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Effects of dietary astaxanthin and ractopamine HCl on the growth and carcass characteristics of finishing pigs and the color shelf-life of longissimus chops from barrows and gilts

Abstract

A total of 160 pigs (initially 198 lb) were used to evaluate the effects of increasing dietary astaxanthin (AX, from Xanthophyllomyces dendrorhous yeast) and Ractopamine HCl (RAC) on the growth and carcass characteristics of finishing pigs as well as the color shelf-life of longissimus muscle (LM) chops from barrows and gilts. Pigs were weighed and randomly allotted to 1 of 8 dietary treatments fed for approximately 26 d preharvest. Dietary treatments consisted of a corn-soybean meal-based control diet, the control diet with 7.5, 15, 30, 60, or 120 ppm AX, and a corn-soybean meal-based diet with 10 ppm RAC and 7.5 or 20 ppm AX. Each treatment had 10 pens, with 2 pigs (1 barrow and 1 gilt) in each pen. A split-plot design with repeated measures was used to compare color characteristics of LM chops from individual barrows and gilts. Overall, pigs fed RAC had increased ($P < 0.01$) ADG and final BW and improved F/G compared with pigs not fed RAC. Among pigs not fed RAC, F/G improved (quadratic, $P < 0.05$) and a trend (quadratic, $P < 0.06$) was observed for increased ADG with increasing AX to 60 ppm. For carcass characteristics, pigs fed RAC had greater ($P < 0.03$) HCW, 10th-rib LM area, 24-h LM pH, and fat-free lean index (FFLI) than those not fed RAC treatments. Among pigs not fed RAC, a trend (quadratic, $P < 0.07$) occurred for increased yield with increasing AX. During 6 d of retail display, the initial (d 0) NPPC color score of LM chops from gilts was greater ($P < 0.03$) than that of chops from barrows. Subjective discoloration scores of LM chops did not differ initially, but increased (linear, $P < 0.01$) daily and were greater ($P < 0.02$) on d 6 for chops from barrows and pigs not fed RAC than chops from gilts and pigs fed RAC, respectively (gender Ã— d and treatment Ã— d interactions, $P < 0.04$). The CIE a* (redness) and CIE b* (yellowness) of LM chops decreased (linear, $P < 0.01$) during retail display, and chops from gilts and pigs fed RAC had lower ($P < 0.04$) CIE b* than chops from barrows and pigs not fed RAC, respectively, especially on d 0 (gender Ã— d and treatment Ã— d interaction, $P < 0.01$). Overall (d 0 to 6), discoloration scores and changes in objective total color were lower ($P < 0.02$) for LM chops from gilts and pigs fed RAC. These observations suggest that color shelf-life was extended for chops from gilts and pigs fed RAC.; Swine Day, Manhattan, KS, November 17, 2011

Keywords

Swine Day, 2011; Kansas Agricultural Experiment Station contribution; no. 12-064-S; Report of progress (Kansas State University. Agricultural Experiment Station and Cooperative Extension Service); 1056; Swine; Astaxanthin; Carcass characteristics; Finishing pig; Pork color; Ractopamine HCl

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Effects of Dietary Astaxanthin and Ractopamine HCl on the Growth and Carcass Characteristics of Finishing Pigs and the Color Shelf-Life of Longissimus Chops from Barrows and Gilts[1]

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Summary

A total of 160 pigs (initially 198 lb) were used to evaluate the effects of increasing dietary astaxanthin (AX, from *Xanthophyllomyces dendrorhous* yeast) and Ractopamine HCl (RAC) on the growth and carcass characteristics of finishing pigs as well as the color shelf-life of longissimus muscle (LM) chops from barrows and gilts. Pigs were weighed and randomly allotted to 1 of 8 dietary treatments fed for approximately 26 d preharvest. Dietary treatments consisted of a corn-soybean meal-based control diet, the control diet with 7.5, 15, 30, 60, or 120 ppm AX, and a corn-soybean meal-based diet with 10 ppm RAC and 7.5 or 20 ppm AX. Each treatment had 10 pens, with 2 pigs (1 barrow and 1 gilt) in each pen. A split-plot design with repeated measures was used to compare color characteristics of LM chops from individual barrows and gilts.

