Influence of Lipopolysaccharide-Induced Immune Challenge and Diet Complexity on Growth Performance and Acute-Phase Protein Production in Segregated Early-Weaned Pigs


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ABSTRACT: Segregated early-weaned pigs (initially 4.0 kg and 14 ± 1.5 d of age) were used to quantify the effects of lipopolysaccharide (LPS)-induced immune challenge and nursery diet complexity (complex, medium, and simple) on growth performance and haptoglobin production. Three treatments of immune challenge consisted of pigs given ad libitum access to feed (control), challenged with LPS and given ad libitum access to feed (LPS-challenged), or pair-fed to receive the same amount of feed as the LPS-challenged pigs (pair-fed). The absence of interactions (P > .10) between diet complexity and immune challenge with LPS indicated that the responses were independent. Control pigs were the heaviest (P < .01), LPS-challenged the lightest (P < .01), and pair-fed intermediate in weight on d 18 after weaning. Approximately two thirds of the decreased growth of LPS-challenged pigs was due to decreased ADFI and one third was due to decreased feed efficiency (G/F). Pigs fed the complex diet were heaviest (P < .05), and pigs fed the simple diet were lightest (P < .05) on d 18 after weaning. The increased growth of pigs fed the complex compared with those fed the medium diet was due to the increased ADFI of the former. The decreased growth of pigs fed the simple diet compared with those fed the medium or complex diets was due to both decreased ADFI and G/F. The LPS-challenged pigs had increased (P < .01) haptoglobin concentrations, suggesting that inflammatory cytokine production was higher in immune-challenged pigs. These data suggest that LPS immune challenge caused decreased growth by decreasing ADFI and altering nutrient partitioning and that growth responses to diet complexity are independent of immune challenge.

Key Words: Pigs, Lipopolysaccharide, Antigens, Growth, Feeding

Introduction

The swine industry is restructuring rapidly to capture the health and performance benefits of segregated-weaning production systems. These systems have developed from the early research of

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Alexander et al. (1980), which sought to develop nonsurgical alternatives to raising caesarean-derived, pathogen-free pigs. Subsequent research has indicated benefits in both disease elimination and growth performance from raising pigs in segregated-rearing production systems (Harris, 1988; Wiseman, 1992; Clark et al., 1994; Dritz et al., 1996a). The increased growth performance is thought to be a result of decreased stimulation of the immune system and is supported by research that has indicated that immune challenge results in decreased feed intake as well as partitioning nutrients away from growth (Klasing et al., 1987; Blecha et al., 1994; Williams et al., 1994). Reduced growth rates from decreased feed intake or reduced efficiency have different economic costs, thus indicating the importance of quantifying the proportion. The goal when formulating nursery diets is to choose ingredients that are highly palatable and digestible (Tokach et al., 1994; Dritz et al., 1994a). Because feed intake is decreased during an immune
challenge, the selection and level of the highly palatable and digestible ingredients may need to be altered. If diet complexity can be reduced in pigs without an immune challenge while maintaining growth performance, diet cost and cost per unit of gain may be reduced.

Our objective was to examine the influence of lipopolysaccharide (LPS)-induced immune challenge and nursery diet complexity on the growth performance and plasma acute-phase protein production of segregated, early-weaned, nursery pigs.

Materials and Methods

Animal Care and Use. The experimental protocol used in this study was approved by the Kansas State University Institutional Animal Care and Use Committee.

Animals and Animal Housing. A total of 270 segregated, early-weaned, crossbred pigs (initially 4.0 kg and 14 ± 1.5 d of age; PIC Camborough or Camborough 15 dams by line 326 or 66 sires) was used. The herd of origin was classified as high-health status according to the procedures of Madec et al. (1993). Neither antibiotics nor vaccines were administered to the pigs at weaning or during the experiment. The experimental treatments were arranged in a 3 × 3 factorial in a randomized complete block design. Main effects included immune challenge and diet complexity. The three treatments of immune challenge consisted of one group injected with endotoxin-free Hanks’ balanced salt solution (HBSS) and given ad libitum access to feed (control), a second group injected with LPS and given ad libitum access to feed (LPS-challenged), and a third group injected with HBSS and pair-fed to receive the same amount of feed per day as the LPS-challenged pigs (pair-fed). Pigs were fed diets of one of three complexities (simple, medium, or complex) for the main effect of diet complexity.

