Variation in the response of multiple genetic populations of pigs to ractopamine

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ABSTRACT: Several research trials have evaluated the impact of ractopamine on barrows and gilts of various genetic populations. Overall, the desirable response of ractopamine to increase daily carcass lean gain, improve feed efficiency, and increase carcass lean percentage has been observed in genetic populations of substantially different lean growth rates and carcass lean percentages. Six trials have evaluated the magnitude of genetic populations × ractopamine interactions. In one trial, carcass muscle accretion (g/d) increased with ractopamine to a greater extent in high-lean-gain (High-Lean) barrows than in low-lean-gain (Low-Lean) barrows ($P < 0.02$). Dissected fat accretion (g/d) was reduced by a greater magnitude in the High-Lean than in the Low-Lean barrows ($P < 0.04$). A second trial evaluated the ractopamine response in five genetic populations of barrows and found significant ractopamine × genetic populations interactions ($P < 0.05$) for daily carcass lean gain. Regression of the carcass lean gain of pigs fed ractopamine on the mean carcass lean gain of the controls for the five genetic populations indicated that the ractopamine effects could be described as a constant percentage (25%) increase in daily lean gain above the controls. The third trial evaluated the response of Paylean in 300 gilts in a 3 × 4 factorial with three genetic populations (commercial terminal crosses) and four ractopamine levels (0, 5, 10, and 20 ppm). The genetic populations had similar carcass lean percentage. No genetic populations × ractopamine interactions were found ($P > 0.10$). Overall, the research indicates that ractopamine has a positive impact on barrows and gilts with substantially different genetic potentials for lean growth and carcass lean percentage. The ractopamine response to increase lean growth has been found to be proportional to the genetic potential of the genetic populations. Recent research has found significant genetic populations × environmental interactions for pigs reared in different health status environments. Environment × ractopamine and environment × ractopamine × genetic populations interactions for compositional growth in pigs need to be evaluated.

Key Words: β-Adrenergic Agonists, Genetics, Lean, Growth, Pigs

 J. Anim. Sci. 80(E. Suppl. 2):E85–E89

Introduction

Ractopamine is a β-adrenergic agonist that, when fed to pigs, increases carcass leanness by increasing muscle accretion and decreasing fat deposition (Watkins et al., 1990). Carcass muscle accretion is increased to a greater extent than visceral organ growth, causing an increase in dressing percentage. With small (0 to 5%) decreases in daily feed intake, ractopamine substantially improves both live weight and lean efficiency (Watkins et al., 1990; Gu et al., 1991a,b).

Genetic selection has substantially increased carcass muscle accretion rates and decreased carcass fat accretion rates (Schinckel and De Lange 1996; Schinckel, 1999). It is possible that genetic populations selected for increased carcass lean gain may express a greater response to dietary ractopamine because of their increased DNA concentration, which may allow increased ractopamine response for increased carcass muscle accretion (Bark et al., 1992). Selection for reduced fat accretion has altered fatty acid metabolism (Mills et al., 1990). It is possible that the responsiveness of the fat tissue to dietary ractopamine could differ among genetic populations of pigs. The objectives of this paper are 1) to review the literature, 2) to discuss potential genetic populations × ractopamine interactions, and 3) to identify areas where future research is warranted.

Evaluation of Ractopamine in Different Genetic Populations

The response to ractopamine (20 ppm) was evaluated in two lines of pigs that were fed either high- or low-protein diets from 60 to 90 kg live weight (Mitchell et al., 1990). The two genetic populations of barrows had

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Received July 28, 2001.
Accepted February 22, 2002.

been selected for seven generations for rapid lean growth when fed either the high- (**HS line**) or low- (**LS line**) protein diet. Pigs of the HS line were leaner and more feed-efficient than LS pigs when fed the control 12 or 24% protein diets. Line × diet × ractopamine treatment interactions ($P < 0.05$) were noted for whole carcass lipid, backfat thickness, dissected fat growth, and longissimus muscle area. This trial supports the conclusion that it is possible that genetic population × ractopamine interactions can be produced by the essential amino acid or crude protein levels used in the trial.