Overall, pigs fed RAC had increased ($P < 0.01$) ADG and final BW and improved F/G compared with pigs not fed RAC. Among pigs not fed RAC, F/G improved (quadratic, $P < 0.05$) and a trend (quadratic, $P < 0.06$) was observed for increased ADG with increasing AX to 60 ppm. For carcass characteristics, pigs fed RAC had greater ($P < 0.03$) HCW, 10th-rib LM area, 24-h LM pH, and fat-free lean index (FFLI) than those not fed RAC treatments. Among pigs not fed RAC, a trend (quadratic, $P < 0.07$) occurred for increased yield with increasing AX. During 6 d of retail display, the initial (d 0) NPPC color score of LM chops from gilts was greater ($P < 0.03$) than that of chops from barrows. Subjective discoloration scores of LM chops did not differ initially, but increased (linear, $P < 0.01$) daily and were greater ($P < 0.02$) on d 6 for chops from barrows and pigs not fed RAC than chops from gilts and pigs fed RAC, respectively (gender × d and treatment × d interactions, $P < 0.04$). The CIE a* (redness) and CIE b* (yellowness) of LM chops decreased (linear, $P < 0.01$) during retail display, and chops from gilts and pigs fed RAC had lower ($P < 0.04$) CIE b* than chops from barrows and pigs not fed RAC, respectively, especially on d 0 (gender × d and treatment × d interaction, $P < 0.01$). Overall (d 0 to 6), discoloration scores and changes in objective total color were lower ($P < 0.02$) for LM chops from gilts and pigs fed RAC. These observations suggest that color shelf-life was extended for chops from gilts and pigs fed RAC.

Key words: astaxanthin, carcass characteristics, finishing pig, pork color, Ractopamine HCl

[1] Appreciation is expressed to IGENE Biotechnology, Columbia, MD, for providing the Nāturxan astaxanthin and partial funding of the trial.

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Introduction

Astaxanthin is a carotenoid without potential for vitamin A activity in mammals that exists naturally in various plants, algae, and seafood. Its unique molecular structure as a xanthophyll may make it a potent antioxidant (Yuan et al., 2011[3]). Although used primarily for the pigmentation of farmed salmonids, astaxanthin may also improve their growth, immunity, and survival (Christiansen et al., 1995[4]). Research and interest in the potential benefits of astaxanthin for human health has increased, and environmentally friendly technologies can produce large quantities of natural astaxanthin.

Little information is available on the effects of dietary astaxanthin on pig performance and fresh pork color and quality. Yang et al. (2006[5]) reported a linear reduction in 10th-rib backfat depth and increases in carcass yield and LM area with the addition of 1.5 and 3 ppm dietary astaxanthin for 14 d preharvest; however, they did not observe any differences in measures of fresh pork color or quality. Using higher levels of astaxanthin, other researchers have reported improved growth, carcass, and pork quality characteristics for pigs fed 48 ppm for 90 d preharvest (Kim et al., 2008[6]) and improved pork color shelf-life for pigs fed 66.7 ppm for 42 d preharvest (Carr et al., 2010[7]).

The effects of Ractopamine HCl and gender on the color shelf-life of fresh pork have not been clarified. Despite observing an increased polyunstaturated fatty acid:saturated fatty acid (PUFA:SFA) ratio and iodine value for backfat samples from pigs fed 10 mg/kg Ractopamine HCl, Apple et al. (2008[8]) reported that the LM quality of these pigs may have been enhanced during 5 d of retail display. Additionally, studies that differentiate the color shelf-life characteristics of fresh pork from barrows and gilts are lacking.

Therefore, we conducted an experiment to determine the effects of feeding various levels of astaxanthin, either with or without Ractopamine HCl, on growth and carcass characteristics of finishing pigs and color shelf-life characteristics of LM chops from barrows and gilts during simulated retail display.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The project was conducted at the K-State Swine Teaching and Research Farm. Pigs were housed in an environmentally controlled

[3] Yuan, J., J. Peng, K. Yin, and J. Wang. 2011. Potential health-promoting effects of astaxanthin: a high-value carotenoid mostly from microalgae. Mol. Nutr. Food Res. 55:150-165.
[4] Christiansen, R., Ø. Lie, and O. J. Torrissen. 1995. Growth and survival of Atlantic salmon, *Salmo salar* L., fed different dietary levels of astaxanthin. First feeding fry. Aqua. Nutr. 1:189-198.
[5] Yang, Y. X., Y. J. Kim, Z. Jin, J. D. Lohakare, C. H. Kim, S. H. Ohh, S. H. Lee, J. Y. Choi, and B. J. Chae. 2006. Effects of dietary supplementation of astaxanthin on production performance, egg quality in layers and meat quality in finishing pigs. Asian-Aust. J. Anim. Sci. 19(7):1019-1025.
[6] Kim, K., J. Lim, M. Shin, Y. Choi, S. Lee, and S. Cho. 2008. Effect of dietary combined probiotics (Any-Lac) supplementation contained with *Phaffia rhodozyma* on the growth performance and meat quality of pigs. Kor. J. Anim. Sci. Technol. 50(5):657-666.
[7] Carr, C. C., D. D. Johnson, J. H. Brendemuhl, and J. M. Gonzalez. 2010. Fresh pork quality and shelf-life characteristics of meat from pigs supplemented with natural astaxanthin in the diet. Prof. Anim. Sci. 26:18-25.
[8] Apple, J. K., C. V. Maxwell, B. R. Kutz, L. K. Rakes, J. T. Sawyer, Z. B. Johnson, T. A. Armstrong, S. N. Carr, and P. D. Matzat. 2008. Interactive effect of Ractopamine and dietary fat source on pork quality characteristics of fresh pork chops during simulated retail display. J. Anim. Sci. 86:2711-2722.

