Effects of Dietary Astaxanthin, Ractopamine HCl, and Gender on the Growth, Carcass, and Pork Quality Characteristics of Finishing Pigs[1]

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Summary

A total of 144 finishing pigs (initially 226 lb) were used to evaluate the effects of various levels and sources of added dietary astaxanthin (AX: 0, 2.5, 5, 7.5, and 10 ppm), as well as ractopamine HCl (Paylean), on growth, carcass, and pork quality characteristics of barrows and gilts. Pigs were blocked by gender and weight and randomly allotted to 1 of 9 dietary treatments fed for approximately 26 d pre-harvest. Dietary treatments consisted of a corn-soybean meal-based control, the control with 5, 7.5, or 10 ppm AX from *Phaffia rhodozyma* yeast, the control with 5 ppm synthetic AX, and the control with 9 g/ton Paylean and 0, 2.5, 5, and 7.5 ppm AX from *Phaffia rhodozyma* yeast. There were 2 pigs per pen and 8 pens per treatment (4 pens per treatment × gender combination). Overall, barrows had greater ($P < 0.01$) ADG and ADFI than gilts, while ADG and final BW increased ($P < 0.01$) and F/G improved for pigs fed Paylean. For carcass characteristics, barrows had greater ($P < 0.01$) backfat depth and less ($P < 0.01$) longissimus muscle area and fat-free lean than gilts. Pigs fed Paylean had greater ($P < 0.01$) HCW, yield, and longissimus muscle area than those that received non-Paylean treatments. Growth performance and carcass characteristics of pigs fed AX were not different than control pigs. Although there were no differences in the initial subjective color scores, the discoloration scores of longissimus chops increased (linear, $P < 0.01$) daily during 7 d of retail display, and were greater ($P < 0.01$) for barrow chops on d 7 compared to gilt chops (gender × day interaction, $P < 0.01$). Also, the overall average discoloration scores and change in d 0 to 3 objective total color were lower ($P < 0.01$) for gilts and pigs fed Paylean, although the difference between gilts and barrows was smaller when they were fed Paylean (gender × treatment interaction, $P < 0.01$). Modest differences in measures of pork color during retail display were associated with added dietary AX, but these did not result in an increase in color shelf-life or reduction in the objective measure of total color change. Collectively, these observations indicated a greater ($P < 0.01$) color shelf-life for chops from gilts and pigs fed Paylean.

Key words: astaxanthin, carcass characteristics, pork color

Introduction

Astaxanthin is a carotenoid that exists naturally in various plants, algae, and seafood. Its unique molecular structure may impart a potent antioxidant capacity. Astaxanthin is used extensively in the aquaculture feed industry for its pigmentation characteristics, but it is not currently approved for use in other food animals in the United States.

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Although it is used primarily for pigmentation of farmed salmonids, astaxanthin may also be essential for their improved growth and survival.

The inclusion of astaxanthin in poultry diets has been reported to improve egg production and the general health of laying hens. In addition, improvements in chick growth and feed utilization during the first 3 wk of life, as well as resistance to Salmonella infection, have also been observed with astaxanthin supplementation (AstaReal, 2006[3]). Astaxanthin also has been found to improve the color shelf-life of poultry products, with studies reporting changes in egg yolk color and poultry muscle color that could improve consumer acceptance (Akiba et al., 2000[4]; 2001[5]; and Yang et al., 2006[6]).

In a study performed in Korea by Yang et al., (2006[6]), feeding 1.5 and 3 ppm astaxanthin to finishing pigs for 14 d before slaughter linearly improved dressing percentage and loin muscle area and decreased backfat thickness. There were no differences in meat color score. More recently, we (Bergstrom et al., 2009[7]) also observed tendencies for reduced backfat thickness and improved carcass leanness when feeding 5, 10, and 20 ppm astaxanthin. We did not observe differences in dressing percentage; however, there were trends for improvements in the instrumental color measurement of the loin muscle surface after 30 m of bloom time at 24 h postharvest. Relatively few animals were used in either of these studies, and the potential effects of astaxanthin on pork color shelf-life have only recently been reported (Carr et al., 2010[8]).

The effects of ractopamine HCl on the growth and carcass characteristics of pigs is well established, but its effects on pork quality are not as well understood. Some research indicates that pigs fed ractopamine HCl may be more prone to stress during preharvest handling, which may have implications for reduced pork quality. Further research is needed to understand those effects.

Therefore, our objective was to evaluate the effects of feeding various levels of astaxanthin, ractopamine HCl, and their combination for approximately 26 d before slaughter on finishing-pig growth performance, carcass characteristics, and pork color shelf-life.