Yen et al. (1990) conducted a trial using obese and lean barrows produced by multiple generations of selection for high or low backfat thickness. The two genetic populations were Duroc obese × Yorkshire obese and Duroc lean × Yorkshire lean pigs. The pigs (14 obese and 12 lean) were fed a 16% crude protein diet for a 48-d feeding period. Dietary supplementation with 20 ppm ractopamine reduced the feed intake and improved feed efficiency in both genetic populations ($P < 0.05$). Ractopamine decreased 10th rib fat depth of both genetic populations ($P < 0.05$) 6.7 to 5.9 cm in the obese pigs and 2.5 to 1.9 cm the lean pigs.

Pigs fed ractopamine had higher dressing percentage (76.4 vs 75.3%, $P < 0.05$), longissimus muscle area (32.7 vs 26.3 cm^2, $P < 0.05$), predicted muscle mass (35.7 vs 33.0 kg, $P < 0.05$), and dissected ham lean mass (15.5 vs 13.1 kg, $P < 0.05$) than the control pigs. Ractopamine increased the percentage of moisture (70 vs 69.5%, $P < 0.05$), reduced the percentage of lipid (8.45 vs 10.35%, $P < 0.05$), and increased the percentage of crude protein (20.25 vs 19.30%, $P < 0.05$) in the dissected ham lean. Although genetic populations and ractopamine effects were significant, no significant genetic population × ractopamine interactions were found ($P > 0.05$).

The effect of ractopamine in contemporary U.S. crossbred, purebred Chinese Meishan, and Meishan-cross pigs was evaluated by Yen et al. (1991). Twenty-four U.S. crossbred (Duroc × White composite), 24 purebred Meishan and 24 Meishan × White composite crossbred barrows were fed 16% CP corn-soybean meal diets with either 0 or 20 ppm ractopamine for 52 d. Ractopamine increased average daily gain, feed efficiency, dressing percentage, and predicted carcass muscle in all three genotypes. A significant genetic population × ractopamine interaction was found for longissimus muscle area (**LMA**). Ractopamine increased LMA in the Duroc × White composite pigs from 37.9 to 45.1 cm^2 ($P < 0.01$) and increased the LMA of the Meishan-cross pigs from 28.0 to 32.3 cm^2 ($P < 0.05$). However, ractopamine did not increase LMA in the pure Meishan pigs (19.0 and 17.8 cm^2 for the control and ractopamine-fed pigs, respectively). Although the lean growth rates were not calculated by the original authors, Bark et al. (1992) predicted that ractopamine increased carcass lean growth by 79 g/d in the U.S. crossbred pigs and only 29 g/d in the purebred and crossbred Meishan pigs.

To evaluate the responses of pigs of different genetic potential for carcass lean growth to ractopamine treatment, Bark et al. (1992) used two genetic populations of pigs representing low (**Low-Lean**) and high (**High-Lean**) genetic potential for lean growth. Within each genetic population, two littermate barrows from eight litters were given ad libitum access to a lysine-supplemented corn-soybean diet (1.08% lysine) containing 0 or 20 ppm of ractopamine from 63 to 104 kg. Barrows of the High-Lean line had higher average daily gain (0.89 vs 0.63 kg/d, $P < 0.05$), and carcass lean growth (282 vs 132 g/d, $P < 0.05$) and had better feed conversion (3.25 vs 4.28, $P < 0.05$) than the Low-Lean barrows on the control diets. Ractopamine increased average daily gain (0.83 to 0.76 kg/d, $P < 0.01$) and improved feed:gain (3.33 vs 3.77, $P < 0.01$). Ractopamine enhanced carcass muscle accretion rate to a greater extent in the High-Lean barrows (282 to 476 g/d) than in the Low-Lean barrows (132 vs 173 g/d). Ractopamine also reduced the accretion rate of dissectible fat tissue by a greater extent in the High-Lean barrows (132 vs 273 g/d) than in the Low-Lean barrows (205 vs 292 g/d, $P < 0.04$). Lean feed efficiency, calculated as the muscle gain (kg) per feed intake (kg), was increased more in the High-Lean pigs (0.102 to 0.179) than in the Low-Lean pigs (0.048 to 0.066, $P < 0.01$).