Pigs were housed in groups of five in pens (1.22 × 1.22 m) with slotted metal flooring and placed in each of two empty environmentally regulated identical nurseries located .8 km from other pig-rearing sites. Complete blocks were located within a single nursery, with one block in one nursery and two blocks in the other nursery. The nurseries were cleaned, disinfected, and allowed to dry for 7 d before arrival of the pigs. The initial room temperature (34°C) was reduced by 1°C each week. Pigs had access to a nipple waterer and a self-feeder (.6 m long). At weaning, pigs were allotted by weight into three randomized complete blocks, with ancestry equalized across treatments within block. Each block contained two replicates per treatment with a total of six replicates per treatment.

Immune Challenge Model. Lipopolysaccharide (E. coli serotype 055:B5, Sigma Chemical, St. Louis, MO) was injected intramuscularly (150 μg/kg BW) on d 5, 8, 11, and 14 postweaning. The LPS dosage used was calculated to result in a 25% decrease in feed intake compared with HBSS-injected controls with ad libitum access to feed. The dosage was based on the results of two pilot studies (data not reported) and experiments of others (van Heugten et al., 1994; Chavis et al., 1994). The LPS solution (400 μg/mL) was made by diluting the LPS in endotoxin-free HBSS. The solution was then sonicated (15 min) to emulsify the mixture and then frozen. The stock solution was thawed, vortexed (10 min), and sonicated (15 min) immediately before injection. Control and pair-fed pigs were injected with endotoxin-free HBSS (2 mL/pig).

Diets. All diets were formulated to include all nutrients in excess of those recommended by NRC (1988) for 1- to 5-kg pigs. Pigs were fed from d 0 to 5 postweaning a common pelleted diet (Table 1) formulated to contain 1.70% lysine and .48% methionine. The common diet was fed to acclimate feed intake in the period immediately after weaning. Pigs then were fed one of the three experimental pelleted diets (complex, medium, or simple) from d 5 to 18 postweaning (5.0 kg and 19 ± 1.5 d of age on d 5 after weaning). The complex diet was formulated using specialty ingredients at high levels to stimulate feed intake and maximize growth performance regardless of cost. The medium complexity diet was formulated based on the recommendations of Dritz et al. (1994a) for 5- to 7-kg pigs. The objective of this diet formulation was to achieve maximum growth performance while minimizing feed cost per kilogram of gain. The medium diet contained many of the same specialty ingredients as the complex diet; however, they were a smaller percentage of the diet. Another major difference was that the complex diet contained moist-extruded soy protein concentrate, and the medium diet contained soybean meal as the soy protein source. The simple diet was corn-soybean meal-based and contained minimal amounts of specialty ingredients. These diets were all formulated to contain 1.60% lysine and .44% methionine. All pigs then were fed a common corn-soybean meal-based diet from d 18 to 32 postweaning formulated to contain 1.30% lysine and .36% methionine.