Procedures

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved the protocol used in this experiment. The project was conducted at the

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[3] AstaReal. 2006. Technical bulletin: NOVASTA™ improves performance and reduces mortality and the incidence of yolk sac infections of broiler chickens.

[4] Akiba, Y., K. Sato, K. Takahashi, M. Toyomizu, Y. Takahashi, S. Konashi, H. Nishida, H. Tsunekawa, Y. Hayasaka, and H. Nagao. 2000. Improved pigmentation of egg yolk by feeding of yeast, *Phaffia rhodozyma*, containing high concentration of astaxanthin in laying hens. Japan. Poult. Sci. 37:162-170.

[5] Akiba, Y., K. Sato, K. Takahashi, K. Matsushita, H. Komiyama, H. Tsunekawa, and H. Nagao. 2001. Meat color modification in broiler chickens by feeding yeast *Phaffia rhodozyma* containing high concentrations of astaxanthin. J. Appl. Poult. Res. 10:154-161.

[6] 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.

[7] Bergstrom et al., Swine Day 2009, Report of Progress 1020, pp. 239 – 244.

[8] 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.

K-State Swine Teaching and Research Farm. Pigs were housed in an environmentally controlled 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 72 barrows and 72 gilts (PIC TR4 × C22, initially 226 lb) were used in this study. Pigs were blocked by gender and weight, and randomly allotted to 1 of 9 dietary treatments. There were 2 pigs per pen and 4 pens per treatment × gender combination (8 replications of each dietary treatment). Dietary treatments consisted of a corn-soybean meal-based control, the control with 5, 7.5, and 10 ppm astaxanthin (AX) from *Phaffia rhodozyma* yeast (Aquasta, IGENE Biotechnology, Columbia, MD), the control with 5 ppm pure synthetic AX (Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland), and the control with 10 ppm ractopamine HCl (Paylean, Elanco, Greenfield, IN) and 0, 2.5, 5, and 7.5 ppm AX from *Phaffia rhodozyma* yeast. Experimental diets were fed in meal form, and AX and/or Paylean were added to the control diet at the expense of cornstarch to achieve the dietary treatments (Table 1). Pigs and feeders were weighed weekly and approximately 18 h before harvest to determine ADG, ADFI, F/G, and final BW.

To ensure that the harvest procedures would occur in accordance with Institutional Animal Care and Use Committee standards and the capabilities of the K-State Meats Lab, the barrow feeding period ended on d 22 when they were transported to the abattoir for humane slaughter. The gilt feeding period ended one week later on d 29, when they were also transported for humane slaughter. This resulted in a similar final BW for barrows and gilts.

Immediately after evisceration, HCW was measured and recorded. First-rib, 10th rib, last-rib, and last-lumbar backfat depth, as well as longissimus muscle area at the 10^{th} and 11^{th} rib interface, were collected from the right half of each carcass 24 h postmortem. After obtaining carcass measurements, an 8-in.-section of the loin, caudal to the 10^{th} and 11^{th} rib interface, was removed from the carcass of 1 randomly selected pig per pen, vacuum-packaged, and frozen at 20°C.

After 7 or 14 d of frozen storage, the loin sections were thawed for 24 h at 4°C and a 1-in.-thick boneless chop was fabricated from the center of each 8-in. loin section. Each longissimus chop was placed on a 1 S polystyrene tray (Dyne-A-Pak Inc., LAVAL, QC, Canada) with an absorbent pad and overwrapped with a polyvinylchloride film (23,250 mL of $O_2/m^2/24$ h oxygen permeability/flow rate). The packages were placed in an open-top retail display case (unit model DMF8, Tyler Refrigeration Corp., Niles, MI) at 2 ± 1.5°C for 7 d. The display case was illuminated with continuous fluorescent lighting (3,000 K, bulb model F32T8/ADV830/Alto, Philips, Bloomfield, NJ) that emitted an average of 2,249 lx. Packages were rotated daily to compensate for any variation in temperature and lighting within the case.

On d 0, 1, 2, and 3 of retail display, objective measures of lean color were determined for all packages 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) to measure CIE L* (lightness), a* (redness), and b* (yellowness). The spectrophotometer was calibrated daily against a standard white tile (Hunter Associates Laboratory) and 3 locations of the lean surface of each sample package were measured and averaged to determine the CIE L*, a*, and b* values. The change in total color (ΔE) from d 0 to 3 was calculated as: $\sqrt{((\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2)}$ (Minolta, 1998[9]).