As in past trials, ractopamine increased the percentage of protein in the dissected muscle (19.0 to 20.0% in the Low-Lean pigs and 20.0 to 21.4% in the High-Lean pigs). The percentage of lipid in the muscle was decreased ($P < 0.01$) by ractopamine from 14.0 to 12.9% in the Low-Lean pigs and from 10.4 to 7.8% in the High-Lean pigs. Genetic population × ractopamine interactions were not significant for the changes in the chemical composition of the dissected muscle tissue ($P = 0.49$), dissected muscle mass, or on a lipid-free basis ($P = 0.61$).

It is important to note that for this trial pigs were fed ractopamine on a weight-constant basis (63 to 104 kg live weight). The ractopamine response diminished with time. The Low-Lean barrows required an additional 21 d (63 vs 42 d) to reach the designated final weight. Ractopamine increased average daily gain approximately 0.20 kg/d during the initial 14-d period in both genetic populations. From 14 to 28 d, the ractopamine response for average daily gain was approximately halved and then became close to zero from 28 to 42 d on test. The Low-Lean barrows fed ractopamine had a numerically lower average daily gain than the control pigs from 42 to 63 d of age.

If the impact of ractopamine to increase lean growth and decrease fat accretion also diminishes with the number of days on test, then the genetic population × ractopamine interactions were increased in magnitude by the 63- vs 42-d test period for Low-Lean and High-Lean pigs. When different genetic populations with different growth potentials are evaluated on control and ractopamine-supplemented diets, the relative magnitude of the ractopamine response may be different when the ractopamine treatment is targeted for a specific duration of time (e.g., 28 or 42 d) vs a constant weight interval (e.g., 70 to 100 kg live weight).

Table 1. Ractopamine (ractopamine) × genotype (GT) least squares means for average daily fat standardized lean growth (g/d)

GT	ADSLG[a], 0 ppm ractopamine	ADSLG[a] 20 ppm ractopamine
1	303 ± 19	318 ± 20
2	305 ± 18	391 ± 20
3	333 ± 18	422 ± 20
4	289 ± 18	342 ± 19
5	313 ± 18	452 ± 19

[a]ADSLG = average daily fat standardized lean growth (Gu et al., 1992).

A factorial experiment using 183 individually fed barrows was conducted by Gu et al. (1991a,b, 1992). Barrows of five genetic populations with two levels of ractopamine (0 and 20 ppm) were fed for one of three treatment periods (59 to 100, 73 to 114, and 86 to 127 kg live weight). Pigs were fed a high-energy 18.5% CP (0.95% lysine) diet with 3,594 cal of ME/kg. As in past trials, ractopamine improved feed conversion (3.17 vs 3.27, $P = 0.07$), increased dressing percentage (75.8 vs 74.5%), increased fat-standardized (10% fat) carcass lean percentage (51.1 vs 48.1%), and increased longissimus area (35.3 vs 32.5 cm^2). There were no significant ($P > 0.10$) ractopamine × genetic population interactions for these variables except for percentage of fat-standardized lean ($P < 0.10$).

Ractopamine increased fat-standardized lean gain (10% fat) by 25% (385 vs 308 g/d) and increased lean feed efficiency (fat-standardized lean gain/feed intake) by 25.5% (0.1270 vs 0.1012). There were significant ractopamine × genetic population interactions for fat-standardized lean gain ($P = 0.03$) and fat-standardized lean efficiency ($P = 0.08$). The fat-standardized lean gain for the pigs of the five genetic populations fed ractopamine were regressed on the mean of the five genetic populations fed control diets with the effects of replicate and weight interval included in the model (Table 1). The regression coefficient was 1.25, indicating that a multiplicative adjustment of 1.25 times the control could be used to predict lean gain for ractopamine-fed pigs.

The data from Bark et al. (1992) were also added to the regression analyses. The overall model for the constant weight interval ractopamine response for lean growth resulted in 1) a greater absolute magnitude in high-lean-growth genetic populations and 2) a constant percentage increase in lean growth as a simple means to predict the response to ractopamine unless actual research data are available.

Recently, a trial was conducted in which gilts of three modern high-lean gain terminal crosses were fed four levels of ractopamine (0, 5, 10, and 20 ppm) for a 4-wk feeding period (Herr et al., 2001a). Gilts started on test at 81.6 kg live weight and were fed diets formulated to contain 18.6% CP and 1.1% lysine. The three genetic populations had similar carcass lean percentage. One genetic population had a 7.0% higher average daily gain than the other two genetic populations. Three hundred gilts were blocked by weight into 60 pens (five pens per ractopamine level × genetic population treatment). Overall, ractopamine increased average daily gain by 14.5% and improved feed conversion by 14.6%. No significant genetic population × ractopamine treatment interactions were found.

