than pulling on the halter to drag the lamb, stand to the side or behind it and let the lamb naturally walk. If you try pulling the halter, your lamb is going to pull back and no progress will be made.

Exercise

Exercise is critical during all stages of your lamb's life. Proper exercise during the early stage of the feeding program helps with muscle development and deposition, while exercise during the later stages will maintain proper condition. All adjustments in exercise should be made gradually. and It is also important to never over-work the lamb as this can cause more harm than good. There are multiple ways to go about exercising your lamb and knowing how and when to adjust your exercise program will be pivotal to your success.

- Treadmilling is a very popular form of exercise for show lambs. You can either utilize a standard human treadmill with a box built around it to keep the lambs' feet on, or there are commercially available treadmills built specifically for lambs. While this method of exercise is not essential, it does allow you walk your lamb backwards, which works other muscles that normally would not get worked and allows for more efficiency when exercising.

- Another way of exercising is on a track. This is a circular or oval shaped pen built with tall panels that lambs are ran around with the assistance of a track dog. If you are going to utilize this method, make sure that panels are at least 42" tall and are free of sharp objects or points. Also, be sure that the dog you are using as been professionally trained to do this job.

- While both of these methods are effective, they are not crucial. You can exercise your lamb just fine by walking/running it on a halter. You can either walk your lamb long distances or perform shorter distance sprints. A common practice is to walk your lamb away from the barn and chase it back to its pen.

Nutrition

While you may be able to find a high-quality lamb for your project, without proper nutrition, your lamb will not succeed. Additionally, it is important to be aware of all aspects of a good feeding program in order for your lamb to be at peak performance.

<u>From the beginning</u>
- Make the process of getting your project home as smooth as possible

- Allow free, constant access to clean feed and water upon arrival

- Try to start your lamb off on the same feed it was eating prior to getting it home, and slowly make changes in its feed

<u>The basics</u>

There are five nutrients that are of primary importance in sheep: water, protein, energy, vitamins and minerals

Water

- Just like humans, water is critical in the digestive health of your show lamb. As soon as you get your project home, be sure to provide clean, fresh water and change water daily. Sheep can consume anywhere from a ½ to 4 gallons of water daily, but decreased water consumption will lead to decreased feed intake, ultimately limiting the performance and the overall look of your project.

Protein

- Protein is an important component in your lambs' diet that can help build muscle. Protein requirements vary depending on the stage of your lambs' feeding program. Younger sheep that are rapidly depositing muscle benefit from higher protein feeds (between 16%-19% Crude Protein). As sheep mature along their natural growth curve, muscle deposition eventually declines and fat deposition increases. When feeding sheep to a finished weight, lower protein feeds work great (between 11%-15% Crude Protein)

Energy

- Energy intake is critically important for your lamb as it usually is the largest component of their diet and can often times be the most limiting nutrient. Energy requirements are typically met from carbohydrates and fats found in grains. Most show feeds contain anywhere from 2.5%-5.0% crude fat. Energy is important for basic biological

maintenance for your lamb, but it also helps with bloom and smoothness of your lamb that will help it appear better on show day. On the same token, excess energy in the diet can result in your lamb depositing too much fat, which is undesirable. Thus, energy levels are adjusted in the diet throughout the feeding stages of your project. Younger lambs are typically fed rations with lower energy(fat), and those levels are typically increased as the lamb matures.

Vitamins

- While vitamins are an essential component of the diet, they are required in much smaller amounts relative to other nutrients. Typically, Selenium and Vitamin A will be added to show feed rations, and you can find information regarding their inclusion on the feed tag. Additionally, supplementation with Vitamin B complex is often a recommended practice to optimize nutrition, especially in diets high in protein and energy.

Minerals

- The most important minerals in sheep rations are calcium, phosphorous and salt. Calcium and phosphorus should be included in diets at a ratio of 2.5 parts calcium to 1 part phosphorous.

- Calcium and phosphorus are necessary for proper growth and development. They should be fed in a ratio of approximately 2.5 parts calcium to 1-part phosphorus. Feed rations that contain high levels of phosphorus in relation to calcium may cause urinary calculi, the formation of stones that block the passage of urine. The addition of ammonium chloride at the rate of 10 pounds per ton of feed will help prevent urinary calculi.

- Most roughages are higher in calcium and lower in phosphorous, while grains typically have lower calcium levels and average phosphorous content.

<u>Things to think about:</u>

Some important factors to keep in mind when thinking about your show lambs feeding program:

Rumen Health

- o Remember that lambs are ruminants – so maintaining the health and function of the rumen is critical

- o If rumen health is compromised, subsequent impacts on feed intake, gain, and overall appearance can be detrimental

Don't Forget Roughage

- o Always supplement a grain-based diet with sufficient roughage

- o Each lamb should consume approximately two large handfuls (¼ pound) of high-quality hay each day, particularly alfalfa

- o Lower-quality hay is digested slower and can increase the amount of belly (depth and roundness) – therefore it is crucial to feed a high-quality roughage

- o Fiber length of your hay is important – a fiber length of 1 ½ to 2 inches is appropriate, as ground or pelleted hay fails to meet your lamb's requirement for NDF, or neutral detergent fiber

Feeding Schedule

- o Finding a time both in the morning and evening to feed your lamb and keeping those times consistent from day to day.

- o It also helps to feed more than one lamb, as they typically perform better with other lambs around them

Clean Out Old Feed

- Never put new hay or grain on top of uneaten feed – always clean the uneaten feed out and reduce the amount you feed for the next 1-3 feedings until you work your lamb back up to the original amount

Making Changes

- It is important that you carefully study your lamb throughout the growing and finishing stages of its life and make changes to the diet accordingly. Also, be sure that changes in your lamb's ration are made slowly. Abrupt changes in your feeding program can negatively affect the digestive system of your lamb.

Monitoring Weight

- It is important to know how much time your lamb will have on feed until your target show, and to carefully monitor its weight throughout the feeding period
- On average, most lambs will gain about ½ pound per day
- Weighing your lamb weekly will help you track its daily gain and determine if you will need to push or hold your lamb going into your target show

<u>What and how much to feed:</u>

You have many options on what to feed your lamb, and the decision can be slightly overwhelming. There are numerous brands of show feeds available to fit a wide variety of needs and budgets, or you can mix your own ration. Don't hesitate to reach out to the breeder you purchased your lamb from for advice! No matter what route you choose to go, there are some important things to remember:

- Start your lamb off with a 16-18% crude protein and 12%-15% crude fiber feed – feed this ration until approximately 100 pounds
- Study your lamb's physical appearance to determine if protein and fat content should be kept the same or decreased as your lamb matures

Rules of thumb on adjusting your feed:

- *If your lamb is too **fat**, reduce the amount of feed and increase crude protein*

- *If your lamb is too **thin**, decrease crude protein and increase fat*

- *<u>**Never**</u> skip a feeding or hold feed to reduce weight or burn fat – this will only work against you*

- On average, feed 1 to 1 ½ pounds of feed twice per day with about ¼ pound of high-quality hay

Remember:

- A high-quality ration should meet the following criteria:

  o Maintain feed intake

  o Promote growth and performance

  o Help maintain a good physical appearance

  o Allow your lamb to reach its genetic potential

Supplements:

- There are many feed additives available to be complementary to your base ration

- High protein supplements can help build muscle or burn excess fat

- High energy supplements can help add fat and create a smooth finish

- Digestive health supplements like probiotics can help keep your lamb on feed

- Remember that supplements should <u>***never***</u> be your sole feed source – they have little impact if they aren't being fed with a complete feed

Show Preparation

Once all of the work at home as been put in, it is time to take your lamb to the show. Everything that you have been practicing for is finally here. However, there are many things to accomplish leading up to the show in order to be successful once you get there. The following information is important to keep in mind as you prepare to leave for the show.

<u>The Week Before</u>
A whole week before your show may seem early, but it is the optimal time to get the final touches put together on your lamb. During this time, it is crucial that your lamb is healthy, eating/drinking well, and has been worked with in order to succeed on show day.

- During this week, it is beneficial to start hydrating your lamb. Providing electrolytes via your lamb's water is one way. There are also many electrolyte mixes and homemade "drench" recipes to use. Be mindful of the show's rules, as drenching may not be allowed. Therefore, it is helpful to add this mixture to your lambs feed.

- Evaluate your lambs "fill" each day throughout this week. The fill is how much belly is on your lamb. A large belly is undesirable in the show ring, but you need time to reduce belly in a healthy way.

  - If you notice extra belly, this can be diminished by adding water to your lambs feed. This "wet feeding" technique helps keep your lamb from filling up on water immediately after eating dry feed, thus causing excess belly.

- Practice loading your lamb on and off the trailer so that they are used to it when you load them to head to the show.

- Make sure your sheep is used to being put on a fitting stand, being blown dry with a blower, and having its legs brushed. These are all things that will happen on show day and it will go smoother if your lamb has already experienced these things.

<u>Shearing/Clipping</u>

Protecting your lamb's hide is very important. Lamb's naturally produce the oil lanolin, which keeps the hide moist and fresh. Washing removes lanolin from the wool, therefore lambs should not be washed except for when you are preparing to clip them for show.

- Shearing of lambs should be done minimally, however during hot summer months it is appropriate to "rough-shear" them. This is often done with a large set of sheep-head clippers *(pictured to the right)* in order to leave wool slightly longer. Sheep do not need to be washed prior to this.
- When clipping lambs for a show, be sure to know the rules of the show regarding wool length and whether clippers are allowed on the show grounds.
  - To clip for a show, you'll need to use a shorter set of blades (typically a "fine" or "surgical" length) on a set of clippers like the one pictured to the right
  - Be sure that your lamb is used to being put on a stand prior to clipping them for the first time
  - Try to clip your lamb as close to show day as possible. The longer you wait between clipping and showing can cause the hide to dry out and wrinkle
  - Before clipping, wash your lamb with any form of shampoo, then blow dry your lamb until the body and legs are completely dry
  - Make sure your clippers are well-oiled

- o Great how-to videos on clipping sheep can be found at these links:

  https://www.youtube.com/watch?v=6XcjHWWt0jg and

  https://www.youtube.com/watch?v=hAtGwiFU7QQ

- o After clipping your lamb, it is important to condition the hide with some form of lotion

Packing for the Show

This checklist can be beneficial when packing supplies for your show. The items listed on this

checklist are considered essential for show day preparation of your lamb. Mark each item off as

it is packed.

☐ Feed (with a feeder)
☐ Water Bucket
☐ Soap
☐ Scrub Brush
☐ Wool card/leg brush
☐ Halters/Blankets
☐ Water Hose
☐ Hay
☐ Electrolytes
☐ Hide lotion (Cornhusker's)
☐ Bedding
☐ Health Papers (if required)
☐ Lamb Stand (if available)
☐ Towels
☐ Blower (if available)

Sheep Showmanship

Showmanship is essential when showing sheep. Of all the livestock species, showing

sheep requires the most physical contact with the animal. The showman and lamb must have a

good working relationship and practice is required prior to the show in order to be prepared. You

must be able to exhibit your animal in a manner that will promote your lambs' strengths and disguise its weaknesses.

<u>At Home</u>

It is essential to work with your lamb at home and practice as frequently as possible if you wish to have success in the show ring.

- As soon as you get your lamb, you need to start spending time with it
    - Lambs are often nervous when you first get them, so you need to develop a relationship with them to build trust
    - The easiest way to do this is to find a bucket and just sit in their pen – eventually they will warm up to you and you can start touching them so they can get used to human contact
- Once your lamb has calmed down, you can begin training them. It's best to start by training them to walk on a halter
    - While they will likely fight you at first, patience is key
    - More information about halter breaking can be found in the KSU Show Lamb Guide: *General Care* section (page 19)
- Another important thing to teach your lamb is to brace
    - The term "bracing" refers to your lamb pushing into you in order to enhance the appearance of their muscles – similar to "flexing" your muscles
    - The judge will approach to handle your lamb, so training them to properly brace is important
    - To properly brace your lamb, you must know how to properly position yourself – this is covered in the following sections

While teaching your lamb how to cooperate is important, knowing

what to do yourself is equally as critical to get the most out of your

lamb (best performance/appearance?)

Figure 25. Proper hand placement on the lamb's head

- When setting up a lamb you have to properly position your
  own body. Your hands should be cupped around the base of
  their ears, with your hands flat against the lamb's' head

- When positioning your legs, your left leg should be the
  one bracing against the lamb. Your left leg should be
  pointed directly at them, pushing diagonally across their chest. Your right leg should be
  slightly behind you, giving you something to brace yourself with

Figure 26. Correct leg position on the lamb while bracing

Feet/Leg Placement

Now that you know how you should be positioned, it's time to focus on the position of your

lamb

- Your lambs' legs should be set square
  and to all four corners so that its' weight
  is evenly distributed
- You want to be sure that your lamb is not
  too stretched out nor too scrunched
  together from the side

Figure 27. Correct feet and leg placement of the lamb

Walking

In the *General Care and Management* section, you will find information about halter breaking

your lamb. Once halter broken, the next important thing is teaching them to walk by hand. Sheep

are shown without a halter (unless a younger exhibitor is unable to keep hold of the animal).

- Your lamb should walk alongside you, with its head slightly in front of you
- If possible, try to follow another exhibitor in the ring; lambs more easily follow one
  another, but often times struggle to lead
- *PRACTICE* is the only way your lamb will properly walk on show day
  - o Sheep will not take to this quickly, therefore patience and practice at home is
    crucial!