Additionally, subjective lean color scores (1 = white to pale pinkish gray to 6 = dark purplish red, National Pork Producers Council, 2000[10]) were determined on d 0 of retail display from the average of scores provided by 11 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; Hunt et al., 1991[11]) on d 0 to 7 of retail display. When an individual package received a mean discoloration score > 4 it was classified as having an unacceptable appearance and removed from display. Also, the number of days that each package maintained an acceptable appearance (≤ 4) was used to determine the color shelf-life. Packages that were removed for an unacceptable appearance were assigned a discoloration score of 5 for the remaining days of retail display.

Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) to evaluate the effects of dietary treatment, gender, and their interactions. Pen was the experimental unit. Pork quality data collected during retail display were analyzed as repeated measures, with d as the repeated variable and loin chop as the subject. Preplanned orthogonal contrasts were used to evaluate the effects of gender, AX, AX from *Phaffia rhodozyma* yeast, synthetic AX, and Paylean; and linear and quadratic polynomial contrasts were used to determine the effects of increasing AX from *Phaffia rhodozyma* yeast within the non-Paylean and Paylean treatments.

Results

The analyzed levels of AX for the experimental diets were 0.05, 4.80, 6.85, and 7.43 ppm for the non-Paylean control diet and 5, 7.5, and 10 ppm AX from *Phaffia rhodozyma* yeast treatments, respectively; 7.48 ppm for the 5 ppm synthetic AX treatment; and 0.47, 2.39, 5.64, and 7.91 ppm for the Paylean treatments with targeted levels of 0, 2.5, 5, and 7.5 ppm AX from *Phaffia rhodozyma* yeast, respectively.

No treatment × gender interactions were observed for growth and carcass characteristics during the study. Overall, barrows had greater ($P < 0.01$) ADG and ADFI than gilts (Table 2). However, the gilts achieved a similar final BW at harvest due to being fed 1 wk longer before harvesting. Pigs fed Paylean had greater ($P < 0.01$) ADG and final BW, and improved F/G ($P < 0.01$) compared with non-Paylean-fed pigs (Table 3). There were no differences in growth for pigs supplemented with AX.

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[9] Minolta. 1998. Precise Color Communication: Color Control from Perception to Instrumentation. Minolta Corp., Ramsey, NJ.

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

[11] Hunt, M. C., J. C. Acton, R. C. Benedict, C. R. Calkins, D. P. Cornforth, L. E. Jeremiah, D. G. Olson, C. P. Salm, J. W. Savell, and S. D. Shivas. 1991. AMSA guidelines for meat color evaluation. Pages 1 – 17 in Proc. 44th Reciprocal Meat Conf., Kansas State University, Manhattan. Am. Meat Sci. Assoc., Savoy, IL.

Barrows had greater ($P < 0.01$) backfat depth and reduced ($P < 0.01$) 10th-rib loin area and percentage fat-free lean compared to gilts. Pigs fed Paylean had greater ($P < 0.03$) HCW, yield, 10th-rib loin area, and fat-free lean than non-Paylean-fed pigs.

The initial subjective color scores of longissimus chops placed on retail display were not different (Table 4). However, the discoloration scores of the chops increased (linear, $P < 0.001$; quadratic, $P < 0.001$) from d 0 to 7 of retail display. Although the discoloration scores were not different among the dietary treatments or gender on d 0, the discoloration scores of chops from gilts were lower (day × gender, $P < 0.001$; barrow vs. gilt, $P < 0.001$) than those of barrows on d 3 to 7 of retail display and overall. The discoloration scores of chops from pigs fed Paylean were lower ($P < 0.001$) than those of pigs not fed Paylean on d 3 to 7 and overall, but the gender differences in discoloration score were less among the chops that originated from pigs fed Paylean (dietary treatment × gender, $P < 0.001$). Among the chops from pigs fed Paylean, the discoloration score was lowest (quadratic, $P < 0.001$) from d 3 to 7 and overall for pigs fed the highest level of 7.5 ppm AX from *Phaffia rhodozyma* yeast.

The repeated, subjective evaluations for discoloration were also utilized to determine the average color shelf-life (Figure 1). Chops from gilts had a greater ($P < 0.0001$) color shelf-life than those from barrows, and chops from pigs fed Paylean had a greater ($P < 0.001$) color shelf-life than those from non-Paylean-fed pigs.