Feeding. The pair-fed pigs were fed the same amount each 24-h period as the LPS-challenged pigs consumed during that same period. Thus, feeders in the pens containing the pigs injected with LPS were weighed daily to calculate feed consumption for the previous 24 h. Because injections and pair-feeding were begun on d 5 after weaning, initial 24-h feed intake was predicted for the pair-fed pens based on observed reductions in feed consumption in the two pilot studies. Subsequently, feed intake per pen by block for each 24-h period was predicted from the average feed consumption of the LPS-challenged pigs for the previous 24 h and feed intake pattern from two pilot studies. Minor adjustments were also made to
Table 1. Diet composition (as-fed basis)

<table>
<thead>
<tr>
<th>Ingredient, %</th>
<th>d 0 to 5 postweaning</th>
<th>d 5 to 18 postweaning</th>
<th>d 18 to 32 postweaning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complex</td>
<td>Medium</td>
<td>Simple</td>
</tr>
<tr>
<td>Corn</td>
<td>31.80</td>
<td>37.71</td>
<td>35.59</td>
</tr>
<tr>
<td>Soybean meal (46.5% CP)</td>
<td>—</td>
<td>—</td>
<td>28.12</td>
</tr>
<tr>
<td>Moist extruded soybean protein concentrate</td>
<td>8.58</td>
<td>9.96</td>
<td>—</td>
</tr>
<tr>
<td>Edible-grade dried whey</td>
<td>30.00</td>
<td>20.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Lactose</td>
<td>5.00</td>
<td>8.50</td>
<td>—</td>
</tr>
<tr>
<td>Select menhaden fish meal</td>
<td>6.00</td>
<td>6.00</td>
<td>2.50</td>
</tr>
<tr>
<td>Spray-dried plasma protein</td>
<td>7.50</td>
<td>7.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Spray-dried blood meal</td>
<td>1.75</td>
<td>1.75</td>
<td>2.50</td>
</tr>
<tr>
<td>Soybean oil</td>
<td>6.00</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Monocalcium phosphate (21% P)</td>
<td>1.13</td>
<td>1.37</td>
<td>1.35</td>
</tr>
<tr>
<td>Limestone</td>
<td>.21</td>
<td>.30</td>
<td>.51</td>
</tr>
<tr>
<td>Antibioticb</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>.38</td>
<td>.38</td>
<td>.38</td>
</tr>
<tr>
<td>Copper sulfate</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Salt</td>
<td></td>
<td>.05</td>
<td>.05</td>
</tr>
<tr>
<td>Vitamin premixc</td>
<td>.25</td>
<td>.25</td>
<td>.25</td>
</tr>
<tr>
<td>Trace mineral premixd</td>
<td>.15</td>
<td>.15</td>
<td>.15</td>
</tr>
<tr>
<td>DL-Methionine</td>
<td>.15</td>
<td>.08</td>
<td>.10</td>
</tr>
<tr>
<td>L-LysineHCl</td>
<td>.10</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Calculated composition, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lysine</td>
<td>1.70</td>
<td>1.60</td>
<td>1.60</td>
</tr>
<tr>
<td>Methionine</td>
<td>.48</td>
<td>.44</td>
<td>.47</td>
</tr>
<tr>
<td>Methionine + cystine</td>
<td>.95</td>
<td>.88</td>
<td>.88</td>
</tr>
</tbody>
</table>

*Diets were formulated to contain .9% Ca and .8% P.
*To provide 55 mg/kg of carbadox.
*To provide (per kilogram) 11,025 IU vitamin A, 1,102 IU vitamin D, 4.4 IU vitamin E, 4.4 mg menadione sodium bisulfite, 8.25 mg riboflavin, 28.6 mg d-pantothenic acid, 49.5 mg niacin, 165 mg choline, and .03 mg vitamin B12.
*To provide the following (milligrams per kilogram of complete diet): 39.6 Mn, 165 Fe, 165 Zn, 16.5 Cu, .3 I, and .3 Se.

Results

Immune Challenge by Diet Complexity Interaction. Interaction means are presented in Table 2. However, no interactions were observed for any of the response criteria between immune status and diet complexity (P > .10).

