

Effects of crude protein and zinc oxide on growth performance, fecal consistency, and health parameters of nursery pigs

by

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Abstract

Two experiments were conducted to evaluate the effects of crude protein and zinc oxide on the health and growth performance of both healthy and Enterotoxigenic *Escherichia coli*-challenged nursery pigs. In the first experiment, a total of 360 weanling pigs (DNA 241 × 600; 5.44 ± 0.03 kg BW) were used to investigate the effects of feeding varying levels of dietary CP (low, medium, high) with 110 or 3,000 mg/kg of ZnO on nursery pig growth performance, fecal dry matter, and circulating Zn in a 42-d growth trial. During the experimental period (d 0 to 25), increasing CP decreased ADFI (linear, $P = 0.011$) and tended to reduce ADG (linear, $P = 0.100$) and tended to improve G:F (quadratic, $P = 0.052$). Pig fed pharmacological Zn had increased ADG, ADFI, and G:F ($P \leq 0.002$). Overall (d 0 to 42), pigs fed increasing CP had a decrease in ADG and ADFI (quadratic, $P \leq 0.098$) with no effect on G:F. Pharmacological Zn tended to increase overall ADG ($P = 0.066$). For fecal DM, a Zn × day interaction was observed ($P = 0.015$) where fecal DM for pigs fed basal Zn level improved from d 10 to 25, but remained similar for pigs fed pharmacological Zn. Plasma Zn was greater on d 10 and 25 ($P < 0.0001$) for pigs fed 3,000 mg/kg Zn. In summary, CP × Zn interactions were limited, and thus the main effects of each feeding strategy were independent. In experiment 2, a total of 90 weanling pigs (DNA 241 × 600; initially 6.59 ± 0.40 kg BW) were used in a 14-d study using two groups (45 pigs/group) to evaluate the effects of low CP formulation strategies with 110 or 3,000 mg/kg of ZnO, on growth performance, fecal dry matter, and health parameters in Enterotoxigenic *Escherichia coli* F18 (ETEC) challenged nursery pigs. Diets were corn-soybean meal-based and formulated as: High CP, Low CP, Low CP +AA, Low CP+3,000 mg/kg Zn from ZnO and Low CP+AA+3,000 mg/kg Zn from ZnO. Overall, pigs fed Low CP+AA+ZnO had greater ($P < 0.05$) ADG compared to pigs fed the High CP, Low CP, or Low CP+AA treatments. Feed intake was

greater ($P < 0.05$) for pigs fed Low CP+ZnO and Low CP+AA+ZnO compared to pigs fed the High or Low CP diets. There was no evidence of a difference ($P = 0.640$) in overall G:F. There was a treatment $\times$ day interaction for fecal DM ($P < 0.0001$). In summary, inclusion of ZnO, particularly when combined with elevated amino acid levels in a low CP formulation, enhanced growth performance in ETEC F18-challenged pigs relative to a low CP diet.

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Dedication

This thesis is in dedication of my grandparents, Anita Squires, Loren Squires, Dale Horton, and Jan Horton. Their dedication to agriculture, education, and livestock production is something I have strived to possess the past two years. It was one of the sweetest pleasures sharing this success with my grandmother Jan Horton and I know my remaining grandparents are grinning ear to ear knowing I am one step farther in my career.

Chapter 1 - Kansas State University Livestock Selection and Competitive Evaluation Guide

Beef Cattle Breeds

With over 1,000 cattle breeds recognized across the world there are many still used in the United States. There are differences in the heritage of the many breeds utilized in large production operations and show cattle operations across the US. This focuses on three large groups of cattle: American, British, and Continental.

American Cattle

American breeds of cattle, or *Bos indicus*, are primarily used in southern beef production due to their heat tolerance, parasite resistance, and ability to perform on low-quality forages in hot, humid environments. They are common in from Florida to South Texas and Brahman is the most prominent American breed which serves as the foundation for composite breeds such as Brangus, Beefmaster, and Santa Gertrudis.

Examples of American Cattle Breeds and Composite American Breeds



Grey Brahman,
photo from V8
Ranch



Beefmaster,
photo from
Beefmaster
Breeders United



Brangus, photo
from International
Brangus Breeders
Association



Santa Gertrudis,
photo from Santa
Gertrudis
Breeders
International

British Cattle

British breeds, developed in the British Isles and brought to U.S. in the late 1700s-1800s, are known for moderate frame size, early maturity, and calving ease. Common breeds are often crosses with continental or Brahman cattle.

Examples of British Cattle Breeds



Angus, photo from the Angus Journal



Hereford, photo from Jensen Bros



Red Angus, photo from Schuler Red Angus



Shorthorn, photo from Bowman Superior Genetics

Continental Cattle

Continental cattle, imported from Europe in the late 1900s, are larger framed, later maturing, heavier muscled, and excel in growth and yield. However, heavier birth weights can increase calving difficulty. These breeds are often used to improve muscling and performance in operations with resources to manage calving.

Examples of Continental Cattle Breeds



Charolais, photo from Circle F Farms



Gelbvieh, photo from American Gelbvieh Association



Limousin, photo from Greenwood Cattle



Simmental, photo from SimGenetics

Beef Cattle Evaluation

When evaluating beef cattle, there are many important traits. Over time, these traits have changed to accommodate selection pressures and fit market demands. It should be noted that these priorities could change depending on your operation's production goals or environment. Regardless of whether you're evaluating breeding cattle (bulls/heifers) or market cattle (steers/heifers), a standard set of priorities are shared. However, the order in which these are prioritized will differ slightly.

Breeding Cattle

When evaluating cattle for the breeding herd, traits of importance include those that correlate to longevity in the herd and heritable traits that can be passed on to offspring. The priorities of which you should evaluate breeding cattle (in order) are:

1. *Structure – How the animal's skeleton is constructed and how it moves.*
2. *Body and Volume – Boldness and depth to the rib cage and dimension of muscularity.*
3. *Balance and Eye Appeal – How does the animal proportion.*

In general, these priorities should guide selection for breeding cattle whether you are evaluating them in production or in a judging competition. Further breakdown of each of these traits is provided in the sections below.

Structure

In breeding cattle, structure is the top priority. Structural soundness refers to how the animal's skeleton is constructed. Cattle should be able to cover various terrains based on the production system with the goal of staying in the herd and being productive as long as possible. Cattle should either be regarded as sound structured or unsound. Then, regarding competitive livestock judging, structure can be broken down further. The subsequent sections will elaborate more on evaluating the structure of beef cattle.

Foot Quality

Feet are the foundation for large animals and as such, should be the first piece of structure evaluated in cattle. The shape of their feet and angle of their foot can impact their structure and their joints greatly, which can in turn, affect their longevity in the herd or the amount of maintenance (feet trimming) that will need done over time. Feet should be big and even. Cattle should have a 45-degree angle at the joint above their hoof to ensure ample flexibility yet prevent their declaw from touching or dragging. Two primary components of evaluating foot quality in cattle are foot angle and claw set. The foot angle references to the depth of the heel, the strength (or weakness) of the pastern, and the length of the toe. The claw set refers to the size, spread, and evenness of the toes as you look at the animals foot. Examples of foot angle and claw set can be found in Figure 1 below. For both parameters, a score of 5 out of 9 is considered ideal.

Figure 1. Foot scoring guidelines provided by American Angus Association

FOOT SCORE GUIDELINES			
FOOT ANGLE (5 IS IDEAL)		CLAW SET (5 IS IDEAL)	
	1 Extremely straight pasterns. Very short toe. Unsound.		1 Extremely weak, open, divergent claw set. Unsound.
	2 Straight front and rear pasterns. Marginally unsound.		2 Open, divergent claw set. Marginally unsound.
	3 Moderately straight front and rear pasterns.		3 Moderately open/divergent claw set.
	4 Slightly straight front and rear pasterns.		4 Slightly open/divergent claw set.
	5 Ideal. Approximately 45-degree angle at pastern joint. Appropriate length of toe and depth of heel.		5 Ideal. Symmetrical claws, with appropriate space between claws.
	6 Slightly shallow heel and long toe.		6 Slight tendency for claws to curl. One claw may be slightly larger than the other.
	7 Moderately shallow heel and long toe. Somewhat weak pasterns.		7 Tendency for claws to curl, with one claw larger than the other.
	8 Shallow heel and long toe. Marginally unsound.		8 Moderate scissor claw and/or screw claw. Curling of one or both claws. Near crossing of claws. Marginally unsound.
	9 Extremely shallow heel and long toe. Extremely weak pasterns. Unsound.		9 Extreme scissor claw and/or screw claw. Pronounced curling of one or both claws. Crossing of claws. Unsound.

Access AA Login at angus.org to submit scores.

Shoulder & Knee Structure

The angles of an animal's skeleton can be evaluated directly from the side, and some angularity to the structure is helpful with locomotion. Starting at the front of the animal, there should be a slight angle (approximately 45-degrees) from the top of the shoulder blade (near the withers) to the point of the shoulder. To evaluate this, you can simply draw a figurative line from the top of their shoulder to the point of their shoulder as shown in Figure 2 below. On the other hand, if an animal's shoulder blade is too forward, we refer to them as 'straight fronted'. If you again draw a line from the top of their shoulder blade to the point of their shoulder, the line will be more vertical and closer to a 180-degree angle. This structural issue can limit the animal's movement and longevity in the herd. From the shoulder down, the animal should have some bend to their knee to provide flexibility while in motion. A great way to assess this is by looking for a slight 'banana' shape to the knee as illustrated in Figure 2. The less set an animal has to their knee the more restricted they will be in motion, and this is often correlated to the angle of the shoulder. If the knee is too far over the front foot, this is termed 'buck-knee' and can cause significant movement issues.

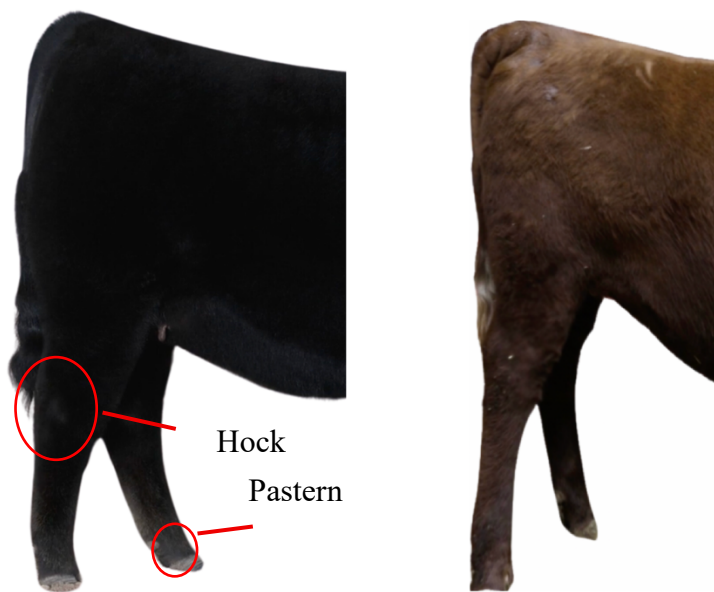
Figure 2. Example of the appropriate shoulder angle (left) and a straight-shouldered animal (right).



Hip & Hind Leg Structure

The structure of the animal's rear end is just as important as their front end. We particularly care about the structure of the hip and hind leg, which can again be evaluated from the side view. Typically, the build of the hip is correlated to how the animal moves off its hind leg. Starting at the hip, we want to evaluate the hook and pin bones relative to each other. Again, if you draw a line from the hook bone to the pin bone, we want the line to be as level as possible. Additionally, the length of the hip can be measured by the length of that line. A short-hipped animal has less range of motion off their hind leg compared to an animal with a longer hip. After studying the length and levelness of the hip, you can move to the animal's hind leg.

Figure 3. Ideal hock set (left) and a straight hock (right)



There should be a moderate amount of set to the hock (Figure 3-left). You can again draw lines to evaluate the set of the hock, whereas minimal set will result in the hock being more vertical (Figure 3-right). Like the shoulder, a straight hocked animal will typically have less flexibility in motion. From the hock joint, you should then evaluate the next joint

in the hind leg,

known as the pastern. The pastern is equivalent to the ankle and should again have a moderate amount of set to it. Like the hock joint, if a pastern is too upright the animal will not plant their rear foot as comfortably.

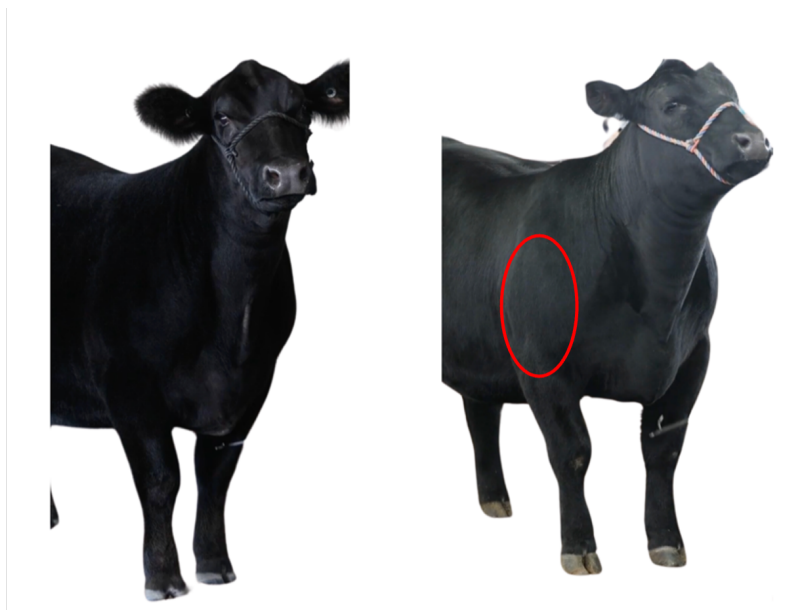
Alternatively, if there is too much set to the pastern, which can be referred to as 'weak pastern', meaning the animal's dewclaw is closer (and sometimes touching) the ground. Over time, weakening of the pastern can cause excess joint pain for the animal, negatively impacting

their movement and longevity. The set of the pastern is often correlated to the shape of the rear feet – particularly the depth of the heel. Hence, evaluating structure at the ground is critical.

Ultimately, evaluating structure begins at the side view, where you should study the angles of the animal's skeleton. In general, we want there to be moderate angulation to most of the skeleton, as too little can result in concerns with structural soundness, and too much can be unappealing. A sound structured animal should be able to move freely. Evaluating structure is complex and should be studied at more than just a side view. Thus, the subsequent sections will discuss evaluating structure at other angles.

Structure at the Front View

Figure 4. Example of the appropriate front view (left) and a course-shouldered animal (right).



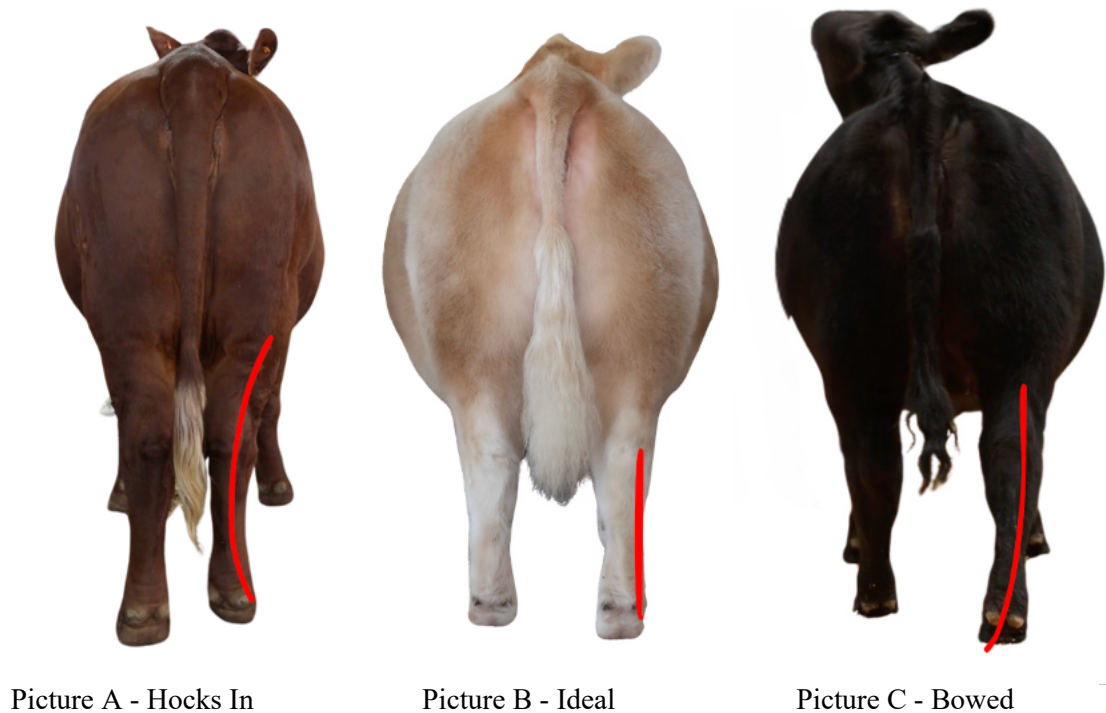
Structure can and should be studied at more viewpoints than solely from the side. At the front view of the skeleton, you should again start at the ground and assess the shape of the feet. Additionally, the front feet should be pointed straight ahead. If an animal turns their front feet in, we refer to this as 'pigeon-toed'. If they turn their front feet out, it is referred to as 'splay-footed'. From

there, the animal should be built square as you work your way up to the knee. The knee should be free from swelling and the joint should be as smooth and clean as possible. As you move up from the knee and get to the shoulder, the shoulder blade should be laid flat and smooth onto the animal's body. This can be studied by looking at the point of the shoulder (circled in Figure 4). If the point of the shoulder sticks out excessively, this means the animal is either coarse or open shouldered. Keep in mind there will likely be differences in the shape and smoothness of a shoulder depending on sex. We want heifers to be smoother and flatter about their shoulder, as this typically relates to refinement and femininity.

Structure at the Rear View

Finally, structure should be evaluated from behind. While you are viewing a different part of the animal and thus, different joints, when compared to the front view, the priorities do not change. You want to evaluate the hock joint, it should be free from swelling. From the hock down to the pastern the animal should be built square. If you draw lines again, the line connecting these two joints should be straight. In Figure 5, you can see three scenarios where the animal either pulls their hock in (Figure 5-A), is square from their hock to the ground (Figure 5-B), or bows their hock out (Figure 5-C).

Figure 5. Example of an animal who pulls their hock in (left), a square hocked heifer (center), and a bow-legged heifer (right)



Structure Summary

Structure is the most important priority when evaluating breeding cattle and should be the first thing you study. Whether you are evaluating heifers or bulls in a judging contest, or studying cattle in your operation, having a good understanding of structure is critical. If an animal is sound structured, they should be ideal at each of the viewpoints discussed above. You should always start your evaluation by determining if the animal is simply sound or unsound.

From there, especially when it comes to competitive livestock judging, you can then break down the structure further to assist in placing the class and constructing your oral reasons.

Body and Volume

It is still of immense importance for cattle within a breeding herd to have muscularity and dimension, as these traits are heritable to the next generation. Depending on your operation's goals, this could depict the importance of how much muscle they have. Regardless, cattle with true muscularity and dimension (also termed power) must be built wide at their foundation for their skeleton to lay on muscle as they progress through their growth curve. Muscularity and dimension can be evaluated in several places, which will be discussed in more detail below.

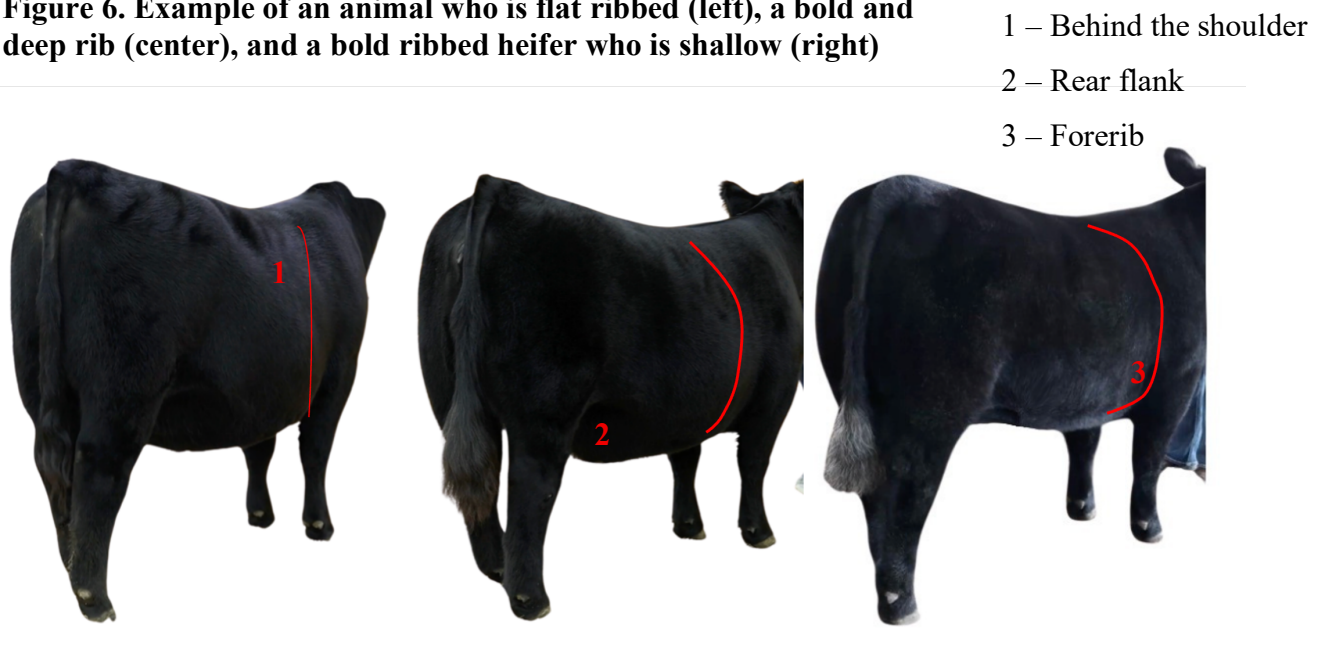
The Rib Cage

The rib cage is a crucial piece of breeding cattle evaluation and should be bold shaped and deep. While these dimensions are different, both have importance in evaluation. The shape of the rib lays the foundation for muscle to be deposited on top of it, and the depth of the rib can be directly tied to fleshing ability. Additionally, when considering females, shape and depth of rib correlate to how much space is available to carry a calf. To evaluate the shape of the rib, you should study the animal from behind – particularly at a three-quarter view. Starting down their top, specifically right behind their shoulder, the ribs should have a bold curvature to them and should carry that boldness all the way down. When studying depth of body, it is easiest to view the animal from the side. Depth of the rib can be assessed as the distance from the spine down to the base of the rib (or the belly), and back into the flank. Throughout an animal's lifetime, the shape of their rib cage will not change much. Therefore, if an animal is flat ribbed at a young age, it will not become bold ribbed as it matures. However, depth of rib is partially tied to fill of the gut and condition (how fat the animal is). So, an animal can deepen in his rib as it matures.