finishing building with pens over a totally slatted floor that provided approximately 10 ft^2/pig. Each pen was equipped with a dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

A total of 80 barrows and 80 gilts (TR4 × C22, PIC, Hendersonville, TN) with an initial BW of 198 lb were used in this study. Pigs were weighed and allotted to 1 of 9 dietary treatments, with 1 barrow and gilt per pen and 10 pens for each of 8 dietary treatments. Dietary treatments consisted of a corn-soybean meal-based control diet formulated to 0.66% SID lysine; the control diet formulated to contain 7.5, 15, 30, 60, and 120 ppm astaxanthin from *Xanthophyllomyces dendrorhous* yeast (formerly *Phaffia rhodozyma*; Nāturxan, IGENE Biotechnology, Columbia, MD); and 2 diets formulated to contain 0.95% SID lysine and 10 ppm Ractopamine HCl with 7.5 and 20 ppm astaxanthin from *Xanthophyllomyces dendrorhous* yeast (Table 1). Experimental diets were fed in meal form, and astaxanthin and/or Ractopamine HCl were added to the control diet at the expense of corn to achieve the dietary treatments. The diets were formulated to meet or exceed the nutrient requirements for pigs of this genotype (NRC, 1998[9]). Pigs and feeders were weighed weekly and approximately 18 h before harvest to determine ADG, ADFI, F/G, and BW.

To ensure that the harvest procedures would occur in accordance with IACUC standards and the capabilities of the K-State University Meats Laboratory, 6 pigs per treatment on d 23, 7 pigs per treatment on d 28, and 7 pigs per treatment on d 30 were transported to the abattoir for humane slaughter. This resulted in a mean feeding duration of 26 d, with all pigs harvested approximately 27 d after the initiation of the experiment.

Immediately after evisceration, the heart, kidneys, liver, and spleen of every pig were weighed and inspected for abnormalities by a veterinarian from the Department of Diagnostic Medicine/Pathobiology in the College of Veterinary Medicine at K-State, and HCW was recorded. First-rib, 10^{th}-rib, last-rib, and last-lumbar backfat depth, as well as the LM area and mean of 2 pH readings obtained at the 10^{th}- and 11^{th}-rib interface, were collected from the left side of each pig carcass 24 h postmortem. After obtaining carcass measurements, an 8-in. section of the LM caudal to the 10^{th}- and 11^{th}-rib interface was removed from the carcass of both pigs (1 barrow and 1 gilt) from each of 9 pens per treatment, vacuum-packaged, and refrigerated at 40°F.

After 7 d of refrigerated storage, two 1-in.-thick boneless LM chops were fabricated from each LM section. One LM chop was placed on simulated retail display for 6 d as in Exp. 2. The second chop was vacuum-packaged and frozen at -20°C immediately after fabrication. After 6 d of display, the chops were vacuum-packaged and frozen at -20°C prior to shipping both chops from each carcass to an outside laboratory (IGENE Biotechnology, Columbia, MD) for the determination of astaxanthin concentration in the LM.

On d 0 to 6 of retail display, objective measures of lean color were determined daily from 2 locations of the lean surface of each sample package using a HunterLab Minis-

[9] NRC. 1998. Nutrient Requirements of Swine. 10^{th} ed. Natl. Acad. Press, Washington DC.

can™ XE Plus spectrophotometer to measure CIE L* (brightness), a*, and b* as in Exp. 2. Additionally, the change in total color (ΔE) from d 0 to 6 was calculated as: $\sqrt{((\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2)}$.

Subjective lean color scores (1 = white to pale pinkish gray to 6 = dark purplish red, National Pork Producers Council, 2000[10]) and marbling scores (1 = very lean to 5 = highly marbled; National Pork Producers Council, 2000) were also determined on d 0 of retail display from the average of scores provided by 8 trained panelists. The same panelists provided scores for lean surface discoloration (1 = no discoloration, very bright pinkish red to 7 = total discoloration, extremely dark pinkish gray/tan) on d 0 to 6 of retail display.