<u>Show Ring Attire</u>

You have put in the hard work to prepare for the show, so it is just as important for you to look the part when in the ring! Here are some things to consider when deciding how to dress for the show:

- Be professional – nice jeans with no holes/rips, a collared shirt or nice blouse, nice boots/durable shoes

- While looking nice is important, flashier is not better – avoid clothes that are distracting or unpractical

<u>Other Tips</u>

After you have the basics down, there are some smaller details that can help take your showmanship game to the next level.

- Be sure to always have your lamb straight in line and leave ample space between you and the other exhibitors around you

- Always be courteous – be mindful of the judge and other exhibitors at all times

- While it may seem basic, be sure that your lamb is clean and presented well

Chapter 2 - Effects of Medium Chain Fatty Acids (MCFA) as alternatives to ZnO or antibiotics in nursery pig diets[2]

Abstract

The objective of this experiment was to evaluate the effects of medium chain fatty acids **(MCFA)** on nursery pig performance in place of ZnO and carbadox. In this trial, 360 weanling pigs (DNA 200 x 400; 5.4 ± 0.07 kg BW) were fed for 35 days, with 6 pigs/pen and 10 replicate pens/treatment. Upon weaning, pigs were weighed and allotted to pens based on BW in a completely randomized design to one of 6 treatment diets: 1) Negative control (no added ZnO or carbadox); 2) Control + 3,000 ppm ZnO in phase 1 and 2,000 ppm ZnO in phase 2; 3) Control + 50 g/ton carbadox; 4) Control + C6:C8:C10 MCFA blend; 5) Control + Proprietary Oil Blend (Feed Energy Corp.); 6) Control + monolaurate blend (FORMI GML from ADDCON). Treatment diets were fed through two dietary phases and a common diet fed through phase three. Pigs and feeders were individually weighed on a weekly basis to determine average daily gain **(ADG)** and average daily feed intake **(ADFI)**. From d 0 to 19, pigs being fed the ZnO or Carbadox diets had the greatest ADG. These pigs had significantly higher ($P < 0.05$) ADG than pigs fed the control or Feed Energy Proprietary Oil Blend, while pigs fed the C6:C8:C10 blend or FORMI GML diets had similar ($P > 0.05$) ADG compared to those fed carbadox. These effects were primarily driven by feed intake, which was greatest ($P < 0.05$) in pigs fed ZnO and carbadox. Treatment diet had a marginally significant effect ($P = 0.078$) on G:F.

Increased d 19 BW ($P < 0.05$) was observed for pigs fed ZnO and carbadox compared to the negative control, while other treatments were intermediate. Additionally, blood data and fecal scores were collected throughout the trial. On d 21, pigs fed ZnO or carbadox had higher ($P < 0.0001$) glucose values than those fed the Feed Energy Proprietary Oil Blend, with other diets being intermediate, showing potential health benefits of carbadox. While ZnO resulted in higher glucose values, it may also contribute to hepatic issues. While replacing ZnO and carbadox with MCFA did not result in significant changes in gut microflora, it did impact fecal consistency by softening the feces during the treatment period. Overall, these results show that ZnO and carbadox are valuable additives to help maximize growth performance in early stages of the nursery. Some MCFA products, like FORMI GML, may result in similar performance, while others restrict it. Thus, additional research is needed to study the effectiveness of MCFA to replace ZnO or feed-based antibiotics.

Introduction

The post-weaning period is typically a time of health challenge and limited growth performance. Pigs can be stressed from being placed in a new environment, and immature digestive systems can result in reduced feed intake and feed efficiency. Additionally, increased risk for intestinal health problems can often be prevalent with diarrhea stemming from bacterial sources (Pluske 2013). Antimicrobial agents have been utilized for decades to treat these conditions and ultimately improve nursery pig health and growth performance. For example, supplementation of pharmacological levels (2,000 to 3,000 ppm) of ZnO is a common practice to reduce post-weaning diarrhea (Liu et al., 2018). Additionally, feed-based antibiotics such as carbadox, are widely used additives in swine diets, especially during the nursery stage when newly weaned pigs are subject to enteric diseases and reduced feed intake. Controlled research

has shown that including antibiotic growth promoters, like carbadox, can increase growth rate and feed efficiency in weanling pigs by 16.4% and 6.9%, respectively (Cromwell 2001). Despite these benefits, concerns with potential antibiotic resistance and antibiotic residue in animal products have surfaced (Bager et al., 2000; Gallois et al., 2009). Additionally, the use of pharmacological levels of ZnO has posed environmental concerns due to increased excretion of zinc in swine waste utilized as fertilizer (Jondreville et al., 2003). That said, their use is strictly regulated by the FDA to avoid the risk of potential residues and to maintain environmental and consumer health. With these regulations increasing and a rise in consumer pressure to eliminate the use of feed-based antibiotics in swine production, this leaves swine producers searching for feed additives that can yield the same positive outcomes, while avoiding any negative consequences (Center for Disease Control, 2013; Landers et al., 2012). One potential alternative is thought to be Medium chain fatty acids **(MCFA)**. Medium chain fatty acids (MCFA) are saturated fatty acids with carbon chains 6 to 12 atoms long and consist of caproic (C6), caprylic (C8), capric (C10), and lauric (C12) acids that naturally occur in triglycerides of various feed ingredients. Their ability to be easily digested allows them to be utilized by the pig for growth, or by cells within the pig's gut to improve development and overall health (Zentek et al., 2011). Since MCFA are directly absorbed into circulation and easily oxidized by the liver, they can also serve as a very rapid energy source for pigs during stressful times (Babayan, 1987, Lee et al., 1994). Their inclusion in swine diets has been demonstrated to reduce the risks of viruses in swine feed, and Cochrane et al. (2018) described their ability to replace 400 g/ton chlortetracycline in phase 2 nursery diets. Additionally, controlled research has reported increased growth performance when MCFA are fed in mid-to-late-nursery diets, even in the absence of health challenges (Thomson et al., 2018, Thomas et al., 2019). However, field

research has shown mixed results, especially when feeding begins in early nursery. Therefore, the objective of this study was to evaluate the effectiveness of three different MCFA combinations as alternatives for ZnO and carbadox on growth performance, fecal consistency, and blood parameters during the nursery phase.

Materials and Methods

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) and were approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC #4036.20).

Animal Housing, Dietary Treatments and Experimental Design

A total of 360 weanling pigs (DNA 200 x 400; 5.4 ± 0.07 kg BW; approximately 21 d of age) were used in a 35-d experiment with 6 pigs per pen and 10 replicate pens per treatment. Upon weaning, pigs were individually weighed and allotted to pens based on BW to one of 6 dietary treatments: 1) Negative control (no added ZnO or carbadox); 2) Control + 3,000 ppm ZnO in phase 1 and 2,000 ppm ZnO in phase 2; 3) Control + 50 g/ton carbadox; 4) Control + C6:C8:C10 MCFA blend; 5) Control + Proprietary Oil Blend (Feed Energy Corp.); 6) Control + monolaurate blend (FORMI GML from ADDCON). Diets were isocaloric, with choice white grease used to balance the energy level. Diets were fed in 3 phases: phase 1 from d 0 to 7; phase 2 from d 7 to 21 and phase 3 from d 21 to 35. Phase 3 was a common diet fed to all pigs. All diets were made at the O.H. Kruse Feed Mill (Kansas State University, Manhattan, KS) and were fed in pellet form in phase 1 and in meal form in phases 2 and 3 of the nursery. Diets were also blinded and analyzed for proximate analysis and fatty acid profile at Midwest Laboratories (Midwest Laboratories, Omaha, NE). Target conditioning temperature for pelleting was ~51.7ºC for 30 s,

with target hot pellet temperature ~71.1ºC. Pelleting parameters were die size of 3/16” x 1 1/4”

(L/D = 6.0), 1.560 lb./h production rates, and approximately 72ºF ambient temperature.

Pigs were housed in a controlled environment nursery facility (Kansas State University

Swine Research and Teaching Center, Manhattan, Kansas) with 6 pigs per pen. Each pen (1.52 x

1.52 m) included a 4-hole dry self-feeder and a cup drinker to provide all pigs *ad libitum* access

to feed and water.

Data Collection (Growth Performance, Blood Sampling and Fecal Swabbing/Scoring)

All pigs and feeders were weighed on a weekly basis to determine average daily gain

(ADG) and average daily feed intake **(ADFI)**. Whole blood samples were collected on d 0 and d

21 and submitted to the Kansas State University Veterinary Diagnostic Laboratory (Kansas State

University, Manhattan, KS) for complete blood panel, serum chemistry, and hepatic profile.

Additionally, fecal swabs were taken from the same three pigs in each pen on days 0, 7, 14, 21,

28, and 35. Three fecal samples from the same pen were pooled for subsequent analysis for fecal

microflora and antimicrobial resistance. Fecal scoring was conducted by two independent,

trained scorers on d 0, 1, 2, 7, 14, 19, 28 and 35 to categorize the consistency of piglet feces per

litter. A numerical scale from 1 to 5 was used: 1 being hard pellet-like feces, 2 a firm formed

stool, 3 a soft moist stool that retains shape, 4 a soft unformed, and 5 a watery liquid stool.

Chemical composition of feed samples were analyzed at Midwest Laboratories (Midwest

Laboratories, Omaha, NE). Assays included DM using a drying oven (method 930.15; AOAC,

2007), crude protein **(CP)** as N × 6.25 using the combustion method (Nitrogen Determinator;

model TruMac N, Leco Corporation, St. Joseph, MI; method 990.03; AOAC, 2007) and total

phosphorous (method 985.01; AOAC, 2007). Additionally, diets were analyzed for fatty acid

profiles to determine the levels of C6:0, C8:0, C:10, and C:12 fatty acids (method 996.06, AOAC, 2007).

Statistical Analysis

Data were analyzed using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit and room as a random effect. Results were considered significant if $P \leq 0.05$ and marginally significant if $0.05 > P \leq 0.10$.

Results and Discussion

Nursery Pig Growth Performance

In the first week post-weaning, pigs fed diets containing carbadox had greater ($P < 0.05$) ADG than those fed the MCFA or Feed Energy Proprietary Oil Blend. Feed intake was greater ($P < 0.05$) when pigs were fed diets supplemented with ZnO compared to those with the MCFA or Feed Energy Proprietary Oil Blend. This led to a marginally significant impact of diet on G/F from d 0 to 7, with the greatest feed efficiency occurring in pigs fed carbadox or FORMI GML and the poorest feed efficiency in pigs fed the MCFA blend. Although the FORMI GML product resulted in similar performance as ZnO and carbadox, the other MCFA products had adverse impacts. These findings somewhat refute research done by Hong et al. (2012), that describes the ability of MCFA to increase ADFI for the first two weeks following weaning when compared to diets containing antibiotics. Similarly, Rodas et al. (1990) found that MCFA inclusion at a rate of 20 to 60 g/kg could increase ADG and G/F in weanling pigs shortly after supplementation. A primary reason to describe this is the piglet's ability to effectively absorb and use MCFA (Odle et al., 1989). More specifically, Odle et al. (1998) explain that MCFA are able to be absorbed without hydrolysis by lipase, and they enter the liver faster, thus they are hydrolyzed quicker and digested easier. However, the discrepancies between results of these experiments and the current

study warrant further research to evaluate MCFA impact on feed intake and feed efficiency during the first week post-weaning.

In phase 2 (d 7 to 19), pigs fed diets containing ZnO had greater ($P < 0.05$) ADG than those fed either the control or diets containing the MCFA or Feed Energy Proprietary Oil Blends. This was due to pigs consuming the ZnO diet having greater ($P < 0.05$) feed intake than those fed the MCFA or Feed Energy Proprietary Oil Blends and greater ($P < 0.05$) G:F than pigs consuming the control diet. Similarly, Cemin et al. (2018) showed that weanling pigs being fed added ZnO had increased ADFI, and enhanced growth performance. Yet, research conducted by Mellick et. al. (2019) showed increased ADFI by inclusion of a MCFA blend. This contrasts results found in the current study, suggesting that further evaluation of feeding MCFA during mid-nursery is needed to better understand how different fatty acid blends and commercial products can impact growth performance.

During the entire treatment period (d 0 to 19), pigs fed diets containing ZnO or carbadox had greater ($P < 0.05$) ADG than those fed control diets or diets containing the Feed Energy Proprietary Oil Blend. Other controlled research has demonstrated that the use of antibiotics, like carbadox, result in increased growth performance. In fact, Puls et al. (2018) found similar results when feeding two antibiotic feeding programs, one of which consisted of carbadox, and comparing them to non-medicated control diets. Their results also displayed an increase in ADG, but no significant effect on feed efficiency. However, in the current experiment, there was a substantial feed intake improvement ($P < 0.05$) in pigs fed diets containing ZnO compared to those fed control diets or the MCFA or Feed Energy Proprietary Oil Blends, but there was no overall difference in feed efficiency during the treatment period.

As expected, there were no discernable differences ($P > 0.10$) in pigs fed common diets during phase 3 (d 19 to 35). However, there was sufficient difference in early growth performance to cause significant differences in both ADG and ADFI overall (d 0 to 35). While all treatments had pigs starting with the same average weight, up to 0.32 kg difference in body weight was observed among treatments just one-week post-weaning. By the end of the 35-d experiment, pigs fed diets containing ZnO or carbadox were at least 1.05 or 0.73 kg heavier than those fed control diets or diets containing the MCFA or Feed Energy Proprietary Oil Blends.