Visuals of rib shape and depth are shown in Figure 7, as well as locations to evaluate these characteristics. In Figure 7 on the left, the animal has a flat shape to its rib (as shown behind the shoulder); however, the animal is deep ribbed. Figure 7-Center illustrates an animal that is both bold sprung in the rib cage as well as deep bodied, as shown in the flank (Figure 7-2). Finally, an animal with a bold rib cage that is shallow in terms of depth is shown in figure 7-

right. These images demonstrate that the rib cage can be constructed in many ways. It is important to balance shape and depth of body in your evaluation of breeding cattle.

Figure 6. Example of an animal who is flat ribbed (left), a bold and deep rib (center), and a bold ribbed heifer who is shallow (right)

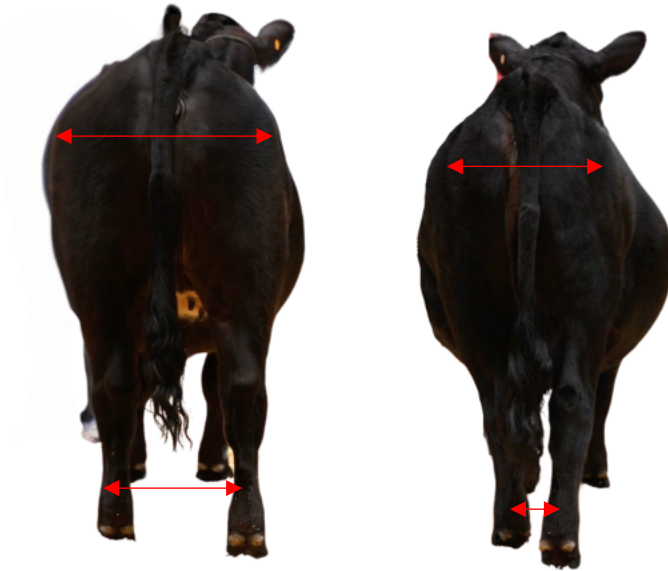


Muscularity

Muscularity is important in breeding animals because of their ability to pass muscle on to their offspring. Muscularity can be evaluated down the animal's top and from behind. It is important to note that an animal's potential for muscularity is of course, genetic, but is also a product of the width of its skeleton. So, a narrow-based animal cannot deposit as much muscle as a wide based animal. Similarly, as mentioned above, muscularity is tied to the rib cage. A flat rib cage does not provide the same room to lay muscle on top of it as a bold rib cage.

To assess whether an animal is truly muscular, you should first study how wide constructed and bold ribbed the animal is. Then, you can evaluate muscularity down the animal's top (or from above). Starting behind the shoulder, the animal should have both width to the top and shape (or definition) of muscle that you can clearly see. From there, the same kind of dimension should be seen down the animal's top back to its hip. Next, you should study muscularity at a rear view. Again, evaluate whether the animal is wide at its base (width between its rear legs). Muscularity can be studied through the animal's hip and quarter at this viewpoint as well. Figure 7 illustrates the places to study muscularity from a top and rear view.

Figure 7. Ideal power and width (left), narrow and light muscled (right)



Balance and Eye Appeal

Balance and eye appeal rank lower on the priority list when evaluating breeding cattle and should not be emphasized more than structural soundness, body volume, and muscularity. These traits can always provide some discussion, as they are more subjective in nature. A good rule of thumb to remember is that balance is equated to how proportional the animal is, while eye-appeal can encompass many things. When it comes to balance, cattle should not be heavier in their front end than their back end. If you place a line in the middle of an animal, this could help illustrate the general sense of balance. If an animal is heavy fronted or shallow bodied these traits could both immediately distract from an overall look of balance. Below, the heifer on the left is better balanced. Her front half better matches her back half. Whereas the heifer on the right is much heavier fronted than her back end. She is also shallow, which largely impacts her looks of balance as well.

Figure 8. Ideal balance (left) and poorer balanced (right)



Sex Characteristics

When evaluating breeding cattle, it is important that heifers look like females and bulls look like males. A feminine heifer would have a smaller head, slimmer front end, and be clean and flat to the top of her neck. Opposite of this, a less feminine heifer will have a coarser head, thicker neck, and shorter-tying, rounder muscle system. Furthermore, udder and teat structure are very important characteristics to understand when evaluating females. Ideally, heifers will have evenly spaced teats, which are refined and not overly big or too small. The udder should be tight and not suspended too far down. See below an informational chart on teat size and udder suspension.

**Figure 9. Udder scoring system to evaluate the suspension of the udder and teat size
 Provided by the Red Angus Association of America**

Udder Suspension			Teat Size		
Score	Description	Example	Score	Description	
9	Very Tight		9	Very small	
7	Tight		7	Small	
5	Intermediate/moderate		5	Intermediate/moderate	
3	Pendulous		3	Large	
1	Very pendulous, broken floor		1	Very large, balloon-shaped	

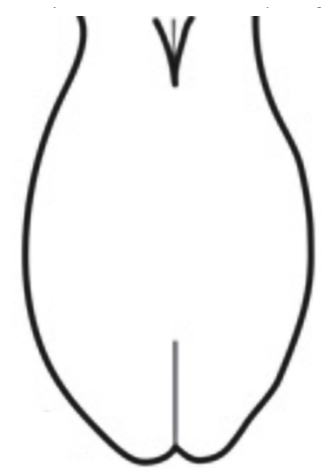
Figure 10. Example of a rugged, masculine bull, provided by Barber Ranch



A beef bull should be masculine and rugged. Bulls should have a more prominent muscle pattern with a more expressive muscle shape. You can evaluate masculinity in a bull by the topside shape of their neck (they should be more pronounced in the crest of their neck), their head shape, and their testicular development.

Finally, the shape, development and carriage of testicles in bulls can be as an indicator of breeding soundness. Testicles should be evenly shaped, approximately the same size, and move freely inside the scrotum as depicted in Figure 11. One should look out for small, wedge-shaped, or straight sided testicles. The most ideal or normal testicle shape is understood as ‘bottle-shaped’. Bulls can also present as twisted in their scrotum, simply meaning their testicles and scrotum do not sit straight down from where they are attached to the body. Size is important because scrotal circumference, or the size of the scrotum/testicles is an indicator of fertility. Sexual maturity and testicle size can vary from one breed to another. For most British and Continental breeds, a bull would require a minimum scrotal circumference of 30-32 cm at one year of age to pass a breeding soundness exam.

Figure 11. Example of the ideal testicle shape and carriage, provided by AgProud



Breeding Condition

Another area of importance when evaluating breeding cattle is their breeding condition. This refers to how much body condition, or fat cover, the animal carries. This is an area where selection and management intersect. It is important for animals to carry an appropriate amount of body condition relative to their age. Specifically, when it comes to breeding-aged females and males, body condition is critically important for reproductive success. Some animals have an

easier time putting on condition or maintaining their body condition than others depending on their growth curve. An animal that more readily deposits body condition or maintains their body condition better with minimal resources is often referred to as ‘easy-doing’ or ‘easy-fleshing’. When using body condition as a discussion and selection point in livestock judging, body condition scores should serve as a baseline for acceptability in flesh and breeding condition. Figure 12 represents body condition scores (3-8). However, BCS is scored with a range of 1 -9. 1 being minimal, to no condition and 9 being obesely fat. Again, from a production standpoint, cattle may be positioned towards a different BCS than the ideal of 5 to 6 to have lower input cost or better fit the producers’ goals.

Figure 12. Example of body condition scores (3-8, scale of 1-9). Images provided by KState Research and Extension



Expected Progeny Differences

In addition to using phenotype as a selection tool both in production and livestock judging, genetics play an important role in the evaluation process as well. Expected Progeny Differences (EPDs) are indicators of how parent traits will be passed to future offspring and can be an extremely useful tool in beef cattle selection. Performance records of individual animals are submitted by producers and statistical models are applied to this information to result in the

EPDs. These EPDs are generated across all breeds of cattle; however, some breeds have EPDs that are specific to that breed of cattle. Regardless of the breed, EPDs are a tool that provide insight into the genetic merit of an animal and are often tied to many phenotypic traits.

Within livestock judging contests, EPD's should be used as a tool to help in finalizing a placing and especially used in talking oral reasons on cattle. However, EPDs should not be the sole factor in which cattle are placed on. It is important for contestants to come to a placing of the class based on a combination of phenotype and genotype when EPDs are provided, particularly as it relates to the given production scenario that the cattle are being used for. More information about EPDs is provided in the subsequent sections. Specifically, we will cover some of the broadly used EPDs across breeds of cattle and examples of how to utilize EPDs in a judging contest setting.

Table 1-1. EPD Definitions for Common Traits Across Breeds

Calving Ease Direct – CED is a prediction of the ease in which a sire's calves will come in first-calf heifers; expressed as a percentage of unassisted births	Birth Weight – BW is a prediction of a sire's ability to transmit birth weight to his calf crop; expressed in pounds	Docility – DOC predicts the average difference of progeny from a sire in comparison with another sire's calves; expressed as a difference in cattle temperament at a year of age
Calving Ease Maternal – CEM predicts how easily a bull's daughters will calve as first-time heifers; expressed as a difference in percentage of unassisted births	Weaning Weight – WW is a prediction if a sire's ability to transmit weaning growth to his calf crop; expressed in pounds	Dry Matter Intake – DMI is a predictor of a sire's transmitting ability for feed intake during the post weaning phase, expressed in pounds/day
Maternal Milk – Milk is a predictor of a sire's genetic merit for mothering ability and milk as expressed in his daughters; the desired level of this EPD depends on the operations forage availability	Scrotal Circumference – SC is a predictor of the difference in transmitting ability for scrotal size; expressed in centimeters; can sometimes be expressed as actual SC (bulls should have greater than 34 cm SC as two-year-olds)	Ribeye Area – REA is a predictor of the difference in ribeye area of a sire's progeny compared to others; expressed in square inches
Yearling Weight – YW is a prediction of a sire's ability to transmit yearling growth to his progeny; expressed in pounds	Carcass Weight – CW is a prediction of differences in hot carcass weight of a sire's calf crop compared to the progeny of other sires; expressed in pounds	Marbling – Marb is expressed as a fraction of the difference in USDA marbling score of a sire's calf crop

Using EPDs and Scenarios in Livestock Judging for Performance Classes

In most cases at a judging contest, every class that contains EPDs will also have a production scenario. This scenario includes information about the operation's goals to help direct the contestant to what phenotypic and genetic characteristics are more important. As such, scenarios can range from different locations, breeds, resources, production targets, and much more.

Steps to use Scenarios and EPD's in Competitive Livestock Judging

1. Read the scenario and determine what the goals of the specific operation are
2. Distinguish what information from the scenario is important by underlining/circling most important things
3. Determine what columns in the EPD section is most relevant to those important aspects of the operation's goals
4. Distinguish what EPD's in each row would be good or bad with a circle for good and underline for bad. This can be done by evaluating the given animals' data and comparing it with breed averages. If significantly out of bounds when compared to the breed average, this should be of concern and noted.
5. Compare the data to the bulls themselves. It is expected that the data will generally match how the bulls should be placed and therefore, a combination of EPD's and phenotypic evaluation should allow the judge to come to a final placing.

Performance Classes in Competitive Livestock Judging – An Example

Scenario #1 (Angus Heifers)

Rank these heifers as they would best be used as potential donors in an elite purebred operation in New Mexico. The operation's primary income is from an annual bull sale where they want cattle with breed leading genetics to attract the interest of progressive breeders and AI studs.

The Breakdown:

- Elite purebred operation in New Mexico tells you where the operation is located, guiding the judge to some hints at what forage and grass type is available. At first reading this sentence, a judge should be prepared to evaluate the MILK EPD and make sure it is close to the breed average. In this case a moderate MILK value or a little below average would be acceptable because there is not an overwhelming amount of forage naturally available in New Mexico. The MILK EPD is not only important to understand a heifer's potential to wean a bigger calf by providing more milk, but this also correlates to what kind of resources an individual animal will require and how much of those nutrients being consumed will go to milk production. An easier way to digest this information is to think of higher MILK EPD values corresponding to the need for more forage.
- The operation having an annual bull sale indicates any traits which are desirable by typical bull buyer customers are relatively important. Now, this could be a variety of traits unless directly listed. It would be thought, any EPD's could be valuable/important.
- Breed leading, game changing genetics tells the judge to look for remarkable genetics which could be promoted to progressive breeders and AI studs.

Scenario #2 (Performance Hereford Bulls)

Rank these bulls as potential herd sires for use on Angus cows and heifers to generate black-baldy females. The top 25% of the female progeny will be retained as replacements. The remainder of progeny will be fed out and marketed on a value-based grid that pays premiums for high cutability cattle that grade high Select or better. Cattle are managed in large pastures with moderate availability of feed resources.

The Breakdown:

- Being taken to Angus cows and heifers tells the judge that Calving Ease and Birth Weight will be important because there will be heifers in the female base. This would mean you want a high calving ease value and small birth weight value. Below, there is only a CED listed.

Indicating that the firm is going to make Black Baldy females, means the Baldy Maternal Index will be important. A more desirable BMI\$ will portray a higher number. BMI\$ is a maternally driven index and is used to identify bulls which will do better in a rotational cross of Hereford on Angus Cross cows.

- The top 25% of females being retained to become replacement females, or females which will be added back into the cow herd, means that maternal traits will be of great importance. The maternal columns below would be Calving Ease Direct (CED), MILK, and Baldy Maternal Index (BMI\$). These 3 traits should all be at least close to the average to be deemed acceptable. If a bull was severely low or far below average for CED and BMI\$ this would be a red flag. If a bull was drastically above or below breed average for MILK, that could be considered problematic. For a milk EPD, typically an intermediate value is optimal.
- The remainder of progeny being fed out and marketed on a grid that pays premiums for high cutability cattle which grade select or better tells you that terminal values are highly important to this side of the operation. Furthermore, the combination of a high Intramuscular Fat (IMF) value, high ribeye area (REA) value, and a high Yearling Weight (YW), and high Certified Hereford Beef (CHB\$) should be more sought after. IMF correlates to quality grade, which is connected to the carcass grading select or better. The more IMF, the more likely a carcass is to receive a higher quality grade. REA is important, as it is an indicator of muscle. The more muscle, the more likely management can feed the cattle to close out as high cutability. The CHB\$ index is based on no fertility traits and is directly correlated to a sire's terminal potential in their offspring.
- Cattle being managed in large pastures indicates that phenotypical structure will be of importance. Cattle who are better structured are considered more fit to cover large pastures. Moderate availability of feed indicates milk should not be much greater than breed average.

Table 1-2. Expected Progeny Differences Example 1

Bull	DOB	CED	WW	YW	Milk	IMF	REA	Act. SC	BMI\$	CHB\$
1	2/6	+3.3	+53	+81	+20	+.26	+.43	39	+352	+130
2	1/30	+2.7	+50	+79	+22	+.29	+.44	34	+355	+127
3	2/4	+3.4	+48	+82	+21	+.27	+.28	36	+347	+118
4	2/22	-0.2	+50	+76	+23	+.22	+.26	36	+333	+111
Breed avg	-	+3.0	+55	+88	+26	+.13	+.42	-	+347	+118

The Breakdown:

- After understanding the scenario, one should take the next step to determine which values would be a “red flag” or least acceptable relative to operation needs. Those which are problematic above are underlined.
- In the example above, there is no BW given, so the judge should use the CED column to understand that the 3 and 4 bull are great, 2 is in bounds, and **4’s CED being negative** and severely below average is problematic.
- When determining problematic areas for maternal values associated to keeping females back, one should interpret MILK and BMI\$. All bulls are acceptable in their milk value in this data set. For BMI\$ 1, 2, and 3 are acceptable. 4 is not unacceptable but does have an undesirable BMI\$ index when compared to the rest and the breed average.
- When interpreting relevant terminal values like YW, 2 and 4 are less acceptable and should be considered as less desirable. For IMF, all bulls are acceptable, but the judge should still conclude that 2s progeny would be most likely to roll the highest quality grades based on EPDs. The REA column should indicate that 1 and 2 are much better, and that 3 and 4 are

unacceptable. In terms of CHB\$, the judge should conclude that 1 and 2 are much better, 3 is acceptable, and 4 is problematic.

The Placing:

- Based on the above information, the judge should conclude the logic of this class to be a bull who wins, a bull to lose and a closer middle pair. 1 doesn't have any issues, reads consistently above breed average and has desired numeric values in each EPD column. After understanding this, the 4 bull is easily the least maternally and terminally driven. The judge should see a middle pair which has some tradeoffs but using only EPD's in this example 2s greater index values and terminal genetics are much more fitting of the scenario. He may not be as strong on CED or YW, but he doesn't have any 'red flags' or major issues of concern. This is why 2 still beats 3. This information would result in a placing of 1234 with cuts of 535.

Scenario #3 (Performance Angus Bulls)

Rank these bulls as they will be turned out onto moderately framed, purebred angus cows and heifers in Western Kansas where resources are usually limited. There is an annual spring bull sale where the operation markets to ranchers looking for sound, functional bulls that can still infuse strong EPD's. The ranch also has a fall female sale where a bulk portion of females are offered to the public.

The Breakdown:

- The female base being compromised of heifers and cows, but more importantly the heifer component reemphasizes the priority to select on BW and CE. Low birth weights and high calving ease figures are desirable.
- The operation being in Western Kansas indicates the milk column will be important. A value a little lower than average to a little above average would be acceptable. A value majorly above average would hint at an animal who requires substantially more resources than could

possibly be available. Feed resources being limited reconfirms the importance of the milk value.

- There being an annual spring bull sale where customers look for functional bulls that are sound and good in their genetic offering, tells you to phenotypically look for a sound bull, but that bulls with a combination of balanced EPD's are important. Each column below should be evaluated.
- The fact the operation has a female sale as well establishes that maternal traits like MILK and \$M will be of importance as well

Table 1-3. Expected Progeny Differences Example

	CE	BW	WW	YW	MILK	MARB	REA	\$M	\$B	\$C
1	9	1.0	71	116	21	.74	.68	67	154	263
2	7	2.1	73	115	26	.63	.75	66	152	263
3	10	-1.1	64	120	19	.70	.67	71	153	270
4	<u>3</u>	<u>4.3</u>	69	107	<u>33</u>	.78	.82	<u>62</u>	163	<u>253</u>
Breed avg.	7	1.2	59	105	26	.59	.59	64	150	257

The Breakdown:

- Working through the columns left to right, the CE column indicates that 4 being a 3 in his CE in tandem with a BW 4x the breed average is a bad combination, and a red flag. The other 3 bulls are acceptable in their CE and BW, with 3 being a double-digit calving ease bull with a low birth weight this would be beneficial to the operation.
- In terms of MILK, this is again important as the operation has limited resources. It is a major red flag that 4 has a milk value of 33. This should be used as a placing factor and brought up in oral reasons. All other bulls are acceptable.
- In terms of growth, all bulls are acceptable. 4 being the smallest still in his YW should be kept in mind but shouldn't be a major placing factor.

- In terms of MARB and REA, all bulls are above breed average and considered acceptable. 4s class leading MARB and REA are an advantage and a talking point, but where all other bulls are acceptable here, this should not be a huge placing factor as the judge is looking for balanced EPDs.
- Maternal Weaned Calf Value (\$M) predicts profitability differences from conception to weaning with the objective being retaining females. Therefore, this is an important trait in determining if a bull is likely to carry maternal value to the next generation. The index is calculated on a combination of traits like CED, CEM, WW, and more. For this, 4 is below the average and should be underlined. The other bulls are acceptable, with 3 being the best.
- Beef Value (\$B) is a terminal index which predicts profitability differences in progeny due to genetics postweaning and carcass traits. Traits associated with this index are REA, MARB, YW, CW, and more. Above all bulls are acceptable with 4 being the class leader.
- Combined Value (\$C) is an index compromised of maternal and terminal EPDs and is expressed in dollars per head. This combines each trait associated with \$M and \$B. 4 is not acceptable for his \$C value. All others are acceptable, and the judge can assume 3 is the class leader in \$C because of his really high CE, low birth weight, and class leading YW, while still being balanced in every other column.

The Placing:

- This class has less variation in numbers than the Hereford Bulls example, however there is still sound logic the judge should come to. There is a bull to lose, and a trio of bulls who genetically are fitting to the operation. Since 4's calving ease, birthweight, and milk are out of bounds, he is least fulfilling of the scenarios request. Despite his strong advantages in terminal value, those are less of an advantage and not clearly demanded in the scenario. Therefore, he is 4th. Using EPD's alone, one can still use comparative advantages to find the best attributes in 3 to win. This would leave a closer middle pair which have minute

differences in their genetic profile. 1s calving ease, birth weight, yearling weight, more conservative milk value are slightly better. 2s WW and REA are better, but these advantages alone are not enough to beat 1. Ultimately, the final placing the judge should come to is 3124 with cuts of 426.

Market Cattle

Market beef cattle are those intended to be harvested for human consumption. While in general, the selection criteria between breeding and market cattle are similar, the order in which you prioritize them differs because of the difference in their endpoint purpose. When evaluating market cattle the priorities in which you should use (in order) are:

1. Composition – The amount of muscle and degree of finish (fat) on the animal.
2. Structure - How the animal's skeleton is constructed and how it moves.
3. Balance and Eye Appeal - How does the animal proportion

Compositional Correctness

When evaluating market beef cattle, the most important characteristic is compositional correctness. This refers to the amount of muscle and fat cover (or finish) the animal has. A good market beef animal should be muscular with an appropriate degree of fat cover to maximize the value of the carcass. Evaluation of these parameters is discussed further in the sections below.

Evaluating Muscularity

Much like in breeding cattle, muscularity all starts at the animal's foundation. A wide based market beef animal has the foundation to lay adequate muscle on top of its skeleton, where a narrow-based animal does not. Width and muscularity can be evaluated from the front view, rear view, and side view. A market animal should be wide through the chest and bold in the rib

Figure 13. Example of a wide, powerful constructed steer on the left and a narrow, flat made steer on the right

- 1 - Chest Width
2 - Rib Shape/Turn of Rib

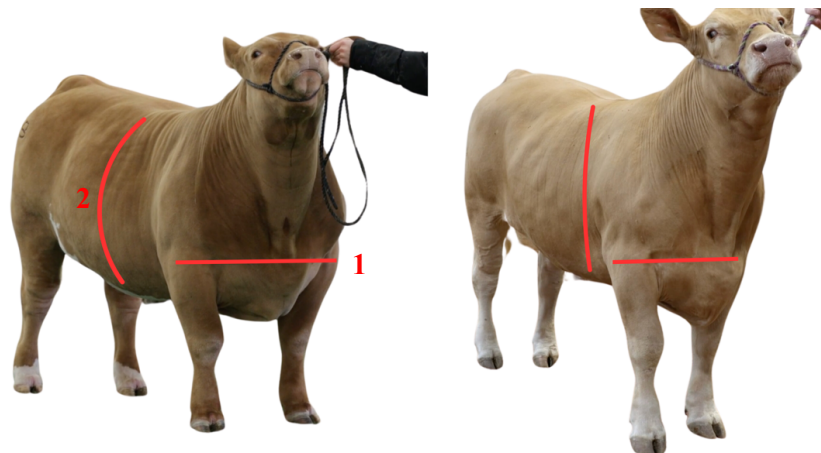
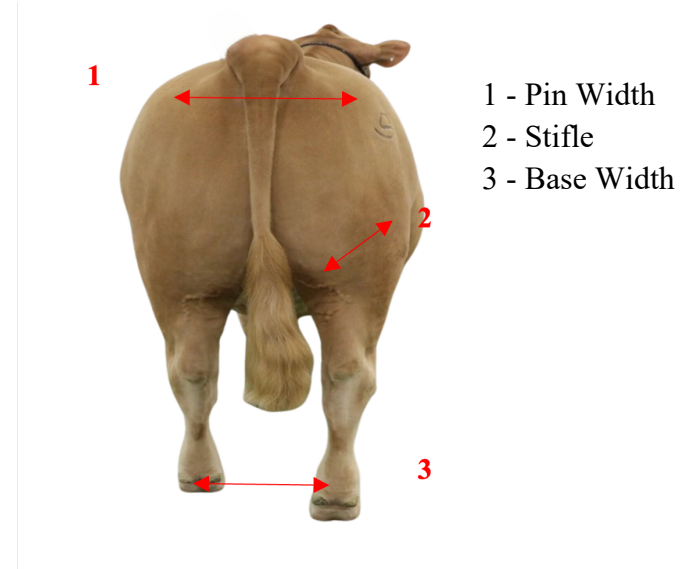


Figure 14. Example of a muscular rear view

cage when viewed from in front (Figure 13). Likewise, when viewed from behind (Figure 14), the animal should be wide between the rear legs and have dimension to its hip and quarter. From the rear view, muscle can be evaluated in multiple places. For ample muscling to be present, there should be shape or power in the following area which are matched to the image on the right.