Immune Challenge Main Effects. From d 5 to 18 postweaning, ADG of the control pigs was higher (P < .05) than for either the LPS-challenged or pair-fed pigs (Tables 2 and 3). Average daily gain of the pair-fed pigs was higher than that of the pigs challenged with LPS (P < .01), although both groups of pigs ate the same amounts of feed (P > .10). The control pigs had higher (P < .05) ADFI than either the LPS-challenged or pair-fed pigs. The pair-fed pigs had a higher G/F (P < .05) than the LPS-challenged pigs for that time period. The pair-fed pigs also had a higher G/F than the control pigs (P < .05). No difference...
Table 2. Interactive means of immune challenge and diet complexity on growth performance and haptoglobin production\(^a\)

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>LPS-challenged</th>
<th>Pair-fed</th>
<th>P-value (P &lt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complex</td>
<td>Medium</td>
<td>Simple</td>
<td>Complex</td>
</tr>
<tr>
<td>ADG, g (g/day)</td>
<td>368(^{be})</td>
<td>331(^{bf})</td>
<td>281(^{bg})</td>
<td>272(^{ce})</td>
</tr>
<tr>
<td>ADFI, g (g/day)</td>
<td>400(^{be})</td>
<td>372(^{bf})</td>
<td>336(^{bg})</td>
<td>300(^{ce})</td>
</tr>
<tr>
<td>G/F</td>
<td>(.92)^{be})</td>
<td>(.88)^{be})</td>
<td>(.84)^{bf})</td>
<td>(.90)^{be})</td>
</tr>
<tr>
<td>Pig weight, kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 18 postweaning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 32 postweaning(^g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haptoglobin, mgHgb/dL</td>
<td>10.7(^{be})</td>
<td>8.7(^{bf})</td>
<td>10.5(^{bd})</td>
<td>28.0(^{ce})</td>
</tr>
</tbody>
</table>

\(^a\)All pigs were fed a complex common diet from d 0 to 5 postweaning. Pigs then were fed the complex, medium, or simple diets from d 5 to 18 postweaning. All pigs were fed a common diet from d 18 to 32 postweaning. The pigs lipopolysaccharide (LPS) challenged were injected with LPS (150 \(\mu\)g/kg BW), and the control and pair-fed were injected with endotoxin-free Hanks' balanced salt solution (HBSS; 2 mL/pig) on d 5, 8, 11, and 14 postweaning. Weight on d 5 postweaning was used as a covariate. Each number represents the mean of six pens with five pigs per pen. Pigs were 5.0 kg and 19 \(\pm\) 1.5 d of age on d 5 after weaning. Interactions between immune status and diet complexity were not observed (P > .10) for any of the response criteria. \(^b\)Means within the main effect of immune challenge and within row lacking a common superscript letter differ (P < .05). \(^c\)Means within the main effect of diet complexity and within row lacking a common superscript letter differ (P < .05). \(^d\)Control vs. LPS-challenged (P < .10). \(^e\)Medium vs. simple diet (P < .10).
Table 3. Main effect means of immune challenge and diet complexity on growth performance and haptoglobin production