When comparing the objective measurements of the lean color of longissimus chops, there were no differences observed in the CIE L* (measure of lightness/darkness, white = 100 and black = 0) measured over 7 d (Table 5). However, there was a dietary treatment × gender interaction ($P < 0.001$) observed for the CIE a* (measure of redness, larger value = more red). This occurred because, among the chops from pigs fed the non-Paylean diets, the decrease (linear, $P < 0.01$) in the CIE a* with increasing concentration of AX from *Phaffia rhodozyma* was more evident among barrows. A day × gender interaction ($P < 0.001$) was also observed for the CIE a* because the decrease (linear, $P < 0.001$) in CIE a* values during the 7 d of retail display was greater for barrows when compared to those of gilts. Nevertheless, the CIE a* of longissimus chops from Paylean-fed pigs was reduced ($P < 0.001$) compared to those from non-Paylean-fed pigs. Among the chops from pigs fed Paylean, the CIE a* was reduced (quadratic, $P < 0.001$) as the concentration of AX from *Phaffia rhodozyma* rose to 5 ppm before it increased at 7.5 ppm AX. The CIE b* (measure of yellowness, larger value = more yellow) of the longissimus chops decreased (linear, $P < 0.001$) during the 7 d of retail display, and was lower ($P < 0.001$) for chops from pigs fed Paylean. Among the chops from pigs fed the non-Paylean diets, the CIE b* decreased (linear, $P < 0.001$) with increasing concentration of AX from *Phaffia rhodozyma*.

Collectively, the changes in the CIE L*, a*, and b* of chops from d 0 to 3 resulted in differences in the change in total color (ΔE) from d 0 to 3 (Figure 2). Chops from pigs fed Paylean and gilts had less ($P < 0.001$) change in total color than pigs fed non-Paylean diets and barrows.

Discussion

These results agree with previous research reporting differences in growth performance and carcass characteristics between barrows and gilts, and the improvements associated with feeding Paylean. However, unlike our previous experiment (Bergstrom et al., 2009[12]), we did not observe improvements in carcass characteristics from feeding AX. Although lower levels of AX were included in the present experiment, Yang et al. (2006[13]) reported improvements in carcass characteristics with feeding 1.5 and 3 ppm AX for 14 d. In the present experiment, it is interesting that the measures of carcass leanness were numerically improved among the pigs fed the non-Paylean diets when they received the highest level of AX from *Phaffia rhodozyma* (10 ppm) and 5 ppm synthetic AX. Likewise, measures of carcass leanness were numerically improved with feeding 7.5 ppm AX from *Phaffia rhodozyma* when the diets contained Paylean. Carr et al. (2010[14]) reported a reduction in backfat depth with feeding 66.7 ppm AX, but the AX carcasses also had a numerically lighter weight than that of the controls in that study.

Pork producers, processors, and food companies are interested in technologies that will improve consumer acceptance of pork products. The product appearance and color shelf-life are important criteria affecting both consumer and retailer preferences. Pork shelf-life 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 *Phaffia rhodozyma* 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 day of retail display affected subjective and objective measures of the lean color of longissimus chops. The subjective discoloration scores provided by the trained panel increased during 7 d of retail display. Although there were no differences in the initial subjective color scores, the lean color of chops from gilts and pigs fed Paylean became discolored more slowly. This agreed with the reduction in the objective measure of total color change from d 0 to 3 for chops from gilts and pigs fed Paylean. Changes in the objective measure of lean color during the first 3 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 Paylean. Collectively, the reduced discoloration and change in total color observed for chops from gilts and pigs fed Paylean were associated with a longer color shelf-life.

Although increasing concentrations of AX were associated with differences in lean color during retail display, there were no significant effects of AX on the overall color shelf-life or total color change from d 0 to 3. However, chops from pigs fed 7.5 ppm AX from *Phaffia rhodozyma* in the diets containing Paylean had the lowest discoloration scores, high CIE a* values on d 3, numerically lowest total color change from d 0 to 3, and numerically longest color shelf-life. Carr et al. (2010) have also reported that AX may improve color characteristics of pork during retail display.

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 increased during retail display for chops from pigs fed Paylean approximately 26 d pre-harvest. Also, longissimus chops from gilts had a greater color shelf-life than chops from barrows. Although modest differences in the color of chops from pigs fed AX were observed, color shelf-life was not significantly influenced by the levels of dietary AX used in this study.