The top view is critical for evaluating muscularity in market cattle, and in some contests, you handle the animal's top to feel for muscle content. Behind the shoulder is a great indicator of top shape and muscle. At this area, a wide, square shape that sits up (like a brick) is ideal. If you handle this area on a steer and it is narrow, round, soft, and your hands easily roll away, then the calf is plain shaped. The steer on the right is a good example of what a narrow topped, poor shaped steer looks like. Shape is a term usually correlated to the tone and expression of muscle. The more tone of muscle and the more expression of muscle, the better the animals muscle shape would be. In addition to shape, cattle should have ample dimension and volume of muscle. Dimension is related to width and volume of muscle. If a calf has an ample amount of width with an ample volume of muscle, this could be considered dimensional. Width and spread from the back of the shoulder to the rib and loin are also ideal.

Figure 15. Example of wide, muscular topped calf on the left, a light muscled steer on the right

- 1 - Width Behind the Shoulder
- 2 - Width Across Rib
- 3 - Width and Fullness of the Loin



Evaluating Degree of Finish

The second factor that makes up a market beef animal's composition beyond muscle is fat cover. Fat, also referred to as 'finish', is both a positive and negative trait. To understand the complexity of finish in market cattle, it is important to grasp quality and yield grades and their role in the beef industry, as both are driving forces in the dollar value of a beef carcass.

Yield Grade

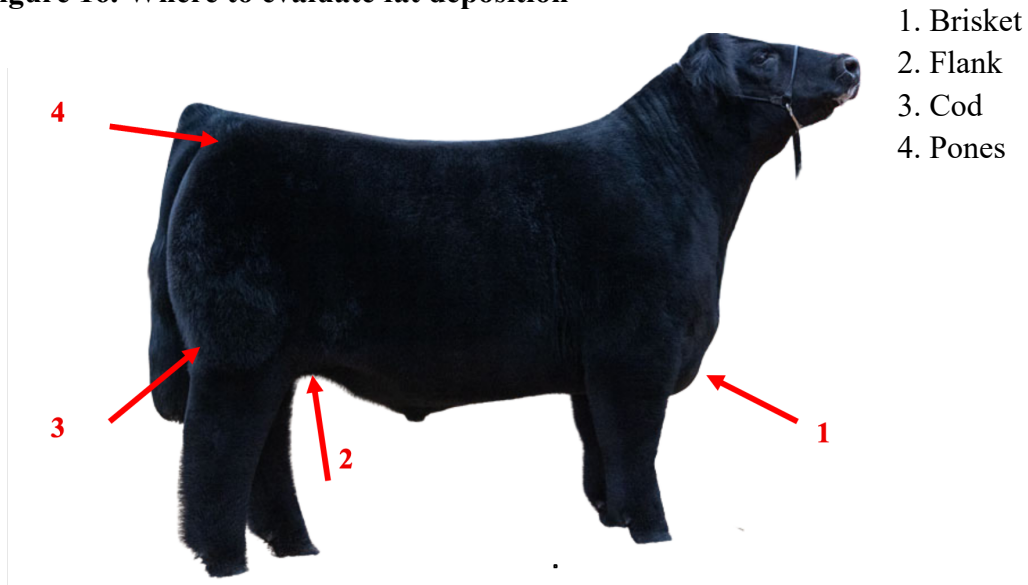
- Correlated to the amount of lean, boneless, retail cuts that can be obtained from a carcass
- Driven off hot carcass weight, ribeye area, fat thickness at 12th rib, and kidney, pelvic and heart fat
- Five USDA Yield Grades: USDA 1, 2, 3, 4, 5 (1 = best; 5 = poorest)

Quality Grade

- Correlated to the amount of intramuscular fat found within the muscle
- Tied to the palatability of meat
- Driven off marbling (intramuscular fat) and maturity of carcass
- Eight Quality Grades: Prime, Choice, Select, Standard, Commercial, Cutter, Canner, and Utility (in order from most ideal to least ideal)

Cattle deposit fat front to back, top to bottom. As an animal matures and their growth curve shifts from muscle deposition to more fat deposition, they will lay fat down over the rib cage, which can easily be assessed if you handle the animal. Over the 12th and 13th rib, where fat is measured in a beef carcass, cattle should ideally have 0.4" to 0.6" fat. Cattle with less than 0.4" of fat are generally not considered ideal in terms of finish, because it is assumed that they may not have deposited as much intramuscular fat, hence negatively impacting their quality grade. Alternatively, if an animal has over 0.6" of fat, it can potentially have negative impacts on their yield grade. Figure 16 illustrates the physical locations on the animal to evaluate fat deposition. As an animal gets fatter, it will deposit more fat and fill the brisket, flank, cod, and pones.

Figure 16. Where to evaluate fat deposition



Structure

Structure is still an important factor to consider in market cattle evaluation, despite it being lower on the order of priorities when compared to breeding cattle evaluation. Market cattle should be functional enough in their structure that it doesn't impact their ability to convert feed to gain and reach an appropriate market point. Thus, small structural issues should not be of concern. If there are major red flags, cattle which are crippled, cannot move off either end, etc. this should be noted. If the class equally has muscle and finish, structure can be a greater priority.

Structure from the Profile

Like breeding cattle, market cattle should be angular through their shoulder, level spined, and have some angle to their hock and a correct pastern like Picture A in Fig. 17. Cattle which are upright in their shoulder or hind leg in Picture B of Fig. 17 are often tighter spined and short in their stride. Cattle which appear completely unable to move when in motion should be deemed a red flag.

Figure 17. Market cattle structure from profile



Picture A - Ideal

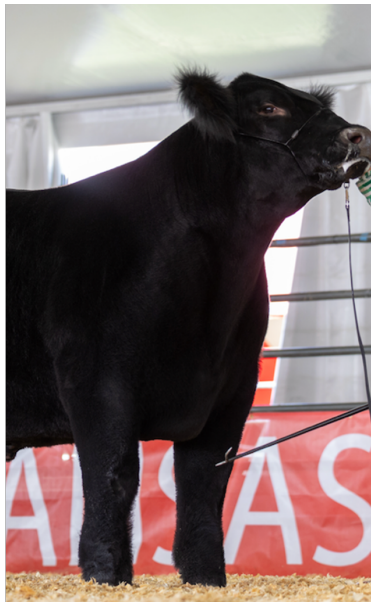


Picture B - Straight

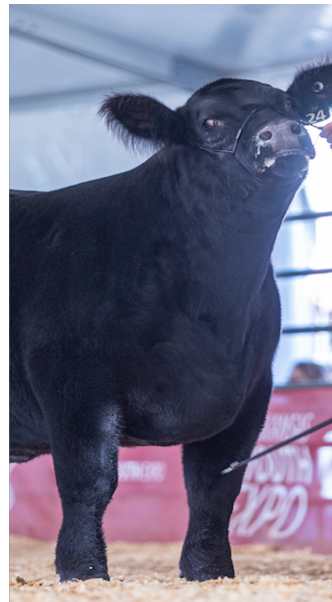
Structure through the Front End

When viewed from the front, steers should be square constructed and relatively smooth through shoulder build like Picture A in Figure 18. However, cattle can sometimes be so big and coarse shouldered it impacts their stride and their ability to balance like the steer in Picture B of Fig 18.

Figure 18. Market cattle structure from the front



Picture A - Ideal



Picture B - Coarse

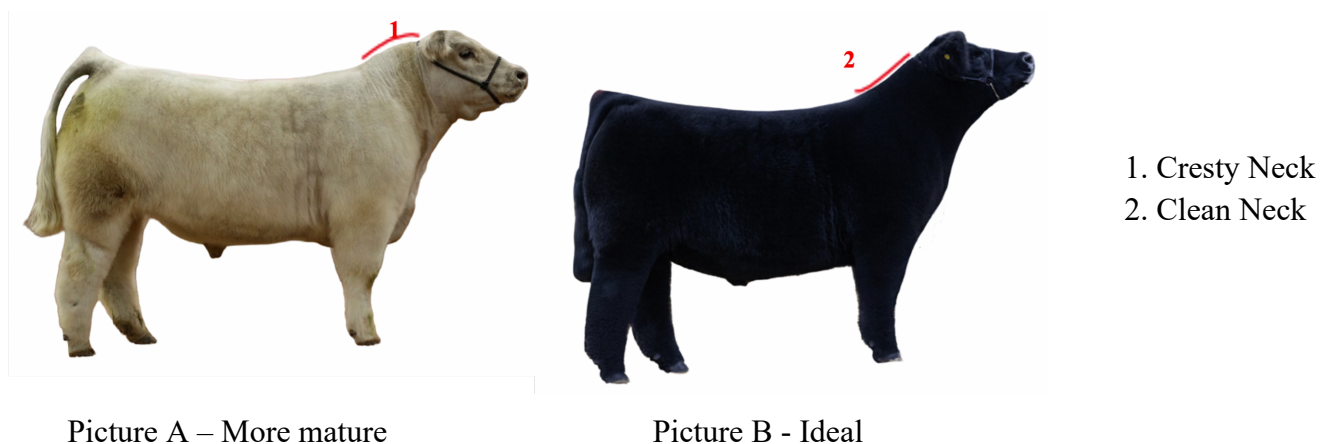
Balance & Eye Appeal

Balance in market beef is a lower priority, but cattle should still maintain proportionality, with their front-end matching equally to their back end. Ideally, a steer should be level topped, deep bodied, and proportional. Additionally, in market beef, a stout foundation still impacts look. Bone and foot size can help draw your eye in and can be a strong talking point to describe an animal, but it is not a large placing factor.

Maturity becomes a large discussion point in beef cattle, as it directly impacts their balance and look. Often, steers showcase advanced maturity in their head, neck, joint work, and bone. From a presentation standpoint, more mature cattle can appear staler in their hide and hair coat. The lack of freshness is commonly described as staleness and reflects a combination of increased maturity and sometimes additional fat cover. Freshness, while difficult to initially learn, refers to animal who exhibits appropriate maturity while maintaining a youthful, clean appearance without extra fat and condition that negatively impact their balance or look. When using the term ‘fresh’, it can be directed to specifics like a fresh hide or fresh hair coat or can be directed at the overall sense of freshness. It is important in competitive, high-quality classes to discuss freshness differences as they relate to the descriptions of animals, but it shouldn’t be a major placing factor.

In Figure 19 below, the steer on the right appears older and more mature. This is evident by the top of his neck, also coined the crest of the neck, looking bulkier and his head being disproportionately large to his body. He exhibits reduced eye appeal with a heavier throat and a bit of extra leather and brisket. The steer on the left also has a patchy, dull hair coat that appears stale. This adds to him looking less attractive and youthful. However, the steer on the right has a slim, yet still stout head shape, clean on the topside of his neck, and is free of extra fat around his chest and brisket. This makes him out to look more attractive, but also more youthful. His haircoat being healthier, smoother, and brighter enhances his appearance of freshness and contributing to a more desirable look.

Figure 19. Example of maturity and freshness differences



Conclusion

Ultimately, beef cattle evaluation encompasses various important traits with emphasis placed on each relative to industry demands and individual production goals. Despite how market cattle and breeding cattle differ somewhat in how traits are prioritized, the baseline criteria for judging are similar.

Common Swine Breeds Exhibited

There are numerous swine breeds used across the world. In commercial production, you may see a few breeds used more than others. Regardless, the purebreds exhibited at livestock shows can generally be categorized a Certified Pedigree Swine (CPS) breed or National Swine Registry (NSR) breed. The exception to this, is that the Berkshire breed, has its own association and is not organized by the CPS or the NSR. Each breed has its own unique breed color identifiers and the limitations of what is acceptable to show may differ. The following images are to allow contestants to build understanding of color patterns and breeds they may see at a livestock judging contest.

CPS Breeds



Chester White,
photo from
Legacy
Livestock
Imaging



Hereford, photo
from Legacy
Livestock
Imaging



Poland China,
photo from
Legacy
Livestock
Imaging



Spot, photo from
Legacy
Livestock
Imaging



Tamworth,
photo from
Crossroads
Genetics

NSR Breeds



Duroc, photo
from Legacy
Livestock
Imaging



Hampshire,
photo from
Premium Blend
Genetics



Landrace photo
from Legacy
Livestock
Imaging



Yorkshire,
photo from
Legacy
Livestock
Imaging

Other Show Breeds



Berkshire, photo from Legacy Livestock Imaging



Light Cross, photo from Legacy Livestock Imaging



Dark Cross, photo from Legacy Livestock Imaging

Selection of Swine

When judging swine there are many important traits to consider depending on the production goals. Over time, pig quality has increased as genetics have progressed, and selection pressures are further communicated. Depending on whether you're evaluating breeding swine or market hogs, there is a set of priorities which should be followed. The order of priorities will shift accordingly.

Breeding Swine

When evaluating swine for the breeding herd, traits of importance include those that correlate to longevity in the herd and heritable traits that can be passed on to offspring. The priorities of which you should evaluate breeding swine (in order) are:

1. Structure – How the animal's skeleton is constructed and how it moves.
2. Body and Volume – Boldness and depth to the rib cage and dimension of muscularity.
3. Balance and Eye Appeal – How does the animal proportion.

In general, these priorities should guide selection for breeding swine whether you are evaluating them in production or in a judging competition. Further breakdown of each of these traits is provided in the sections below.

Structure

Structure is the greatest priority in selecting swine to be added into breeding programs. Operations might have various housing systems, but regardless, an animal's ability to withstand concrete, slatted floors, dirt pens, and group housing is important.

Pastern and Foot Structure

Like cattle, feet and pasterns are the foundation for excellent structured swine. An ideal structured pig will have strong pasterns, even, big toes, with slight spread of their toes like Figure 20.

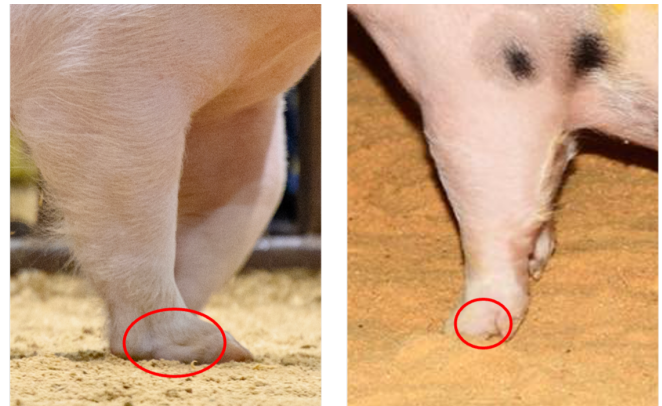
The pastern, if too weak will cause dewclaws to touch the ground and can result in sore pads, cracked feet,

Figure 20. Example of toe spread



and likely restricted movement. Their rear pastern should have slight cushion, but over time with maturity and added weight, pasterns can weaken. Often, pigs can be weak in their pastern and roll their feet towards each other. Figure 21 has depicted an example of weak pastern on the left and an ideal pastern on the right. Notice, the weak example on the left has the pastern completely on the ground. The strong pastern example on the right is off the ground, and the dewclaw is off the ground as well.

Figure 21. Examples of pastern strength

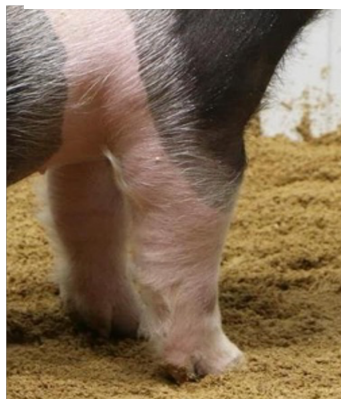


Shoulder Blade and Knee Structure

An ideal structured breeding gilt will have an angular shoulder blade, some curvature at her knee, and some bend in her pastern like the image on the right (Fig 22, Picture A).

Problematic examples of the front-end structure typically fall into two different categories: straight or too laid back. Often, pigs are too upright or straight in their skeletal structure (Fig 22, Picture B). This can lead to pigs being tighter structured and unsound and even bucking over in their knee. The later issue mentioned is when pigs can have too much bend, also known as too laid back in their blade and knee (Fig. 22, Picture C). It can lead to pigs being weak in the pastern.

Figure 22. Examples of shoulder blade and knee structure



Picture A - Ideal



Picture B - Straight



Picture C – Too laid back

Hip and Hock Structure

The rear skeleton should consist of a long and level hip, high tail setting, and hock structure that has some angularity and set so the animal can freely move and take a long step (Figure 23, Picture B). Again, pigs can become straight hocked, also known as post legged. At the rear view of swine, you wish to see clean joints and a square shape figure the top of the hip to the hock, all the way to the ground.

Figure 23. Examples of hip and hock structure



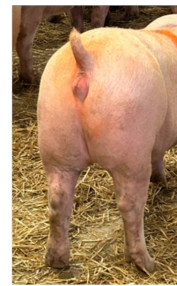
Picture A –
Steep hiped
and too much
set to hock



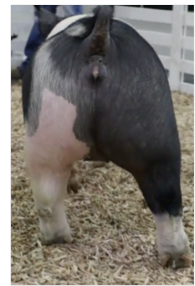
Picture B –
Ideal hip and
hind leg



Picture C –
Straight hind
leg



Picture D –
Pulls hock
inside



Picture E –
Bows at hock,
toes rear feet in

Muscle, Width, and Body

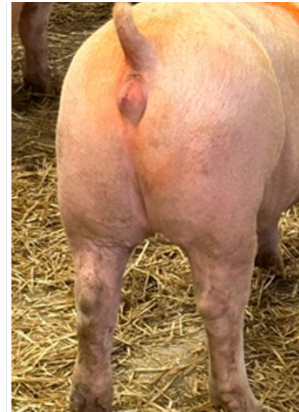
Muscle

Since many breeding swine will produce market animals, it is a priority for breeding swine to have ample muscle, skeletal width, and depth. It is easiest to indicate muscularity at the top view and rear view. Directly from above, you can assess how much shape, spread and width up high a pig possesses. From behind, an ideal muscled pig will have a wide pin set, lots of shape, and full ham. Indicated below in Figure 24, picture A displays a very muscular wide made gilt, who has lots of shape to her ham and width from the top of her hip to her hock, and all the way to the ground. Whereas in picture B of Figure 24, this gilt is all narrow hiped, light muscled and narrow at her foundation or base.

Figure 24. Examples muscle and width from behind



Picture A – Heavy Muscled and Wide



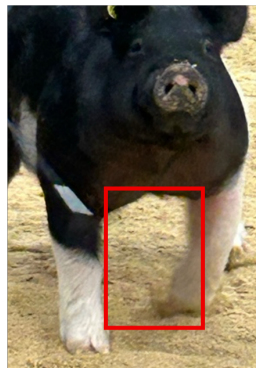
Picture B – Light Muscled and Narrow

Width

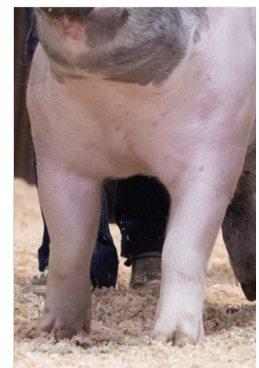
In determining skeletal width, the ideal gilt should be square at the base of her chest and maintain that all the way down to her feet. The same squareness and width should be seen at the rear view. There are multiple differences one could see on front skeletons of pigs, below are examples of wide

Figure 25. Examples of width through the front end

chested, squared
chested, narrow
chested with a
narrow base, and
narrow chested
with knees turned
inside toward each
other.



Picture A – Wide and square to the ground



Picture B – Narrow chested and in at knee

Body

Like cattle, body or rib is viewed as depth and the roundness of the ribcage in swine. Because female breeding swine spend most of their time getting up and laying down in confinement operations, we select females who have bolder rib cages. Bolder ribbed females can roll and get up easier. The flatter ribbed an animal is, the harder it is for a breeding female to roll over and stand up. Imagine, you have a square box and a barrel (cylindrical shaped). If both are laid on their side, which one would take more power to move to the other side? The barrel would move with much more ease. The ideal gilt will have ample softness to her rib, allowing for some depth of body, but not be over conditioned.

Figure 26. Examples of body depth



Picture A – Deep Bodied



Picture B – Shallow Bodied

Balance/Design

Balance

The ideal breeding swine should still be well proportioned and nicely balanced. Moreover, if you can split pigs into thirds (front, middle, rear) each of these should match in length and depth. Like other species, you don't want their front end to be heavier or more noticeable in a negative way than their back end. As far as eye appeal or look, females should look feminine and maternal. Feature is certainly a buzz term in show pigs, and as such is an important aspect of look. Feature is simply another word for bone, skull, toe, ankle, tail root, and forearm. Essentially, any place that showcases the density, circumference, or size of animal's bones in a skeleton are described by feature. Pigs which are stouter in their feature, like the gilt in picture A of Figure 27 are more desirable, but these are not requirements in selecting for females but are a bonus. Below are traits which are desirable and undesirable.

Figure 27. Examples of design



Picture A – Ideal Design



Picture B – Poor Design

1. Jaw	2. Crest of neck	3. Neck
4. Jowl	5. Forearm	6. Ankle
7. Topline	8. Ribcage	9. Hip

Reproductive Traits

When selecting gilts on reproductive traits, these are the main areas of consideration: general makeup looking feminine, underline and teat quality, and a correct vulva. However, it is traditionally accepted in livestock judging contest to not put an emphasis on underlines and vulvas in placing the class, but to describe those differences in oral reasons. Overall, females should have long, smooth muscle patterns and look more refined. To further explain this, the muscle should not be coarse, bulky, bunchy, or chunky looking. It should lay on the skeleton smooth and flat.

The teats should be the size of a pencil eraser, to comfortably fit into a piglet's mouth, like the example in Figure 28. More terminal or less female like gilts will have teats which are coarse and poorly spaced.