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>LPS-challenged</th>
<th>Pair-fed</th>
<th>Diet complexity</th>
<th>P-value (P&lt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Complex</td>
<td></td>
</tr>
<tr>
<td>Day 5 to 18 postweaning</td>
<td></td>
<td></td>
<td></td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>ADG, g</td>
<td></td>
<td>327b</td>
<td>246c</td>
<td>273d</td>
<td>309e</td>
</tr>
<tr>
<td>ADFI, g</td>
<td>371³b</td>
<td>281c</td>
<td>279f</td>
<td>.93e</td>
<td>.93e</td>
</tr>
<tr>
<td>G/F</td>
<td>.88b</td>
<td>.87b</td>
<td>.97c</td>
<td>.95e</td>
<td>.95e</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Simple</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>246c</td>
<td>273d</td>
<td>309e</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medium</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Simple</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CV</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 18 to 32 postweaning</td>
<td></td>
<td></td>
<td></td>
<td>Complex</td>
<td></td>
</tr>
<tr>
<td>ADG, g</td>
<td>571</td>
<td>549</td>
<td>556</td>
<td>557</td>
<td>.14</td>
</tr>
<tr>
<td>ADFI, g</td>
<td>849³k</td>
<td>813³b</td>
<td>855³e</td>
<td>833³e</td>
<td>.07</td>
</tr>
<tr>
<td>G/F</td>
<td>.68</td>
<td>.68</td>
<td>.66</td>
<td>.67</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medium</td>
<td>.52</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Simple</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CV</td>
<td>6.9</td>
</tr>
<tr>
<td>Day 5 to 32 postweaning</td>
<td></td>
<td></td>
<td></td>
<td>Complex</td>
<td></td>
</tr>
<tr>
<td>ADG, g</td>
<td>453³b</td>
<td>403c</td>
<td>419³d</td>
<td>437³e</td>
<td>.01</td>
</tr>
<tr>
<td>ADFI, g</td>
<td>619³b</td>
<td>556c</td>
<td>578³f</td>
<td>593³e</td>
<td>.01</td>
</tr>
<tr>
<td>G/F</td>
<td>.73</td>
<td>.73</td>
<td>.73</td>
<td>.74³e</td>
<td>.80</td>
</tr>
<tr>
<td></td>
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<td>4.9</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>CV</td>
<td>5.6</td>
</tr>
<tr>
<td>Pig weight, kg</td>
<td></td>
<td></td>
<td></td>
<td>Control vs. LPS-challenged (P &lt; .10)</td>
<td></td>
</tr>
<tr>
<td>d 18 postweaning</td>
<td>9.2³b</td>
<td>8.1³c</td>
<td>8.5³d</td>
<td>9.0³e</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>17.2³b</td>
<td>15.8³c</td>
<td>16.3³d</td>
<td>16.8³e</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>10.0³b</td>
<td>23.3³c</td>
<td>8.6³d</td>
<td>15.5³e</td>
<td>.01</td>
</tr>
<tr>
<td>Haptoglobin, mgHgb/dL</td>
<td></td>
<td></td>
<td></td>
<td>Medium vs. simple diet (P &lt; .10)</td>
<td></td>
</tr>
<tr>
<td>d 18 postweaning</td>
<td>10.0³b</td>
<td>23.3³c</td>
<td>8.6³d</td>
<td>15.5³e</td>
<td>.01</td>
</tr>
</tbody>
</table>

All pigs were fed a common diet from d 0 to 5 postweaning. Pigs then were fed the complex, medium, and simple diets from d 5 to 18 postweaning. All pigs were fed a common diet from d 18 to 32 postweaning. The pigs lipopolysaccharide (LPS) challenged were injected with LPS (150 µg/kg BW) and the control and pair-fed were injected with endotoxin-free Hanks' balanced salt solution (HBSS; 2 mL/pig) on d 5, 8, 11, and 14 postweaning. Weight on d 5 postweaning was used as a covariate. Each number represents the mean of 18 pens with five pigs per pen. Pigs were 5.0 kg and 19 ± 1.5 d of age on d 5 after weaning. Interactions between immune status and diet complexity were not observed (P > .10) for any of the response criteria.

Means within the main effect of immune challenge and within row lacking a common superscript letter differ (P < .05). Means within the main effect of diet complexity and within row lacking a common superscript letter differ (P < .05). Control vs. LPS-challenged (P < .10). Medium vs. simple diet (P < .10).

occurred in G/F between LPS-challenged and control pigs (P > .10).

When all pigs were fed a common diet from d 18 to 32 postweaning, ADG of the LPS-challenged pigs was similar to that of the pair-fed pigs. However, pigs previously challenged with LPS had lower ADFI than either the control (P < .10) or pair-fed (P < .01) pigs. No differences (P > .10) occurred between immune challenge treatments for G/F for this period, but the pair-fed pigs had numerically lower G/F than either the control or pigs injected with LPS.