This study shows that ZnO and carbadox are valuable additives to help maximize performance in the early nursery period. These findings coincide with other research that states ZnO can promote growth performance during the post-weaning period when included at pharmacological levels (Sales, 2013). However, this research also demonstrates that some lipid-containing feed additives, such as FORMI GML, may result in similar performance as ZnO and feed-based antibiotics. Yet, it was also determined that other MCFA products may actually reduce feed intake and subsequent growth when included in early nursery diets. Thus, when comparing the results of this study to others within this field, findings are variable. The current experiment showed that the FORMI GML product can yield similar growth performance as ZnO and carbadox, but it is unknown what specific mode of action allowed this product to perform in such a way. One possibility could be the specific MCFA profile in FORMI GML. The analyzed feed samples suggest there was some variation in levels of MCFA in each diet, which could've impacted the efficacy of each product in this scenario. Controlled research by Gebhardt et al. (2017) described that a blend of MCFA in nursery pig diets can result in improvement in growth performance, however, the effects of MCFA depend on the type and inclusion rate. Improvements in nursery pig growth performance were observed by Gebhardt et al. (2017) by

including 0.50% C6 or C8 with 0.25 to 1.50% of a 1:1:1 blend of C6, C8, and C10. Therefore, further research is needed to study specific MCFA concentrations and how they affect growth performance at different inclusion levels.

Nursery Pig Blood Parameters

Day 0 blood data were collected and analyzed as a baseline for comparison. While discrepancies were detected ($P = 0.04$) for d 0 bicarbonate concentrations, by d 21 these values became similar. On d 21, pigs fed ZnO or carbadox had higher ($P < 0.0001$) glucose values than those fed the Feed Energy Proprietary Oil Blend, with all other treatments intermediate. Pigs fed carbadox had higher ($P = 0.0002$) total calcium than the negative control, MCFA blend, Feed Energy Proprietary Oil Blend, or FORMI GML diets, with ZnO being intermediate. Sodium-potassium ratio was higher ($P = 0.04$) for pigs fed ZnO than carbadox, with all other diets intermediate. On d 21, aspartate transaminase concentrations were greater ($P = 0.04$) for pigs fed ZnO than those fed MCFA blend, with all other treatments being intermediate. Similarly, the ZnO treatment resulted in higher ($P < 0.0001$) alkaline phosphatase concentrations compared to all other treatments. Differences in d 21 urea nitrogen and anion gap were marginally significant ($P = 0.06$ and $P = 0.07$, respectively). No significant impact ($P > 0.10$) was found for d 21 concentrations of creatinine, protein, albumin, globulin, phosphorus, sodium, potassium, chloride, sorbitol dehydrogenase, creatine kinase, or bilirubin. These findings indicate that carbadox may provide a health benefit to pigs. While the ZnO diet proved higher blood glucose values, it may also contribute to hepatic issues. Other diets remain intermediate. Further research is necessary to better comprehend the effects of MCFA on blood serum chemistry and hepatic profiles.

Nursery Pig Fecal Consistency and Microflora

Initial fecal scoring on d 0 of the experiment showed similar fecal scores for all pigs at placement. However, on d 1, 2, 7, 14, and 19 pigs fed the ZnO and carbadox treatment had significantly lower fecal scores ($P < 0.05$) when compared to those being fed the control diet or diets containing MCFA blend, Feed Energy Proprietary Oil Blend, or FORMI GML. Similarly, findings from Cochrane et al. (2018) and Mohana Devi et. al. (2014) also showed minimal impact of MCFA supplementation on fecal score. While this study demonstrated the ability of FORMI GML to result in similar growth performance as ZnO and carbadox, it did not have the same impact on fecal consistency, as piglets being fed the product had softer feces. Finally, upon transitioning pigs to the phase 3 common diet on d 21, fecal scores standardized across treatment.

Fecal samples were collected on d 0 to determine baseline microflora. All 36 pigs sampled at d 0 were positive at various increments for *Clostridium perfringens.* Across *E. coli* strains, 28 pigs tested positive, with 3 pigs showing moderate to high *E. coli haemolytic* growth. Additionally, 11 pigs were positive for *Enterococcus spp* and 2 pigs were positive for *Streptococcus suis.* On d 21, microflora were greatly reduced with no evidence of differences across treatments. Of 33 samples, 25 showed no significant microbial growth. Only two species were present in detectable levels – 2 samples showed moderate to high growth of Lactose-hemolytic *E. coli*, and 6 displayed high growth of haemolytic *E. coli*. Three haemolytic *E. coli* cultures from the d 0 fecal swabs and one culture from d 21 swabs were analyzed for antimicrobial resistance. All three d 0 cultures showed resistance to clindamycin, penicillin, tiamulin, and tilmicosin. Two samples showed resistance to ampicillin, sulfadimethoxine, tetracycline, and trimethoprim. The d 21 culture showed resistance to clindamycin, penicillin,

sulfadimethoxine, tetracycline, tiamulin, tilmicosin, and neomycin. Ultimately, diet had no significant impact on nursery pig fecal microbiota or antibiotic resistance among bacterial strains. Research should be continued with greater replication to further evaluate the effects of MCFA on gut microflora and fecal consistency.

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Table 2.1. Diet formulation (as-fed basis)[1]

	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn	44.8	56.7	65.6
Soybean meal, 46.5% CP	18.1	29.1	30.2
Fish meal	4.5	-	-
Spray dried whey	25.0	10.0	-
Monocalcium phosphate, 21% P	0.30	0.90	0.95
Limestone	0.25	0.98	1.00
Sodium chloride	0.30	0.55	0.58
L-Lysine	0.43	0.50	0.55
DL-Methionine	0.23	0.21	0.23
L-Threonine	0.21	0.24	0.25
L-Tryptophan	0.06	0.04	0.07
L-Valine	0.11	0.11	0.14
Trace mineral premix[2]	0.15	0.15	0.15
Vitamin premix[3]	0.25	0.25	0.25
Phytase[4]	0.08	0.08	0.08
Hamlet Protein 300[5]	3.75	-	-
Feed Additive[6]	Varied	Varied	n/a
Total	100.0	100.0	100.0
Calculated analysis			
Standardized ileal digestibility (SID) amino acids, %			
Lys	1.40	1.35	1.24
Ile:Lys	56	55	57
Lue:Lys	109	112	119
Met:Lys	38	36	36
Met & Cys:Lys	58	57	58
Thr:Lys	65	65	65
Trp:Lys	20.3	19.1	18.6
Val:Lys	68	67	67
ME, Mcal/kg	3.42	3.28	3.42
CP, %	21.0	20.6	20.0
SID Lys:ME, g/Mcal	5.43	5.55	3.72
Total Lys, %	1.54	1.48	1.68
Ca, %	0.65	0.75	0.69
P, %	0.64	0.62	0.68
Available P, %	0.55	0.47	0.38

[1] A total of 360 weanling pigs (DNA 241 × 600) were used in a three-phase nursery trial with 6 pigs per pen and 10 replicates per treatment. Treatment diets were fed from d 0 to 7 (Phase 1) and d 7 to 19 (Phase 2). A common diet was fed from d 19 to 35 (Phase 3).

[2] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[3] Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[4] Ronozyme HiPhos 2700, DSM Nutritional Products, Parsippany, NJ.

[5] Hamlet Protein, Findley, OH.

[6] Diets included either 1.5% choice white grease (control); 1.5% choice white grease plus 3,000 ppm ZnO in phase 1 or 2,000 ZnO in phase 2; 1.5% choice white grease plus 50 g/d Carbadox (Phibro Animal Health, Teaneck, NJ); 0.5% choice white grease plus 1.0% C6:0, C8:0, and C10:0 in a 1:1:1 blend; 0.5% choice white grease plus 1% Feed Energy proprietary vegetable oil blend (Feed Energy Company, Des Moines, IA); or 0.5% choice white grease plus 1% FORMI GML (ADDCON GmbH, Bitterfeld-Wolfen, Germany).

Table 2.2. Chemical analysis of experimental diets[1]

Item;	Control	3,000 ppm P1 2,000 ppm P2 ZnO	50 g/ton Carbadox	C6:C8:C10 Blend	Proprietary Oil Blend by Feed Energy	FORMI GML by ADDCON
Phase 1						
Dry matter, %	88.4	88.6	89.1	88.6	89.2	88.6
Crude protein, %	20.8	21.0	21.2	20.8	21.1	20.8
P, %	0.70	0.67	0.71	0.72	0.71	0.70
Ca, %	0.97	0.90	1.17	1.00	0.97	0.96
C6:0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C8:0	<0.01	<0.01	<0.01	0.05	0.05	<0.01
C10:0	<0.01	<0.01	<0.01	0.10	0.10	0.01
C12:0	<0.01	<0.01	<0.01	0.05	0.05	0.10
Phase 2						
Dry matter, %	86.9	87.0	87.3	86.7	87.4	86.8
Crude protein, %	21.3	20.5	21.6	21.1	21.8	22.3
P, %	0.66	0.6	0.65	0.65	0.71	0.67
Ca, %	1.25	1.04	1.54	1.15	1.27	0.99
C6:0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C8:0	<0.01	<0.01	<0.01	0.07	<0.01	0.01
C10:0	<0.01	<0.01	<0.01	0.12	<0.01	0.02
C12:0	<0.01	<0.01	<0.01	<0.01	<0.01	0.09
Phase 3						
Dry matter, %	88.3	-	-	-	-	-
Crude protein, %	21.5	-	-	-	-	-
P, %	0.63	-	-	-	-	-
Ca, %	1.08	-	-	-	-	-
C6:0	<0.01	-	-	-	-	-
C8:0	<0.01	-	-	-	-	-
C10:0	<0.01	-	-	-	-	-
C12:0	<0.01	-	-	-	-	-

[1]Complete diet samples were obtained from each dietary treatment and the common phase 3 diet during daily feed additions, representing at least 10 different samples per diet. Samples of diets were pooled and analyzed for DM, CP, P, Ca, and medium chain fatty acids (Midwest Laboratories Inc., Omaha, NE).

Table 2.3. Effects of ZnO, carbadox, or medium chain fatty acids (MCFA) on nursery pig growth performance[1]

	3,000 ppm P1 2,000 ppm P2 ZnO	Control	50 g/ton Carbadox	C6, C8, C10 Blend	Proprietary Oil blend by Feed Energy	FORMI GML by ADDCON	SEM	P =
BW, kg								
d 0 (weaning)	5.42	5.42	5.41	5.42	5.41	5.42	0.009	0.696
d 7	6.10^a	6.02^{ab}	6.13^a	5.79^b	5.82^{ab}	6.11^a	0.075	0.003
d 19	10.26^a	9.23^c	10.05^{ab}	9.34^{bc}	9.11^c	9.71^{abc}	0.170	< 0.0001
d 35	18.70	17.66	18.49	17.84	17.47	17.99	0.316	0.06
Phase 1 (d 0 to 7)								
ADG, g/d	97^{abc}	85^{abc}	103^a	52^c	59^{bc}	98^{ab}	10.7	0.003
ADFI, g/d	137^a	116^{abc}	117^{ab}	92^{bc}	85^{bc}	119^{ab}	7.3	< 0.0001
G:F	0.68	0.72	0.87	0.57	0.66	0.81	0.071	0.055
Phase 2 (d 8 to 19)								
ADG, g/d	347^a	270^c	325^{ab}	297^{bc}	278^{bc}	300^{abc}	11.4	0.0001
ADFI, g/d	428^a	370^{ab}	407^{ab}	361^b	355^b	381^{ab}	14.2	0.004
G:F	0.81^{ab}	0.74^b	0.80^{ab}	0.81^a	0.79^{ab}	0.79^{ab}	0.019	0.043
Overall Treatment (d 0 to 19)								
ADG, g/d	255^a	202^c	242^{ab}	207^{bc}	197^c	226^{abc}	8.7	< 0.0001
ADFI, g/d	321^a	276^b	298^{ab}	262^b	255^b	284^{ab}	10.6	0.0004
G:F	0.79	0.73	0.81	0.79	0.77	0.80	0.018	0.078
Common Phase 3 (d 20 to 35)								
ADG, g/d	523	516	533	531	517	518	12.6	0.873
ADFI, g/d	793	756	781	757	723	743	17.9	0.089
G:F	0.66	0.69	0.68	0.70	0.72	0.70	0.015	0.158
Overall (d 0 to 35)								
ADG, g/d	377^a	344^{ab}	374^{ab}	355^{ab}	339^b	359^{ab}	8.5	0.012
ADFI, g/d	536^a	492^{ab}	517^a	488^{ab}	463^b	494^{ab}	11.5	0.001
G:F	0.70	0.70	0.72	0.73	0.73	0.73	0.012	0.32

^{abc}Means within a row that do not share a common superscript differ $P < 0.05$.