Figure 28. Example of refined and even spaced underline



Figure 29. Example of coarse rear teats



For example, the gilt in Figure 29 has coarse rear teats which would make suckling for piglets more challenging. Gilts can also be short counting, simply meaning they do not have enough teats to feed a litter with lots of piglets. Therefore, gilts should have at least 6 teats visible on both sides of the underline. Vulvas should not be too small, fishhook, or turn upward at the tip of the vulva. Larger vulvas are preferred to smaller ones.

Ideal Underline Characteristics	Less Ideal Underline Characteristics
Evenly Spaced	Coarse teats
Finer textured teats (pencil sized)	Uneven spacing
Prominent Underline	Pin nipple
At least 6 teats on each side	Inverted nipple
Free of pin, inverted or abnormal nipples	Short Counting

Market Swine

Market swine are those intended to be harvested for human consumption. While in general, the selection criteria between breeding and market swine are similar, the order in which you prioritize them differs because of the difference in their endpoint purpose. When evaluating market swine the priorities in which you should use (in order) are:

1. Muscle and Width – the total amount of muscularity and product
2. Composition – The amount of muscle and degree of finish (fat) on the animal.
3. Structure - How the animal's skeleton is constructed and how it moves.
4. Balance – How attractive and proportional an animal is.

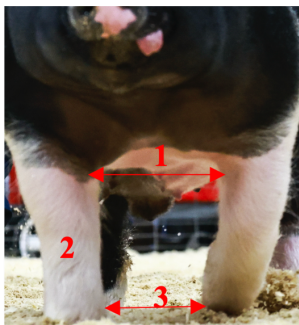
Muscle and Width

Front View

The first indicator in if an animal will enough muscle relates to its skeletal foundation. This is why it is preferred for market animals to have a wide foundation. In other words, it is optimal for market hogs to be wide based and maintain that width through their chest and all the way back. Therefore, at the front view when a pig drives at you, you expect a good market hog to be wide at the base of their chest, square at their knee, and wide where their feet touch the ground.

For example, in Figure 30, the barrow in Picture A was square in his foundation and wide at the base of his chest.

Figure 30. Examples skeletal width through the front end



Picture A –
Square



Picture B – Narrow base of
chest, feet are close together

1. Base of chest
2. Knee
3. Width at front feet/base width

Whereas, in Figure 30 Picture B, the black barrow was very narrow chested and planted on a narrow base. He consequently did not come stout enough or muscular enough to be a very good market hog.

Topside

Muscle can also be viewed down the top. A square, expressive muscle shape or bunchier muscle pattern is preferred to a smooth muscle pattern with plain shape. Furthermore, when you evaluate a pigs topside spread, a judge should let the pig drive right next to them to evaluate width, spread, and muscle shape down the top. At that time, one should look directly behind the shoulder blade, this area is initial indicator of how much width and total mass a pig carries at the top of his skeleton.

Once assessing width, one should determine if shape from the center of the spine is flat and makes a square shape like Figure 31, Picture A or if it is rounded like a hill. If the pig has a round, plain topside shape like Picture B, in Fig. 31, the pig is undesirable. This is also an important view when discussing composition which is covered later in the text.

Figure 31. Examples of top shape



Picture A – Ideal Top Shape



Picture B – Undesirable Top Shape

Rear View

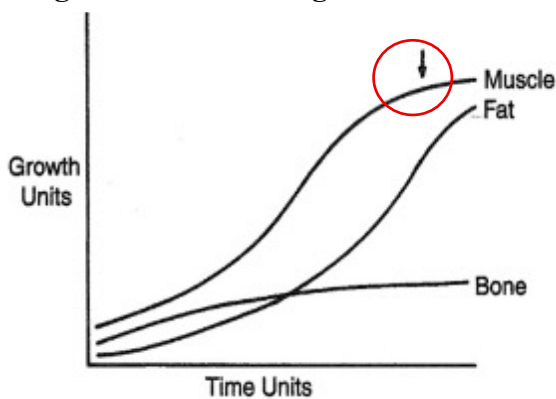
When studying a market hog from behind, it is important to see if they are wide across their hip, wide across their ham, and wide based. This is very similar to the front view.

Composition

Overview

Composition is a simple term that equates to the ratio of muscle to fat. To understand composition, one must not only understand how to evaluate muscle like above but also understand fat deposition of swine. To further understand their value in relation to muscling and fat, Figure 33 is provided to further depict a pig's growth curve. As livestock mature overtime,

Figure 33. Livestock growth curve

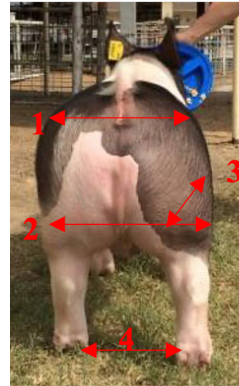


they will eventually reach a point where their muscle deposition is not greater than their fat deposition. As a result, they may have less economic value than intended. Swine which are ideal in their composition are muscular and have less fat than they have muscle. This is because swine carcasses are more valuable when they have more muscle. Therefore, understanding where fat deposition happens and the degree of condition in those areas can further help a judge understand the pig's maturity and value. Pigs deposit fat front to back, top to bottom, which helps us determine where to look at a pig's fat. There are several examples of indicators of fat cover shown in Figure 34 and ideal and less ideal characteristics defined below.

Ideal Composition

- Heavy muscled
- Expressive top shape
- Shapely throughout
- Clean jowl
- Not excessive or wastey body
- Dimple in front of tail

Figure 32. Example of ideal rear view



1. Width across hip
2. Width across stifle/ham
3. Stifle shape
4. Base width

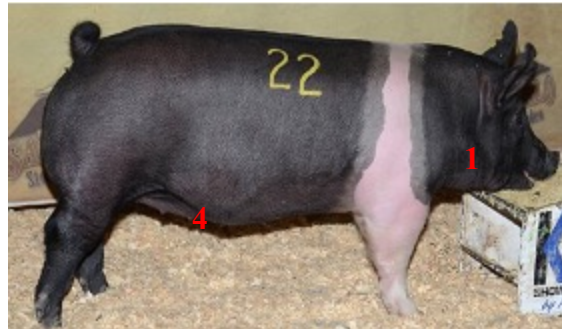
Less Ideal Composition

- No muscle shape
- Fatty Jowl
- No expression to top
- Light muscled
- Smooth, full elbow pocket
- Ham seam fatty

Figure 35. Examples of composition



Picture A – Ideal Composition



Picture B – Poor Composition

1. Jowl
2. Elbow Pocket
3. Top Shape
4. Bottom Line/Belly

Structure and Balance

Once the basics of muscle, width and composition are found, one can prioritize structural correctness and balance or look. Like good breeding swine, excellent market hogs will be sound structured and not labor when moving. Structure of pigs should be evaluated when the

pig is moving. Understanding structure in market swine is the same as breeding swine. Feet are the foundation to correctly made animals and should have adequate cushion in their pastern, but not too much to where dewclaws touch the ground. Ideal structured market hogs should be angular at the blade, knee, and hock.

Figure 34. Example of appropriate structure and balance



Figure 36. Example of structural issues being related

Straight made pigs or pigs with too much extra set to their front skeleton or hock are not ideal. To appraise structure further, look for a level topline, squareness to their skeleton, and flexibility at the ground. Often, one structural flaw is correlated to other issues in structure, like the barrow in Figure 36. In terms of balance, we can appreciate height of blade, extension, and stoutness of skull, but it should not be a placing on lower quality animals who have major differences in muscle and composition.



Conclusion

Swine judging should be based on the fundamental priorities noted above for breeding and market swine, respectively. As quality increases and the pigs are more likely to be competitive at higher levels, priorities tend to look like they shift towards balance and eye-appeal, but contestants should still orient their priorities respectively to muscle and composition for market swine and structure and volume for breeding swine. Despite how market cattle and breeding cattle differ somewhat in how traits are prioritized, the baseline criteria for judging are similar.

Show Sheep Breeds

While each show has different breeds, the common breeds at livestock shows and contests are below. This provides visual references to recognize these more common breeds by their maturity, skeletal designs, and color patterns.



Dorset, photo from Continental Dorset Club



Natural, photo from Legacy Livestock Imaging



Southdown, photo from Legacy Livestock Imaging



White Face Cross, photo from Legacy Livestock Imaging



Dorper, photo from Legacy Livestock Imaging



Hampshire, photo from MacCauley Suffolks



Shropshire, photo from American Shropshire Registry Association



Suffolk, photo from MacCauley Suffolks



Blackface Cross, photo from Legacy Livestock Imaging

Boer Goat Color Markings

In the 1990s, the first Boer goats were brought to the United States and are known for carcass strengths, docility, and fertility amongst in the meat goat industry. For show livestock, Boer goats are the only breed exhibited and that does not require competitors to know breed type differences in the goat division. However, there are many differences in color pattern and color within the Boer goat breed that are commonly seen in livestock judging contests and shows.



Traditional, Photo provided from Legacy Livestock Imaging



Paint, Photo provided from Legacy Livestock Imaging



White Ear/Frosted Ear, Photo provided from Legacy Livestock Imaging



Blonde/Light Headed, Photo provided from Legacy Livestock Imaging



Photo provided from Legacy Livestock Imaging



Black/Solid Black, Photo provided from Willoughby Livestock Sales

Selection of Sheep & Goats

When evaluating sheep or goats, the priorities are largely like those for other species, but the anatomical terms used to describe small ruminants are unique.

Breeding Ewes & Does

When evaluating sheep or goats for the breeding herd, traits of importance include those that correlate to longevity in the herd and heritable traits that can be passed on to offspring. The priorities of which you should evaluate breeding sheep and goats (in order) are:

1. Structure – How the animal's skeleton is constructed and how it moves.
2. Body and Volume – Boldness and depth to the rib cage and dimension of muscularity.
3. Balance and Eye Appeal – How does the animal proportion.

In general, these priorities should guide selection for breeding sheep and goats whether you are evaluating them in production or in a judging competition. Further breakdown of each of these traits is provided in the sections below.

Structure

Structural correctness simply refers to the skeleton being aligned and put together in an organized manner. For sheep and goats structure evaluation starts at the ground with proper feet. Then, the skeleton should also be evaluated at the front and rear view. Ultimately, sheep and goats should be able to naturally carry their head high and be level down their top without giving up correct angularity to the shoulder blade, knee, and hock.

Figure 37. Examples of foot structure in small ruminants



Picture A – Ideal

Picture B – Too much set

Picture C – Too Straight

Feet and Legs

At the ground, small ruminants should have feet somewhat like cattle. They should be big, and each digit should be even or nearly matching the shape and size of the digit of the same foot. If the pastern is too long or has too much of an angle it is not ideal. Opposite of this, if a sheep or goat has no angle to their pastern and is straight up and down from their dewclaw, through the pastern to their feet, this is also not ideal.

In terms of proper front-end structure, a sheep or goat should have approximately a 45-degree angle to their shoulder blade with some bend at the knee like the first doe in Figure 37. If the doe or ewe is straight up and down in their shoulder blade or in their knee, also termed straight, they will not be able to adequately take a comfortable step, resulting in a skeleton which will not hold up as long, like the dapple doe in the bottom picture of Fig. 37. If the shoulder blade is laid back more than ideal, the sheep or goat will likely be less attractive in their front-end look and could have structural issues in their front feet.

The hip and hind leg should be composed of a long, nearly level hip and dock, paired with a hind leg that has some angularity and correct pastern setting. Often, sheep and goats can be round out of their hip or dock (in sheep). Sheep tails are banded, and this area is called the dock.

Figure 38. Examples of structure



Figure 39. Parts of a sheep, provided by KSU Show Lamb Guide

Whereas, goat's tails are left alone, so this is referred to as the hip. Furthermore, the posture of the hind leg can often be straight or have too much set. See Figure 39, for a better anatomical understanding of sheep.

Front View

At the front view, you wish to see a flat, smooth shoulder build, square knee, and front feet which point straight forward like Picture D in Figure 40. Sheep or goats can also be in

at their knee, known as knock kneed. Like Picture B, sheep can turn their front feet in towards each other known as pigeon toed. Opposite of this, in Picture C, sheep can turn their feet outward, known as splay footed.

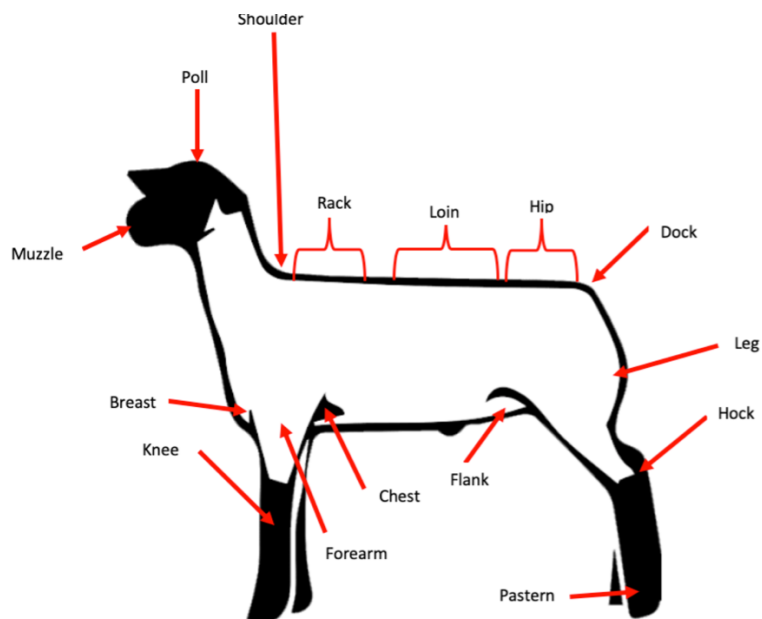


Figure 40. Examples of front-end structure



Picture A – In at the Knee



Picture B – Pigeon Toed



Picture C – Splay Footed



Picture D – Correct

Rear View

At the rear view you wish to see a sheep dock or goat with a square pin set, width between the hind legs, and square rear feet which point towards the head, and plant the ground evenly. If an animal pulls their rear legs towards each other, also known as in at the hock, this is not ideal. If a female bows their hind leg, meaning their hock sets outside of the rest of the skeleton or makes the shape of a semi-circle, this is not ideal either.

Figure 41. Ideal rear view



1. Hip and Pins
2. Lower Leg
3. Width of Base

Summary of Structure

Sheep and goats with ideal front end structure should have some bend in their pastern, the neck tying high to the top of a smooth shoulder blade which represents nearly a 45-degree angle, the knee with some bend and squareness throughout when viewed on their front side. An ideal rear structure would include a level topline, out to the hip, the hind leg with some bend, and squareness throughout from behind.

Muscle and Width

Muscle Down the Top

Ewes and does should have ample muscling and width throughout. Muscling and dimension are identified down the top, the ribcage, and across the hip and leg muscle. Width is determined throughout the skeleton.

When studying muscle down the top, the evaluator should look for width and shape behind the shoulder blade, this is known as the rack. There should also be fullness or width to the loin. Essentially, a wider topped female would be more powerful, where a narrower topped female would have less muscling.

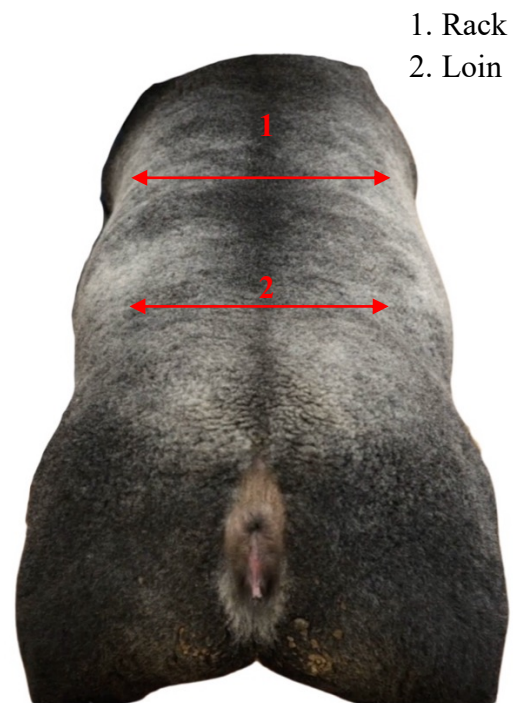
Rib Shape

Rib shape can be evaluated from above, where the judge can determine the outward turn of the ribcage. In Fig. 43, the sheep on the right displays a much more round, robust rib shape which allows for muscle and shape through her rack and loin. Whereas the ewe on the left in Fig. 43, does not have much shape or spread down her top. This is a product of there being no outward turn to her ribcage. Essentially, it is preferred if the sheep or goat has a ribcage the shape of barrel.

Figure 43. Examples of rib shape



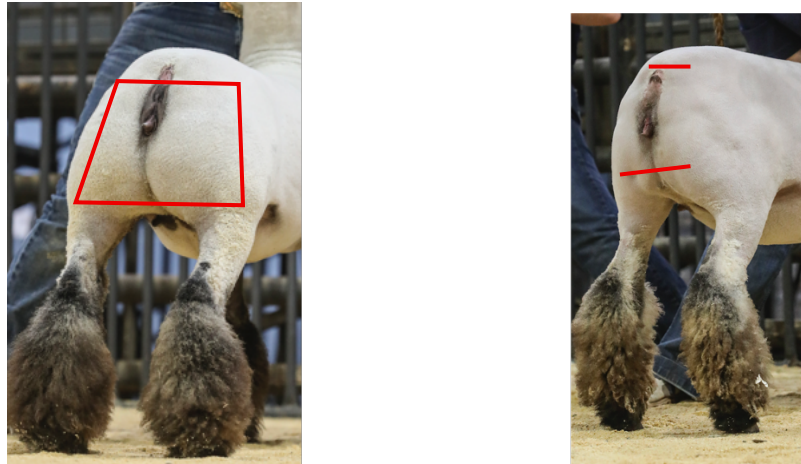
Figure 42. Example of appropriate top view



Rear View Muscle

At the rear view, muscle can be equated to how much mass, width, or dimension is seen through the pin set and the stifle, also termed the lower leg. The pin set should be wide and full like the sheep on the left in Figure 44. The stifle should be shapely and large, but the inside of the lower leg should also have ample expression and volume. Sheep lacking in muscle and width at the rear view, may look like the right picture from Fig. 44.

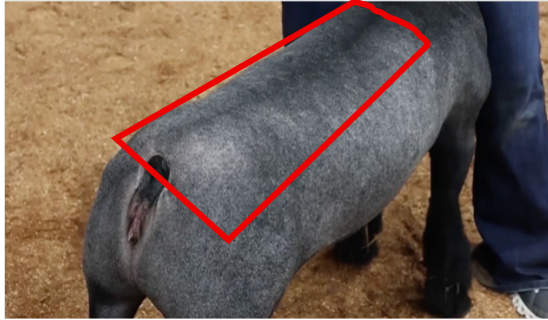
Figure 44. Examples of muscle at the rear view



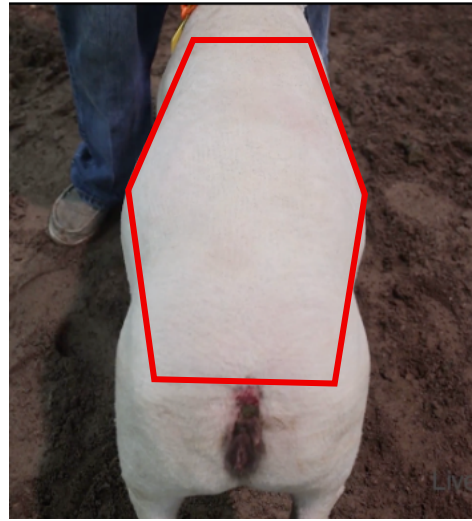
Progression of Width

Progression of width simply means that small ruminants should start square and have some width at the front of their skeleton and get wider the further you move to the rear end of their skeleton. This would mean the rear end of the sheep or goat would be the widest part of their skeleton. Picture A, Figure 45 shows the ideal progression of width, as the ewe starts with some squareness and width at the front of her skeleton and the widest part of her is her hip and hind end. Picture B, Figure 45 showcases where the body is much larger than the front end and the back end, this is not ideal progression of width. Picture C, Figure 45 shows an ewe who starts out narrow and continues narrow all the way back to her dock.

Figure 45. Examples of progression of width



Picture A – Ideal progression of width



Picture B – Not ideal



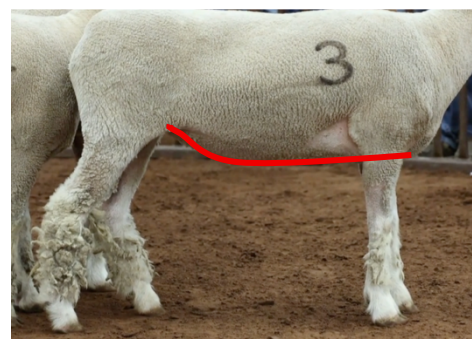
Picture C – No progression of width

Balance

Balance relates to an animal's ability to proportion. The front half of the body should match the back half in length and height to form an outline that looks symmetrical or even. This does not correlate to how attractive a sheep or doe is. Bone should also comparatively match the amount of dimension the female has. A thick, very dimensional female should have ample foot size and bone. A light dimensioned female with frail, small bones and feet would not be balanced.

An important area to look for balance is through the lower body, also called the underline in sheep and goats. Like the example on the left in Figure 46, the ewe or doe should be shallower in the depth of their chest, compared to their blade. That way, from chest back to the flank, the sheep or goat gets progressively deeper.

Figure 46. Examples of lower body balance



Eye Appeal

However, when talking about look, the front end should be neat and clean. For example, the doe on the left of Figure 47, has a clean, attractive neck which ties into the top of her shoulder and the front end should be tall and extended and comes back to a level topline.

Whereas the doe on the right of Figure 46, represents an ill-balanced and unattractive doe who has a thicker neck, weaker spine, and frailer bone work.

Figure 47. Examples of balance and eye-appeal



Market Goats & Lambs

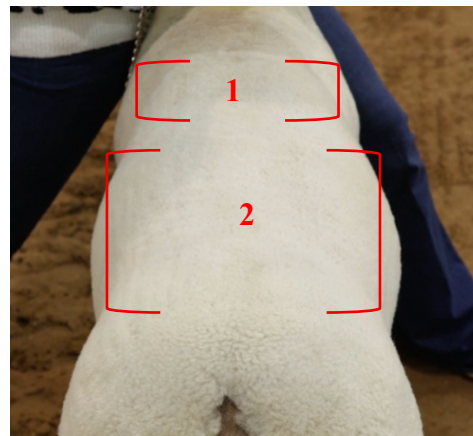
Market lambs and goats are those intended to be harvested for human consumption. While in general, the selection criteria between breeding and market sheep or goats are similar, the order in which you prioritize them differs because of the difference in their endpoint purpose. When evaluating market lambs or goats the priorities in which you should use (in order) are:

1. Composition – The amount of muscle and degree of finish (fat) on the animal.
2. Structure - How the animal's skeleton is constructed and how it moves.

Muscle

Muscle is the most important priority in selecting market goats or lambs. Muscle is indicated in the same locations as discussed in females, down the top and from behind. It is important to describe the major differences in muscle expression and total volume of muscle. Evaluators are often allowed to handle market animals down over their rack, loin, and ribcage.