Table 1. Composition of the experimental control diet[1]

Item	Percent
Ingredient	
Corn	72.85
Soybean meal (46.5% CP)	25.14
Monocalcium P (21% P)	0.35
Limestone	0.85
Salt	0.35
L-lysine HCl	0.15
Vitamin premix	0.08
Trace mineral premix	0.08
Cornstarch[2]	0.15
Total	100.00
Calculated analysis	
Standardized ileal digestible (SID) amino acids, %	
Lysine	0.95
Isoleucine:lysine ratio	70
Leucine:lysine ratio	156
Methionine:lysine ratio	28
Met & Cys:lysine ratio	58
Threonine:lysine ratio	61
Tryptophan:lysine ratio	19
Valine:lysine ratio	79
Total lysine, %	1.07
Protein, %	18.1
ME, kcal/lb	1,521
SID lysine:ME ratio, g/Mcal	2.83
Ca, %	0.50
P, %	0.45
Available P, %	0.20

[1] Experimental diets were fed for approximately 26 d before slaughter.
[2] Astaxanthin (10,000 ppm from *Phaffia rhodozyma*, Aquasta, IGENE Biotechnology, Columbia, MD; or pure synthetic, Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland) and/or ractopamine HCl (Paylean, Elanco, Greenfield, IN) replaced cornstarch in the control diet to achieve dietary treatments with 2.5, 5, 7.5, and 10 ppm AX and/or 10 ppm ractopamine HCl.

Table 2. Growth performance and carcass characteristics of barrows and gilts[1]

	Barrows	Gilts	SEM	*P* <
Growth performance				
Feeding period, d	22	29		
Initial BW, lb	229.1	222.0	6.92	---[2]
ADG, lb	2.69	2.51	0.034	0.001
ADFI, lb	8.42	7.65	0.142	0.001
F/G	3.15	3.08	0.043	---
Final BW, lb	289.2	294.8	5.84	---
Carcass characteristics				
HCW, lb	206.5	210.7	4.46	---
Yield, %	71.4	71.6	0.21	---
10th-rib				
backfat, in.	0.90	0.67	0.023	0.001
loin area, sq. in.	7.54	8.27	0.172	0.01
FFLI[3]	52.0	55.4	0.35	0.001

[1] A total of 144 barrows (72) and gilts (72) were blocked by gender and weight, with 2 pigs per pen and 36 pens per gender.
[2] Not significant ($P > 0.05$).
[3] FFLI = fat-free lean index

Table 3. Growth performance and carcass characteristics of finishing pigs fed various levels of astaxanthin with or without ractopamine HCl[1]

Ractopamine HCl[2], ppm:	None					10					
Astaxanthin source:	*Phaffia rhodozyma*[3]				Synthetic[4]	*Phaffia rhodozyma*					*P* <
Astaxanthin level, ppm:	0	5	7.5	10	5	0	2.5	5	7.5	SEM	Ractopamine HCl[5]
Growth performance											
ADG, lb	2.49	2.34	2.45	2.41	2.31	2.83	2.88	2.88	2.83	0.077	0.001
ADFI, lb	8.06	8.06	8.03	8.01	7.84	8.05	8.19	8.27	7.79	0.226	---
F/G	3.24	3.44	3.28	3.35	3.40	2.86	2.85	2.88	2.76	0.075	0.001
Final BW, lb	288.9	287.6	287.4	286.2	284.2	297.1	298.6	298.8	299.1	4.55	0.001
Carcass characteristics											
HCW, lb	204.4	202.6	203.4	202.5	201.5	213.9	216.1	215.3	218.0	3.53	0.001
Yield, %	70.7	70.4	71.5	70.8	70.9	72.0	72.4	72.1	72.9	0.36	0.001
10th-rib											
-backfat, in.	0.78	0.84	0.81	0.77	0.78	0.81	0.78	0.82	0.70	0.049	---
-loin area, sq. in.	7.26	7.55	7.36	7.53	7.78	8.29	8.25	8.19	8.92	0.255	0.001
FFLI[6]	53.0	52.8	52.9	53.7	54.0	53.8	54.1	53.6	55.7	0.75	0.03

[1] A total of 144 barrows and gilts (initially 226 lb) were blocked by weight and gender to evaluate the effects of various levels of astaxanthin with or without 10 ppm ractopamine HCl.
[2] Ractopamine HCl from Paylean, Elanco, Greenfield, IN.
[3] Aquasta, IGENE Biotechnology, Columbia, MD.
[4] Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland.
[5] No ractopamine HCl × astaxanthin interactions or astaxanthin effects (linear or quadratic) were observed for any of these criteria.
[6] FFLI = fat-free lean index.