[1]A total of 360 weanling pigs (6 pigs per pen, 10 pens/treatment) were fed treatment diets during Phase 1 (d 0 to 7) and Phase 2 (d 8 to d 19). A common diet was fed from d 20 to 35.
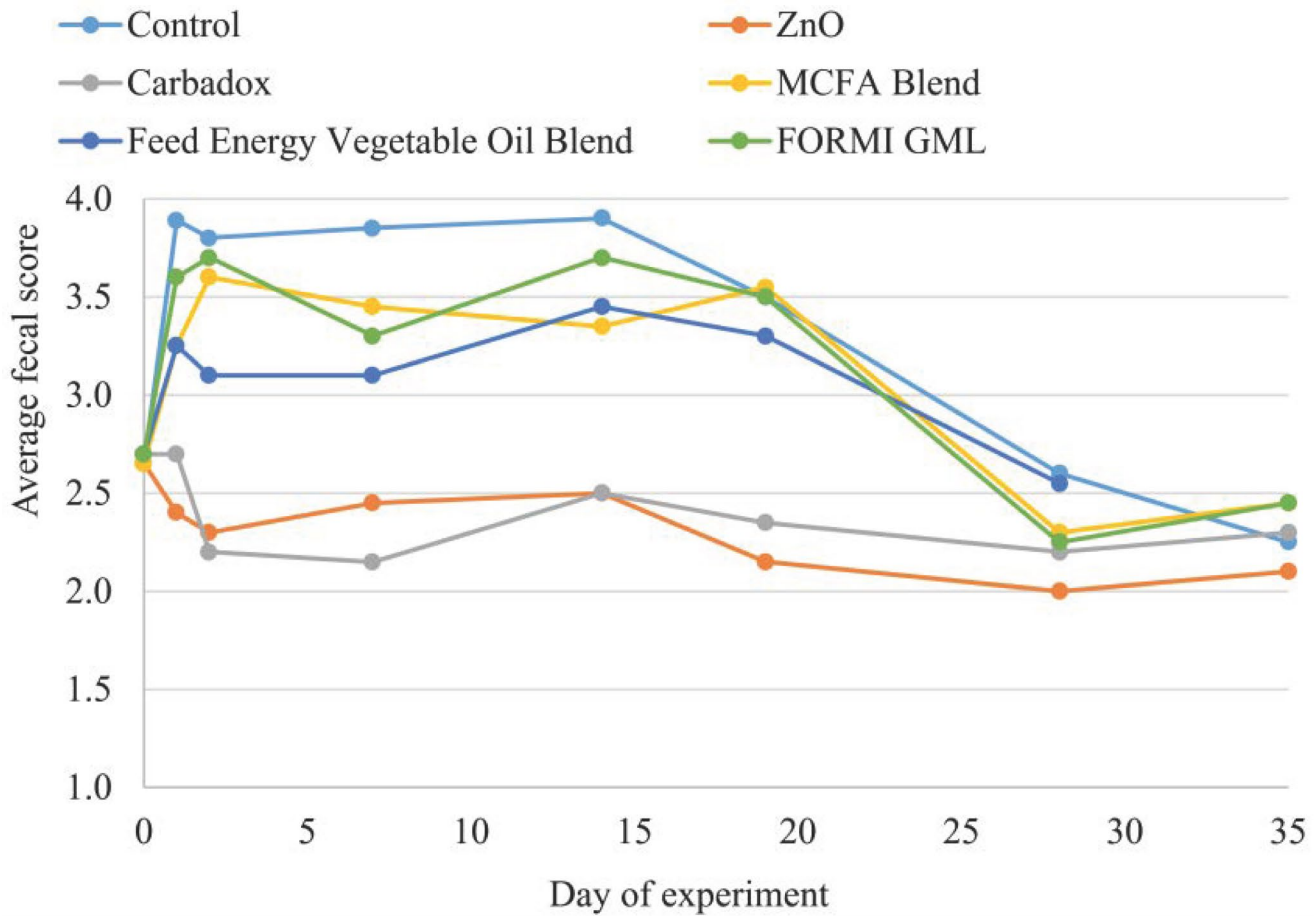
Figure 28. Impact of dietary treatment on fecal score

Chapter 3 - Evaluating dietary acidifiers as alternatives for conventional feed-based antibiotics in nursery pig diets[3]

Abstract

A total of 360 weanling pigs (DNA 200 x 400; initially 9.7 ± 0.23 kg BW) were used in a 21-d experiment with 6 pigs/pen and 10 replicate pens/treatment. Pigs were weighed and allotted to pens based on BW in a completely randomized block design to one of 6 treatment diets: 1) Negative control (no organic acids or antibiotics) and the control with 2) 0.25% Acidifier A; 3) 0.3% Acidifier B; 4) 0.5% Acidifier C; 5) 50 g/ton Carbadox; 6) 400 g/ton Chlortetracycline. A common diet was fed in phase 1 and 2 with treatments fed in phase 3. Pigs and feeders were individually weighed on a weekly basis to calculate average daily gain **(ADG)**, average daily feed intake **(ADFI)** and feed efficiency **(G:F)**. Data were analyzed using the PROC GLIMMIX procedure of SAS (v 9.4, SAS Inst., Cary, NC) with pen as the experimental unit, treatment as a fixed effect and room as a random effect. Dietary treatment had a significant impact ($P < 0.05$) on ADG, ADFI and G:F each week and for overall (d 0 to 21). Specifically, from d 0 to 7, pigs fed CTC had increased ($P = 0.001$) ADG compared to those fed Acidifier B, Acidifier C and Carbadox, while pigs fed the negative control and Acidifier A diets were intermediate. Additionally, pigs fed the CTC diet had improved ($P = 0.0002$) ADFI when compared to all other treatments. From d 7 to 14 and d 14 to 21, pigs fed the Carbadox diet had decreased ($P < 0.0001$) ADG compared to all other treatments. During the overall period (d 0 to 21), pigs fed

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diets containing Carbadox had reduced ADG and ADFI ($P < 0.0001$), while pigs fed CTC had improved ($P < 0.0001$) ADG compared to all other treatments. Additionally, blood parameters, fecal consistency and fecal microbial populations were analyzed. Dietary treatment significantly impacted ($P < 0.05$) concentrations of protein, globulin, phosphorus, alkaline phosphatase, and sorbitol dehydrogenase in the blood. Treatment also significantly impacted ($P = 0.0005$) fecal score but did not affect ($P = 0.59$) fecal microbial growth from d 0 to 21. In summary, CTC continues to be a valuable additive to improve performance in the nursery. Further investigation surrounding the efficacy of dietary acidifiers as antibiotic alternatives is warranted given inconclusive evidence in this study.

Introduction

During the transition from a liquid milk diet to solid feed, the intestinal morphology of the weanling pig drastically changes. In order to maximize nutrient absorption and utilization, the addition of feed additives is common. Since the post-weaning period is one of the most stressful times in a pig's life, negative impacts on the digestive system and a reduction in subsequent performance are typical. Feed intake is often limited immediately post wean, and Le Dividich et al. (2000) reported that an 8- to 14-day recovery period is often required by piglets following weaning before their energy intake returns to normal. Historically, feed-based antibiotics were among the most common additives to nursery pig diets due to their therapeutic potential and growth promoting capabilities (Jacela et al., 2009). Antibiotics have been shown to improve growth performance by many mechanisms, including suppressing the growth of pathogenic bacteria and increasing the digestion and utilization of nutrients through the intestinal wall (Gaskins et al., 2002). In addition to antibiotics, the use of pharmacological levels of Zn and Cu can effectively treat and control post-weaning diarrhea and improve growth performance in

the nursery (Shelton et al., 2011; Coble et al., 2017). Despite these benefits, there is consumer and regulatory pressure to limit their use given concerns over the development of antimicrobial resistant bacteria in humans or negative environmental impacts (Bager et al., 2000; Jondreville et al., 2003). Thus, animal scientists are actively investigating biological alternatives for these conventional antimicrobials.

Many alternate feed additives, such as probiotics, oligosaccharides, sea plants, spices and herbs have been studied as potential alternatives, but their efficacy is variable (Turner et al., 2001). Data suggest there is potential for dietary acidifiers to provide prophylactic effects similar to antibiotics, specifically by limiting the growth of harmful enteric pathogens and simultaneously allowing beneficial organisms to proliferate (Kim et al., 2005). Acidifiers are compounds typically classified as organic or inorganic acids and can improve growth performance by reducing or stabilizing gastric pH, ultimately increasing nutrient digestibility, and limiting the growth of pathogenic bacteria (Jacela et al., 2009). While acidifiers have been heavily evaluated in recent years, very few studies directly compare these products under controlled conditions. Most dietary acidifiers are used as blends of acids and the response of these products depends on the inclusion level, types of acids included and other nutritional components of the diet. Based on previous studies, organic acids have proven more beneficial to growth performance of weanling pigs when compared to inorganic acids (Kil et al., 2011; Liu et al., 2018). While literature is generally supportive of organic acids improving nursery pig growth performance, little direct comparison of such products is available with economic application, limiting producers' ability to make relevant, science-based decisions to include them. Thus, the objective of this experiment was to evaluate three commercially available dietary acidifiers and

their impacts on nursery pig growth performance, fecal score, fecal microbial populations and blood serum metabolites when compared to two commonly used feed-based antibiotics.

Materials and Methods

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) and were approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC #4036.31).

Animal Housing, Dietary Treatments and Experimental Design

A total of 360 weanling pigs (DNA 200 × 400; initially 9.4 ± 0.23 kg BW; approximately 21 d old) were utilized in a 21-d experiment at the Kansas State University Swine Teaching and Research Facility (Manhattan, KS). Upon weaning, pigs were individually weighed, tagged and allotted to pens according to BW in a completely randomized block design. Blocking was completed by utilizing two separate environmentally controlled nursery rooms, each with 30 pens. Each pen (1.52 × 1.52 m) included a 4-hole dry self-feeder and a nipple waterer to provide pigs *ad libitum* access to feed and water. A total of 6 pigs were placed into each of the 60 pens (10 replicate pens per treatment) and randomly assigned to one of 6 dietary treatments: 1) Negative control (no organic acids or antibiotics) and the control with 2) 0.25% Acidifier A (KEM-GEST™, Kemin Industries, Des Moines, IA); 3) 0.3% Acidifier B (ACTIVATE® DA, Novus International, Saint Charles, MO); 4) 0.50% Acidifier C (OutPace®, PMI Additives, Arden Hills, MN); 5) 50 g/ton Carbadox (Mecadox® 10, Phibro Animal Health, Teaneck, NJ, or 6) Control + 400 g/ton chlortetracycline (CTC) (Deracin® 100, PharmGate Animal Health, Wilmington, NC). Pigs were fed common Phase 1 and Phase 2 starter diets without antimicrobials for 21 days, then fed experimental diets for 21 days. All diets were formulated to

meet or exceed NRC (2012) nutrient requirements. Treatments consisted of a standard corn- and soybean meal-based diet whereas addition of dietary acidifiers or medications were included by the substitution of corn. Diets were manufactured by Hubbard Feeds (Hubbard Feeds, Beloit, KS) and were fed in pellet form during the common feed period and meal form during the experimental period.

Chemical Analysis of Diets

Complete diet samples were collected from 10 different feeders per dietary treatment on d 0 and 21 and composite subsamples were submitted for chemical analysis (Midwest Laboratories, Omaha, NE). Assays included DM (method 930.15; AOAC, 2007), crude protein (CP) as N × 6.25 using the combustion method (Nitrogen Determinator; model TruMac N, Leco Corporation, St. Joseph, MI; method 990.03; AOAC, 2007), acid detergent fiber (ADF) (ANKOM Tech. Method 200), Ca (AOAC 985.01, 2006), P (AOAC 985.01, 2006), and ME by calculation (Table 2).

Data Collection (Growth Performance, Blood Sampling and Fecal Swabbing/Scoring)

All pigs were weighed individually on d 0 and 21 and pen weights were collected utilizing a floor scale on d 7 and 14. Feeders from each pen were individually weighed on d 0, 7, 14 and 21 to record feed disappearance. Average daily gain (ADG) and average daily feed intake (ADFI) were calculated on a weekly basis. Whole blood samples were collected from the same 30 pigs (5 pigs per treatment) on d 0 and 21 of the experiment. Blood was collected from the jugular vein by venipuncture using a sterile 3 ml vacuum-sealed tube. Following collection, samples were placed on ice and immediately transported to the Kansas State University Veterinary Diagnostic Laboratory (Kansas State University, Manhattan, KS) for complete blood panel, serum chemistry, and hepatic profile analysis via spectrophotometry. Briefly, samples

were centrifuged for 5 minutes at 3000 rpm (Eppendorf North America, Enfield, CT). Chemistry assays were then performed utilizing the Cobas c501 (Roche Diagnostics, Indianapolis, IN).

Additionally, fecal samples were collected from 30 pigs (5 pigs per treatment) on d 0 and 21 for analysis of enteric bacteria and antimicrobial resistance. Samples were analyzed by the Iowa State University Veterinary Diagnostic Laboratory (Iowa State University, Ames, IA) for bacterial isolation and identification. Samples were collected aseptically utilizing sterile cotton-tipped collection swabs (Copan Diagnostics, Murrieta, CA) by rectal massage and stored in transport tubes with reduced oxygen at 4°C until analyzed. Samples were then plated without incubation or enrichment on selective media and incubated at 37°C for 24 hr. as described by the FDA Bacteriological Analytical Manual (2020). Suspect colonies were serogrouped for final identification. Bacterial colonies were then tested for antimicrobial susceptibility by comparing a modified minimum inhibitory concentration to a susceptibility breakpoint as described by Brooks et al. (2003). Fecal scoring was also conducted by two independent, trained scorers on d 0, 1, 2, 7, 14, and 21 to categorize the consistency of piglet feces per pen. A numerical scale from 1 to 5 was used: 1 being hard pellet-like feces, 2 a firm formed stool, 3 a soft moist stool that retains shape, 4 a soft unformed, and 5 a watery liquid stool.

Statistical Analysis

Data were analyzed as a completely randomized block design using the PROC GLIMMIX procedure of SAS Studio (SAS Institute, Inc., version 9.4, Cary, NC) with pen as the experimental unit. Treatment was included as a fixed effect and room was included as a random effect in the statistical model. All comparisons incorporated Tukey-Kramer multiple comparison adjustments. Pre-planned pairwise contrasts were also utilized to compare medicated diets and none (chlortetracycline or carbadox vs. control) as well as acidified diets and none (acidifier A,

B, or C vs. control). Results were considered significant if P ≤ 0.05 and a trend if 0.05 > P ≤ 0.10.