Figure 48. Example of the muscle system from the top view



1. Rack
2. Loin

Handling Market Lambs or Goats

When handling market goats and lambs, one should position the hand on top of the rack to determine if there is a hard, square and upstanding shape to the muscle. To do this, the judge place the palm of the hand over the rack (Picture A, Figure 49) and should close their fingers to ensure there is no space between each finger, using slight pressure to touch the rack. From there, the judge's hand should glide back to the loin muscle where the loin edge should be wide and square (Picture B, Figure 49). At the loin edge, the evaluator should try to gauge how wide the loin is. Additionally, upon touching the hide, the hide should feel clean and tight, and not overly thick.

Figure 49. Example of where to handle market lambs



Picture A – Handle at the rack

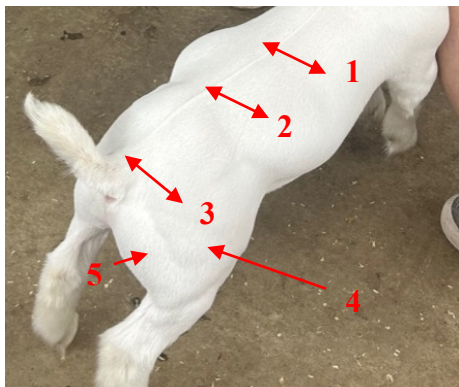


Picture B – Handle at the loin

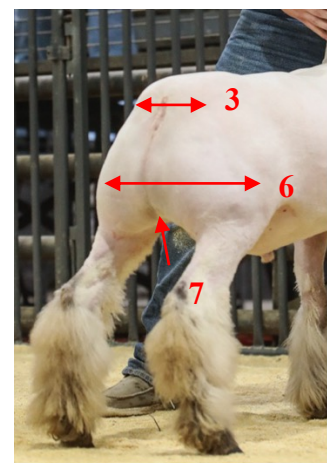
Rear View Muscle

At the rear view, muscle should primarily be evaluated through the hip/pinset and lower leg. The hip should be wide and full and the lower leg should be thick and dimensional but still be shapely like Picture A of Fig. 50. It should noticeably bulge outward. Additionally, the twist, the area where the lower leg muscles meet, known as the twist, should be deep, rather than shallow, shown in Picture B. The plane of the stifle, stifle to stifle, and across the lower leg are three terms which are explained by Picture B, point 6.

Figure 50. Locations to read rear view muscle



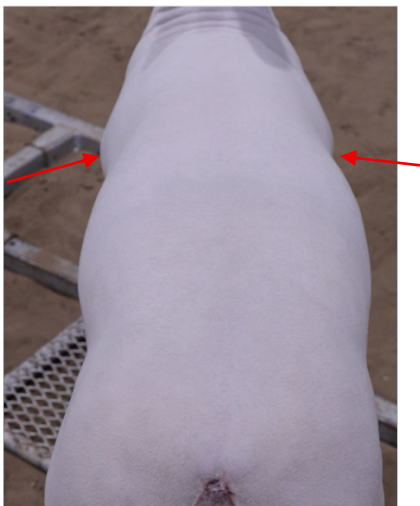
1. Rack
2. Loin
3. Hip/Pin set
4. Outside of lower leg
5. Inside of lower leg
6. Across the lower leg
7. Twist



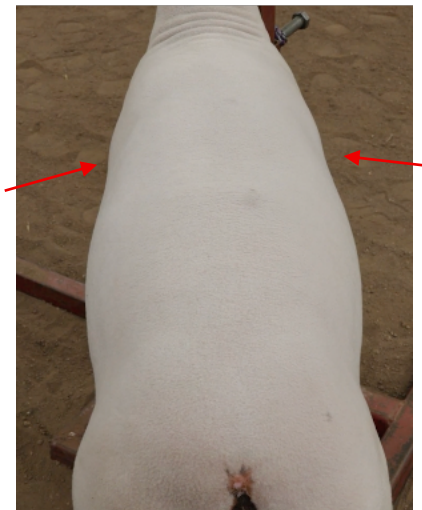
Leanness

Leanness is a term which relates to the amount of fat cover a market animal has or does not have. Specific fat cover requirements to be termed 'finished' or correct in their fat cover depends on the weight of the market animal. A fat thickness range of a .10 inch to .25 inch is generally acceptable. A judge can determine if a sheep is correct in their fat cover by handling over the forerib or by visually appraising if there is an indentation by the forerib. If upon handle the forerib feels overly smooth and plush like a marshmallow, then the wether is likely over conditioned and not optimal in their leanness.

Figure 51. Fat cover differences



Picture A – More ideal fat cover, slight indentation



Picture B – No indentation, over conditioned

Structural Correctness

Like breeding does or ewes, market wethers are evaluated in the same manner in terms of structure. Although market wethers are most often judged in a stationary rack, structure can require more diligence to evaluate correctly.

Evaluating Structure at the Profile

The neck should tie comfortable into shoulder blade, and the shoulder blade should approximately be 45 degrees. Below the shoulder, the knees should have slight bend and work down to a correct pastern setting. The spine should stay level when standing and when in motion and work back to a level hip and correctly set hind leg.

Figure 52. Structure at the profile



Picture A – Nice structured from the side

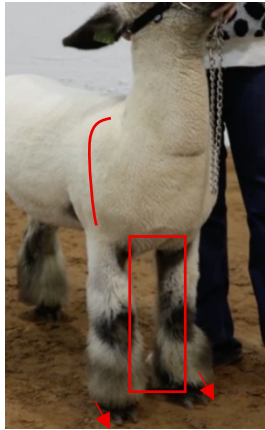


Picture B – Ill-structured from the side

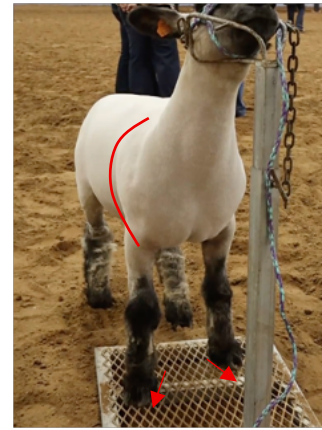
Chest/Front View Structure

At the front view, a market goat or lamb should be square and look powerful, without sacrificing their structural integrity. Ideally, a market lamb would have a smooth shoulder, square chest, and square front feet like Picture A, Figure 53.

Figure 53. Structure differences through the front end



Picture A – Smooth shoulder and square chest to ground

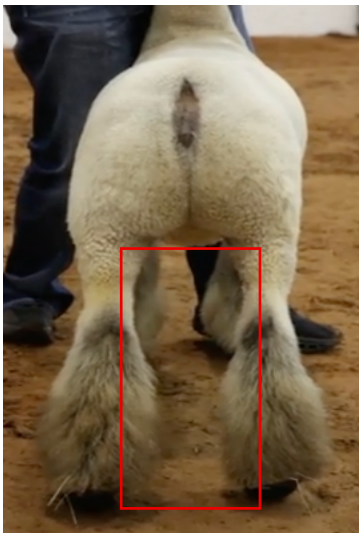


Picture B – Coarse shoulder and toes out at the ground

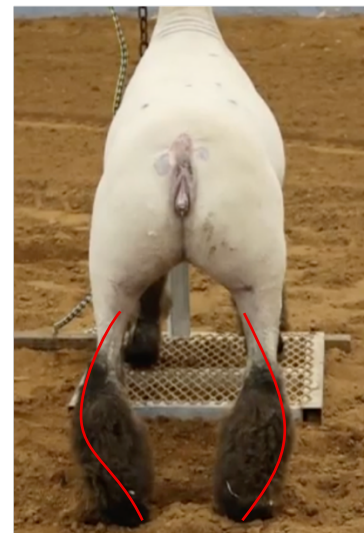
Rear View

At the rear view, the judge should have preference for a square hock and square rear feet like Picture A, Fig. 54. A common structural issue viewed from behind is a bow leg or when the hock sits outside the rest of the sheep's skeleton.

Figure 54. Structure differences from behind



Picture A – Ideal rear view



Picture B – Bow legged

Balance

As discussed, balance is a term used to describe how well each part of the animal fits together. This is not one of the most important traits and if pairs within market lamb classes are close on muscle, leanness, and structure balance can be emphasized. Balance includes how well a market goat or lambs front end, body, and rear end match in length. Furthermore, heavy muscled wethers should have adequate bone and foot size like the wether in Picture A, Figure 55. Whereas a light muscled wether's bone and muscle should match his volume and mass. As discussed in the breeding section, lower body balance is one of the biggest components to overall balance in small ruminants.

Figure 55. Examples of balance and proportion



Picture A – Acceptable balance and proportion



Picture B – Ill-balanced and not proportional

Competitive Livestock Judging

Overview

Competitive livestock judging is one of the most rewarding contests for young agriculturalists to be involved with. The objective of this section is to provide tips to better a young evaluator for contests success. Furthermore, it covers the benefits of livestock judging, note taking advice, outlines steps to be successful at oral reasons, and explains standard contest scoring and logistics.

Contest Logistics

A traditional livestock judging contest at the collegiate level consists of 12 placing classes and 8 sets of oral reasons. For 4-H, FFA and other youth competitions, the number of placing classes is generally the same; however, there are often fewer sets of oral reasons. In general, the steps of a livestock judging contest are as follows:

“The Floor”

- a. This is where you’ll place the 12 classes of livestock and turn a card in with your placing for each one – make sure the card is filled out properly!
- b. Typically, you will have 12 to 15 minutes per class to evaluate the animals and make your placing.
- c. The classes which are designated as oral reasons should be communicated to you before the contest begins. Make sure to take notes on these classes throughout the day!
- d. Before the contest has officially started, contest coordinators will separate participants into several groups to allow each participant as much room and separation from others as allowed.
- e. The participant should stay with the group they start with the entire time duration of the placings portion.
- f. If students are turning in placing cards, they should turn in their placing cards to the group leader who is with their class at the time of judging.

- g. This portion of the contest normally finishes up mid-day depending on the number of classes and time allotted to judge each class.

Reasons

- h. After contestants have placed all 12 classes, the oral reasons division begins.
- i. You will give a set of oral reasons on all classes that were designated as reasons classes to explain to the judge why you placed the class how you did (see the reasons section of this guide for more information).
- j. Immediately after turning in the last card for the placings portion, students are generally placed in rows and assigned an order for which oral reasons class to give first. This will traditionally include participants sitting down in chairs, in the order outlined by contest coordinators. Then coordinators will instruct participants which order the oral reasons will be given for the reasons group.
- k. Students will give one set of oral reasons and are generally only allowed to stand up or be walking around when they are one of the next 3 individuals to give their set of reasons.
- l. Once the participant concludes their final set of oral reasons, the student will be allowed to find their parent, coach, and teammates who are also concluded with the contest. At the conclusion of the contest, official placings will be released, and participants may learn what officials placed classes.

Materials Needed & General Rules

A contestant should carry with them placing cards or the scantron which was handed out by those running the contest, a notebook or a spiral steno pad, and pencils. The contestant should be mindful of contest rules and remember to leave electronic devices turned off, put away, or left out of reach for the entire duration of the contest. Additionally, contestants should be reminded that talking to other contestants or teammates during a contest is not allowed and looked down upon. Livestock judges are to test their own knowledge and not rely on others. If contestants have questions or emergencies, they should be directed to contest coordinators.

Livestock Classes

What is a Class?

Livestock classes consist of four animals. In market classes, animals can be various breeds and sometimes will be male and female. However, in breeding classes, the four animals are the same sex and frequently the same breed. Animals will be clearly marked or denoted with a number. If the animals are shown, typically the animals are numbered left to right, 1-4 or the showman will wear a harness with the number on the harness. Classes are also numbered for clarity, starting with one and ending with the total number of classes in the contest. A contestant must make sure they clearly understand which animal is which number before turning in their placing card.

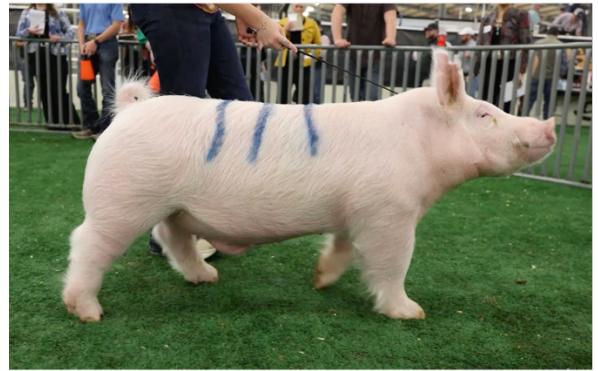
Approach to Placing a Class

As the contestants approach a class, they should keep their back turned to the class until it is announced the time to judge the class has started. While waiting for the class to begin, the contestant should note what the class number and name is, and make sure if the contest uses placing cards, the card is clearly marked with the class name and number.

Once the contestants are allowed to begin judging, the contestants should start by:
Observe each animal from the front, side, and rear

1. Identify the good and bad of each animal compared to the ideal
2. Big differences place the class, finalize a placing
3. Record the differences in notes or mentally notate
4. If an animal combines each aspect like the ideal animal of their specie, they should not be ranked towards the bottom.

Figure 56. Examples of number identification



Turning in a Placing Card

After taking note of how each animal compares to the ideal:

1. Contestant may begin comparing each animal to the other animals in the class to further come to a ranking.
2. The judge may come to a final placing
3. Clearly mark in notebook your final placing and on the placing card or scantron under the right class number and name

Figure 57. Example of note taking

Note Taking

Before preparing oral reasons, an evaluator should take notes at the class. Note taking is done to help the competitor remember the class and remember the important details which will be used in formulating a set of oral reasons. Note taking should be personalized to best accommodate the individual's ability to outline details of importance. It is recommended a contestant should take notes on the good, the bad, and unique identifications of each animal. Figure 56 is an example of a competitor should set up their notebook or steno to properly take notes over a class. Additionally, the student should write down in their notes section if the class is to be placed and have oral reasons over it or strictly just placing.

Class Name: 1 - Breeding Gilts	Placing: 1-2-3-4
#1 – Good Traits #1 – Bad Traits #1 – Identification's (ID's)	
#2 – Good Traits #2 – Bad Traits #2 – Identification's (ID's)	
#3 – Good Traits #3 – Bad Traits #3 – Identification's (ID's)	
#4 – Good Traits #4 – Bad Traits #4 – Identification's (ID's)	

Oral Reasons

What are Oral Reasons?

Oral reasons are a spoken explanation of why you placed a class in a particular order. Essentially, they serve as a defense of your reasoning for the placement. Oral reasons are primarily evaluated based on the accuracy of the information presented, the format of the explanation, and the clarity, engagement, and volume of the delivery.

Accuracy

Accuracy in oral reasons refers to a contestant's ability to describe livestock as precisely as possible in the same manner as the reasons taker, the person contestants deliver reasons to, would describe the livestock. Accuracy is most important in obtaining a high reasons score. While a correct or nearly correct placing naturally leads to a more accurate set of reasons, contestants should focus on clearly communicating their observations of the class, including both the strengths and weaknesses of each animal.

Beginners may find it tempting to rely on pre-written reasons; however, this practice is discouraged. Pre-written reasons often lead to significant accuracy issues, resulting in lower scores. For example, if a reasons taker, thought the class winner in the market hogs was the most muscular, but the contestant inaccurately states in their oral reasons the second-place market hog was the most muscular, this would be an inaccurate statement which leads to a lower reasons score.

Format

The format of oral reasons refers to the contestant's ability to present information in an organized manner that clearly conveys their evaluation. The recommended format is known as the 9-box format, which is widely accepted and expected by most reasons takers. This system helps contestants structure their reasoning effectively while also making it easier for the reasons taker to follow their thought process.

The 9-box system begins with an opening statement. The opening statement should include the name of the class and your placing. The next sentence should include why the first-place animal in the ranking won the class.

The first box of the format details why the contestant placed the first animal over the second-place animal. The second box, known as the grant box, highlights the strengths of the

second-place animal in comparison to the first. The third box, called the criticism box, outlines the weaknesses of the second-place animal. These three boxes form the top pair of reasons. At the conclusion of oral reasons, it is common practice to say “Thank you” to the official listening to your reasons. This is a respectful and easy way to end your reasons.

This structure repeats in the middle pair, where the fourth box explains why the second-place animal was ranked above the third. The fifth box provides a grant for the third-place animal, followed by the sixth box, which is a criticism of the third-place animal. The bottom pair follows the same pattern, with the seventh box explaining the ranking of the third-place animal over the fourth, the eighth box offering a grant for the fourth-place animal, and the ninth box listing its weaknesses. By following the 9-box system, contestants ensure their oral reasons are structured, clear, and easy for the reasons taker to follow, ultimately improving their scores and communication skills.

Figure 58. Ideal Format with description of each box for notes

Class Name:		Placing:
Opening Statement: This is where the contestant will say the class name, class placing, and give an overview of the most important traits of why the class winner won or if the top pair was close, this could also be said here.		
☐ Describe the good traits which allows 1 to beat 2.	☐ Describe 2's direct advantages back over 1. This is called the grant box of the top pair.	☐ Describe 2s faults and your reasoning for placing 2 second in terms of negative traits.
☐ State the placing of the middle pair. Then describe the good traits which allows 2 to beat 3.	☐ Describe 3's direct advantages back over 2. This is called the grant box of the middle pair.	☐ Describe 3s faults and your reasoning for placing 3 third in terms of negative traits.
☐ State the placing of the bottom pair. Then describe the good traits which allows 3 to beat 4.	☐ Describe 4's direct advantages back over 3. This is called the grant box of the bottom pair.	☐ Describe 4s faults and your reasoning for placing 4 fourth in terms of negative traits.

Top Pair

Middle Pair

Bottom Pair

Figure 59. Example oral reasons with format in notes

Class Name: 1 - Breeding Gilts		Placing: 1-2-3-4	
Opening Statement: I like the breeding gilts 1-2-3-4. 1 best combines structural correctness, depth of body, and width.			
1/2 When compared to 2, my class winner is specifically wider through her chest and plants at the ground with more correct pastern and toe spread and drives away more flexible.	2/1 Sure, 2 is more attractive about her front end, being cleaner and longer through neck.	2 However, she is narrow through her skeleton and not as comfortable in her build.	
2/3 Still, in my middle pair I liked 2 over 3. 2 is taller fronted, longer bodied, and deeper middled.	3/2 No doubt, 3 is the stoutest in her bone work,	3 but unfortunately, she never came with the same look of quality or power to compete with my top pair.	
3/4 Nonetheless, in my bottom pair I kept 3 over 4. As 3 is still more correct in her skeleton being laid back more comfortably in her blade and correct in her hind leg.	4/3 For what it's worth, 4 is the biggest outlined and the longest bodied.	4 That doesn't mean much when she is the straightest made, shallowest bodied, and worst kind. She's 4th.	

Presentation

Oral reasons should be given without use of looking at a notebook and should be smoothly presented with as few stutters or overly long pauses as possible. Reasons should be presented in a conversational, but respectful manner. The reasons giver should stand straight up, with their hands behind their back or placed an area where they will not be distracting.

Oral Reasons Example

Market Hogs

I like cross barrows 2341. I love when barrows are powerful, but excel in their skeleton like 2. Not only does he drive at me big and square and carries his power back to a big hip, but where he's truly uncontested is skeletal build. He's even and square in his toe spread, allowing him to drive the most comfortable and coordinated. Now, he could be a bit more competitive with aspects of 3. I love how rugged the other high presented barrow is. Plus, he works such a deep groove from blade to tail root, even though that's why I initially wanted to label him as a power option, I just can't. He's too flat ribbed and closed-up underneath. When he's uneven in his rear toes causing him to pull his hock in, I'll leave him 2nd.

In middle, I see where they both could be modified in their rear skeleton, but feature, look, and proportion give 3 the edge over 4. No doubt, 4 comes at me broader at the base of his chest, allowing him to be a bit bolder in his forerib, but the barrow who toes in upfront and gets thicker necked, hit me more ordinary and when he pushes his hock and gets more awkward going away from me, I'll leave him to bottom pair.

But between the like notched barrows, it's the -5 thin belts powerful opened up kind that beat 1. Catch the black headed barrow going away, and his hind leg is more secure and correct than the pair ahead of him, but the plain shaped barrow never hit me with the design or power to contend.

Scoring

Contests that involve both placings and oral reasons are scored using the same set of scoring principles. Each placings class is worth 50 points, and each set of oral reasons is also worth 50 points. For instance, in a contest with 8 placings classes, each worth 50 points, the total possible score for placings would be 400 points. If the contest includes 3 sets of oral reasons, each worth 50 points, the highest possible score for reasons would be 150 points. This would give an overall maximum possible score of 550 points.

Benefits of Competitive Livestock Judging

Competitive livestock judging offers a wealth of benefits that enhance both interpersonal and intrapersonal skills, providing participants with valuable learning experiences that extend beyond the contest itself. Placing four animals in a class requires individuals to make quick and well-reasoned decisions, which in turn improves their ability to think critically and assess multiple factors in each situation. This process fosters the development of strong decision-making skills that are applicable in various contexts throughout life.

Additionally, the oral reasons portion of livestock judging contests plays a crucial role in honing a participant's ability to communicate clearly and persuasively. Articulating the rationale behind their placings helps individuals refine their public speaking and presentation skills, encouraging them to convey complex thoughts in a concise, structured manner. This form of communication is invaluable in both professional and personal settings, as it teaches the importance of listening, reasoning, and expressing oneself confidently.

Moreover, livestock judging provides participants with an in-depth education about the livestock industry. They gain insight into animal selection, breeding, and management practices, deepening their understanding of animal science and the economic factors that influence the industry. This knowledge can lead to a greater appreciation of the work that goes into food production and animal care, as well as an increased sense of responsibility toward sustainable practices.

Ultimately, the skills acquired through livestock judging extend far beyond the arena of competition. They promote personal growth, improve critical thinking, and provide a foundation for future success in various career paths. Whether in agriculture or any other field, the lessons

learned through livestock judging can be applied to a wide range of life situations, making it a valuable educational experience.

Conclusion

Livestock evaluation is one of the most subjective youth-based activities. As a result, winning can often seem unattainable. However, competitors who utilize specie priorities to guide their placing decisions will be successful on the floor. Those who aren't afraid to speak their opinion and use accurate, clearly communicated oral reasonings in livestock judging will find success in reasons.