For the d 5 to 32 postweaning period, ADG of the control pigs was higher (P < .05) than either that of the LPS-challenged or pair-fed pigs. The ADG of the LPS-challenged pigs was lower (P < .05) than that of the pair-fed pigs. Average daily feed intake of the control pigs was higher (P < .05) than for either the pigs challenged with LPS or pair-fed pigs for this period.

The control pigs were heavier (P < .01) than either the LPS-challenged or pair-fed pigs on d 18 and 32 postweaning. Pair-fed pigs were heavier (P < .01) than the LPS-challenged pigs on d 18 and 32 postweaning.

**Diet Complexity Main Effects.** From d 5 to 18 postweaning, pigs fed the complex diets had greater ADG and ADFI (P < .05) than pigs fed either the medium or simple diets (Tables 2 and 3). Furthermore, pigs fed the medium complexity diet had greater ADG and ADFI (P < .05) than pigs fed the simple diet from d 5 to 18 postweaning. Pigs fed the complex and medium diets had better G/F (P < .05) than pigs fed the simple diets.

In the subsequent d 18 to 32 postweaning period when all pigs were fed the same diet, ADG was similar (P > .10) for pigs fed the complex, medium, and simple diets. However, pigs previously fed the simple diet had numerically higher ADG than pigs previously fed the complex or medium diet. Pigs previously fed the simple diet from d 5 to 18 postweaning had higher ADFI (P < .05) than the pigs previously fed the medium diet.

For the overall d 5 to 32 postweaning period, pigs fed the complex diets had higher ADG (P < .05) than pigs fed the simple diet. No differences (P > .10) were observed in ADFI. Feed efficiency was similar (P > .10) for pigs fed the complex diet and those fed the medium diet; however, pigs fed the simple diet had lower G/F (P < .05) than pigs fed the complex or medium diet.

Pig weights on d 18 postweaning were the heaviest (P < .05) for pigs fed the complex diet and lightest (P < .05) for pigs fed the simple diet, with pigs fed the medium diet being intermediate in weight. Pigs fed...
the complex diet were heavier (P < .05) than pigs fed the simple diet on d 32 postweaning. Pigs fed the medium diet tended to be heavier (P < .10) than pigs fed the simple diet on d 32 postweaning.

Haptoglobin. Mean plasma haptoglobin concentrations were 17.5, 13.0, and 11.3 ± 1.3 mg Hgb/mL on d 8, 11, and 14 postweaning, respectively, and were different across day (P < .01). However, no sampling day × treatment interactions occurred, so the data were pooled across day (Tables 2 and 3). No diet × immune status interactions occurred. Pigs injected with LPS had higher (P < .01) mean haptoglobin concentrations than control or pair-fed pigs. Diet did not have an effect (P > .10) on haptoglobin concentration.

Discussion

When pigs are exposed to infectious agents, several immune defenses are activated. These include antigen-specific defenses such as cell-mediated or antibody-mediated responses. Other defenses include nonspecific measures such as the inflammatory and acute-phase responses. In addition to being integral components of the immune system, these nonspecific responses have an impact on growth and nutrient partitioning (Klasing, 1994). The inflammatory and acute-phase responses are mediated by hormone-like compounds termed cytokines (Kuby, 1992). Many cytokines decrease voluntary food intake, increase resting energy expenditure and body temperature, and alter nutrient metabolism (Klasing, 1988).

Pigs raised in environments with low levels of endotoxin have better growth performance than those raised in environments with high levels of endotoxin (Crowe et al., 1994). Lipopolysaccharide is a potent endotoxin. Wan et al. (1989) showed that LPS can be absorbed readily into the systemic circulation via the gastrointestinal tract. Research has indicated that growth performance is improved and cytokine production decreased when animals are raised in an environment of high sanitation (i.e., filtered air to remove dust, endotoxin, and dander along with frequent cleaning and removal of manure) compared with a less sanitary environment (Roura et al., 1991). Animals raised in both environments were free from any detectable infectious pathogens. Thus, the negative effects on growth performance of the inflammatory and acute-phase responses may be due not only to infectious pathogens but to the amount of immunostimulants in the environment as well. Consequently, using an LPS model of immune challenge may be more representative of actual on-farm conditions than using individual infectious pathogens.