Results

Nursery Pig Growth Performance

Dietary treatment had a significant effect ($P < 0.05$) on nursery pig ADG, ADFI and G:F in each phase and for the overall experiment (d 0 to 21). From d 0 to 7 pigs fed the diet containing CTC had improved ($P = 0.001$) ADG compared to those fed diets with acidifier B, acidifier C or carbadox, while pigs fed the control or acidifier A treatments were intermediate. Additionally, ADFI was greater ($P = 0.0002$) for pigs fed the CTC diet when compared to those fed all other treatments. Feed efficiency was improved ($P = 0.007$) for those pigs fed the CTC or acidifier A diets when compared to pigs fed carbadox and pigs fed the control and diets containing acidifiers B or C were intermediate.

From d 7 to 14 pigs fed the CTC diet had improved ($P < 0.0001$) ADG compared to those fed the control or carbadox diets. Pigs consuming the three acidifier blend diets were intermediate. Feed intake was increased ($P = 0.002$) for pigs fed the CTC diet when compared to pigs fed acidifier B or carbadox, with the remaining treatments being intermediate. Differences in G:F across treatments during this period were significant ($P = 0.05$).

During the final week of the experiment (d 14 to 21), ADG was greatest ($P < 0.0001$) for pigs fed the CTC diet and poorest for pigs fed the carbadox diet (ADG: 0.89 and 0.58 kg/d, respectively). Again, ADFI was the highest ($P < 0.0001$) for pigs fed the CTC treatment and lowest for those fed the carbadox diet (ADFI: 1.26 and 0.94 kg/d, respectively). Feed efficiency was greater ($P = 0.001$) for pigs fed the control, acidifier A and acidifier B diets when compared to those fed carbadox, with pigs fed the acidifier C treatment being intermediate.

Finally, during the overall experiment (d 0 o 21), ADG was the greatest ($P < 0.0001$) for pigs fed CTC when compared to all other treatments. Likewise, ADFI was increased ($P < 0.0001$) for pigs fed the CTC diet when compared to those fed the control, acidifier A, acidifier B and carbadox diets, while those fed acidifier C were intermediate. Feed efficiency was decreased ($P < 0.0001$) for pigs fed the carbadox treatment when compared to those on all other diets. There was no evidence for differences ($P = 0.129$) in piglet BW on d 0 of the experiment, however by d 7, pigs fed CTC were heavier ($P = 0.001$) compared to those fed the control, acidifier B or carbadox treatments. Thus, by the end of the 21 d experiment pigs fed CTC were the heaviest ($P < 0.0001$) and those fed carbadox were the lightest (BW: 24.6 kg and 19.5 kg, respectively).

Economic Application

Feed costs were calculated for dollars per kg of feed, dollars per pig and dollars per kg of gain utilizing current ingredient prices. Income over feed (IOF) was also calculated by subtracting the feed cost per pig from a predicted revenue. The predicted revenue was a fixed amount, set at $0.25 per kg of gain, taking into consideration the current market price at the time of the experiment. This calculation was done on a per pen basis in order to have proper replication for statistical analysis. Economic data was included in the statistical model previously described.

Given all treatment diets were formulated from the control, differences in the cost of each diet depend solely on the price of the additive included. When compared to the control diet, which was the least expensive, the diet including carbadox was the most expensive per kg of feed (Feed Cost, $/kg of feed: $0.0596 and $0.0666, respectively). Feed cost per pig was calculated: Feed Cost, $/pig = Feed Cost, $/kg of feed × (ADFI Overall × 21). Feed cost per kg

of gain was also calculated: Feed Cost, $/kg of gain = Feed Cost, $/pig ÷ (ADG Overall × 21). Significant differences in feed cost, both per pig and per kg of gain were observed across treatments ($P < 0.0001$). While costs associated with feeding the diet containing CTC were statistically higher ($P < 0.0001$), IOF calculations determined that the margin of profit is potentially greater ($P < 0.0001$) by including CTC in the diet when compared to the other additives used in this study.

Nursery Pig Blood Parameters

From d 0 to d 21, dietary treatment significantly impacted ($P < 0.05$) the concentrations of protein, globulin, phosphorus, alkaline phosphatase, and sorbitol dehydrogenase in nursery pig blood. A main effect of day was also observed for urea nitrogen, creatinine, protein, albumin, globulin, phosphorus, bicarbonate, calcium, anion gap, sodium-potassium ratio, and sorbitol dehydrogenase. The only blood parameters for which a significant treatment × day interaction was observed ($P \leq 0.03$) were calcium, alkaline phosphatase and sorbitol dehydrogenase.

Blood data indicate that pigs fed CTC had lower total protein concentrations ($P = 0.01$) compared to those fed carbadox, while the remaining treatments were intermediate. Globulin levels were increased ($P < 0.0001$) in pigs fed the carbadox treatment compared to those fed CTC, acidifier A or the negative control. The pigs consuming carbadox also showed increased ($P = 0.04$) alkaline phosphatase concentrations compared to pigs fed acidifier A, while other dietary treatments were intermediate. Finally, pigs fed carbadox had significantly increased ($P = 0.02$) levels of sorbitol dehydrogenase when compared to pigs consuming all other treatments.

Nursery Pig Fecal Consistency and Microflora

For the duration of the experiment, there was no evidence ($P = 0.11$) of a significant dietary treatment × day interaction with regards to fecal score. However, the main effect of

treatment significantly impacted fecal score (P = 0.0005), with a mean fecal score of 3.2 for

treatments 1, 2, 3, 4, and 6, This indicates that pigs fed the carbadox treatment had a lower

average fecal score throughout the experiment when compared to all other diets, suggesting that

these pigs had firmer feces when compared to their contemporaries. Additionally, fecal score

was also impacted by sampling day (P < 0.0001), with mean scores of 3.1, 3.1, 3.0, 3.2, 3.3, and

3.3 for d 0, 1, 2, 7, 14, and 21, respectively.

No impact (P = 0.59) was observed by dietary treatment on nursery pig fecal microbial

growth, with mean growth values of 3.37, 3.60, 3.47, 3.44, 3.23 and 3.38 reported for the

negative control, acidifier A, B, C, carbadox and CTC, respectively. However, the main effect of

day (P = 0.0016) indicated that the growth of enteric bacteria was reduced from d 0 to d 21 (d 0

average growth = 3.6; d 21 average growth = 3.2).

Discussion

This study validates knowledge that the addition of antibiotic agents to nursery diets can

improve piglet health and performance. Research has demonstrated that ADG, ADFI and G:F of

weanling pigs can be enhanced by the addition of feed-based antibiotics (Zimmermann, 1986;

Cromwell et al., 2002). Similar to previous research, the overall ADG of pigs in the current study

fed diets containing chlortetracycline was greatest when compared to those fed a control or diets

with commercial acidifiers. Interestingly, the addition of carbadox to the diet negatively

impacted ADG and G:F. While this response was not expected, others have reported this in

literature (Walsh et al., 2007).

It is known that during the post-weaning check period, the immature digestive systems of

pigs are not yet adapted to diet changes and environment, therefore apparent decreases in HCl

secretion within the gastrointestinal tract allows rapid proliferation of harmful gut bacteria

(Kidder and Manners, 1978). Thus, pigs experience reduced feed intake, suppressed weight gain and diarrhea, which pose potential economic loss for swine producers. As a result, organic acids are typically most beneficial when fed within a few weeks of weaning (Roth and Kirchgessner, 1998). The current work fed a common diet to all pigs for 21 d immediately following weaning (Phase 1 and Phase 2 of the nursery) and followed this with a 21-d experimental period (Phase 3 of the nursery). While the common diet allowed pigs a longer acclimation period post-wean, waiting until phase 3 to introduce the acidifiers could explain the lack of response observed in the trial. Future work should introduce dietary acidifiers earlier in the nursery to evaluate their efficacy.

It has also been established that the ability of organic acids to lower dietary pH helps to increase gastric proteolysis and nutrient absorption through the intestinal wall, while subsequently limiting the growth of negative bacteria in the gut (Roth and Kirchgessner, 1998). This ultimately allows them to counteract some of the detrimental effects of the post-weaning period. While the increase in buffering capacity of the pig's gut has been reported as a primary mechanism of organic acids, many studies suggest that their mode of action extends well beyond this. Roth and Kirchgessner (1998) describe that various organic acids can also improve protein and energy digestibility, alter gastrointestinal bacterial populations and work as antimicrobial agents – suggesting that their mode of action is multifunctional.

Fumaric and citric acids have typically been the most widely studied. Meanwhile, the current work evaluated a larger variety of acids, specifically blends of acids in the form of commercial feed additives. One constant among previous studies and the current is the variability in nursery pig response to different acids. Ravindran and Kornegay (1993) described that causes

for this variability could be linked to the type and dose of acids included, other nutritional components of the diet, or the age and existing performance of the pigs.

A review by Partanen (1999) compiled data from 35 experiments and summarized a slight improvement in both ADG and G:F in weaned pigs supplemented with increasing levels of formic, fumaric and citric acids compared to a control diet without acidification. However, the data did not provide evidence of an optimal inclusion level nor significant differences in performance between these acids. Likewise, the current experiment did not observe differences between the organic acid treatments. Despite this, similar ADG and G:F was observed by the second week of the experiment in pigs supplemented with organic acids when compared to those fed the antibiotic chlortetracycline. Unfortunately, these differences were no longer apparent by the end of the trial. This coincides with previous research which suggests that the ability of organic acids to promote growth performance is limited when compared to antibiotics (Petersen and Oslage, 1982). Interestingly, some studies indicate that organic acids can actually improve the absorption of antibiotics and boost their therapeutic effects when the two additives are used together (Edmonds et al., 1985), but the current study provided the two in separate treatments, so this interaction was not observed. However, data from this study does show that of the acidifiers evaluated, Acidifier C was the only product which yielded similar ADFI to the leading treatment, CTC. McManus et al. (2017) fed the same product, acidifier C, at a rate of 2.5 lb./ton with the inclusion of CTC and found improved growth performance when the combination was fed.

Another factor that could explain the outcome of our experiment are the changes in feed intake. Previously, improvements in the growth of weaned pigs fed diets with acidifiers has been credited to enhanced palatability (Cole et al., 1968; Bolduan et al., 1988), and literature strongly indicates that feed intake in weanling pigs is extremely variable among different organic acids.

The review by Partanen (1999) describes that typically, formic acid has a positive effect, fumaric acid has no effect, and citric acid has a negative effect on feed intake. Therefore, it is necessary to consider the ingredients in commercial organic acid products and how they can impact palatability. For example, acidifier A primarily contains a blend of phosphoric, fumaric, citric and lactic acids. A study by Henry et al. (1985) allowed free choice of two diets to weanling pigs: a control with no acidifier and a diet acidified with both citric and fumaric acids. A significant increase in feed intake was observed for the control diet, suggesting a negative palatability affect associated with citric and fumaric acids. In our study, no difference in ADFI was observed between pigs fed a diet containing acidifier A and a control, or those fed acidifier A and carbadox. Interestingly, pigs fed a diet containing acidifier A had improved ADG when compared to those fed carbadox, suggesting potential merit in this acidifier blend as a potential antibiotic alternative. This agrees with findings from Walsh et al. (2007), where pigs fed a diet with 0.2% acidifier A had similar growth performance to pigs fed carbadox.

Additionally, acidifier B is a combination of organic acids and 2-Hydroxy-4-Methylthio Butanoic acid (HMTBa). The compound HMTBa is a methionine (**MET**) hydroxy analog, structured very similar to MET itself, and is proposed to have antimicrobial properties. In this experiment, no improvements in nursery pig ADG or ADFI were observed in pigs fed acidifier B when compared to pigs fed CTC. However, G:F was similar between pigs across these two treatments, suggesting that nutrient absorption could be similar among the two products. A study by Jendza et al. (2010) reported increased ileal digestibility of both CP and fiber in pigs fed a diet with HMBTa as the source of MET, as a result of more rapid absorption of HMBTa by the pig. A notable difference between these two experiments is the composition of diets. Jendza fed higher fiber diets with wheat middling's, whereas the current study fed standard corn-soybean

meal -based diets. This suggests that future work should evaluate products like acidifier B, which contain HMBTa, and their ability to impact nutrient digestion and utilization relative to antibiotics with more uniform diet composition.

While our experiment did not see significant differences in fecal microbial populations among dietary treatments, previous research has indicated that dietary acidifiers can positively impact the pig's gut microbiota. The mode of action by which this is achieved is not precise, but literature suggests that undissociated forms of organic acids can diffuse across the cell membrane of pathogens, damage their cytoplasm and hinder growth (Mroz, 2005). Research by Long et al. (2018) fed pigs two blends of organic acids, collectively containing formic, acetic, propionic, butyric and sorbic acids, and found that these acids reduced fecal *E. coli* counts and subsequently improved nutrient digestibility when compared to pigs fed a control or antibiotic. Likewise, Ahmed et al. (2014) found that feeding dietary acidifiers in the nursery could reduce the counts of pathogenic *E. coli*, meanwhile promoting the growth of beneficial *Lactobacilli* and *Bacilli* in the gut. The current experiment did observe a main effect of day ($P = 0.002$) on nursery pig microbial populations, whereas counts of enteric bacteria were reduced from d 0 to d 21. Ultimately, further investigation is needed to adequately describe how dietary acidifiers can impact the nursery pig gut microbiome.

Blood serum parameters showed pigs consuming carbadox had lower phosphorus concentrations compared to those fed the remaining treatments. While statistically, this difference is significant, the mean phosphorus value of pigs fed the carbadox treatment was still normal, suggesting no biological significance. Pigs fed the carbadox diet also had higher concentrations of sorbitol dehydrogenase. It is known that increased levels of sorbitol dehydrogenase can be associated with hepatocellular injury (Makoto and Galambos, 1963),

however, given that carbadox is metabolized by the liver and these pigs were overall healthy, this parameter could be due to drug metabolism.