The data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (v. 8.2; SAS Institute, Inc., Cary, NC) to evaluate the effects of the dietary treatments, and preplanned orthogonal contrasts were performed to compare the effects on pigs fed treatments containing 0 and 10 ppm Ractopamine HCl. Linear and quadratic polynomial contrasts were also used to determine the effects of increasing astaxanthin within the non-Ractopamine HCl treatments. Pen served as the experimental unit. Additionally, data collected from the LM chops during retail display were analyzed as a split plot to evaluate the effects of gender using repeated measures, with d as the repeated variable and LM chop as the subject. For all analyses, differences with a *P*-value less than 0.05 were considered to be statistically significant, and trends were considered to have a *P*-value less than 0.10.

Results

Overall, pigs fed Ractopamine HCl had greater ($P < 0.001$) ADG and final BW and improved ($P < 0.001$) F/G compared with non-Ractopamine HCl-fed pigs (Table 2). Pigs fed the non-Ractopamine HCl diets exhibited a tendency (quadratic, $P < 0.06$) for greater ADG and improved (quadratic, $P < 0.05$) F/G with increasing dietary astaxanthin to 30 and 60 ppm, respectively; however, no differences were detected in the final BW of pigs fed the various levels of astaxanthin, and ADFI was similar among all the dietary treatments.

Notable differences or abnormalities of the heart, kidneys, liver, and spleen were not observed during their gross inspection at harvest. Although the absolute weight of the heart or spleen of pigs was not different among the dietary treatments, the relative weight (% of final BW) of the heart was reduced ($P < 0.01$) for pigs fed Ractopamine HCl. Also, the liver and kidney weights of pigs fed Ractopamine HCl were greater ($P < 0.001$), and tended ($P < 0.07$) to have a greater relative weight (% of final BW), than that of pigs not fed Ractopamine HCl. Organ weights associated with feeding astaxanthin did not differ, but the relative kidney weight (% of final BW) tended (quadratic, $P < 0.08$) to be reduced for pigs fed 30 and 60 ppm astaxanthin.

Pigs fed Ractopamine HCl had greater ($P < 0.03$) HCW, LM area, 24-h LM pH, and FFLI than non-Ractopamine HCl-fed pigs. Among pigs fed the non-Ractopamine HCl diets, a trend (quadratic, $P < 0.07$) was observed for greater yield with increasing dietary

[10] National Pork Producers Council. 2000. Pork Composition and Quality Assessment Procedures. Natl. Pork Producers Counc., Des Moines, IA.

astaxanthin. Other carcass characteristics of pigs fed increasing dietary astaxanthin were not different from those fed the control diet.

No treatment × gender interactions were observed for any of the simulated retail display criteria, and negligible amounts of astaxanthin were detected in the assayed samples of LM chops. The initial subjective color scores were reduced (quadratic, $P < 0.01$) for LM chops from pigs fed increasing levels of astaxanthin in the diets without Ractopamine HCl (Table 3). Also, LM chops from gilts had a slightly greater ($P < 0.03$) initial color score than those from barrows, but no differences were observed in the initial color score of chops from pigs fed 0 and 10 ppm Ractopamine HCl. The marbling score was slightly greater ($P < 0.05$) for LM chops from pigs fed Ractopamine HCl, but no differences were observed between barrows and gilts or with increasing dietary astaxanthin. Discoloration scores of the LM chops increased (linear, $P < 0.001$) from d 0 to 6 of simulated retail display. Although the discoloration scores were not different among the dietary treatments or genders on d 0, the discoloration scores of LM chops from gilts were lower (d × gender, $P < 0.001$; barrow vs. gilt, $P < 0.001$) than those of barrows on d 4 to 6 of retail display and overall. Also, the discoloration scores of chops from pigs fed Ractopamine HCl were lower (d × treatment, $P < 0.001$; Ractopamine HCl vs. non-Ractopamine HCl, $P < 0.001$) than those of pigs not fed Ractopamine HCl on d 3 to 6 and overall. No differences in discoloration scores were observed in LM chops from pigs fed increasing levels of astaxanthin without Ractopamine HCl.