Immune Challenge by Diet Complexity Interaction. The absence of detectable interactions between diet complexity and immune challenge with LPS indicates that the responses are independent. Therefore, if the LPS stimulation model is representative of the complex interplay of immunostimulants present in many commercial swine production systems, these results indicate immune status does not need to be taken into account when determining the appropriate complexity of nursery diets.

The two major differences in the complexity of the diets were the level of specialty protein sources and lactose. The stimulatory effects of spray-dried plasma protein on feed intake have been well characterized in young weanling pigs (Hansen et al., 1993; Kats et al., 1994). However, the biological mechanism has not been well defined. Some studies have indicated that the increased feed intake response to feeding spray-dried plasma protein to weanling pigs is greater in a dirty environment than in a clean environment and greater in pigs with a high degree of antigen exposure than in those with a low degree of exposure (Coffey and Cromwell, 1994b; Stahly et al., 1995a). Further research has shown that when spray-dried plasma protein is fractionated into different molecular weight components, the immunoglobulin in fraction retained the stimulatory effects on feed intake (Gatnau et al., 1995; Owen et al., 1995; Pierce et al., 1995, Weaver et al., 1995). It is hypothesized that an interaction occurs between the immunoglobulin fraction and immune system to facilitate the increased feed intake. This hypothesis is based on the premise that the immunoglobulin fraction decreases exposure of the immune system to antigens, leading to a decreased production of inflammatory cytokines. A similar mechanism has been proposed to explain the growth-promoting response to antibiotics (Roura et al., 1991). These researchers have shown that animals raised in clean environments have better growth performance and lower inflammatory cytokine concentrations than animals raised in dirty environments. They also found an interaction in the growth response to dietary antibiotics and environment. Growth response was absent in the clean environment; however, in the dirty environment, antibiotic inclusion increased growth performance and decreased inflammatory cytokine production. Other research in swine has indicated a similar growth response to the inclusion of dietary antibiotics (Stahly et al., 1994, 1995b). Nonetheless, other research has failed to detect an interaction between growth-promoting agents (antibiotics and copper sulfate) and the inclusion of spray-dried plasma protein in nursery diets (Coffey and Cromwell, 1994a). Our research agrees with that of Coffey and Cromwell (1994a) that the ADFI response to spray-dried plasma protein is independent of an inflammatory challenge and presumably the concentrations of inflammatory cytokines. Therefore, in summary, growth-promoting agents such as antibiotics appear to alter the balance of inflammatory cytokines, leading to increased feed intake. However, the stimulatory effects on feed intake of diet complexity and spray-dried
animal plasma protein do not seem to be the results of an altered balance of inflammatory cytokines.

Immune Challenge Main Effects. Average daily feed intake was the same for pigs on the LPS treatment compared with pigs on the pair-fed treatment for the d 5 to 18 postweaning period and was 24% lower than that of the control pigs. The pair-feeding was performed to determine the portion of the decreased growth caused by decreased feed intake and the portion caused by altered nutrient partitioning to the immune system. Thus, the increased ADG of the pair-fed pigs compared with the pigs challenged with LPS was due to the pair-fed pigs having a better G/F. This can be explained by the fact that challenge of the immune system with endotoxin has been shown to increase the production of metabolic heat (Gump et al., 1970, Baracos et al., 1987). Because more energy is partitioned to metabolic heat production, the efficiency of utilization of dietary energy and therefore the efficiency of growth is reduced.

The increased G/F of the pair-fed pigs compared with control pigs may be accounted for by the fact that heat production is lower in animals fed below ad libitum levels (Graham et al., 1959; Baracos et al., 1987). Heat production is related to ME intake and BW (Noblet et al., 1994). These researchers reported that 26% of ME intake is partitioned to heat production. Thus, the metabolic heat production in immune-challenged pigs was the sum of the increased rate from immune stimulation and the decreased rate from decreased feed intake.