In summary, feeding CTC was effective benefit nursery pig health and growth performance. The addition of dietary acidifiers did not alter nursery pig growth performance when compared to a control. Continued investigation into optimal inclusion levels, the mode of action and economic benefits of utilizing dietary acidifiers in place of antibiotics is warranted.

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Table 3.1. Diet composition (as-fed basis)[1]

	Control	Acidifier A	Acidifier B	Acidifier C	Carbadox	CTC
Ingredient, %						
Corn	65.69	65.34	65.44	65.09	64.90	65.39
Soybean meal, 46.5% CP	30.20	30.20	30.20	30.20	30.20	30.20
Calcium Carbonate	1.00	1.00	1.00	1.00	0.66	1.00
Limestone Phosphate, 21%	0.95	0.95	0.95	0.95	0.95	0.95
Sodium Chloride	0.58	0.58	0.58	0.58	0.58	0.58
L-Lysine	0.55	0.55	0.55	0.55	0.55	0.55
DL-Methionine	0.27	0.27	0.27	0.27	0.27	0.27
L-Threonine	0.25	0.25	0.25	0.25	0.25	0.25
L-Tryptophan	0.07	0.07	0.07	0.07	0.07	0.07
L-Valine	0.14	0.14	0.14	0.14	0.14	0.14
Trace Mineral Premix	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin w/ Phytase	0.25	0.25	0.25	0.25	0.25	0.25
Experimental ingredient	N/A	0.25	0.30	0.50	1.00	0.20
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestibility (SID) amino acids, %						
Lys	1.33	1.33	1.33	1.33	1.33	1.33
Ile:Lys	51	51	51	51	51	51
Leu:Lys	107	107	107	107	107	107
Met:Lys	38	38	38	38	38	38
Met & Cys:Lys	58	58	58	58	58	58
Thr:Lys	63	63	63	63	63	63
Trp:Lys	20	20	20	20	20	20
Val:Lys	69	69	69	69	69	69
Total Lys, %	1.47	1.47	1.47	1.47	1.47	1.47
ME, kcal/kg	3,264	3,255	3,258	3,247	3,242	3,258
NE, kcal/kg	2,320	2,313	2,315	2,306	2,302	2,316
CP, %	20.2	20.2	20.2	20.2	20.2	20.2
Ca, %	0.74	0.74	0.74	0.74	0.75	0.74
P, %	0.58	0.59	0.58	0.57	0.57	0.58
Available P, %	0.29	0.31	0.29	0.29	0.29	0.29

The table columns under "Dietary Treatment[2]" are: Control, Acidifier A, Acidifier B, Acidifier C, Carbadox, CTC.

[1] A total of 360 weanling pigs (DNA 200 × 400) were used in a three-phase nursery trial with 6 pigs per pen and 10 replicates per treatment. A common diet was fed from d -21 to d 0 (Phases 1 and 2). Treatment diets were fed from d 0 to 21 (Phase 3).
[2] Diets included either 0.25% Acidifier A (KEM-GEST™, Kemin Industries, Des Moines, IA); 0.3% Acidifier B (ACTIVATE® DA, Novus International, Saint Charles, MO); 10 lb./ton Acidifier C (OutPace®, PMI Additives, Arden Hills, MN); 50 g/ton Carbadox (Mecadox® 10, Phibro Animal Health, Teaneck, NJ); or 400 g/ton CTC (Deracin® 100, Pharmgate Animal Health, Wilmington, NC).
[3] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[4] Provided per kilogram of premix: 750,000 IU vitamin A; 300,000 IU vitamin D3; 8,000 IU vitamin E; 1,500 mg riboflavin; 5,000 mg pantothenic acid; 9,000 mg niacin; and 6 mg vitamin B12.

Table 3.2. Chemical analysis of experimental diets[1]

Item;	Dietary Treatment[2]					
	Control	Acidifier A	Acidifier B	Acidifier C	Carbadox	CTC
d 0						
Dry matter, %	86.0	86.2	86.7	86.7	86.6	86.6
Crude protein, %	20.4	20.7	20.0	20.2	19.6	21.6
ADF, %	3.6	3.8	3.6	3.3	4.0	3.3
Ca, %	0.74	0.78	0.84	0.70	0.59	0.74
P, %	0.67	0.63	0.65	0.57	0.55	0.60
ME, Mcal/lb.	1.31	1.30	1.31	1.32	1.32	1.30
d 21						
Dry matter, %	87.3	87.0	87.6	87.3	87.2	87.3
Crude protein, %	20.1	22.8	16.5	21.0	21.0	20.2
ADF, %	3.5	6.2	4.8	5.0	4.2	3.6
Ca, %	0.83	1.00	1.05	0.97	0.76	0.75
P, %	0.63	0.85	0.61	0.81	0.60	0.64
ME, Mcal/lb.	1.34	1.27	1.35	1.30	1.32	1.34

[1]Complete diet samples were obtained from each dietary treatment on d 0 and d 21, representing at least 10 different samples per diet. Samples of diets were pooled and analyzed for DM, CP, ADF, Ca, P and ME (Midwest Laboratories Inc., Omaha, NE).

[2]Diets included either 0.25% Acidifier A (KEM-GEST™, Kemin Industries, Des Moines, IA); 0.3% Acidifier B (ACTIVATE® DA, Novus International, Saint Charles, MO); 10 lb./ton Acidifier C (OutPace®, PMI Additives, Arden Hills, MN); 50 g/ton Carbadox (Mecadox® 10, Phibro Animal Health, Teaneck, NJ); or 400 g/ton CTC (Deracin® 100, Pharmgate Animal Health, Wilmington, NC).

Table 3.3. Effects of dietary treatment on nursery pig growth performance and economics[1]

Item;	Control	Acidifier A	Acidifier B	Acidifier C	Carbadox	CTC	SEM	Treatment	Medicated vs. None	Acidifier vs. None
			Dietary Treatment[2]						*P =*	
BW, kg										
d 0	9.4	9.7	9.6	9.9	9.5	10.1	0.23	0.129	0.074	0.102
d 7	12.3^b	12.8^{ab}	12.5^b	12.8^{ab}	12.3^b	13.7^a	0.25	0.001	0.026	0.165
d 14	16.2^{bc}	17.0^b	16.7^{bc}	17.1^{ab}	15.4^c	18.4^a	0.33	< 0.0001	0.102	0.069
d 21	22.0^b	22.4^b	22.4^b	22.7^b	19.5^c	24.6^a	0.39	< 0.0001	0.904	0.233
(d 0 to 7)										
ADG, kg/d	0.45^{ab}	0.47^{ab}	0.43^b	0.41^b	0.39^b	0.52^a	0.035	0.001	0.766	0.649
ADFI, kg/d	0.61^b	0.62^b	0.60^b	0.63^b	0.62^b	0.70^a	0.022	0.0002	0.007	0.839
G:F	0.74^{ab}	0.75^a	0.71^{ab}	0.66^{ab}	0.63^b	0.75^a	0.038	0.007	0.189	0.389
(d 7 to 14)										
ADG, kg/d	0.55^b	0.58^{ab}	0.60^{ab}	0.62^{ab}	0.45^c	0.67^a	0.021	< 0.0001	0.701	0.037
ADFI, kg/d	0.81^{ab}	0.84^{ab}	0.80^b	0.89^{ab}	0.75^b	0.95^a	0.039	0.002	0.415	0.459
G:F	0.68^{ab}	0.70^{ab}	0.80^a	0.70^{ab}	0.61^b	0.70^{ab}	0.062	0.050	0.604	0.255
(d 14 to 21)										
ADG, kg/d	0.80^b	0.78^b	0.81^{ab}	0.80^b	0.58^c	0.89^a	0.020	< 0.0001	0.007	0.816
ADFI, kg/d	1.09^b	1.07^{bc}	1.09^b	1.16^{ab}	0.94^c	1.26^a	0.036	< 0.0001	0.911	0.758
G:F	0.74^a	0.74^a	0.74^a	0.69^{ab}	0.62^b	0.71^b	0.023	0.001	0.009	0.614
(d 0 to 21)										
ADG, kg/d	0.60^b	0.61^b	0.61^b	0.61^b	0.47^c	0.69^a	0.015	< 0.0001	0.349	0.548
ADFI, kg/d	0.84^{bc}	0.84^{bc}	0.83^{bc}	0.89^{ab}	0.77^c	0.97^a	0.033	< 0.0001	0.282	0.537
G:F	0.72^a	0.73^a	0.74^a	0.69^a	0.62^b	0.72^a	0.017	< 0.0001	0.004	0.994
Feed Cost, $/kg feed[3]	0.059	0.061	0.061	0.063	0.067	0.062	-	-	-	-
Feed Cost, $/pig[4]	1.048^c	1.080^{bc}	1.067^{bc}	1.169^{ab}	1.075^{bc}	1.267^a	0.044	< 0.0001	0.001	0.085
Feed Cost, $/kg gain[5]	1.048^c	1.080^{bc}	1.067^{bc}	1.169^{ab}	1.075^{bc}	1.267^a	0.044	< 0.0001	0.001	0.085
Income Over Feed[6]	3.018^b	2.993^b	3.153^b	3.140^b	2.430^c	3.509^a	0.099	< 0.0001	0.580	0.352

[abc]Means within a row that do not share a common superscript differ, *P* < 0.05.

[1]A total of 360 weanling pigs (6 pigs/pen, 10 pens/treatment) were fed a common diet during Phase 1 and Phase 2 with treatment diets fed during Phase 3.

[3]Diets included either 0.25% Acidifier A (KEM-GEST™, Kemin Industries, Des Moines, IA); 0.3% Acidifier B (ACTIVATE® DA, Novus International, Saint Charles, MO); 10 lb./ton OutPace®, PMI Additives, Arden Hills, MN); 50 g/ton Carbadox (Mecadox® 10, Phibro Animal Health, Teaneck, NJ); or 400 g/ton CTC (Deracin® 100, Pharmgate Animal Health, Wilmington, NC).

[3]Caclulated using ingredient prices as of April 28, 2020.

Table 3.4. Effects of dietary treatment on nursery pig blood parameters[1]

Item	Control	Acidifier A	Acidifier B	Acidifier C	Carbadox	CTC	SEM	$P =$
			Dietary Treatment[2]					
Glucose, mg/dL	118.40	112.50	111.90	112.10	100.80	114.60	4.614	0.14
Urea nitrogen[x]	7.30	6.80	7.70	80	9.80	9.60	0.886	0.08
Creatinine, mg/dL[x]	0.68	0.76	0.82	0.75	0.83	0.82	0.056	0.19
Protein, g/dL[x]	5.00[ab]	5.00[ab]	5.30[ab]	5.00[ab]	5.40[a]	4.90[b]	0.146	0.01
Albumin, g/dL[x]	3.59	3.66	3.53	3.38	3.50	3.67	0.125	0.33
Globulin, g/dL[x]	1.41[bc]	1.30[c]	1.73[ab]	1.62[abc]	1.94[a]	1.26[c]	0.108	<0.0001
Calcium, mg/dL[xy]	11.06	11.04	11.06	11.04	10.93	10.86	0.172	0.88
Phosphorus, mg/dL[x]	10.26[a]	10.61[a]	10.04[a]	10.48[a]	7.98[b]	10.61[a]	0.397	<0.0001
Sodium, mmol/L[x]	142.7	144.00	142.42	142.80	142.12	143.40	0.896	0.68
Potassium, mmol/L[x]	6.93	6.78	7.09	6.60	6.24	7.00	0.363	0.47
Chloride, mmol/L	90.10	100.75	99.25	100.50	99.50	100.60	4.483	0.40
Bicarbonate, mmol/L[x]	24.36	22.75	22.00	24.78	24.40	24.66	1.574	0.43
Anion gap, mmol/L[x]	26.30	28.38	29.50	25.31	25.76	26.30	1.864	0.18
Na:K[x]	21.60	21.50	20.50	21.90	23.38	20.80	0.940	0.27
Aspartate transaminase P5P, U/L	70.80	74.13	106.83	58.40	128.00	89.30	27.379	0.42
Alkaline phosphatase, U/L[y]	390.90[ab]	299.25[b]	359.17[ab]	421.99[ab]	498.74[a]	394.70[ab]	56.204	0.04
Gamma glutamyltransferase[x]	60.55	45.88	54.50	61.46	67.01	68.65	9.701	0.26
Sorbitol dehydrogenase, U/L[xy]	1.41[b]	0.76[b]	0.52[b]	0.44[b]	24.48[a]	0.31[b]	5.552	0.02

[abc]Means within a row that do not share a common superscript differ P > 0.05. Values reported are least square means, representing the main effects of dietary treatment.

[x]Main effect of day is significant (P < 0.05).

[y]Interaction of treatment × day is significant (P < 0.05).

[1]A total of 30 whole blood samples (5 pigs/treatment) were collected on d 0 and d 21 of the experiment and submitted to the Kansas State University Veterinary Diagnostic Laboratory (Kansas State University, Manhattan, KS).

[2]Diets included either 0.25% Acidifier A (KEM-GEST™, Kemin Industries, Des Moines, IA); 0.3% Acidifier B (ACTIVATE® DA, Novus International, Saint Charles, MO); 10 lb./ton Acidifier C (OutPace®, PMI Additives, Arden Hills, MN); 50 g/ton Carbadox (Mecadox® 10, Phibro Animal Health, Teaneck, NJ); or 400 g/ton CTC (Deracin® 100, Pharmgate Animal Health, Wilmington, NC).