Table 4. Subjective lean color and color shelf-life evaluation of pork longissimus chops from barrows and gilts fed various levels of astaxanthin with or without ractopamine HCl[1]

Ractopamine HCl[2], ppm:	None										10								
Astaxanthin source:	*Phaffia rhodozyma*[3]								Synthetic[4]		*Phaffia rhodozyma*								
Astaxanthin level, ppm:	0		5		7.5		10		5		0		2.5		5		7.5		
Gender[5]:	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	SEM
Initial color[6], d 0	3.3	3.2	3.6	3.5	3.3	3.6	3.2	3.4	3.3	3.6	3.3	3.3	3.4	3.4	3.4	3.3	3.5	3.6	0.22
Discoloration[7, 8]																			
d 0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.1	1.2	1.1	0.22
d 1	1.4	1.6	1.4	1.3	1.4	1.5	1.6	1.4	1.4	1.3	1.4	1.4	1.2	1.4	1.5	1.4	1.3	1.4	0.22
d 2	2.5	2.5	2.4	2.4	2.7	2.4	2.8	2.1	3.2	2.3	2.6	2.1	2.3	2.3	3.4	2.3	2.0	2.1	0.22
d 3	3.5	3.3	3.6	3.2	3.6	3.2	3.5	2.8	3.3	3.0	3.5	2.8	2.8	3.0	3.3	2.9	2.7	2.7	0.22
d 4	4.2	3.8	4.3	3.7	4.3	3.7	4.3	3.5	3.9	3.6	4.0	3.2	3.3	3.5	3.9	3.5	3.0	3.0	0.22
d 5	4.8	4.2	4.8	3.9	4.9	3.8	4.9	4.0	4.5	4.0	4.4	3.6	3.8	3.9	4.5	3.8	3.5	3.4	0.22
d 6	5.0	4.4	5.0	4.5	5.0	4.5	5.0	4.4	5.0	4.3	5.0	4.0	4.1	4.6	5.0	4.4	4.4	4.0	0.22
d 7	5.0	4.7	5.0	4.9	5.0	4.9	5.0	4.8	5.0	4.9	5.0	4.9	4.7	4.9	5.0	4.9	5.0	4.5	0.22
Overall	3.4	3.2	3.5	3.1	3.5	3.1	3.5	3.0	3.4	3.1	3.4	2.9	2.9	3.1	3.5	3.0	2.9	2.8	0.08
Color shelf-life, d[9]	3.3	4.5	3.0	5.0	3.0	4.3	3.0	4.8	3.8	4.8	3.5	5.5	5.3	4.5	3.8	5.3	5.3	5.5	0.54

[1] Longissimus chops from barrows (36) and gilts (36) were visually evaluated daily by a trained panel during 7 d of retail display.
[2] Ractopamine HCl from Paylean, Elanco, Greenfield, IN.
[3] Aquasta, IGENE Biotechnology, Columbia, MD.
[4] Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland.
[5] B = barrow and G = gilt.
[6] Color score: 1 = white to pale pinkish gray to 6 = dark purplish red (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). Individual sample packages that received a mean discoloration score ≥ 4 were deemed to have an unacceptable appearance and removed from display. Sample packages removed for an unacceptable appearance were given a discoloration score of 5 for the remaining days of retail display.
[8] Discoloration statistics: dietary treatment × gender ($P < 0.001$), day × gender ($P < 0.001$), day (linear, $P < 0.001$; quadratic, $P < 0.001$), barrow vs. gilt ($P < 0.001$), ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), astaxanthin from *Phaffia rhodozyma* within ractopamine HCl (linear, $P < 0.03$; quadratic, $P < 0.01$).
[9] Color shelf-life statistics: barrow vs gilt ($P < 0.0001$), ractopamine HCl vs non-ractopamine HCl ($P < 0.001$).

Table 5. Objective lean color measurements of pork longissimus chops from barrows and gilts fed various levels of astaxanthin with or without ractopamine HCl[1]