When comparing the objective color measurements of LM chops, CIE L* increased (quadratic, $P < 0.01$) for chops from pigs fed increasing astaxanthin in diets without Ractopamine HCl throughout the simulated retail display (Table 4). No gender differences occurred in the CIE a* of LM chops, but the CIE a* of chops from pigs fed Ractopamine HCl decreased ($P < 0.02$) compared with chops from pigs fed non-Ractopamine HCl diets. Although the CIE a* of chops from all pigs decreased (quadratic, $P < 0.001$) from d 0 to 6 of retail display, the change in CIE a* was greater (d × treatment and d × gender, $P < 0.02$) for chops from pigs fed non-Ractopamine HCl diets and barrows. The CIE b* of LM chops was lower ($P < 0.04$) for chops from pigs fed Ractopamine HCl and gilts, but these differences were greater (d × treatment and d × gender, $P < 0.02$) on d 0 of retail display than on d 6. No differences were detected in the CIE a* or CIE b* values of LM chops from pigs fed increasing astaxanthin without Ractopamine HCl. Overall, the differences and changes in the CIE L*, a*, and b* of LM chops from d 0 to 6 of simulated retail display resulted in differences in the change in total color (ΔE, d 0 to 6). Chops from pigs fed Ractopamine HCl and gilts had a lower ($P < 0.01$) ΔE than pigs fed non-Ractopamine HCl diets and barrows, respectively.

Discussion

Although few studies have reported on the effects of feeding diets with added astaxanthin on the growth performance of finishing pigs, these results generally agree with observations from previous studies. Yang et al. (2006) reported no differences in the growth performance of finishing pigs fed 0, 1.5, and 3 ppm dietary astaxanthin during 14 d preharvest. More recently, Carr et al. (2010) indicated no differences in the growth performance of pigs fed 0 and 66.7 ppm of natural astaxanthin from *Haematococcus pluvialis* algae for 42 d preharvest. Kim et al. (2008) suggested feeding a probiotic

mixture that provided 48 ppm of astaxanthin from *Xanthophyllomyces dendrorhous* yeast for 90 d improved the growth performance of finishing pigs. They observed similar improvements in ADG and F/G as those obtained for pigs fed 30 and 60 ppm astaxanthin from *Xanthophyllomyces dendrorhous* in the current experiment. Whether the improvements in F/G observed in these studies resulted from improved intestinal health, digestibility from the astaxanthin of *Xanthophyllomyces dendrorhous* yeast, or the yeast itself is not clear.

Pork producers, processors, and food companies are interested in technologies that will improve consumer acceptance of pork products. The appearance and color shelf-life of pork products are important criteria affecting both consumer and retailer preferences. The shelf-life of pork is most limited by the development of brown or gray discoloration during retail display, which generally occurs long before it has spoiled. A growing number of consumers are also interested in minimally processed products that are enhanced "naturally." Astaxanthin from *Xanthophyllomyces dendrorhous* yeast may qualify as a natural feed ingredient, and is currently used in diets for other food animals in other parts of the world.

As expected, the days of retail display affected subjective and objective measures of the lean color of LM chops. The subjective discoloration scores provided by the trained panel increased during 6 d of retail display. Although differences in the initial subjective color scores were not large, the lean color of chops from gilts and pigs fed Ractopamine HCl became discolored more slowly. This agreed with the reduction in the objective measure of total color change from d 0 to 6 for chops from gilts and pigs fed Ractopamine HCl. Changes in the objective measure of lean color during the 6 d of display involved reductions in the CIE a* and CIE b* measurements. The CIE a* and CIE b* measurements were also initially lower for chops from pigs fed Ractopamine HCl. Collectively, the reduced discoloration and change in total color observed for chops from gilts and pigs fed Ractopamine HCl suggest that their color shelf-life was improved.

In conclusion, although there were no differences in the color of fresh longissimus chops to indicate any consumer preferences initially, the color shelf-life was improved during retail display for chops from pigs fed Ractopamine HCl approximately 26 d preharvest. Also, LM chops from gilts had improved color shelf-life compared with chops from barrows. Although modest differences in the color of chops from pigs fed astaxanthin from *Xanthophyllomyces dendrorhous* yeast were observed, color shelf-life was not significantly influenced by the addition of dietary astaxanthin in this study.

Table 1. Composition of the experimental diets[1]

Ingredient, %	Control diet	Ractopamine HCl diet
Corn[2]	83.80	70.71
Soybean meal (46.5% CP)	12.30	25.44
Soybean oil	2.00	2.00
Monocalcium P (21% P)	0.225	0.10
Limestone	0.90	0.90
Salt	0.35	0.35
L-Lysine HCl	0.20	0.15
L-Threonine	0.025	0.025
Vitamin premix	0.10	0.10
Trace mineral premix	0.10	0.10
Ractopamine HCl, 20 g/kg[2]	---	0.05
Nāturxan (10,000 ppm astaxanthin)[3]	---	0.075
Total	100.00	100.00
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine, %	0.66	0.95
Isoleucine:lys, %	67	69
Leucine:lysine, %	176	155
Methionine:lysine, %	31	30
Met & Cys:lysine, %	63	60
Threonine:lysine, %	64	63
Tryptophan:lysine, %	17	19
Valine:lysine, %	80	78
Total lysine, %	0.74	1.07
CP, %	13.0	18.0
ME, kcal/lb	1,568	1,566
SID lysine:ME, g/Mcal	1.91	2.75
Ca, %	0.45	0.48
P, %	0.37	0.40
Available P, %	0.21	0.21