Table 3.5. Effects of dietary treatment on nursery pig average fecal score and fecal microbial growth[1]

Item;	Control	Acidifier A	Acidifier B	Acidifier C	Carbadox	CTC	SEM	Treatment	Day	Treatment × Day
			Dietary Treatment[1]						$P =$	
Average Fecal Score[2]	3.2^a	3.2^a	3.2^a	3.2^a	2.9^b	3.2^a	0.05072	0.0005	< 0.0001	0.11
Average Microbial Growth[3]	3.37	3.60	3.47	3.44	3.23	3.38	0.144	0.59	0.002	0.47

[abc]Means within the same row that do not share a common superscript differ P < 0.05. Values reported are least square means, representing the main effect of dietary treatment.

[1]Diets included either 0.25% Acidifier A (KEM-GEST™, Kemin Industries, Des Moines, IA); 0.3% Acidifier B (ACTIVATE® DA, Novus International, Saint Charles, MO); 10 lb./ton Acidifier C (OutPace®, PMI Additives, Arden Hills, MN); 50 g/ton Carbadox (Mecadox® 10, Phibro Animal Health, Teaneck, NJ); or 400 g/ton CTC (Deracin® 100, Pharmgate Animal Health, Wilmington, NC).

[2]Fecal scores were collected on d 0, 1, 2, 7, 14 and 21 of the experiment by two trained, independent scorers using a numerical scale: 1 = hard, pellet-like feces; 2 = firm, formed stool; 3 = soft, moist stool that retains shape; 4 = soft, unformed stool; 5 = watery, liquid stool.

[3]Fecal samples from 30 pigs (5 pigs/treatment) were collected on d 0 and 21 via rectal swab and plated for analysis of enteric bacteria by the Iowa State University Veterinary Diagnostic Laboratory (Iowa State University, Ames, IA). Culture growth from d 0 to d 21 was reported using a numeric scale: 0 = No significant growth; 1 = Low; 2 = Few; 3 = Moderate; 4 = High.

Chapter 4 - The impacts of feeding corn co-products and ionophores to growing Boer goats[4]

Abstract

Two experiments were conducted to evaluate corn dried distiller grains with solubles (**DDGS**) v. corn gluten feed (**CGF**) as alternatives for soybean meal (**SBM**) and determine the impact of an ionophore on Boer goat growth performance and carcass characteristics. In Exp. 1, a total of 75 Boer-goat kids (26.9 ± 0.2 kg) were allotted to one of 5 dietary treatments: 1) Negative control (100% SBM, 0% DDGS and 0% CGF; **100SBM**); 2) Positive control (100% DDGS, 0% CGF and 0% SBM; **100DDGS**); 3) 66% DDGS, 33% CGF and 0% SBM (**66DDGS/33CGF**); 4) 66% CGF, 33% DDGS and 0% SBM (**33DDGS/66 CGF**); and 5) 100% CGF, 0% DDGS and 0% SBM (**0DDGS/100CGF**). Goats and feeders were weighed weekly to determine average daily gain **(ADG)**, average daily feed intake **(ADFI)**, and feed efficiency **(G:F)**. Dietary treatment did not impact ($P \leq 0.21$) any of the measured growth response criteria. Ingredient prices for the tested ingredients dictated changes in diet cost and goats fed diets with corn co-products, regardless of inclusion level, had a lower ($P = 0.0008$) feed cost. There was no difference ($P = 0.941$) in cost/kg of gain. In Exp. 2, a total of 72 Boer-goat kids (21.7 ± 0.8 kg) were allotted (3 goats/pen, 6 pens/treatment) in a completely randomized design. Goats were fed acclimation diets for 21 d and followed by experimental diets for 21 d. Protein source and

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ionophore inclusion varied: 1) SBM/no ionophore (**SBM-NI**; Diet 2) SBM with ionophore (**SBM-I**); Diet 3) DDGS/no ionophore (**DDGS-NI**); and Diet 4) DDGS with ionophore (**DDGS-I**). On d 21, goats were reallocated to 2 pens according to protein source and fed the corresponding ionophore for an additional 10 d (Group 1: DDGS-I; Group 2: SBM-I, respectively). The 15 heaviest goats from each group were harvested and carcass data collected. There were no significant protein source × ionophore interactions ($P = 0.15$) for any growth criteria. Goats fed the SBM-I diet had significantly increased ($P = 0.04$) ADG compared to goats fed DDGS-NI. No differences were observed across treatments for ADFI. Ingredient prices for tested ingredients dictated changes in diet cost, but no differences were observed across treatments for feed cost per goat and cost/kg of gain ($P = 0.90$). Dietary treatments did not impact ($P > 0.05$) carcass characteristics. In summary, these data suggest that corn co-products can be economically included in Boer-goat diets, however their impact on growth performance is variable compared to that of soybean meal. Thus, further research is needed to evaluate the efficacy of feeding both corn co-products and ionophores to Boer goats.

Introduction

The United States goat population has grown exponentially in recent years (USDA NASS, 2010, 2020), along with an increase in ethnic populations and niche markets demanding goat meat (Spencer, 2008). Increasing goat production is accompanied by the need for economically viable feedstuffs for producers to formulate least-cost rations, especially in larger feeding operations. One component of reducing diet cost is the addition of co-products like corn dried distiller's grains with solubles (**DDGS**) or corn gluten feed (**CGF**). Aside from reduced costs, DDGS provide ample energy and protein in the form of rumen undegradable protein (**RUP**), making the feedstuff potentially suitable for goat diets (Schingoethe et al., 2009). With

U.S. ethanol production continuing to rise, the U.S. has the capacity to produce approximately 44 million metric tons of DDGS each year (U.S. Grains Council, 2020). The increasing availability of DDGS allows for it to be affordable for producers to utilize as a protein and energy source, however the goat industry has yet to capitalize on this economic incentive due to a lack of published research surrounding its efficacy. In fact, the 2007 Nutrient Requirements of Small Ruminants lacks any information regarding feeding corn co-products like DDGS or CGF to goats (NRC, 2007). With the per protein unit cost advantage of DDGS over the conventionally used soybean meal (**SBM**) being $1.86 at the time of this experiment, it is evident that DDGS could be used to reduce feed cost if performance was not decreased (October 26, 2017 U.S. Grains Council Report). However, a lack of data with feeding DDGS to goats limits the use compared to other ruminant species like cattle and sheep. Walter et al. (2012) found increased nutrient digestibility in feedlot heifers fed corn DDGS. Meanwhile, Crane et al. (2017) demonstrated the ability of DDGS to totally replace soybean meal SBM in lamb feedlot diets. Ultimately, this lack of knowledge limits the goat industry's ability to use corn co-products and hinders the corn industry's ability to market this product into a growing livestock sector, therefore, the objective of experiment 1 was to evaluate the efficacy of DDGS or CGF as alternatives for SBM in growing Boer goat diets.

There is also limited research regarding the role of including ionophores in diets containing DDGS or CGF to goats. Ionophores are antimicrobial feed additives that target the ruminal bacterial population to improve feed efficiency (Callaway et al., 2003). The use of ionophores has been common practice in the beef cattle industry for decades. More recently, Crane et al. (2017) studied the growth performance of feedlot lambs fed varying levels of DDGS with and without the ionophore, lasalocid, where the inclusion of lasalocid resulted in increased

body weight (BW), average daily gain (ADG) and gain to feed (G:F). Again, the limited amount of peer-reviewed, published research evaluating DDGS and ionophore inclusion in goat diets severely restricts producers' ability to utilize these ingredients, thus, experiment 2 aimed to determine the effects of feeding DDGS or SBM with and without ionophore inclusion on Boer goat growth performance.

Materials and Methods

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) and were approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC #4040.2).

Animal Housing, Dietary Treatments and Experimental Design

In Exp. 1, a total of 75 Boer goat kids (26.9 ± 0.2 kg) were fed for 35 d to evaluate the impacts of feeding corn DDGS or CGF in place of SBM on Boer goat growth performance and economics. Goats were housed in total confinement (3 m × 1.5 m pens) in an environmentally controlled (13° C) building at the Kansas State University Sheep and Meat Goat Center (Kansas State University, Manhattan, KS). On d 0, goats were individually weighed and allotted to one of 25 pens (3 goats/pen, 5 replicate pens/treatment) in a completely randomized design. Each pen was then randomly assigned to one of 5 dietary treatments, with titrated levels of three protein sources: Diet 1) Negative control (100% SBM, 0% DDGS and 0% CGF; **100SBM**); 2) Positive control (100% DDGS, 0% CGF and 0% SBM; **100DDGS**); 3) 66% DDGS, 33% CGF and 0% SBM (**66DDGS/33CGF**); 4) 66% CGF, 33% DDGS and 0% SBM (**33DDGS/66 CGF**); and 5) 100% CGF, 0% DDGS and 0% SBM (**0DDGS/100CGF**). All diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center (Kansas State

University, Manhattan, KS). Diets were pelleted and contained roughage to eliminate the need

for supplemental forage and allowing for more precise calculation of average daily feed intake

(ADFI) and feed efficiency (G:F). Each pen was equipped with a self-feeder and bucket waterer

to provide *ad libitum* access to feed and clean water. All goats and feeders were weighed weekly

to determine ADG, ADFI, and G:F. All incidences of illness and medications administered were

recorded.

In Exp. 2, 72 Boer goat kids (21.7 ± 0.8 kg) were fed for 21 d to evaluate the impacts of

feeding two different protein sources (DDGS vs. SBM) with and without an ionophore on goat

growth performance and carcass characteristics. Animals were housed in total confinement (3 m

× 1.5 m pens) in the environmentally controlled (13°C) building at the Kansas State University

Sheep and Goat Center. On d -21 goats were individually weighed and allotted to pens (3

goats/pen and 6 replicate pens/treatment) in a completely randomized design according to initial

BW. Goats were then fed an acclimation ration for 21 d. On d 0, all goats were weighed and

transitioned to one of four dietary treatments: 1) SBM/No ionophore (**SBM-NI**); 2) SBM with

ionophore (0.22 lb./ton Rumensin™ 90, Elanco Animal Health, Greenfield, IN) (**SBM-I**); 3)

DDGS/No ionophore (**DDGS-NI**); and 4) DDGS with Ionophore (0.22 lb./ton Rumensin™ 90,

Elanco Animal Health, Greenfield, IN) (**DDGS-I**). Diets were manufactured by Countryside

Feed, LLC (Countryside Feed, LLC, Hillsboro, KS) and were pelleted and fed as a sole source

ration. Each pen was equipped with a self-feeder and bucket waterer to provide *ad libitum* access

to feed and clean water. Goats were fed experimental diets for 21 d with goats and feeders

weighed weekly to calculate ADG, ADFI and G:F. All incidences of illness and medications

administered were recorded. On d 21, goats were reallocated to 2 pens according to protein

source and fed the corresponding ionophore diet for an additional 10 d until slaughter (Group 1: DDGS-I; Group 2: SBM-I, respectively).

Economic Calculations

For both Exp 1. and Exp 2., economic analysis was conducted to determine feed cost per kg of feed, feed cost per goat, feed cost per kg of gain, and value of gain (**VOG**). In Exp. 1 and Exp. 2, cost per kg of feed was calculated as: % of ingredient included × ingredient price at time of formulation (Exp. 1: January 2019 and Exp. 2: January 2020.) Feed cost per goat was calculated as: ADFI overall × feed cost per kg of feed × d on feed (Exp. 1: 35 d and Exp. 2: 21 d). Feed cost per kg of gain was calculated as: feed cost per goat ÷ total weight gain. Finally, for Exp. 1, VOG was calculated as: [(ending BW × $0.80/kg) – (beginning BW × $0.70/kg)] ÷ overall gain. For Exp. 2, VOG was calculated using the same equation, but adjusted to the current market prices for the experiment: [(ending BW × $0.82/kg) – (beginning BW × $0.63/kg)] ÷ overall gain (USDA AMS, 2019, 2020; Rasby et al., 2015).

Carcass Data Collection

In Exp. 2, at d 21 goats were reallocated to 2 groups according to the protein source of dietary treatment and fed for an additional 10 d. The 15 heaviest goats from each group (Group 1 avg. BW = 27.63 ± 2.6 kg; Group 2 avg. BW = 28.11 ± 1.5 kg) were then selected to be harvested where carcass data were collected by trained individuals following a 24-h chill period. Carcass characteristics recorded include: hot carcass weight (**HCW**; kg; measured on d of slaughter), loin eye area (**LEA**; cm2; measured between the 12th and 13th rib using a grid), body wall thickness (**BWT**; cm; measured at the 12th rib), backfat (**BF**; cm; measured at the 12th rib) and dressing percentage (**DP**; calculated as: HCW ÷ live weight).

In both Exp. 1 and Exp. 2, data were analyzed as a completely randomized design using the PROC GLIMMIX procedure of SAS v9.4 (SAS Inst., Cary, NC) with pen as the experimental unit. All comparisons included Tukey-Kramer multiple comparison adjustments. In Exp. 1, pre-planned contrasts were also included in the statistical model to evaluate linear and quadratic trends. In Exp. 2, the model included main effects of protein source, presence or absence of an ionophore, and the interaction of protein source × ionophore inclusion. For both experiments, data were considered significant if $P < 0.05$, and marginally significant if $0.05 < P < 0.10$.

Results and Discussion

Dietary treatment did not impact BW ($P = 0.999$), ADG ($P = 0.723$), ADFI ($P = 0.210$), or G:F ($P = 0.796$). This is similar to reports by Gurung et al. (2009), who found no difference in ADG in Kiko × Spanish goats fed DDGS compared to those fed SBM diets; however, breed influence could play a role in these observations. Research by Solaiman et al. (2012) compared the growth performance of Boer and Kiko goats under similar feeding conditions and reported increased ADG and shorter time to harvest in goats of Boer breed influence. Likewise, Urge et al. (2004) reported increased ADG in Boer goats compared to Alpine, Angora or Spanish breeds when fed diets containing 50-75% concentrate, but this study included coarsely ground hay in the ration, whereas the current work included roughage in the pellet, eliminating supplemental forage.