Variation in the Response to the Level of Ractopamine

The responses of pigs fed 5 to 20 ppm ractopamine have been summarized (Watkins et al., 1990; Elanco, 1999; Table 2). In the initial trials completed in the late 1980s to early 1990s, pigs were fed 16% corn-soybean meal diets from 67 to 104 kg live weight. The duration on test was approximately 41 to 42 d. The control pigs averaged 2.74 cm 10th rib backfat depth at 104 kg live weight.

In a recent trial (Herr et al., 2001a) gilts were fed for a 4-wk period starting at 83.5 kg live weight. The modern high-lean pigs were substantially leaner (1.78 cm backfat at 112 kg) and had better feed conversion and lower feed intakes than pigs of the past trials. In the recent trial, the proportion of maximal response (20 ppm) achieved by the gilts fed 5 ppm was greater than in the past trials conducted with lower-lean-growth, lower-percentage-lean pigs (Table 2). The environment, health status, and other factors may have changed such that the pigs' relative response to the lower level of ractopamine changed. It is important to note that the length of feeding was much shorter in the recent trial, and that may have affected the relative response to ractopamine. However, it is also possible that pigs selected 10 yr for lean growth and lean efficiency are more sensitive to lower levels of ractopamine (5 ppm).

Variation in the Response to Ractopamine

The response to ractopamine also changes with duration of feeding (Bark et al., 1992; Williams et al., 1994; Herr et al., 2001b,c). The greatest response occurs during the first 14 to 21 d and declines slowly thereafter. In past research, pigs fed ractopamine had higher growth rates than control pigs in both wk 5 (0.85 vs 0.73 kg/d) and wk 6 of ractopamine feeding (0.90 vs 0.86 kg/d, N = 141 per mean, Williams et al., 1994). By wk 7, the improvement in growth rate diminished (0.81 vs 0.79 kg/d). In two recent trials, pigs fed a constant level of 11.6 or 20 ppm had slower growth rates and poorer feed efficiency than control pigs by the 5th wk on test (Herr et al., 2001b,c). Only increasing the level of ractopamine can increase the growth rate after 5 and 6 wk on ractopamine (Herr et al., 2001b; Schinckel et al., 2001). It is possible that high-lean-growth pigs have a shorter duration of response to ractopamine. Only research trials evaluating past and current genetic populations of

Table 2. Relative responses of feeding 5 ppm vs 20 ppm ractopamine in past and recent research trials

	Past trials[a]					Recent trials[b]				
Growth variable	0 ppm	5 ppm	20 ppm	SE	Response 5 ppm/20 ppm	0 ppm	5 ppm	20 ppm	SE	Response 5 ppm/20 ppm
Average daily gain, g/d	834	894	916	5	0.72	884	993	1,025	13	0.90
Average feed intake, kg/d	2.99	2.95	2.87	0.02	0.33	2.61	2.55	2.48	0.05	0.55
Feed conversion	3.62	3.33	3.16	0.02	0.63	2.95	2.56	2.43	0.05	0.75
Carcass variables										
Dressing percentage	73.3	73.7	74.4	0.1	0.36	73.3	74.3	74.4	0.2	0.90
Percentage lean	51.8	53.9	57.5	0.1	0.37	54.7	55.3	56.2	0.3	0.55
10th Rib backfat depth, cm	2.74	2.69	2.41	0.05	0.24	1.78	1.68	1.65	0.05	0.77

[a]Summary of 20 trials with 479, 486, and 469 pigs per ractopamine level. Percentage dissected muscle tissue. Pigs fed from 67 to 104 kg on 16% CP diets (Watkins et al., 1990; Elanco, 1999).

[b]Summary of 75 gilts per ractopamine level of three terminal crosses (Herr et al., 2001a). Gilts fed 18.6% CP, 1.1% lysine diets for 4 wk, starting at 83.5 kg. Percentage lean was predicted from optical probe measurements.

pigs can evaluate whether genetic selection has altered the ractopamine response relative to time or weight on test.