Chapter 2 - Effects of dietary crude protein and zinc level on nursery pig growth performance and fecal dry matter

Abstract

A total of 360 weanling pigs (DNA 241 × 600; 5.44 ± 0.03 kg BW) were used to investigate the effects of feeding varying levels of dietary CP with or without pharmacological Zn from ZnO on nursery pig growth performance, fecal dry matter, and circulating Zn in a 42-d growth trial. Pigs were balanced for sex, stratified by weight, and assigned to one of six treatments in a randomized complete block design with five pigs per pen and 12 pens per treatment. Treatments were arranged as a 3×2 factorial with diet crude protein (CP; low, medium, high) and Zn level (110 or 3,000 mg/kg) as main effects. Dietary CP levels were 20.5, 22, and 23.5% in phase 1 (d 0 to 10) and 20, 21.5, and 23% in phase 2 (d 10 to 25) for low, medium, and high diets, respectively. All basal diets contained 110 mg/kg Zn from ZnSO₄; ZnO was added to reach 3,000 mg/kg where applicable. A common diet was fed from d 25 to 42. Growth performance was measured every 7 d. During phase 1, a quadratic CP × Zn interaction was observed for G:F ($P = 0.035$), where numerically pigs fed the medium CP diet had the best G:F in the basal Zn diet but the poorest G:F in the 3,000 mg/kg Zn. Increasing CP linearly decreased ADG and ADFI ($P \leq 0.047$). In phase 2, increasing CP tended to decrease ADFI ($P = 0.063$) while G:F quadratically improved ($P = 0.005$). Pharmacological Zn increased ADG and ADFI ($P \leq 0.034$). During the experimental period (d 0 to 25), increasing CP decreased ADFI (linear, $P = 0.011$) and tended to reduce ADG (linear, $P = 0.100$) and tended to improve G:F (quadratic, $P = 0.052$). Pigs fed pharmacological Zn had increased ADG, ADFI, and G:F ($P \leq 0.002$). During the common phase (d 25 to 42), pigs previously fed medium CP had the lowest ADG (quadratic, $P = 0.018$) compared to the pigs fed the low and high CP diets and increasing

prior CP worsened G:F (linear, $P \leq 0.051$). Pigs previously fed pharmacological Zn tended to reduce ADG ($P = 0.052$). Overall (d 0 to 42), pigs fed increasing CP had a decrease in ADG and ADFI (quadratic, $P \leq 0.098$) with no effect on G:F. Pharmacological Zn tended to increase overall ADG ($P = 0.066$). For fecal DM, a Zn $\times$ day interaction was observed ($P = 0.015$), where fecal DM for pigs fed basal Zn level improved from d 10 to 25, but remained similar for pigs fed pharmacological Zn. Pigs fed 3,000 mg/kg Zn had higher fecal DM on d 10 and 25 ($P \leq 0.024$) than pigs fed the basal Zn level. Plasma Zn was greater on d 10 and 25 ($P < 0.0001$) for pigs fed 3,000 mg/kg Zn. In summary, CP $\times$ Zn interactions were limited; thus, the main effects of each feeding strategy were independent. Pigs fed higher CP reduced early nursery intake and gain, whereas pharmacological Zn improved performance and fecal DM consistently during the treatment period, but limited significant effects overall.

Introduction

Weaning stress driven by dietary, environmental, and management changes can be the onset for poor growth performance and increased incidence of post-weaning diarrhea (PWD) in nursery pigs (Zheng et al., 2021). Several feeding strategies have been utilized to mitigate the effects of PWD, with varying degrees of efficacy.

Historically, antibiotics have been used to mitigate the effects of PWD (Canibe et al., 2022), but antimicrobial resistance in human pathogens has been considered a global human health challenge (Barton, 2014). While the major culprit of antimicrobial resistance in humans has been human medicine, antibiotic use in animals is still thought to be a contributor (Barton, 2014). Considering concerns and the need for non-antibiotic options, many alternative nutrition and management practices have been explored.

Zinc oxide (ZnO), fed at pharmacological levels (2,000 – 3,000 mg/kg of the diet) is a common practice in the United States in post-weaning diets to reduce PWD and enhance growth performance (Hill et al., 2001). However, scrutiny has been placed on the continued use of pharmacological levels of Zn from ZnO as a substantial proportion of consumed Zn is excreted in feces (Jondreville et al., 2003). Subsequently, manure from pigs fed high dietary Zn levels when applied as fertilizer can lead to increased accumulation of soil Zn (Gourlez et al., 2024). Thus, other practices need to be investigated to reduce future reliance on high Zn levels in nursery diets.

Since piglets have low feed intake immediately post-weaning, a higher crude protein (CP) diet (20 to 23%) can be fed to meet the requirement for protein deposition, but high CP diets can result in more nitrogen and undigested protein reaching the large intestine (Connolly et al., 2024). This substrate contributes to the proliferation of harmful bacteria that can lead to PWD (Gloaguen et al., 2014; Connolly et al., 2024). Therefore, another strategy used to mitigate PWD is to lower the CP level of the diet post-weaning. However, lowering CP levels can negatively affect growth performance (Connolly et al., 2024). Nutritional strategies must balance limiting excess dietary nitrogen that contributes to PWD while still supplying adequate amino acids to support growth performance (Gloaguen et al., 2014). Since pharmacological levels of Zn from ZnO improve growth and fecal DM post-weaning, it has been hypothesized that the amount of nitrogen in the hindgut may influence the efficacy of Zn. Currently, limited information exists regarding the interaction between dietary CP and pharmacological Zn levels. Previous research evaluating CP and ZnO's relationship in nursery diets has more frequently reported interactions for fecal DM or fecal scores, rather than growth performance outcomes. For example, Rattigan et al. (2020) and Hutchens et al. (2021) found no significant interactions between diet CP and ZnO

on ADG, ADFI, or G:F, but Rattigan et al. (2020) did observe an interaction between CP and ZnO on fecal DM. The minimal and variable data available in this area prompts the need for further research in the area of CP and ZnO interactions, especially as genetics continue to change. Thus, the objective of this study was to investigate the effects of feeding varying levels of dietary CP with or without pharmacological Zn from ZnO on nursery pig growth performance, fecal dry matter, and circulating Zn.

Materials and Methods

Experimental procedures followed the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2012) and were approved by the Kansas State University Institutional Animal Care and Use Committee (IACUC #4942). The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, Kansas.

Animals and Diets

A total of 360 pigs (DNA 241 × 600; initially 5.44 ± 0.03 kg BW) were used in a 42-day growth trial. Pigs were weaned at approximately 20 d of age, individually weighed, balanced for sex, and stratified into three weight blocks (light, medium and heavy). Pigs were then randomized to pens with five pigs per pen (either 3 gilts and 2 barrows, or 2 gilts and 3 barrows). Pens were allotted to one of six dietary treatments in a generalized randomized block design to provide twelve replicate pens per treatment. Each pen had tri-bar floors (1.5×1.5 m) and was equipped with a 4-hole dry self-feeder and nipple waterer to supply *ad libitum* access to feed and water.

Dietary treatments were arranged in a 3×2 factorial design with factors of crude protein level (low, medium, high) and Zn level (110 or 3,000 mg/kg). Crude protein levels were low (20.5% phase 1; 20% phase 2), medium (22% phase 1; 21.5% phase 2), and high (23.5% phase 1; 23% phase 2). All basal diets contained 110 mg/kg Zn from ZnSO₄; ZnO (72% Zn) was added to reach 3,000 mg/kg where applicable. Diets were formulated and manufactured in three dietary phases (phase 1 = d 0 to d 10; phase 2 = d 10 to d 25; phase 3 = d 25 to d 42) such that experimental diets were fed from d 0 to 25, and a common diet was fed to all pigs from d 25 to 42. Treatment diets were fed in pellet form in phase 1 and mash form in phases 2 and 3. All diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center.

Chemical Analysis

Representative diet samples were obtained from each treatment and stored at -20 °C until analysis and composite samples were submitted to Midwest Labs (Omaha, NE). Assays included dry matter (DM; method 930.15; AOAC, 2023), crude protein (CP; 990.03; AOAC, 2023), fat (method 2003.05; AOAC, 2023), acid detergent fiber (ADF; ANKOM Tech. Method), and Zn (method 985.01; AOAC, 2023).

Fecal Dry Matter

Fecal samples were collected from 3 randomly selected pigs per pen on d 10 and 25 for analysis of fecal DM. Briefly, a sterile, cotton-tipped applicator was gently inserted into the rectum to stimulate defecation. Samples were pooled on a per pen basis to form one composite sample for each collection point and stored at -20° C until analysis. To determine fecal DM,

samples were dried for 48 h at 55° C in a forced air oven and the ratio of dried-to-wet fecal weight determined the percentage fecal dry matter.

Plasma Zinc Analysis

Blood samples were collected from the middle BW pig in each pen on days 0, 10, and 25 ($n = 12$ pigs/treatment, 72 total). The same pigs sampled on day 0 were re-sampled on days 10 and 25. Samples were collected via jugular venipuncture using a 9 mL lithium heparin collection tube (Fisher Scientific, Hampton, NH) and immediately placed on ice and transported for serum separation. Samples were centrifuged at $1,800 \times g$ for 30 minutes at 4 °C. Plasma was then transferred to a 5 mL polypropylene conical tube using a disposable transfer pipette and then stored at –80 °C until analysis. On the day of analysis, samples were thawed at 37 °C in a bead bath for two hours. Then, the samples were centrifuged at $1,800 \times g$ for 30 minutes at 4 °C. After which, 1.5 mL of plasma was combined with 6 mL of 0.5 M nitric acid in a 10 mL polypropylene conical tube. Samples were then vortexed with a multi-tube vortex mixer and centrifuged at $1,800 \times g$ for 30 minutes at 4 °C. The supernatant was transferred to a new 10 mL polypropylene conical tube using a disposable transfer pipette. Samples were analyzed in duplicate using inductively coupled plasma optical emission spectrometry (ICP-OES model 5,800, Agilent Technologies, Santa Clara, CA) at the K-State Research and Extension Soil Testing Laboratory (Sposito et al., 1982).

Statistical Analysis

Experimental data were analyzed using the lme4 package of R (Version 4.0.0, R Foundation for Statistical Computing, Vienna, Austria) with pen serving as the experimental

unit. The analysis accounted for BW block and dietary treatment as fixed effects. Pre-planned contrasts were performed to evaluate the statistical significance of the main effects of CP and ZnO, and their interaction on growth performance, fecal DM and plasma Zn. For fecal dry matter, in addition to the previously mentioned variables, the model incorporated the day as a fixed effect and the pen as a random effect to account for the subsampling associated with multiple fecal samples collected and analyzed from each pen. Model assumptions were evaluated using visual assessment of studentized residuals and plasma Zn data were log-transformed prior to analysis. Plasma Zn data were analyzed as a completely generalized randomized block design with individual pig as the experimental unit. The model included dietary treatment, day, and their interaction. Significance was set at $P < 0.05$, and tendencies were considered at $0.05 \leq P \leq 0.10$.

Results

Growth Performance

Growth performance data are presented in Table 4 and Table 5. During phase 1 (d 0 to 10), there was a quadratic CP $\times$ Zn interaction ($P = 0.035$; Table 4) where numerically pigs fed the medium CP diet had the best G:F in the basal Zn diet but the poorest G:F in the 3,000 mg/kg Zn. There were no other CP $\times$ Zn interactions observed during phase 1 or the remainder of the trial ($P > 0.10$).

During phase 1, increasing CP resulted in a linear decrease in ADG ($P \leq 0.047$; Table 5) and ADFI ($P \leq 0.009$; Table 5), but there was no evidence of a difference in G:F ($P \geq 0.375$).

For the main effect of added Zn in phase 1, pigs fed 3,000 mg/kg added Zn diets resulted in improved ADG, ADFI, and G:F ($P \leq 0.001$). On d 0, there were no differences observed in body weight ($P \geq 0.05$). However, at d 10, there was a significant difference in BW ($P \leq 0.001$),

whereas pigs fed 3,000 mg/kg added Zn diets resulted in higher body weights than pigs fed diets containing 110 mg/kg added Zn. In phase 2 (d 10 to 25), increasing CP resulted in a tendency for a linear reduction in ADFI ($P = 0.063$) and G:F was poorest for the medium CP treatment (quadratic, $P = 0.005$), but there was no evidence of a difference in ADG based on CP level ($P \geq 0.367$). Pigs fed a diet containing pharmacological levels of Zn had increased ($P \leq 0.034$) ADG and ADFI ($P = 0.026$) compared to pigs fed a diet without pharmacological Zn, with no effect on G:F ($P = 0.93$). Thus, for the experimental period (d 0 to 25), as the dietary CP level increased, there was a linear decrease in ($P = 0.011$) ADFI, a tendency (linear, $P = 0.100$) for reduced ADG, and a tendency (quadratic, $P = 0.052$) for the medium CP treatment to have the poorest G:F. Pigs fed pharmacological levels of Zn had greater ADG ($P \leq 0.001$), ADFI ($P \leq 0.001$), and improved G:F ($P \leq 0.002$).

During the common phase (d 25 to 42), pigs previously fed the medium CP level had the lowest (quadratic, $P = 0.018$) ADG, and increasing the CP level worsened G:F (linear, $P = 0.045$; quadratic, $P = 0.051$). Pigs previously fed pharmacological Zn tended ($P = 0.052$) to have lower ADG, with no evidence of a difference for ADFI or G:F.

For the overall trial (d 0 to 42), pigs fed the medium CP diets tended (quadratic, $P \leq 0.098$) to have the lowest ADG and ADFI. There was no evidence of a difference ($P \geq 0.254$) for G:F based on CP level. This suggests that the medium CP diet did not support optimal growth performance throughout the nursery period of this trial. Pigs fed pharmacological levels of Zn tended ($P = 0.066$) to have greater overall ADG, with no evidence of a difference for ADFI ($P \geq 0.346$) or G:F ($P \geq 0.242$).

Fecal Dry Matter

Fecal DM data are presented in tables 4 and 5. There was no evidence of a CP $\times$ ZnO interaction ($P \geq 0.173$; Table 4) on fecal DM on d 10 or 25. Fecal DM was not significantly impacted by CP at either collection ($P \geq 0.222$).

There was no evidence of a CP $\times$ Zn $\times$ day interaction ($P \geq 0.209$) or CP $\times$ day interaction ($P \geq 0.498$) for fecal DM. A Zn $\times$ day interaction was observed ($P = 0.015$) for fecal DM, where pharmacological Zn increased fecal DM on d 10 ($P < 0.001$) and d 25 ($P = 0.024$), but the magnitude of improvement was greater on d 10.

Plasma Zn Concentration

Concentrations of plasma Zn were impacted by a Zn $\times$ day interaction. On d 0, there was no evidence of difference in plasma Zn concentrations ($P = 0.416$). However, on d 10 and d 25, pigs fed pharmacological Zn diets had a greater concentration of plasma Zn ($P < 0.0001$). There was no evidence of a Zn $\times$ CP $\times$ day interaction ($P = 0.196$).

Discussion

There are many stressors that can potentially induce PWD in nursery pigs (Zheng et al., 2021) and there are several feeding strategies which have been used to mitigate the detrimental effects of PWD, but feeding strategies have different efficacies. Antibiotics, acidifiers, peptides, medium-chain fatty acids, and most notably pharmacological levels of Zn have all been used as mitigation techniques, but each has its own limitation (Thacker, 2013). Since scrutiny has been placed on the continued use of pharmacological ZnO and has led to regulations on ZnO feeding in places like the European Union, the aim of the current study was to evaluate a potential feeding strategy that would yield a similar response to ZnO.

Reducing the CP of the diet is a potential practice that has been studied. Soon after weaning, piglets have low voluntary feed intake; thus, feeding a higher CP diet that contains higher amino acid levels is a strategy that can be used to meet the needs for protein deposition. However, high CP diets can result in extra nitrogen and undigested protein entering the large intestine which may induce PWD and the proliferation of pathogenic bacteria (Connolly et al., 2024). Although low CP diets can mitigate PWD by limiting additional undigested protein, growth performance is negatively impacted as amino acid concentrations are generally lowered to achieve a reduced CP diet. Nutritional strategies must balance limiting excess dietary nitrogen that contributes to PWD while still supplying adequate amino acids to support growth performance (Gloaguen et al., 2014).

The present study resulted in a limited number of interactions between CP and Zn on growth performance which is consistent with findings from Hutchens et al. (2021). Previous research evaluating CP and ZnO's relationship in nursery diets has more frequently reported interactions for fecal DM or fecal scores, rather than growth performance outcomes. For example, Rattigan et al. (2020) found no significant interactions between diet CP and ZnO on growth ADG, ADFI, or G:F, but did report an interaction between CP and ZnO on fecal DM. However, the only interaction reported in this study for fecal DM was a Zn $\times$ day interaction, suggesting in this study CP and ZnO acted independently of each other.

The linear reduction in ADG during phase 1 with increasing diet CP was driven by a decrease in feed intake, feed efficiency was not affected. During the experimental diet period of the present study, when CP level increased, there was a linear decrease in ADFI, a tendency for reduced ADG, and a tendency for the medium CP treatment to have the poorest G:F. Le Bellego and Noblet (2002) reported that a high CP diet (22.4%) resulted in the lowest ADFI and

numerically the lowest ADG when compared to three lower CP (20.4%, 18.4%, and 16.9%) diets. Le Bellego and Noblet's (2002) 22.4% CP diet had a higher soybean meal inclusion to achieve protein deposition, whereas the lower CP diets had altered synthetic AAs. They deducted differences in feed intake and gain were likely due to amino acid imbalances in their study. Also, Li and Patience (2017) reported high protein diets that jeopardize ADFI could be from imbalances amongst the large neutral amino acids (leucine, isoleucine, valine, phenylalanine, and tyrosine). However, in our study, diets were generally balanced for essential amino acids when practical, and no noticeable imbalances were present in amino acid ratios across the different CP diets. However, in the present study, as the level of diet CP increased, the level of soybean meal increased.

During the common phase, pigs previously fed the medium CP level had the lowest ADG, and increasing the CP level worsened G:F. For the overall trial period, pigs fed the medium CP diets tended to have the lowest ADG and ADFI, driven mainly by the numerical increase for pigs fed the lowest diet CP. There was no evidence of a difference for G:F based on diet CP level. These data indicate that the improvement in growth observed post-weaning in pigs fed the lowest-protein diet maintained this advantage to the end of the nursery period.

Previous research on the impact of nursery diet CP on fecal DM has shown improvements when a lower CP diet is fed. For example, Marchetti et al. (2023) found that a low CP (15.5% CP) diet resulted in less diarrhea than piglets fed a high CP (17.5% CP) diet. However, Correia et al. (2023) observed no differences in fecal DM between high and low CP diets which is similar to our findings. Heo et al. (2009) observed low crude protein diets (17.5%, 21.3%) fortified with additional crystalline Ile and Val increased fecal DM in *E. coli* challenged piglets when compared to a higher (25.6%) CP diet without sacrificing growth. Kim et al. (2023)

observed when decreasing the nursery dietary CP level from 21% to 16% while maintaining consistent ratios for essential amino acids, such as lysine, methionine, threonine and tryptophan, there was reduced incidence of diarrhea. The reasons for the lack of improvement in fecal DM are unclear, but pigs fed the high CP diet had lower ADFI which has been shown to improve fecal DM (Engelsmann et al., 2023). These factors could be offsetting where we did not find a change in fecal DM in our study.

The responses to pharmacological Zn in the present study are generally consistent and well documented during the post-weaning period (Carlson et al., 1999; Hill et al., 2001). The reduced impact of ZnO in phase 2 aligns with previous research indicating ZnO's impact is most pronounced in the early post-weaning period and becomes less as piglets' intestinal function further develops (Luise et al., 2024).

Additionally, in the common phase of the present experiment, pigs previously fed pharmacological Zn tended to have lower ADG, with no evidence of a difference for ADFI or G:F. Poulsen (1989) observed a reduction in ADG and ADFI when piglets were fed 4,000 mg/kg of ZnO diets, but attributed issues to toxicity. Piglets in our study did not appear to undergo Zn toxicity or exhibit symptoms of toxicity such as lameness, depression, or elevated plasma Zn. However, Batson et al. (2021) and Feldpausch et al. (2018) observed piglets previously fed pharmacological ZnO experienced reduced feed efficiency after pigs transitioned to a common diet but did not observe consequences to ADG or ADFI.

Similar to the Zn $\times$ day interaction observed for fecal DM in the present study, Laskoski et al. (2021) observed pigs fed diets with pharmacological Zn had improved fecal consistency compared to other post-weaning fecal strategies such as lower CP, wheat bran diet, and their negative control diet. Feeding pharmacological levels of Zn from ZnO has shown to reduce post-

weaning diarrhea because of its ability to reduce the colonization of pathogenic bacteria along the GI tract (Hu et al., 2013a; Hu et al., 2013b).

In the present study, pigs fed pharmacological Zn diets (3,000 mg/kg ZnO) had higher plasma Zn on day 10 and 25, which confirms effective Zn delivery during both time points in the experimental period. Dalto et al. (2023) observed similar results where piglets fed diets with 3,000 mg/kg of ZnO resulted in higher plasma Zn concentrations than pigs fed either 1,000 mg/kg or 100 mg/kg of ZnO.

In summary, there was minimal evidence of interactions between dietary CP and Zn level in the present study. In phase 1, pigs fed lower CP diets had greater ADFI and ADG, resulting in a tendency for improved gain and feed intake overall. Pharmacological Zn resulted in improved in ADG, ADFI, and G:F during the experimental period which resulted in a tendency for improved ADG and final BW for the overall trial period. Also, pigs fed pharmacological levels of Zn had higher fecal DM and were numerically higher than pigs fed different levels of diet CP. These collective results suggest diet CP and pharmacological Zn are independent responses.

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Table 2-1. Diet composition (as-fed basis)¹

		Phase 1			Phase 2			Phase 3
Item	Crude protein:	Low	Medium	High	Low	Medium	High	
Ingredient, %								
Corn		45.82	41.73	37.78	60.30	56.21	52.28	67.81
Soybean meal, 47.7% CP		16.82	21.30	25.61	20.24	24.71	29.03	28.13
Whey powder		25.00	25.00	25.00	10.00	10.00	10.00	---
Soy protein concentrate ²		7.50	7.50	7.50	5.00	5.00	5.00	---
Soybean oil		1.00	1.00	1.00	---	---	---	---
Calcium carbonate		0.45	0.46	0.48	0.69	0.71	0.73	0.73
Monocalcium phosphate, 21.5% P		0.90	0.85	0.80	1.11	1.05	0.99	1.05
Salt		0.58	0.58	0.58	0.65	0.65	0.65	0.60
L-Lys-HCl		0.36	0.22	0.08	0.45	0.31	0.17	0.55
DL-Met		0.21	0.17	0.13	0.21	0.17	0.13	0.22
L-Thr		0.17	0.10	0.04	0.20	0.14	0.08	0.24
L-Trp		0.05	0.03	---	0.05	0.03	---	0.06
L-Val		0.15	0.07	---	0.16	0.08	---	0.16
Trace mineral premix ³		0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix ⁴		0.25	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride, 60%		0.05	0.05	0.05	---	---	---	---
Phytase ⁵		0.06	0.06	0.06	0.06	0.06	0.06	0.06
ZnO ⁶		+/-	+/-	+/-	+/-	+/-	+/-	---
TiO ₂ ⁷		0.50	0.50	0.50	0.50	0.50	0.50	---
Calculated analysis								
SID amino acids, %								
Lys		1.35	1.35	1.35	1.30	1.30	1.30	1.30
Ile:Lys		60	66	71	57	63	68	53
Leu:Lys		117	125	132	116	125	133	113
Met:Lys		37	35	34	37	36	34	37
Met & Cys:Lys		58	58	58	58	58	58	58

Thr:Lys	64	64	64	64	64	64	64
Trp:Lys	21.1	21.2	21.1	20.2	20.2	20.1	20.0
Val:Lys	74	74	74	73	73	73	70
His:Lys	34	38	41	35	39	42	35
SID Lys:CP	6.59	6.13	5.75	6.50	6.04	5.66	6.50
NE, kcal/kg	2,533	2,505	2,478	2,458	2,430	2,401	2,443
SID Lys:NE, g/Mcal	5.33	5.39	5.45	5.64	5.64	5.64	5.32
CP, %	20.5	22.0	23.5	20.0	21.5	23.0	20.0
STTD P, %	0.58	0.58	0.58	0.54	0.54	0.54	0.48
Ca:P	1.01	1.01	1.01	1.10	1.10	1.10	1.10

¹Phase 1 diets were fed in pellet form, phase 2 and 3 were fed in meal form. All diets were manufactured at the O.H. Kruse Feed Technology Center in Manhattan, KS.