While diet costs in our study differed due to differences in price between SBM and DDGS or CGF, there were no differences ($P = 0.941$) for feed cost per kg of gain between treatments. However, goats fed diets containing DDGS or CGF, regardless of the level, had a

lower ($P = 0.0008$) feed cost per goat. This suggests a potential savings of up to $1.83 per goat when fed corn co-products compared to a conventional SBM-based diet. There were no significant differences observed ($P = 0.663$) across treatments for VOG.

In Exp. 2, there was no significant protein source × ionophore interaction ($P = 0.15$) for measured growth responses. However, the main effect of protein source significantly impacted ADG, where goats fed a diet containing SBM had increased ($P = 0.04$) ADG compared to those fed DDGS. Research regarding the impacts of DDGS on the growth performance in small ruminants is highly variable. Work by Paine et al. (2018) demonstrated that Boer goat ADG and G:F increased linearly with increasing inclusion of DDGS in the diet. Likewise, Crane et al. (2018) observed a linear increase in ADG as the level of DDGS inclusion increased from 0 to 45% in ram lamb diets. Conversely, the current experiment observed that goats fed DDGS as their protein source experienced reduced ADG compared to those fed SBM.

Ionophores are typically associated with increased feed efficiency, and Crane et al. (2017) found that feedlot lambs fed DDGS and lasalocid had improved feed efficiency by a factor of 0.23%. The current experiment only observed a marginally significant effect ($P = 0.06$) on G:F with the inclusion of an ionophore. Limited knowledge of appropriate inclusion levels and time frames for feeding ionophores to goats restricts the ability of scientists to evaluate their efficacy. Future work should continue to investigate how ionophores can alter growing goat feed conversion. While there were no statistical differences in the number of goats treated with antibiotics per dietary treatment, numeric differences indicated that goats fed the SBM-I diet were treated most frequently (33.2%), while those fed the DDGS-I diet were treated the least (16.7%).

Economically, the DDGS-I diet was $2.01/ton less expensive than the SBM-I diet based on ingredient prices at the time of the study. Yet, no evidence for differences were observed across treatments for feed cost per goat and $/kg of gain ($P = 0.90$). However, protein source had a significant effect ($P = 0.03$) on VOG, with goats being fed diets containing DDGS, regardless of ionophore inclusion, having improved VOG compared to those fed SBM-based diets. While there was no statistical significance in the difference in feed costs between treatments, the improved VOG for goats fed DDGS diets could potentially be explained by a numeric difference in diet costs, whereas the DDGS-based diets were both less expensive compared to SBM. For carcass traits, protein source and ionophore inclusion in the diet had no significant impact on HCW ($P = 0.51$), DP ($P = 0.25$), LEA ($P = 0.20$), BWT ($P = 0.94$) or BF ($P = 0.48$). There is extremely limited data surrounding the impacts of DDGS or ionophore inclusion on goat carcass characteristics, however Van Emon et al. (2012) found similar results in finishing lambs, where no carcass parameters were affected when fed differing levels of DDGS. Likewise, Felix et al. (2012) observed no differences in backfat, yield grade and marbling score between lambs fed 0, 20, 40, or 60% DDGS.

In summary, the results of these experiments indicate that corn co-products can be economically included in Boer-goat diets, however their impact on growth performance is variable compared to that of soybean meal. Further research is warranted to fully understand the impacts of feeding corn-co products and ionophores on goat performance, cost of gain, and carcass characteristics.

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Table 4.1. Experiment 1: Diet formulation and calculated nutrient composition[1]

Ingredient, %	Treatment[2]				
	100SBM	100DDGS	66DDGS/33CGF	33DDGS/66CGF	0DDGS/100CGF
Corn gluten feed	0.0	0.00	12.6	25.3	37.9
Corn DDGS	0.0	20.2	13.5	6.8	0.0
Corn	42.7	11.5	13.7	15.8	18.0
Soybean meal, 48% CP	15.0	0.0	0.0	0.0	0.0
Soybean hulls	35.7	62.2	54.2	46.2	38.1
Molasses	2.50	2.50	2.50	2.50	2.50
Ammonium chloride	1.00	1.00	1.00	1.00	1.00
Limestone	1.58	1.23	1.48	1.73	1.98
Salt	0.50	0.50	0.50	0.50	0.50
Se Selenite	0.001	0.0001	0.001	0.0001	0.009
Copper sulfate	0.008	0.008	0.008	0.008	0.008
Zn Oxide	0.008	0.008	0.008	0.008	0.008
Monocalcium phosphate	0.96	0.83	0.55	0.00	0.00
Vit A 30,000	0.015	0.015	0.015	0.015	0.015
Vit D 30,000	0.004	0.004	0.004	0.004	0.004
Vit E 20,000	0.001	0.001	0.001	0.001	0.001
Total	100.0	100.0	100.0	100.0	100.0
Calculated Nutrients, % as-fed					
Crude protein, %	16.5	16.5	16.5	16.5	16.5
Crude fat, %	3.00	2.75	2.50	2.25	2.00
ADF, %	12.0	16.0	28.0	25.0	18.0
Net energy, Mcal/kg	2.23	2.23	2.23	2.23	2.23
Ca, %	1.05	1.05	1.05	1.00	1.05
P, %	0.40	0.40	0.40	0.40	0.40

[1]Treatment diets were fed to 75 growing Boer goats (3 goats/pen, 5 pens/treatment) for 35 d.
[2]Treatments were: 100SBM = 100% SBM, 0% DDGS, and 0% CGF; 100DDGS = 100% DDGS, 0% CGF, and 0% SBM; 66DDGS/33CGF = 66% DDGS, 33% CGF, and 0% SBM; 33DDGS/66CGF = 66% CGF, 33% DDGS, and 0% SBM; and 0DDGS/100CGF = 100% CGF, 0% DDGS, and 0% SBM.

Table 4.2. Experiment 2: Diet formulation and calculated nutrient composition[1]

Ingredient, %	Cost/kg	Treatment[2]				Cost, $/ton			
		SBM-NI	SBM-I	DDGS-NI	DDGS-I	SBM-NI	SBM-I	DDGS-NI	DDGS-I
Corn DDGS	$0.04	0.00	0.00	30.24	30.24	-	-	$10.98	$10.98
Soybean Meal, 48%	$0.07	11.88	11.88	0.00	0.00	$8.33	$8.33	-	-
Corn	$0.03	15.00	15.00	2.37	2.37	$4.03	$4.03	$0.63	$0.63
Wheat Midds	$0.02	26.44	26.44	8.25	8.25	$6.60	$6.60	$2.06	$2.06
Soybean Hulls	$0.03	39.00	38.98	51.51	51.50	$10.18	$10.18	$13.45	$13.45
Dehydrated Alfalfa	$0.04	3.00	3.00	3.00	3.00	$1.33	$1.33	$1.33	$1.33
Ammonium Chloride	$0.03	0.50	0.50	0.50	0.50	$0.14	$0.14	$0.14	$0.14
Limestone	$0.01	1.97	1.97	1.97	1.97	$0.14	$0.14	$0.14	$0.14
Salt	$0.08	1.00	1.00	1.00	1.00	$0.82	$0.82	$0.82	$0.82
Se Selenite	$0.07	0.01	0.01	0.01	0.01	$0.005	$0.005	$0.005	$0.005
Cu Sulfate	$0.50	0.00	0.00	0.00	0.00	$0.02	$0.02	$0.02	$0.02
Soy Oil	$0.17	0.50	0.50	0.50	0.50	$0.86	$0.86	$0.86	$0.86
Vit A 30,000	$0.05	0.04	0.04	0.04	0.04	$0.02	$0.02	$0.02	$0.02
Vit D 30,000	$0.05	0.01	0.01	0.01	0.01	$0.003	$0.003	$0.003	$0.003
Vit E 20,000	$0.18	0.15	0.15	0.15	0.15	$0.27	$0.27	$0.27	$0.27
Premix	$0.20	0.48	0.48	0.48	0.48	$0.98	$0.98	$0.98	$0.98
Ionophore	$5.23	0.00	0.01	0.00	0.01	-	$0.58	-	$0.58
Total	-	100.00	100.00	100.00	100.00	$33.72	$34.29	$31.70	$32.28
Calculated nutrients, % as fed									
Crude protein, %		16.00	16.00	16.00	16.00				
Crude fat, %		2.48	2.48	2.79	2.80				
ADF, %		23.40	23.39	29.88	29.87				
Net Energy, Mcal/kg		2.23	2.23	2.23	2.23				
Ca, %		1.05	1.05	1.00	1.00				
P, %		0.40	0.40	0.40	0.40				

[1]Treatment diets were fed to 72 growing Boer goats (3 goats/pen, 6 pens/treatment) for 21 d.
[2]Treatments were: SBM-NI = SBM with no ionophore; SBM-I = SBM with 0.01% ionophore inclusion; DDGS-NI = DDGS with no ionophore; and DDGS-I = DDGS with 0.01% ionophore inclusion.

Table 4.3. Experiment 1: Impact of protein source being soybean meal (SBM) or corn dried distillers' grains (DDGS) on Boer goat growth performance and economics

Item;	100SBM	100DDGS	66DDGS/ 33CGF	33DDGS/ 66CGF	0DDGS/ 100CGF	SEM	Treatment	P - value Linear	Quadratic
BW, kg									
d 0	26.9	27.1	26.7	26.7	27.1	2.81	1.000	0.997	0.901
d 35	32.2	32.2	31.3	31.3	31.5	2.87	0.999	0.877	0.854
ADG, g/d	152	146	128	132	126	16.0	0.723	0.444	0.712
ADFI, g/d	1,080	1,110	1,022	1,074	1,140	34.7	0.210	0.371	0.038
G:F	0.14	0.13	0.13	0.12	0.11	0.015	0.796	0.442	0.949
Feed cost, \$/kg of feed[1]	0.239	0.204	0.201	0.199	0.196	---	---	---	---
Feed cost, \$/goat[2]	9.03[a]	7.93[b]	7.20[b]	7.45[b]	7.81[b]	0.258	0.0008	0.937	0.049
Feed cost, \$/kg of gain[3]	1.72	1.64	1.73	1.75	1.89	0.214	0.941	0.417	0.919
Value of gain, \$/gain[4]	1.32	1.44	1.51	1.60	1.53	0.138	0.663	0.191	0.484

[1]Calculated as: % of ingredient included × ingredient price as of September 1, 2018.
[2]Calculated as: feed cost per kg of feed × ADFI over 35 d experiment
[3]Calculated as: feed cost per goat ÷ BW gained from d 0 to d 35.
[4]Calculated as: [(ending BW × \$0.80) – (beginning BW × \$0.70)] ÷ (ending BW – beginning BW).

Table 4.4. Experiment 2: Impact of protein source being soybean meal (SBM) or corn dried distillers' grains (DDGS) and ionophore inclusion (I) or none (-NI) on Boer goat growth performance, economics and carcass characteristics

| | Treatment[1] | | | | | P- value | | |
| | | | | | | Protein | | Protein Source × |
Item;	SBM-NI	SBM-I	DDGS-NI	DDGS-I	SEM	Source	Ionophore	Ionophore
Growth								
BW, kg								
d 0	21.8	21.8	21.7	21.7	0.80	0.89	0.96	0.10
d 21	26.6	26.7	25.2	26.4	0.77	0.25	0.38	0.47
ADG, kg/d	0.227	0.233	0.168	0.222	0.0167	0.04	0.07	0.15
ADFI, kg/d	0.775	0.678	0.692	0.762	0.0700	0.10	0.84	0.22
G:F	0.293	0.355	0.250	0.315	0.0344	0.21	0.06	0.96
Treated with antibiotic, %	27.7	33.2	26.6	16.7	0.13	0.49	0.86	0.54
Economics								
Feed cost, $/kg of feed[2]	$0.0467	$0.0473	$0.0447	$0.0453	-	-	-	-
Feed cost, $/goat[3]	$0.76	$0.67	$0.65	$0.72	0.067	0.61	0.90	0.21
Feed cost, $/kg of gain[4]	$0.76	$0.67	$0.65	$0.72	0.067	0.61	0.90	0.21
Value of gain, $/gain[5]	$1.79	$1.75	$2.33	$1.86	0.153	0.03	0.09	0.15
Carcass traits								
Hot carcass weight, kg	13.1	14.0	13.4	13.5	0.75	0.92	0.44	0.51
Dressing percentage, %	46.4	48.9	48.7	47.7	1.74	0.73	0.61	0.25
Loin eye area, cm^2	15.0	15.4	15.7	13.9	1.01	0.64	0.41	0.20
Body wall thickness, cm	1.40	1.37	1.34	1.33	0.135	0.68	0.88	0.94
Backfat, cm	0.11	0.10	0.10	0.10	0.008	0.48	0.48	0.48

[1] Treatments were: SBM-NI = SBM with no ionophore; SBM-I = SBM with 0.01% ionophore inclusion; DDGS-NI = DDGS with no ionophore; and DDGS-I = DDGS with 0.01% ionophore inclusion.

[2] Calculated as: % of ingredient included × ingredient price as of April 5, 2020.

[3] Calculated as: feed cost per kg of feed × ADFI over 21 d experiment.

[4] Calculated as: feed cost per goat ÷ BW gained from d 0 to d 21.

[5] Calculated as: [(ending BW × $0.82) – (beginning BW × $0.63)] ÷ (ending BW – beginning BW).