Genetic Population × Ractopamine × Environmental Interactions

Pigs reared under average commercial conditions have live weight growth rates from 0.70 to 0.80 kg/d, compared to 0.90 to 1.10 kg/d when reared in less-limiting, almost ideal research facilities (Holck et al., 1998; Schinckel, 1999). Lines selected for increased lean feed efficiency, increased carcass lean percentage, and reduced feed intake can be substantially more sensitive to poorer health status environments in terms of growth rate, feed conversion, morbidity, and mortality (Frank et al., 1997; Kendall et al., 1999).

What is the expected response to ractopamine in pigs only achieving 60% to 70% of their maximal genetic potential observed under more ideal conditions? Will ractopamine allow greater expression of the high-lean-growth pigs and overcome the environmental effects? Or will the ractopamine response be limited by the environment? In this case, the response to ractopamine may be greater in the less-sensitive genetic populations of pigs that achieve a higher percentage of their maximal genetic potential of lean growth when raised under typical commercial conditions.

Swine growth models assume that ractopamine produces a consistent percentage improvement in carcass lean growth and protein accretion. The model assumes a consistent increase based on the commercially achieved performance levels (phenotype). The effects of the pigs' maximal genetic potential for lean growth (protein accretion), the environmental effects, and genetic × environmental interactions are not taken into account.

Ractopamine by Sex Interactions

Several trials have evaluated the effect of ractopamine in barrows and gilts (Uttaro et al., 1993; Williams et al., 1994; Elanco, 1999). In general, similar responses to ractopamine on growth rate, feed intake, lean gain, and carcass measurements for barrows and gilts were found. The responses of barrows and gilts to 20 ppm dietary ractopamine were similar for carcass characteristics, processing yields, and measures of pork quality (Uttaro et al., 1993).

One 6-wk trial evaluated the ractopamine response when the levels of ractopamine increased (5, 10, and 20 ppm), decreased (20, 10, and 5 ppm), or remained constant (11.65 ppm) for the three biweekly periods (Herr et al., 2001a). No sex × ractopamine treatment interactions were significant for any growth performance or carcass trait.

Another trial evaluated the effect of 20 ppm dietary ractopamine on boars, barrows, and gilts (Dunshea et al., 1993). The pigs were fed from 60 to 90 kg live weight. Ractopamine increased average daily gain in barrows (1,399 vs 1,156 g/d, $P < 0.05$) and gilts (1,204 vs 1,031 g/d, $P < 0.05$), but not in boars (1,268 vs 1,276 g/d; 20 ppm/0 ppm). Dietary ractopamine increased daily protein accretion by 26, 51, and 53 g/d in boars, gilts, and barrows, respectively.

The ratio of daily empty body lipid to protein deposition was affected by sex ($P < 0.001$) and ractopamine ($P < 0.001$) without any significant sex × ractopamine interactions. No significant sex × ractopamine interactions were found for empty body composition, carcass measurements, or organ weights. One possible explanation for the smaller live weight growth and protein accretion response in the boars is that the dietary lysine (18.3% CP, 1.1% lysine formulated, 17.7% CP, 1.07% lysine actual values) may have been limiting (Dunshea et al., 1993).

Summary

Overall, ractopamine has increased the carcass lean growth rate and feed efficiency of pigs with substantially different genetic backgrounds. The average daily gain, feed efficiency, and carcass muscle growth varies from trial to trial, depending on the duration of the

trial and the lysine level fed. In general, the impact of ractopamine to increase lean growth rate is greater in genetic populations of pigs selected for increased lean growth.

The 5 ppm level of ractopamine is effective in producing substantial improvements in performance in modern high-lean-gain pigs. However, the duration of the response to ractopamine may have decreased as a result of genetic selection. Also, modern high-lean-gain pigs may require diets containing higher concentrations of lysine and other essential amino acids to allow maximum performance levels to be achieved.

Implications

The desirable response of ractopamine to increase daily carcass lean gain, improve feed efficiency, and increase carcass lean percentage has been observed in genetic populations of substantially different lean growth rates and carcass lean percentages. The magnitude of the ractopamine responses increases in genetic populations selected for increased lean growth. The pork industry can incorporate the use of ractopamine with the use of selected genetic populations and improved management to further increase the efficiency of pork production.

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