²Bunge SPC Pure Pro (Bunge, Chesterfield, MO).

³Provided per kilogram of feed: 110 mg of Zn as zinc sulfate; 17 mg of Cu as copper sulfate; 33 mg of Mn as manganese oxide; 110 mg of Fe as ferrous sulfate; 0.30 mg of I as ethylenediamine dihydriodide; 0.30 mg of Se as sodium selenite.

⁴Provided per kilogram of feed: 4,134 IU of vitamin A; 1,653 IU of vitamin D; 44 IU of vitamin E; 3.31 mg of vitamin K3; 33 µg of vitamin B12; 8 mg of riboflavin; 28 mg of pantothenic acid; 50 mg of niacin.

⁵HiPhorius 2,400 (2,400 FYT/g; DSM-Firmenich, Parsippany, NJ) provided at 1,500 FYT/kg with an assumed release of 0.12% STTD P.

⁶All diets contained 110 mg/kg added zinc from ZnSO₄. Treatment diets for phases 1 and 2 with pharmacological levels of Zn had additional Zn provided in the form of ZnO added at 0.40% to provide a total of 3,000 mg/kg added Zn.

⁷Titanium dioxide (Brenntag Specialties, Inc., South Plainfield, NJ) was included at 0.50% in all diets as an indigestible marker for fecal Zn excretion.

Table 2-2. Analyzed composition of phase 1 and phase 2 experimental diets (as-fed basis)¹

Added Zn, mg/kg:		110			3,000		
Crude protein:		Low	Medium	High	Low	Medium	High
Phase 1							
DM, %		88.1	87.8	88.2	88.1	88.2	88.5
CP, %		19.7	21.9	24.2	20.8	21.7	25.5
Fat, %		3.2	2.8	2.7	3.0	3.0	3.0
ADF, %		2.7	3.2	2.9	2.8	2.7	2.8
Zn, mg/kg		166	138	148	2,265	2,325	2,350
Phase 2							
DM, %		88.2	88.4	88.4	88.3	88.5	88.7
CP, %		20.3	20.8	22.7	20.9	22.6	23.3
Fat, %		2.6	2.3	2.2	2.1	2.1	2.1
ADF, %		3.3	2.6	3.2	3.7	3.6	3.6
Zn, mg/kg		274.0	240.0	253.0	2,075	2,280	2,415

¹Complete diet samples were collected from every third bag at the time of feed bagging to create composite samples. Samples were stored at -20 °C until submission to Midwest Laboratories (Omaha, NE) for proximate and Zn analyses.

²Phase 3 analyzed composition: DM, 86.6%; CP, 19%; Fat, 2.4%; ADF, 3.7%; Zinc, 96.5 mg/kg.

Table 2-3.Interactive effects of dietary crude protein and added Zn on nursery pig growth performance and fecal DM¹

	Added Zn, mg/kg:			3,000			SEM	CP × Zn, <i>P</i> =	
	Crude protein ² :	Low	Medium	High	Low	Medium	High	Linear	Quadratic
BW, kg									
d 0		5.44	5.44	5.44	5.43	5.42	5.44	0.029	0.965
d 10		7.12	7.04	6.91	7.71	7.47	7.56	0.092	0.792
d 25		13.56	13.67	13.15	14.38	14.16	14.15	0.201	0.651
d 42		24.76	24.47	23.92	25.21	24.49	24.95	0.341	0.404
Phase 1 (d 0 to 10)									
ADG, g		168	160	147	223	204	209	9.0	0.669
ADFI, g		210	192	186	238	233	217	8.0	0.870
G:F ³ , g/kg		812	834	796	940	880	965	28.0	0.458
Phase 2 (d 10 to 25)									
ADG, g		430	428	416	445	446	440	11.0	0.675
ADFI, g		616	591	586	639	608	620	13.0	0.693
G:F, g/kg		701	723	712	696	734	708	10.0	0.945
Experimental period (d 0 to 25)									
ADG, g		325	319	309	355	349	347	7.0	0.563
ADFI, g		454	429	426	477	458	457	9.0	0.665
G:F, g/kg		722	744	726	744	763	758	9.0	0.622
Common phase (d 25 to 42) ⁴									
ADG, g		658	635	634	637	594	635	12.0	0.360
ADFI, g		966	953	947	933	909	964	20.0	0.207
G:F, g/kg		684	667	673	685	654	660	9.0	0.461
Overall (d 0 to 42)									
ADG, g		460	445	440	468	448	463	7.0	0.324
ADFI, g		661	638	637	660	640	661	11.0	0.247
G:F, g/kg		700	698	694	710	701	700	7.0	0.745
Fecal dry matter, % ⁵									
d 10		16.9	13.6	15.4	19.7	20.4	20.8	1.15	0.258
d 25		19.4	18.7	18.3	20.8	20.5	21.4	1.13	0.433

¹A total of 360 pigs (DNA 240 × 600; initially 5.44 ± 0.03 kg) were used in a 42-d growth study with five pigs per pen and 12 pens per treatment.

²Phase 1 CP %: 20.5 (Low), 22.0 (Medium), 23.5 (High). Phase 2 CP %: 20.0 (Low), 21.5 (Medium), 23.0 (High).

³Quadratic effect of CP in 110 mg/kg Zn diets, $P = 0.375$; quadratic effect of CP in 3,000 mg/kg Zn diets, $P = 0.035$.

⁴All experimental groups were fed the same common diet containing 110 mg/kg added Zn.

⁵The same three middle BW pigs per pen were sampled on days 10 and 25. Linear and quadratic CP × Zn × day, $P \geq 0.209$.

Table 2-4. Main effects of dietary crude protein and added Zn on nursery pig growth performance and fecal DM¹

Item	Crude protein			SEM	<i>P</i> =		Added Zn, mg/kg		SEM	<i>P</i> =
	Low	Med	High		Linear	Quadratic	110	3,000		
BW, kg										
d 0	5.43	5.43	5.44	0.021	0.849	0.988	5.44	5.43	0.017	0.722
d 10	7.42	7.26	7.24	0.065	0.055	0.417	7.02	7.58	0.053	< 0.001
d 25	13.98	13.92	13.65	0.142	0.110	0.559	13.46	14.23	0.116	< 0.001
d 42	24.99	24.47	24.43	0.241	0.110	0.432	24.38	24.88	0.197	0.078
Phase 1 (d 0 to 10)										
ADG, g	196	182	178	6.0	0.047	0.496	159	212	4.9	< 0.001
ADFI, g	224	213	202	5.8	0.009	0.969	196	230	4.7	< 0.001
G:F, g/kg	876	858	881	19.5	0.875	0.375	814	929	15.9	< 0.001
Phase 2 (d 10 to 25)										
ADG, g	437	437	428	7.5	0.367	0.644	425	443	6.1	0.034
ADFI, g	627	599	603	9.2	0.063	0.171	598	622	7.6	0.026
G:F, g/kg	698	729	710	7.0	0.246	0.005	712	713	5.7	0.930
Experimental period (d 0 to 25)										
ADG, g	340	334	328	5.3	0.100	0.975	318	350	4.3	< 0.001
ADFI, g	465	444	442	6.3	0.011	0.214	436	464	5.2	< 0.001
G:F, g/kg	733	754	742	6.7	0.363	0.052	730	755	5.5	0.002
Common phase (d 25 to 42) ²										
ADG, g	648	615	634	8.8	0.286	0.018	642	622	7.2	0.052
ADFI, g	950	931	955	13.9	0.784	0.217	956	935	11.3	0.210
G:F, g/kg	685	660	667	6.3	0.045	0.051	675	666	5.1	0.253
Overall (d 0 to 42)										
ADG, g	464	447	452	5.3	0.094	0.084	448	460	4.3	0.066
ADFI, g	661	639	649	7.7	0.300	0.098	645	654	6.3	0.346
G:F, g/kg	705	699	697	4.8	0.254	0.751	697	704	3.9	0.242

Fecal dry matter, %³

d 10	18.3	17.0	18.1	0.81	0.825	0.222	15.3	20.3	0.66	< 0.001
d 25	20.1	19.6	19.9	0.81	0.828	0.704	18.8	20.9	0.66	0.024

¹A total of 360 pigs (DNA 240 ' 600; initially 5.44 ± 0.03 kg) were used in a 42-d growth study with five pigs per pen and 12 pens per treatment.

²All experimental groups were fed the same common diet containing 110 mg/kg added Zn.

³The same three middle BW pigs per pen were sampled on days 10 and 25. Linear and quadratic CP $\times$ day, $P \geq 0.498$; Zn $\times$ day, $P = 0.015$.

Table 2-5. Effects of pharmacological ZnO on serum plasma Zn in nursery pigs¹

Item	Added Zn, mg/kg		SEM	Zn within day, <i>P</i> =
	110	3,000		
d 0	1.04	1.08	0.033	0.416
d 10	0.64	1.96	0.113	< 0.0001
d 25	0.78	1.49	0.062	< 0.0001

¹A total of 360 pigs (DNA 240 × 600; initially 5.44 ± 0.03 kg) were used in a 42-d growth study with five pigs per pen and 12 pens per treatment. A blood sample from the middle BW pig from each pen was taken on days 0, 10, and 25 and analyzed in duplicate at the K-State Research and Extension Soil Testing Laboratory for Zn concentration. There was no evidence of a Zn × CP × day, *P* = 0.196. Zn × day interaction (*P* < 0.0001); Zn effects are presented within day. CP × Zn, *P* = 0.356.

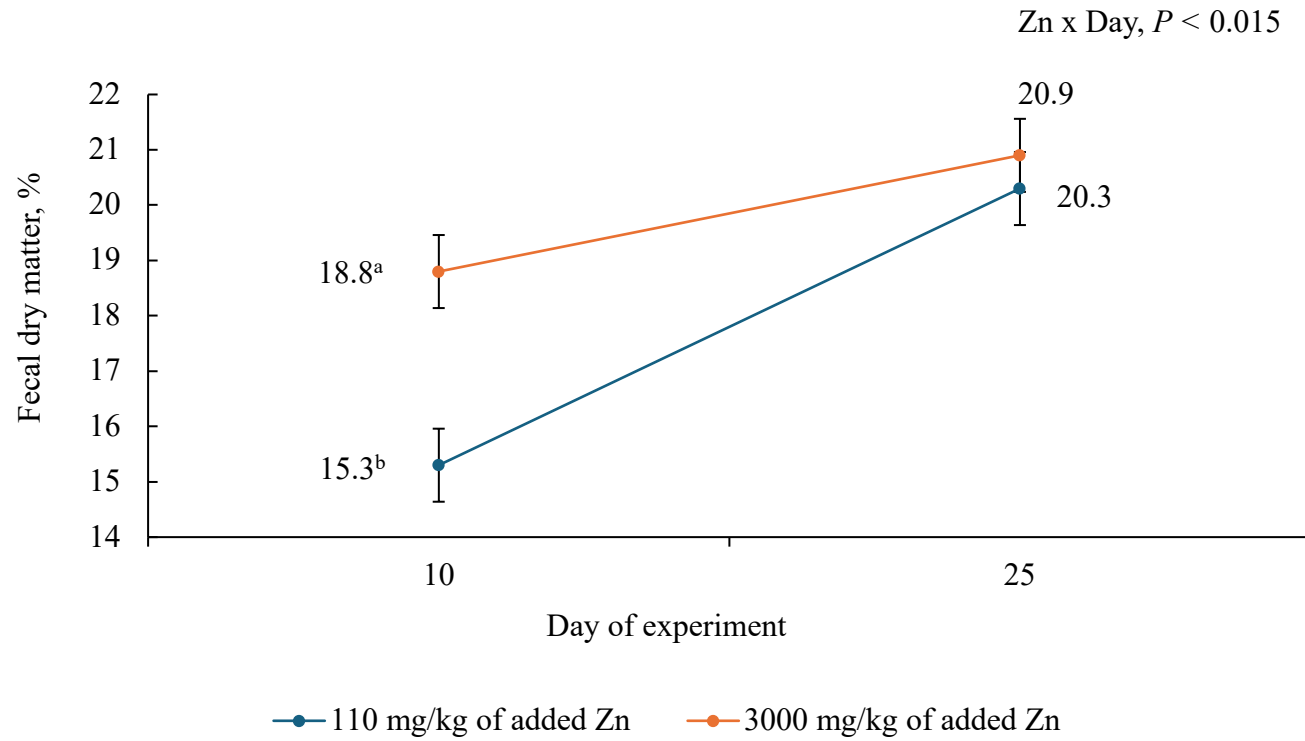


Figure 60. Effect of dietary Zn level on fecal DM. On d 10 and 25, a fresh fecal sample was collected from the same 3 pigs per pen. Samples were pooled and dried for 48 hours in a 55° C forced air oven. ab differ, $P < 0.05$.

Chapter 3 - Effect of low crude protein formulation strategies with and without pharmacological ZnO on the growth performance, fecal dry matter, and health parameters of nursery pigs challenged with Enterotoxigenic *Escherichia coli* F18

Abstract

A total of 90 weanling pigs (DNA 241 × 600; initially 5.97 ± 0.36 kg BW) were used in a 21-d study using two groups (45 pigs/group) to evaluate the effects of low crude protein (CP) formulation strategies with and without pharmacological zinc oxide (ZnO) on growth performance, fecal dry matter, and health parameters in Enterotoxigenic *Escherichia coli* F18 (ETEC) challenged nursery pigs. Within group, pigs were balanced for sex, stratified by weight, and allotted to one of five dietary treatments in a generalized randomized block design with 9 pigs per treatment. Diets were corn-soybean meal-based and formulated as: High CP (20.7% CP, 1.35% SID Lys), Low CP (17.9% CP, 1.17% SID Lys), Low CP + AA (17.9% CP, 1.35% SID Lys, similar SID AA:Lys ratios to high and low CP treatments by increasing synthetic AA inclusion), Low CP + ZnO (17.9% CP, 1.17% SID Lys, 3,000 mg/kg Zn from ZnO), and Low CP + AA + ZnO (17.9% CP, 1.35% SID Lys, 3,000 mg/kg Zn from ZnO). Following weaning (~19 d of age) pigs were group housed by treatment (4 or 5 pigs/pen) and provided their respective treatment during the pre-challenge period. Pigs were then moved to individual pens and continued their treatment diet on d 7. Inoculation occurred on d 7 with 6 mL of 10^7 CFU/mL ETEC F18 administered via orogastric gavage and followed with 6 mL of phosphate buffered saline. Performance measures were collected on d 0, 7, 14 and 21 to calculate ADG, ADFI, and

G:F. On d 7, 10, 14, 17, and 21 fecal samples were collected from each pig for fecal dry matter analysis. Overall, pigs fed low CP + AA + ZnO had greater ($P < 0.05$) ADG compared to pigs fed the high CP, low CP, or low CP + AA treatments. Feed intake was greater ($P < 0.05$) for pigs fed low CP + ZnO and low CP + AA + ZnO compared to pigs fed the high or low CP diets. There was no evidence of a difference ($P = 0.640$) in the overall challenge period G:F. There was a treatment $\times$ day interaction for fecal DM ($P < 0.0001$). On d 7 and 21, there were no differences in fecal DM between treatments. On d 17, fecal DM was greater ($P < 0.05$) for pigs fed diets containing ZnO. On d 14, pigs fed low CP + AA + ZnO had greater ($P < 0.05$) fecal DM compared to pigs fed the Low CP diet. On d 17, pigs fed Low CP had greater ($P < 0.05$) fecal DM compared to pigs fed high CP. In summary, inclusion of ZnO, particularly when combined with elevated AA levels in a low CP formulation, enhanced growth performance in ETEC F18-challenged pigs relative to a low CP diet.

INTRODUCTION

The period immediately post-weaning is one of the most stressful times in a piglet's life, where environmental and dietary changes combined with potential exposure to pathogens can lead to post-weaning diarrhea (PWD). While the cause of PWD can be multifaceted, it is commonly attributed to pathogenic bacteria like enterotoxigenic *Escherichia coli* (ETEC), which can lead to reduced growth performance, increased morbidity, and higher mortality rates (Castillo et al., 2007). Zinc oxide (ZnO) has been relied on in the swine industry because it has been shown to mitigate the post-weaning growth lag by reducing PWD and enhancing growth performance when included at pharmacological levels (2,000 to 3,000 mg/kg; Hill et al., 2001). However, scrutiny has been placed on the continued use of pharmacological ZnO as a substantial proportion of consumed Zn is excreted in feces (Jondreville et al., 2003). Subsequently, manure

is applied as fertilizer which has led to increased accumulation of Zn in the soil (Gourlez et al., 2024).

Piglets have reduced feed intake immediately post-weaning due to dietary, environmental, social stressors, and morphological changes of the gastrointestinal tract (Zheng et al., 2021). In a time of reduced feed intake, a higher CP diet (20 to 23% CP) can be fed to maximize protein deposition. However, high CP diets can result in more nitrogen and undigested protein reaching the large intestine (Connolly et al., 2024). This substrate contributes to the proliferation of harmful bacteria that can lead to PWD (Gloaguen et al., 2014; Connolly et al., 2024). Therefore, another strategy used to mitigate PWD is to lower the dietary CP level. However, when lowering CP levels, especially when SID Lys levels are reduced, there can be negative effects on growth performance (Connolly et al., 2024). Nutritional strategies must consider how to limit excess dietary nitrogen that contributes to PWD while still supplying adequate AA's for pigs to support growth performance (Gloaguen et al., 2014). To address this, it has been proposed that increasing standardized ileal digestible (SID) Lys in low-CP diets could maintain growth while improving gut health (Langley et al., 2025). Additionally, it has been hypothesized that extra nitrogen entering the large intestine may modulate ZnO's efficacy by indirectly aiding in bacteria proliferation potentially influencing its protective effects against ETEC (Connolly et al., 2024). There remains to be limited understanding of how dietary CP levels interact with pharmacological ZnO and increased SID Lys which could offset the performance losses often associated with reduced protein. A better understanding of these relationships during an enteric challenge is critical for developing nutrition strategies that minimize PWD while maintaining performance and promoting environmental sustainability in swine production. Thus, the objective of this experiment was to evaluate the effects of low CP

formulation strategies with and without pharmacological ZnO and their interactive effects on growth performance, fecal DM, serum cytokine concentration in Enterotoxigenic *Escherichia coli* F18 challenged nursery pigs.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee (IACUC #5018) and Institutional Biosafety Committee (IBC-1768) approved the protocols used in these experiments. This experiment was conducted at the K-State Swine Enteric Health Research Center facility in Manhattan, KS, under biosafety level 2 (BSL-2) operating conditions. Each pen had metal tri-bar flooring, a stainless-steel self-feeder, and nipple waterer to provide *ad libitum* access to feed and water. Pigs were placed in solid sided pens to prevent cross contamination between adjacent pens.

Animals and Treatment Structure

A total of 90 weanling pigs (DNA 241 × 600; initially 5.97 ± 0.36 kg BW) were used in a 21-d study using two groups (45 pigs/group). Within group, pigs were randomly allotted to one of five dietary treatments in a generalized randomized block design and grouped with four to five pigs per pen during a pre-challenge period prior to transfer to the BSL-2 facility and the challenge period. Diets were provided to piglets starting on d 0 and were corn-soybean meal-based with high or low CP, with or without the addition of pharmacological ZnO, synthetic amino acids, or both. Treatment diets consisted of 1) high CP diet (1.35% SID Lys, 20.7% CP), 2) low CP diet (1.17% SID Lys, 17.9% CP) 3) low CP + AA (1.35% SID Lys, 17.9% CP) 4) low CP + ZnO (1.17% SID Lys, 17.9% CP, approx. 3,000 mg/kg Zn from ZnO) 5) low CP + AA + ZnO (1.35% SID Lys, 17.9% CP, approx. 3,000 mg/kg Zn from ZnO). All diets met or exceeded the nutrient requirement estimates of other amino acids as a ratio to Lys (NRC, 2012) for the

weight ranges of the pigs (Table 1). A single 227 kg batch of feed was manufactured for each treatment and used to feed both groups. Diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center (Manhattan, KS) and fed in pelleted form. On the day of inoculation (d 7), pigs were placed in the research facility in individual pens. Pig weights were measured on d 0, 7, 14 and 21 to determine ADG, and feed intake was measured from d 7 to d 21 to determine ADFI and G:F.

Animal Selection Criteria

Selected piglets came from sows not previously vaccinated for *E. coli* F18. Piglets were confirmed for genetic susceptibility to the F18 strain of ETEC by sequencing the α (1,2) fucosyltransferase-1 (FUT1) gene via PCR at the Iowa State University Veterinary Diagnostic Laboratory (VDL). To identify susceptible piglets, an initial group of 96 piglets with similar body weights and an equal distribution of sow parities were selected within each group of pigs used in the experiment. A tail tissue sample was collected at litter processing from the selected piglets. Samples were frozen and shipped on dry ice. After identifying susceptible piglets (GG/AG genotype) from the initial group, 45 pigs with similar body weights, evenly distributed across litters, were randomly chosen to be used within each group of the experiment (90 pigs total).

Bacterial Strains, Culture Preparations, and Inoculation Methods

The ETEC F18 strain was obtained and cultured at the Kansas State University College of Veterinary Medicine. The isolate used was an F18 fimbrial type, with genes for heat labile enterotoxin (LT), heat stable toxin A (STa), heat stable toxin B (STb), and shiga toxin type 2e (Stx2e) as determined via polymerase chain reaction (PCR) and was derived from a field clinical case submission to the Iowa State Veterinary Diagnostic Laboratory. On d 7, all pigs were

inoculated with 6 mL of solution containing 10^7 CFU/mL of ETEC F18 and followed with 6 mL of phosphate buffered saline (PBS). The inoculum was administered via orogastric gavage with a rubber catheter.

Fecal Dry Matter

On d 7, 10, 14, 17 and 21 fecal samples were collected from each pig to determine fecal DM. Using a cotton-tipped applicator to stimulate defecation, fecal samples were collected into plastic bags and frozen at -20°C until fecal dry matter analysis. Fecal samples were dried at 55°C in a forced air oven for 48 hours, and the ratio of dried-to-wet fecal weight was used to determine the percentage fecal DM.

Immune Parameters

On d 7 (before challenge), 14, and 21, a blood sample was collected via jugular venipuncture into a 10 mL vacutainer tube. Samples were centrifuged ($3,000 \times g$ for 10 min) and serum was recovered in four separate aliquots. An aliquot of serum was sent to Eve Technologies, Calgary, AB, Canada and analyzed using a multiplex immunoassay that quantifies 13 cytokines (GM-CSF, IFN- γ , IL-1 α , IL-1 β , IL-1RA, IL-2, IL-4, IL-6, IL-8, IL-10, IL-12, IL-18, and TNF- α).