Ractopamine HCl[2], ppm:	None										10								
Astaxanthin source:	*Phaffia rhodozyma*[3]								Synthetic[4]		*Phaffia rhodozyma*								
Astaxanthin level, ppm:	0		5		7.5		10		5		0		2.5		5		7.5		
Gender[5]:	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	B	G	SEM
CIE L^* (lightness)[6]																			
d 0	54.5	57.2	57.3	54.3	55.5	54.7	57.3	55.8	56.1	54.0	55.2	54.3	55.5	55.0	55.2	55.0	54.3	54.2	1.33
d 1	54.5	55.8	55.8	53.8	55.0	53.5	55.0	54.6	55.9	53.5	54.3	54.6	54.8	53.7	54.5	54.8	52.9	53.6	1.33
d 2	54.9	56.3	56.2	54.1	55.4	53.7	55.4	54.3	55.5	53.1	54.1	53.9	54.3	53.9	54.8	53.8	52.9	53.6	1.33
d 3	54.0	56.0	55.7	54.0	55.3	53.3	55.2	53.6	55.4	53.2	53.8	54.0	53.6	54.0	54.2	54.4	53.0	54.1	1.33
Overall	54.5	56.3	56.2	54.0	55.3	53.8	55.7	54.6	55.7	53.4	54.4	54.2	54.5	54.1	54.7	54.5	53.3	53.9	0.67
CIE a^* (redness)[7,8]																			
d 0	11.5	10.0	10.4	10.2	10.7	9.1	8.9	10.4	10.2	10.0	9.9	9.2	9.7	8.8	9.1	8.4	9.9	9.1	0.44
d 1	10.6	10.2	10.0	10.1	9.9	9.1	9.0	10.4	9.8	10.0	9.5	9.1	9.6	9.0	8.7	8.4	10.0	9.4	0.44
d 2	8.6	8.9	8.4	9.0	8.3	8.4	7.6	9.5	8.6	9.3	8.4	8.7	8.9	8.4	7.8	8.0	9.2	9.1	0.44
d 3	8.4	8.5	8.1	8.7	7.6	8.2	7.3	9.4	8.2	9.0	8.1	8.7	8.7	8.3	7.5	7.8	9.4	9.0	0.44
Overall	9.8	9.4	9.2	9.5	9.1	8.7	8.2	9.9	9.2	9.6	9.0	8.9	9.2	8.6	8.3	8.1	9.6	9.1	0.22
CIE b^* (yellowness)[9,10]																			
d 0	17.5	16.9	16.3	16.5	17.3	15.7	15.9	15.9	17.1	16.4	16.1	16.0	16.5	15.4	15.7	15.5	16.3	15.6	0.42
d 1	17.0	17.1	16.6	16.6	16.4	16.0	16.4	16.3	16.5	16.3	16.1	15.8	16.3	15.7	15.6	15.5	15.9	15.7	0.42
d 2	15.8	16.5	15.7	15.8	15.4	15.2	15.7	15.9	16.1	15.8	15.5	15.7	15.6	15.3	14.9	15.3	15.2	15.5	0.42
d 3	16.0	15.9	15.6	15.2	14.9	15.2	15.0	15.8	16.0	15.7	15.4	15.6	15.7	15.2	14.6	14.9	15.1	15.3	0.42
Overall	16.6	16.6	16.1	16.0	16.0	15.5	15.8	15.9	16.4	16.0	15.8	15.8	16.0	15.4	15.2	15.3	15.6	15.5	0.21
ΔE (d 0 to 3)[11,12]	3.6	2.4	3.1	2.3	4.2	2.6	3.7	2.7	2.6	1.7	2.6	1.2	2.4	2.5	2.5	1.5	2.1	1.7	0.40

[1] Longissimus chops from barrows (36) and gilts (36) were measured daily for objective lean color analysis (CIE L*, a*, and b*) during 7 d of 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] Ractopamine HCl from Paylean, Elanco, Greenfield, IN.
[3] Aquasta, IGENE Biotechnology, Columbia, MD.
[4] Carophyll Pink, F. Hoffman La Roche Ltd., Basel, Switzerland.
[5] B = barrow and G = gilt.
[6] CIE L^* = measure of darkness to lightness (black = 0 to white = 100).
[7] CIE a^* = measure of redness (a larger value indicates a more red color).
[8] CIE a^* statistics: dietary treatment × gender ($P < 0.001$), day × gender ($P < 0.001$), day (linear, $P < 0.001$), ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), controls vs. astaxanthin from *Phaffia rhodozyma* ($P < 0.03$), astaxanthin from *Phaffia rhodozyma* within non-ractopamine HCl (linear, $P < 0.01$), astaxanthin from *Phaffia rhodozyma* within ractopamine HCl (quadratic, $P < 0.001$).
[9] CIE b^* = measure of yellowness (a larger value indicates a more yellow color).
[10] CIE b^* statistics: day (linear, $P < 0.001$), ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), controls vs. all astaxanthin ($P < 0.001$), controls vs. astaxanthin from *Phaffia rhodozyma* ($P < 0.001$), astaxanthin from *Phaffia rhodozyma* within non-ractopamine HCl (linear, $P < 0.001$).
[11] ΔE = total color change, calculated as $\sqrt{((\text{d } 0\ L^* - \text{d } 3\ L^*)^2 + (\text{d } 0\ a^* - \text{d } 3\ a^*)^2 + (\text{d } 0\ b^* - \text{d } 3\ b^*)^2)}$.
[12] ΔE statistics: ractopamine HCl vs. non-ractopamine HCl ($P < 0.001$), barrow vs. gilt ($P < 0.001$).