The lower ADFI of the LPS-challenged pigs from d 18 to 32 postweaning indicates a carry-over effect of LPS-induced immune challenge on feed intake, because they had the same feed intake as the pair-fed pigs from d 5 to 18 postweaning.

The difference in average weight on d 18 postweaning between the pair-fed and control pigs was due to the decreased growth from decreased feed intake by the former. The difference in weights between the LPS and pair-fed pigs probably was due to the different efficiency of nutrient use for growth, because both groups ate the same amount of feed. Consequently, the lower weight of 1.1 kg per pig at d 18 postweaning for the LPS-challenged pigs compared with the control pigs was the result of both decreased efficiency of gain and decreased feed intake. The difference in pig weight (.4 kg) between pair-fed and pigs injected with LPS was due to the decreased efficiency of gain from immune challenge, and the difference in pig weight (.7 kg) between control and pair-fed pigs is indicative of the amount of decreased growth due to the lower feed intake of the LPS and pair-fed pigs.

Therefore, when the decreased growth performance from LPS-induced immune challenge is considered, approximately two thirds of the decrease was due to decreased nutrient intake and one third was due to decreased efficiency of nutrient use for growth. The magnitude of the ratio between the two factors is important for economic considerations, because inefficient nutrient use for growth will have a larger economic impact than decreased nutrient intake. This is because the former use for growth incurs the expense of the increased nutrients used per unit of output (gain). Although decreased nutrient intake results in decreased gain, it does not incur increased cost per unit of gain. The only cost incurred is the lost opportunity cost that more kilograms of pork can be generated per unit of time and space.

Diet Complexity Main Effects. The growth performance from d 5 to 18 postweaning indicates that the difference in performance between pigs fed the complex and medium diets was due solely to the pigs fed the complex diet eating more feed per day. The differences in growth performance from d 5 to 18 postweaning between pigs fed the simple diet and pigs fed the medium or complex diet was due to both decreased ADFI and G/F. The decreased G/F of pigs fed the simple diet could be an indication that either the ingredients used were not as digestible or the absorptive capacity of the intestine was damaged by the diet.

Other research has indicated that the advantage to feeding complex diets is maintained through market weight (Tokach et al., 1990; Stairs et al., 1991). Further work by Dritz et al. (1994b) indicated that pigs weaned at 9 d of age and fed simple diets from weaning to 18 kg tended to have more carcass fat and smaller longissimus muscle area than pigs weaned at 9 d of age and fed medium or complex diets. The results of Dritz et al. (1994b) indicated that differences in ADG from diet complexity were influenced by feed intake and(or) efficiency of gain.

Haptoglobin. Lipopolysaccharide is a potent stimulator of inflammatory cytokine production. Interleukin-1 and other proinflammatory cytokines elicit the synthesis of acute-phase proteins, which increase rapidly during inflammatory responses (Gauldie and Baumann, 1991). Haptoglobin is one of several acute-phase proteins produced in an initial immune response (Gauldie and Baumann, 1991). Decreased concentrations of haptoglobin indicate lower inflammatory cytokine production and are correlated with increased weight gain in pigs (Eurell et al., 1992). Thus, increased haptoglobin concentrations in the pigs injected with LPS indicate increased inflammatory cytokine production. The lack of an influence of diet on haptoglobin concentration suggests that diet complexity does not influence feed intake by altering the balance of inflammatory cytokines.

Implications

Determining the optimum diet complexity for a nursery feeding program will depend on the desired balance between growth performance and feed cost per kilogram of gain but seem to be independent of
immune response to inflammatory challenge. On a practical basis, this suggests that nursery diet complexity should not be influenced by health status. When eating the same amount of feed, pair-fed pigs were more efficient at using nutrients for growth than pigs injected with lipopolysaccharide.

Literature Cited