[1] Experimental diets were fed for approximately 26 d before slaughter.
[2] Astaxanthin (Nāturxan, 10,000 ppm from *Xanthophyllomyces dendrorhous*, IGENE Biotechnology, Columbia, MD) replaced corn in the control diet to achieve dietary treatments with added astaxanthin (7.5, 15, 30, 60, and 120 ppm).
[3] Provided 10 ppm Ractopamine HCl in the complete diet (Paylean, Elanco Animal Health, Greenfield, IN).
[4] Additional astaxanthin (Nāturxan, 10,000 ppm from *Xanthophyllomyces dendrorhous*, IGENE Biotechnology, Columbia, MD) replaced corn in the Ractopamine HCl diet containing 7.5 ppm astaxanthin to achieve the dietary treatment with 20 ppm astaxanthin.

Table 2. Growth performance, selected organ weights, and carcass characteristics of finishing pigs fed various levels of astaxanthin with or without Ractopamine HCl[1]

	Ractopamine HCl, ppm[2]									*P* <		
	0						10			Astaxanthin within 0 ppm Ractopamine HCl		Ractopamine HCl vs. non-Ractopamine HCl
Astaxanthin, ppm[3]:	0	7.5	15	30	60	120	7.5	20	SEM	Linear	Quadratic	
Preharvest growth performance, 26 d												
ADG, lb	2.14	2.09	2.11	2.30	2.26	2.19	2.63	2.64	0.066	---[4]	0.06	0.001
ADFI, lb	6.21	6.23	6.14	6.38	6.21	6.22	6.45	6.15	0.174	---	---	---
F/G	2.91	3.00	2.94	2.78	2.75	2.85	2.47	2.34	0.065	---	0.05	0.001
Final BW, lb	255.3	254.3	254.6	259.7	258.6	256.5	267.8	268.4	2.71	---	---	0.001
Postharvest organ weights												
Heart, lb	0.95	0.91	0.92	0.95	0.93	0.92	0.92	0.92	0.020	---	---	---
Heart, % of BW	0.37	0.36	0.36	0.37	0.36	0.36	0.34	0.34	0.007	---	---	0.01
Kidney, lb	0.39	0.37	0.38	0.37	0.37	0.37	0.42	0.41	0.010	---	---	0.001
Kidney, % of BW	0.15	0.15	0.15	0.14	0.14	0.15	0.15	0.15	0.003	---	0.08	0.06
Liver, lb	3.62	3.59	3.64	3.76	3.70	3.67	3.91	4.00	0.083	---	---	0.001
Liver, % of BW	1.42	1.41	1.43	1.45	1.43	1.43	1.46	1.49	0.026	---	---	0.07
Spleen, lb	0.41	0.40	0.41	0.44	0.42	0.45	0.44	0.46	0.022	---	---	---
Spleen, % of BW	0.16	0.16	0.16	0.17	0.16	0.17	0.16	0.17	0.008	---	---	---
Carcass characteristics												
HCW, lb	183.5	183.7	186.2	189.1	186.7	186.3	195.0	195.7	2.12	---	---	0.001
Yield, %	71.9	72.3	73.1	72.8	72.2	72.6	72.8	72.9	0.36	---	0.07	---
Avg. backfat depth, in.	0.88	0.93	0.90	0.88	0.90	0.92	0.87	0.87	0.029	---	---	---
10th-rib backfat depth, in.	0.76	0.80	0.79	0.74	0.78	0.82	0.73	0.72	0.039	---	---	---
10th-rib LM area, sq. in.	7.67	7.32	7.45	7.74	7.39	7.46	8.14	8.30	0.191	---	---	0.001
10th-rib LM pH, 24 h	5.50	5.49	5.47	5.50	5.49	5.52	5.57	5.53	0.015	---	---	0.001
FFLI[5]	54.7	53.9	54.0	54.8	54.0	53.6	55.4	55.7	0.66	---	---	0.03

[1] A total of 160 barrows and gilts (PIC, TR4 × C22, Hendersonville, TN; initially 198 lb) were used with 2 pigs per pen (1 barrow and gilt) and 10 pens per treatment to evaluate the effects of various levels of dietary astaxanthin with or without 10 ppm Ractopamine HCl.