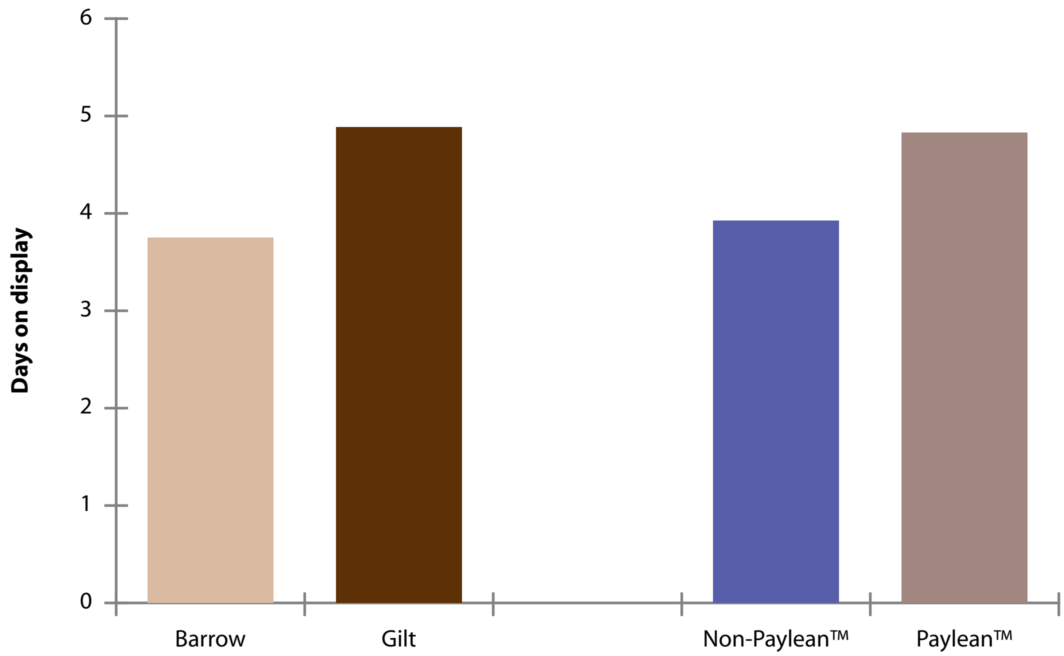

Figure 1. The effects of gender and dietary ractopamine HCl (Paylean, 9g/ton) on the color shelf-life of longissimus chops during retail display.

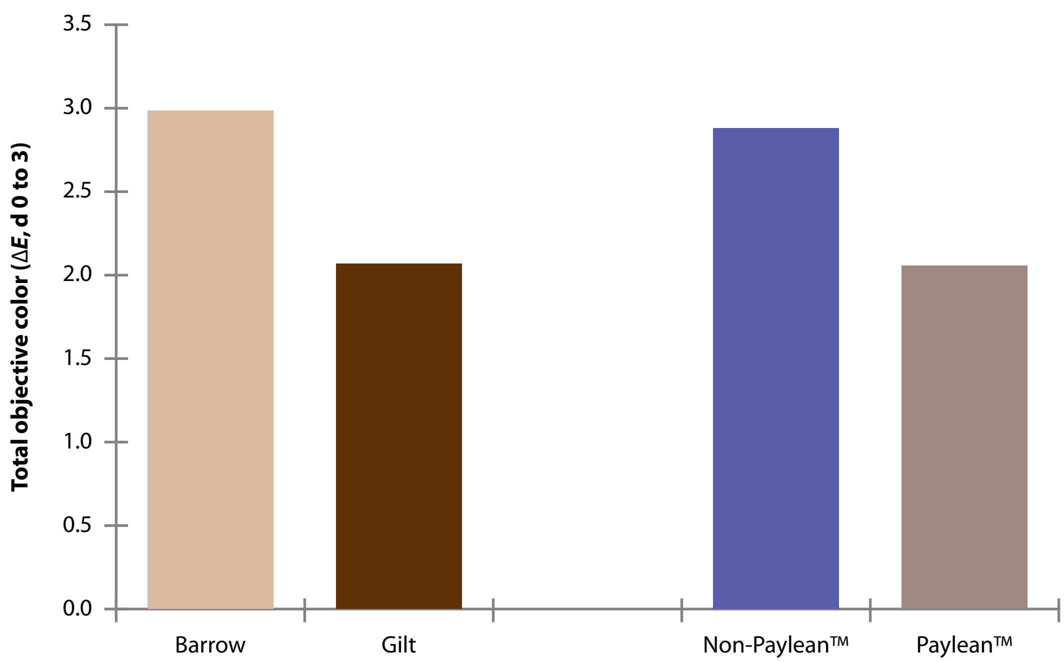

Figure 2. The effects of gender and dietary ractopamine HCl (Paylean, 9g/ton) on the change in total objective color (ΔE) of longissimus chops from d 0 to 3 of retail display.