Statistical Analysis

Data were analyzed using the GLIMMIX procedure of SAS OnDemand for Academics (SAS Institute Inc., Cary, NC). Individual pig served as the experimental unit, with dietary treatment as a fixed effect and body weight block and group included as random intercepts. Serum cytokine data were log-transformed for analysis and back-transformed for presentation of least squares means. Following implementation of the base statistical model for each response, data points with absolute studentized residuals greater than 4 were removed from data analysis.

When treatment was a significant source of variation, differences were determined by pairwise comparison using the Tukey-Kramer multiplicity adjustment to control for Type I Error. Results were considered significant at $P \leq 0.05$ and were considered marginally significant at $P \leq 0.10$.

Results

Growth Performance

Growth performance data are presented in Table 3. On d 7, there were no observed differences in BW. From d 7 to 14, pigs fed either diet with pharmacological ZnO had greater ($P < 0.05$) ADG than pigs fed each treatment diet without ZnO, regardless of the CP formulation strategy. Pigs fed diets with pharmacological ZnO, regardless of the CP formulation strategy, had greater ($P < 0.05$) ADFI compared to pigs fed a high CP diet, with other treatments intermediate. Pigs fed the low CP + ZnO diet had improved feed efficiency ($P < 0.05$) compared to those fed either a high CP diet or a low CP diet without pharmacological ZnO. Also, pigs fed pharmacological ZnO in the low CP diet with or without synthetic amino acids resulted in significantly improved ($P < 0.05$) feed conversion compared to a low CP diet without pharmacological ZnO.

From d 14 to 21, there was a treatment tendency ($P = 0.060$) for ADG to differ among treatments, but no mean separation between treatments was detected. Pigs fed the low CP diet formulated with additional amino acids and pharmacological ZnO had increased ($P < 0.05$) ADFI compared to those fed a high CP or low CP diets without pharmacological ZnO. Pigs fed a low CP diet with pharmacological ZnO had significantly reduced ($P < 0.05$) G:F compared to those fed a high CP, low CP, or low CP + AA diet.

During the challenge period (d 7 to 21), pigs fed the low CP + AA + ZnO diet had greater ($P < 0.05$) ADG compared to pigs fed the high CP, low CP, or low CP + AA treatments. Feed

intake was greater ($P < 0.05$) for pigs fed low CP + ZnO and low CP + AA + ZnO compared to pigs fed the high or low CP diets. There was no evidence of a difference ($P = 0.640$) in G:F from d 7 to d 21.

Fecal Dry Matter

Fecal DM data are presented in Table 3. There was a significant treatment $\times$ day interaction for fecal dry matter ($P < 0.0001$). On d 7 there was no evidence of a difference ($P > 0.05$) in fecal DM between treatments. By d 10, fecal DM was greater ($P < 0.05$) for pigs fed diets containing ZnO, regardless of CP formulation strategy. On d 14, pigs fed low CP + AA + ZnO had greater ($P < 0.05$) fecal DM compared to pigs fed the low CP diet, with the other treatments being intermediate. On d 17, pigs fed low CP had greater ($P < 0.05$) fecal DM compared to pigs fed high CP, with the other treatments being intermediate. By d 21, there was no evidence of a difference ($P > 0.05$) in fecal DM across dietary treatments.

Serum Cytokine Panel

Serum cytokine concentrations are presented in Table 4. There was a significant difference ($P = 0.001$) in IL-8, where pigs fed the high CP diet had increased IL-8 compared to those fed a low CP diet with ZnO, regardless of amino acid inclusion. Pigs fed the low CP diet had significantly increased ($P = 0.05$) levels of IL-1RA compared to pigs fed a low CP + ZnO diet, with the other treatments being intermediate. There was no evidence of differences ($P \geq 0.186$) between treatments for other measured serum cytokines.

Discussion

Post-weaning diarrhea can be the result of many challenges in a piglet's post-weaned life, but PWD is often attributed to pathogenic bacteria like ETEC and can result in reduced growth performance, increased morbidity, and higher mortality rates (Castillo et al., 2007). While

pharmacological levels of ZnO have been used as an alternative to antibiotics to help piglets through the immediate post-weaning period, restrictions on usage have been placed on pharmacological levels of ZnO in the European Union (Luise et al., 2024). One heavily investigated alternative to feeding pharmacological levels of ZnO is altering the CP level of the nursery diet.

It's well understood that high crude protein diets can maintain growth performance by meeting requirements for protein deposition but can lead to higher incidence of PWD (Gloaguen et al., 2014). Contrastingly, lowering the CP level of a diet can improve fecal consistency, but this has been observed to reduce growth performance (Connolly et al., 2024). Specifically, Limbach et al. (2021) observed an experimental diet with a 16% CP and total analyzed Lys at 1.2% reduce overall ADG and improved fecal consistency when compared to a 19% CP diet with total Lys at 1.61% in phase 1 and 1.48% in phase 2. The same low CP 16% diet resulted in lower final body weights and poorer feed efficiency when compared to the 22% CP diet and the 19% CP diet with total Lys of 1.53% in phase 1 and 1.42% in phase 2. While lowering the CP level of a diet has shown to improve fecal consistency, the reduction in CP can simultaneously reduce ADG, especially if feed intake is low and pigs are in a protein dependent phase of growth. To counteract this, formulating a diet to a low CP, but fortifying it with synthetic AA's to meet SID Lys and other essential AA's can attempt to maintain growth performance and improve fecal consistency. Thus, the diets in the present study were formulated to understand how low CP strategies compare to each other and to a high CP diet in a health challenged setting. More specifically, this study was designed to determine if a diet with a lower CP level, supplemented with synthetic essential AA's could be a better alternative to pharmacological Zn than low CP alone.

In the present study, there were no differences in body weight on d 7 of the experiment. Thus, indicating there was no evidence of a treatment difference on BW during the pre-challenge period. However, ADG differences in the second week appear to be driven by pharmacological ZnO inclusion, regardless of the CP formulation strategy. While this appears to be derived from intake, feed intake was only higher for pharmacological Zn diets when compared to the high CP diet. Hansen et al. (2024) reported similar effects when pigs were challenged with ETEC F18, whereas pigs fed diets with 1,400 mg/kg of ZnO had increased ADFI from d 5 to 7 of the experiment, compared to a diet with 150 mg/kg of ZnO and observed pigs fed diets with 150 mg/kg of ZnO had reduced ADG compared to pigs fed pharmacological Zn diets. Pharmacological ZnO's effect for improved growth performance in the first week post-weaning is well documented (Carlson et al., 1999; Hill et al., 2001). The increase in feed intake observed in pigs fed pharmacological levels of Zn is likely due to pharmacological levels of ZnO stimulating appetite in piglets by increasing ghrelin, a peptide hormone that's produced in the stomach (Yin et al., 2009). Menegat et al. (2019) noted a reduction in dietary CP allows for a reduction of soybean meal and trypsin inhibitors which can lead to reduced feed intake if present at high levels in the diet. This is due to piglets not easily digesting protein soybean meal and it may lead to a hypersensitivity reaction (Menegat et al., 2019). In the present study the high CP diet consisted of 20% soybean meal, where the low CP diets had ~11 to 13% soybean meal inclusion. Therefore, pigs fed the high CP diet in the present study could have reduced ADG and the feed intake possibly due to the greater amount of soybean meal and trypsin inhibitors.

In the present study, there was nearly an inverse outcome for feed efficiency from week 2 to week 3. Specifically, when comparing the combination of pharmacological Zn and elevated

AA's to the low CP diet in the present study, the combination diet resulting in greater ADG could be due to the addition of pharmacological Zn, elevated AA's, or both.

From d 14 to 21, pigs fed diets with pharmacological Zn had worse feed efficiency when compared to the low CP + AA and high CP diet. The peak of the clinical infection occurred in the first 7 days post-challenge (d 7 to 14), and growth performance from d 14 to 21 improved substantially. In particular, during this period of recovery in growth performance pigs fed diets with low CP + AA and high CP performed particularly well. This could be at least partially attributed to the higher level of SID Lys during this period for these treatments allowing for greater feed efficiency during this period of recovery from the peak infection.

Pigs fed the low CP diet formulated with synthetic AA's and pharmacological ZnO had improved growth performance for the entire experiment. The overall outcomes indicate that there was a greater pharmacological Zn effect regardless of AA supplementation. Overall, the changes in feed efficiency from week 2 to week 3, resulted in no evidence of an overall difference G:F.

Post-weaning diarrhea is a common challenge in the nursery and is typically associated with pathogen growth and limited digestive function. To improve fecal consistency and mitigate diarrhea, nutritional strategies such as reducing dietary CP and supplementing pharmacological levels of ZnO have been widely used (Hill et al., 2001; Connolly et al., 2024). On d 7 of the present study, there were no differences observed in fecal DM between pigs fed the different treatment diets prior to the enteric challenge. There were different fecal DM outcomes on d 10, 14, and 21 during the post-enteric challenge, suggesting during peak infection, the treatments had an impact on fecal outcomes. By d 10, fecal DM was greater for pigs fed diets containing pharmacological levels of ZnO, regardless of CP formulation strategy. This coincides with work by Heo et al. (2010), which observed similar results when evaluating CP and ZnO effects on

fecal DM in an ETEC challenged study. Whereas pigs fed a low CP diet or a diet with pharmacological Zn resulted in less PWD in 21 days compared to a high CP diet or a diet without pharmacological zinc.

However, in the present study on d 14, pigs fed low CP + AA + ZnO had greater fecal DM compared to pigs fed the low CP diet, with the other treatments being intermediate. This suggests there could be additive benefit with pharmacological Zn and added AA's. On d 17, pigs fed low CP had greater fecal DM compared to pigs fed high CP, with the other treatments being intermediate. High CP diets are often thought to lead to PWD and pathogen proliferation because added nitrogen from the diet leads to more undigested nitrogen moving to the large intestine (Connolly et al., 2024). With the results of the present study on fecal DM, it supports this other research that pigs fed the high CP diet had poorer fecal DM outcomes. Ultimately, it appears the addition of pharmacological Zn had the largest impact in the present study on fecal DM. It is generally considered when ZnO is fed at pharmacological levels, it reduces diarrhea in the post-weaning phase because of its ability to reduce pathogenic bacteria from colonizing along the G.I. tract (Hu et al., 2013; Hu et al., 2014).

E. coli, which is characterized by adhesions and enterotoxins, can act harmfully on the intestine, leading to PWD (Rhouma et al. 2017). After ETEC has colonized and fimbriae attach, diarrhea stems from enterotoxin production which leads to electrolyte loss and secretion of fluid into the lumen of the intestine (Dahmer et al., 2023). Therefore, the lack of evidence of a difference on d 21 fecal DM suggests the enteric challenge and GI tract could have stabilized and that dietary interventions had greater influence on fecal DM during d 7 to 14.

Cytokines are mediators in the activation and regulation of the adaptive immune system response to infections and inflammation, but the levels of interferons and interleukins (IL) vary

depending on the status of health or disease (Lu et al., 2013). Anti-inflammatory cytokines, including IL-4 and IL-10, suppress excessive inflammation and promote immune regulation, but pro-inflammatory cytokines, such as IL-1, IL-2, IL-6, and IL-18, promote immune cell activation and inflammatory signaling (Dinarello, 2000). While higher serum cytokine concentrations reflect systemic inflammation, past research observed that a high dietary CP (24.6% CP) diet led to a greater concentration of IL-8 in colon tissue when compared to a low CP (17.4% CP) diet (Pearce et al., 2024). However, Pearce et al. (2024) found no differences between IL-8 concentrations in ileum tissue samples and concluded a high CP diet did not have an impact on inflammation throughout the body. Thus, the lower concentration of IL-8 cytokines in pigs fed pharmacological Zn diets reflects ZnO's ability to assist the body during an enteric challenge. The results of the present study do indicate piglets fed high CP diets had greater concentrations of IL-8, but only when compared to the low CP + ZnO diet, supporting the idea that high CP diets may result in greater inflammation. Opapeju et al. (2010) observed a high crude protein diet exhibited increased IL-1 β concentrations after an ETEC K88 challenge, relative to pigs fed a low CP diet, suggesting that higher CP levels may exacerbate inflammatory responses. However, the present study observed no evidence of a difference ($P = 0.319$) between IL-1 β serum cytokine concentrations.

Additionally, IL-1Ra binds to IL-1 and therefore blocks the signaling cascade from IL-1 which causes inflammation (Nedumpun et al., 2017). IL-1Ra is an indication of how strongly the immune system is working to regulate inflammation. Pharmacological levels of Zn from ZnO can modulate intestinal immunity through suppressing pro-inflammatory cytokines and during infection it can alleviate oxidative stress induced by inflammation (Ng'ang'a et al., 2025). The

balance between pro- and anti-inflammatory cytokines is thought to play a critical role in determining disease outcome and recovery following infection (Dinarello, 2000).

Conclusion

Together, these results suggest that pharmacological Zn from ZnO provides the greatest benefit during the immediate post-weaning period, while low CP diets supplemented with amino acids may serve as a complementary strategy to support growth and gut health as pigs undergo PWD challenges.

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Table 3-1. Ingredient composition of experimental diets (as-fed basis)¹

Ingredient, %	High CP	Low CP	Low CP + AA	Low CP + ZnO	Low CP + AA + ZnO
Corn	54.92	61.79	62.65	61.36	62.22
Soybean meal, 47.7% CP	20.18	13.32	11.41	13.35	11.44
Whey powder	14.00	14.00	14.00	14.00	14.00
Soy protein concentrate ²	6.25	6.25	6.25	6.25	6.25
Soybean oil	1.00	1.00	1.00	1.00	1.00
Calcium carbonate	0.50	0.48	0.47	0.48	0.47
Monocalcium phosphate, 21.5% P	0.98	1.08	1.11	1.08	1.11
Salt	0.73	0.73	0.73	0.73	0.73
L-Lys-HCl	0.41	0.40	0.69	0.40	0.69
DL-Met	0.18	0.14	0.26	0.14	0.26
L-Thr	0.19	0.17	0.32	0.17	0.32
L-Trp	0.06	0.06	0.11	0.06	0.11
L-Val	0.10	0.09	0.26	0.09	0.26
L-Ile	---	0.01	0.15	0.01	0.15
L-His	---	---	0.11	---	0.11
Trace mineral premix ³	0.15	0.15	0.15	0.15	0.15
Vitamin premix ⁴	0.25	0.25	0.25	0.25	0.25
Choline chloride, 60%	0.05	0.05	0.05	0.05	0.05
Phytase ⁵	0.06	0.06	0.06	0.06	0.06
ZnO	---	---	---	0.40	0.40
Total	100	100	100	100	100
Calculated analysis					
SID amino acids, %					
Lys	1.35	1.17	1.35	1.17	1.35
Ile:Lys	58	58	58	58	58
Leu:Lys	117	121	101	121	101

Met:Lys	35	34	38	34	37
Met & Cys:Lys	56	56	56	56	56
Thr:Lys	64	64	64	64	64
Trp:Lys	21	21	21	21	21
Val:Lys	70	70	70	70	70
His:Lys	35	35	35	35	35
SID Lys:CP	6.51	6.51	7.51	6.51	7.51
NE, kcal/kg	2,520	2,557	2,577	2,546	2,567
SID Lys:NE, g/Mcal	5.36	4.57	5.24	4.59	5.26
CP, %	20.7	18.0	18.0	18.0	18.0
STTD P, %	0.54	0.54	0.54	0.54	0.54
Ca:P	1.00	1.00	1.00	1.00	1.00

¹Treatment diets were fed in a pellet form from d 0 to 21. All diets were manufactured at the O.H. Kruse Feed Technology Center in Manhattan, KS.

²AX3 Digest; Protekta, Newport Beach, CA.

³Provided per kilogram of feed: 110 mg of Zn as zinc sulfate; 17 mg of Cu as copper sulfate; 33 mg of Mn as manganese oxide; 110 mg of Fe as ferrous sulfate; 0.30 mg of I as ethylenediamine dihydriodide; 0.30 mg of Se as sodium selenite.

⁴Provided per kilogram of feed: 4,134 IU of vitamin A; 1,653 IU of vitamin D; 44 IU of vitamin E; 3.31 mg of vitamin K3; 33 µg of vitamin B12; 8 mg of riboflavin; 28 mg of pantothenic acid; 50 mg of niacin.

⁵Ronozyme HiPhos 2700 (DSM-Firmenich; Parsippany, NJ) provided an estimated release of 0.12% STTD P with 2,027 FYT/kg.

Table 3-2. Chemical analysis of diets (as-fed basis)¹

Item	High CP	Low CP	Low CP + AA	Low CP + ZnO	Low CP + AA + ZnO
DM, %	88.8	88.7	87.8	88.6	88.6
CP, %	19.6	17.8	16.8	17.2	16.2
Ash, %	5.21	4.95	4.66	5.33	5.03
Zn, mg/kg	284	126	323	1,996	2,213
Total Amino Acids, %					
Lys	1.36	1.24	1.45	1.26	1.36
Ile	0.85	0.75	0.83	0.79	0.84
Leu	1.69	1.54	1.49	1.55	1.51
Met	0.42	0.36	0.43	0.38	0.51
Cys	0.32	0.28	0.27	0.28	0.30
Thr	0.90	0.79	0.90	0.84	0.87
Trp	0.28	0.25	0.26	0.24	0.25
Val	1.02	0.88	0.99	0.94	1.00
His	0.50	0.44	0.51	0.46	0.51
Phe	0.95	0.83	0.80	0.85	0.81

¹ Feed samples were collected from every third bag at the time of bagging and combined to form a composite sample for each dietary treatment. Duplicate subsamples of each composite were submitted to the Experiment Station Chemical Laboratories (University of Missouri, Columbia, MO) for proximate analysis and total amino acid analysis.

Table 3-3. Effects of low crude protein formulation strategies with and without pharmacological ZnO on nursery pig growth performance following Enterotoxigenic *Escherichia coli* F18 challenge.

Item	Dietary treatment ¹					SEM	P =
	High CP	Low CP	Low CP + AA	Low CP + ZnO	Low CP + AA + ZnO		
BW, kg							
d 0	5.96	5.97	5.97	5.97	5.96	0.361	1.000
d 7	6.50	6.57	6.71	6.53	6.64	0.406	0.874
d 14	7.20 ^c	6.96 ^c	7.38 ^{bc}	8.32 ^{ab}	8.49 ^a	0.599	< 0.0001
d 21	9.40 ^b	9.86 ^{ab}	10.18 ^{ab}	10.13 ^{ab}	10.97 ^a	0.625	0.018
d 0 to 7							
ADG, g	78	86	105	80	96	15.1	0.584
d 7 to 14							
ADG, g	100 ^b	47 ^b	93 ^b	257 ^a	264 ^a	97.7	< 0.0001
ADFI, g	208 ^b	212 ^{ab}	255 ^{ab}	302 ^a	301 ^a	59.1	0.006
G:F, g/kg	177 ^{bc}	-122 ^c	-152 ^c	976 ^a	819 ^{ab}	404.7	< 0.0001
d 14 to 21							
ADG, g	315	273	393	267	354	60.2	0.060
ADFI, g	339 ^b	325 ^b	447 ^{ab}	451 ^{ab}	523 ^a	57.1	0.001
G:F, g/kg	973 ^a	860 ^{ab}	977 ^a	588 ^c	688 ^{bc}	68.8	< 0.0001
Challenge period (d 7 to 21)							
ADG, g	202 ^b	177 ^b	243 ^{ab}	263 ^{ab}	310 ^a	32.3	0.001
ADFI, g	269 ^b	265 ^b	343 ^{ab}	376 ^a	412 ^a	31.9	< 0.0001
G:F, g/kg	776	728	719	715	756	50.5	0.640
Fecal DM, ²							
d 7	14.7	16.9	17.0	14.0	18.2	1.62	0.317
d 10	10.7 ^c	10.0 ^c	13.0 ^{bc}	20.5 ^a	17.1 ^{ab}	1.65	< 0.0001
d 14	16.7 ^{ab}	14.5 ^b	18.8 ^{ab}	20.8 ^{ab}	22.1 ^a	1.95	0.024
d 17	15.5 ^b	25.5 ^a	18.7 ^{ab}	20.1 ^{ab}	21.2 ^{ab}	2.36	0.027
d 21	18.0	22.1	22.9	18.7	19.5	1.71	0.115

¹A total of 90 pigs were used in two 21-d growth studies with 1 pig per pen and 18 replicates per treatment. Dietary treatments consisted of: High CP (1.35% SID Lys, 20.7% CP), Low CP (1.17% SID Lys, 17.9% CP), Low CP + AA (1.35% SID Lys, 17.9% CP), Low CP + ZnO (1.17% SID Lys, 17.9% CP, approx. 3,000 mg/kg Zn from ZnO), and Low CP + AA + ZnO (1.35% SID Lys, 17.9% CP, approx. 3,000 mg/kg Zn from ZnO). Treatment diets were fed in a pellet form from d 0 to 21. On d 7 pig were challenged with 6 mL of solution containing 10^7 CFU/mL of ETEC F18 and followed with 6 mL of phosphate buffered saline. On d 21, all pigs were euthanized.

² Treatment $\times$ day interaction, $P < 0.0001$.

Table 3-4.Effect of low crude protein formulation strategies with and without pharmacological ZnO on serum cytokine concentrations (fluorescence intensity values) of F18 *E. coli* challenged nursery pigs^{1, 2}

Item	Dietary Treatment					SEM	P =
	High CP	Low CP	Low CP + AA	Low CP + ZnO	Low CP + AA + ZnO		
GM-CSF	15.8	19.7	16.7	17.9	21.0	3.48	0.186
IFN γ	38.6	47.0	33.9	40.4	42.2	17.08	0.736
IL-1 α	44.9	65.0	49.7	41.4	63.4	63.42	0.677
IL-1 β	69.0	108.1	72.5	71.3	104.4	53.48	0.319
IL-2	35.8	50.4	39.9	38.3	53.4	35.54	0.772
IL-4	47.0	66.9	51.7	45.2	65.3	39.77	0.693
IL-6	48.3	75.3	52.7	52.1	83.8	44.85	0.293
IL-8	374.3 ^a	340.6 ^{ab}	269.6 ^{abc}	95.7 ^c	120.6 ^{bc}	148.70	0.001
IL-10	54.2	70.6	59.5	48.8	76.0	43.51	0.693
IL-12	971.7	948.6	896.0	1097.9	986.9	94.65	0.327
IL-18	66.4	84.8	61.7	70.7	92.3	41.01	0.562
TNF α	26.7	40.6	32.2	26.4	38.1	13.56	0.328
ILra	227.0 ^{ab}	537.2 ^a	306.6 ^{ab}	161.6 ^b	223.9 ^{ab}	145.97	0.014

¹ A total of 90 pigs were used in two 21-d growth studies with 1 pig per pen and 18 replicates per treatment. Cytokines were analyzed at Eve Technologies, Calgary, AB, Canada using a multiplex immunoassay that quantifies 13 cytokines.

² Blood was collected on d 7, 14, and 21, with d 14 serum cytokines being analyzed to determine differences after piglets were challenged with ETEC.