[2] Paylean, Elanco Animal Health, Greenfield, IN.

[3] Nāturxan (astaxanthin from *Xanthophyllomyces dendrorhous*), IGENE Biotechnology, Columbia, MD.

[4] Not significant ($P > 0.10$).

[5] Fat-free lean index.

Table 3. Subjective color evaluation during simulated retail display of longissimus muscle chops from barrows and gilts fed various levels of astaxanthin with or without Ractopamine HCl1

													P <			
	Ractopamine HCl, ppm[2]									Gender			Astaxanthin within 0 ppm Ractopamine HCl		Ractopamine HCl vs. non-Ractopamine	
	0						10									
Astaxanthin, ppm[3]:	0	7.5	15	30	60	120	7.5	20	SEM	Barrow	Gilt	SEM	Linear	Quadratic	HCl	Gender
Pigs, n	18	18	18	18	18	18	18	18		72	72					
Color score, d 0[4]	3.6	3.2	3.4	3.4	3.1	3.4	3.4	3.3	0.08	3.3	3.4	0.04	---[5]	0.002	---	0.03
Marbling score, d 0[6]	1.6	1.4	1.5	1.5	1.5	1.6	1.7	1.5	0.08	1.6	1.5	0.04	---	---	0.05	---
Discoloration scores[7,8]																
d 0	1.2	1.5	1.4	1.3	1.4	1.4	1.3	1.4	0.11	1.4	1.3	0.05				
d 1	1.5	1.7	1.7	1.6	1.7	1.6	1.5	1.7	0.11	1.7	1.6	0.05				
d 2	1.8	2.2	2.2	2.0	2.2	2.0	1.8	2.1	0.11	2.1	2.0	0.05				
d 3	2.2	2.7	2.6	2.4	2.6	2.3	2.1	2.3	0.11	2.5	2.3	0.05				
d 4	2.7	3.1	3.0	2.8	3.0	2.7	2.3	2.6	0.11	2.9	2.6	0.05				
d 5	3.0	3.5	3.3	3.1	3.3	3.0	2.5	2.7	0.11	3.2	2.9	0.05				
d 6	3.3	3.8	3.7	3.4	3.6	3.3	2.8	2.9	0.11	3.5	3.2	0.05				
Overall	2.2	2.6	2.6	2.4	2.5	2.3	2.0	2.2	0.10	2.5	2.3	0.05	---	---	0.001	0.02

[1] Longissimus muscle chops from barrows (72) and gilts (72) were visually evaluated daily by a trained panel during 6 d of retail display.
[2] Paylean, Elanco Animal Health, Greenfield, IN.
[3] Nāturxan (astaxanthin from *Xanthophyllomyces dendrorhous*), IGENE Biotechnology, Columbia, MD.
[4] Color score: 1 = white to pale pinkish gray to 6 = dark purplish red (National Pork Producers Council, 2000).
[5] Not significant ($P > 0.10$).
[6] Marbling score: 1 = very lean to 5 = highly marbled (National Pork Producers Council, 2000).
[7] Discoloration score: 1 = no discoloration, very bright pinkish red to 7 = total discoloration, extremely dark pinkish gray/tan (Hunt et al., 1991).
[8] Effect of d (linear, $P < 0.001$; quadratic, $P < 0.05$), treatment × d ($P < 0.001$), gender × d ($P < 0.04$).

Table 4. Objective color measurements during simulated retail display of longissimus muscle chops from barrows and gilts fed various levels of astaxanthin with or without Ractopamine HCl[1]

	Ractopamine HCl, ppm[2]									Gender			*P* <			
	0						10						Astaxanthin within 0 ppm Ractopamine HCl		Ractopamine HCl vs. non-Ractopamine	
Astaxanthin, ppm[3]:	0	7.5	15	30	60	120	7.5	20	SEM	Barrow	Gilt	SEM	Linear	Quadratic	HCl	Gender
Pigs, n	18	18	18	18	18	18	18	18		72	72					
CIE L*[4,5]																
d 0	56.4	59.3	58.3	58.3	59.0	57.7	57.2	58.6	0.52	58.6	57.6	0.26				
d 1	56.4	59.2	58.6	58.5	59.1	58.0	57.4	58.8	0.52	58.7	57.8	0.26				
d 2	56.3	59.2	58.3	58.5	59.1	58.0	57.4	59.0	0.52	58.5	57.8	0.26				
d 3	56.8	59.5	58.7	58.6	59.3	58.2	57.5	59.0	0.52	58.8	58.1	0.26				
d 4	56.6	59.2	58.4	58.5	59.1	58.0	57.4	58.7	0.52	58.5	58.0	0.26				
d 5	56.7	59.3	58.4	58.5	59.2	57.9	57.5	58.6	0.52	58.5	58.0	0.26				
d 6	57.1	59.4	58.6	58.9	59.3	58.3	57.8	59.0	0.52	58.8	58.3	0.26				
Overall	56.6	59.3	58.5	58.5	59.2	58.0	57.5	58.8	0.51	58.6	58.0	0.25	---[6]	0.01	---	0.06
CIE a*[7,8]																
d 0	10.9	10.6	10.7	10.4	10.4	10.6	9.3	9.0	0.25	10.4	10.1	0.13				
d 1	11.1	10.6	10.7	10.6	10.4	10.7	9.9	9.5	0.25	10.4	10.4	0.13				
d 2	10.6	9.9	10.0	10.0	9.8	10.2	9.7	9.2	0.25	9.9	10.0	0.13				
d 3	9.9	9.2	9.5	9.4	9.2	9.6	9.3	8.8	0.25	9.3	9.4	0.13				
d 4	9.5	8.7	8.9	8.9	8.7	9.0	9.1	8.5	0.25	8.8	9.0	0.13				
d 5	9.0	8.2	8.5	8.5	8.2	8.7	8.8	8.3	0.25	8.4	8.6	0.13				
d 6	8.5	7.7	8.0	8.0	7.8	8.2	8.6	7.8	0.25	7.9	8.2	0.13				
Overall	9.9	9.3	9.5	9.4	9.2	9.6	9.2	8.7	0.23	9.3	9.4	0.12	---	0.10	0.02	---

continued

Table 4. Objective color measurements during simulated retail display of longissimus muscle chops from barrows and gilts fed various levels of astaxanthin with or without Ractopamine HCl[1]

													P <			
	Ractopamine HCl, ppm[2]												Astaxanthin within 0 ppm Ractopamine HCl		Ractopamine HCl vs. non-Ractopamine	
	0						10			Gender						
Astaxanthin, ppm[3]:	0	7.5	15	30	60	120	7.5	20	SEM	Barrow	Gilt	SEM	Linear	Quadratic	HCl	Gender
CIE b*[8,9]																
d 0	17.2	17.5	17.4	17.2	17.2	17.1	16.3	16.5	0.16	17.2	16.8	0.08				
d 1	17.2	17.5	17.4	17.1	17.1	17.0	16.5	16.7	0.16	17.2	17.0	0.08				
d 2	16.9	17.2	17.2	16.9	17.0	16.8	16.4	16.5	0.16	17.0	16.8	0.08				
d 3	16.6	17.0	16.9	16.7	16.8	16.6	16.3	16.3	0.16	16.8	16.5	0.08				
d 4	16.6	17.0	17.0	16.7	16.8	16.6	16.4	16.3	0.16	16.8	16.6	0.08				
d 5	16.5	17.0	16.9	16.6	16.6	16.6	16.3	16.4	0.16	16.7	16.5	0.08				
d 6	16.3	16.8	16.8	16.5	16.6	16.4	16.3	16.2	0.16	16.6	16.4	0.08				
Overall	16.8	17.1	17.1	16.8	16.9	16.7	16.4	16.4	0.15	16.9	16.6	0.07	---	---	0.001	0.02
ΔE, d 0 to 6[10]	3.0	3.2	3.0	2.8	3.0	3.0	1.5	1.7	0.23	2.9	2.4	0.12	---	---	0.001	0.01

[1] Longissimus muscle chops from barrows (72) and gilts (72) were measured daily for objective lean color analysis (CIE L*, a*, and b*) during 6 d of simulated retail display using a HunterLab Miniscan XE Plus spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA).

[2] Paylean, Elanco Animal Health, Greenfield, IN.

[3] Nāturxan (astaxanthin from *Xanthophyllomyces dendrorhous*), IGENE Biotechnology, Columbia, MD.

[4] CIE L* = measure of darkness to lightness (black = 0 to white = 100).

[5] Effect of d (linear, $P < 0.01$).

[6] Not significant ($P > 0.10$).

[7] CIE a* = measure of redness (a larger value indicates a more red color).

[8] Effect of d (a* quadratic, $P < 0.001$; b* linear, $P < 0.001$), treatment × d ($P < 0.02$), gender × d ($P < 0.01$).

[9] CIE b* = measure of yellowness (a larger value indicates a more yellow color).

[10] ΔE = total color change, calculated as $\sqrt{((d\ 0\ L^* - d\ 6\ L^*)^2 + (d\ 0\ a^* - d\ 6\ a^*)^2 + (d\ 0\ b^* - d\ 6\ b^*)^2)}$ (Minolta, 1998).