Using Current On-Line Carcass Evaluation Parameters to Estimate Boneless and Bone-In Pork Carcass Yield as Influenced by Trim Level[1,2]

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ABSTRACT: The objective of this study was to develop prediction equations for estimating proportional carcass yield to a variety of external trim levels and bone-in and boneless pork primal cuts. Two hundred pork carcasses were selected from six U.S. pork processing plants and represented USDA carcass grades (25% USDA #1, 36% USDA #2, 25% USDA #3, and 14% USDA #4). Carcasses were measured (prerigor and after a 24 h chill) for fat and muscle depth at the last rib (LR) and between the third and fourth from last rib (TH) with a Hennessy optical grading probe (OGP). Carcasses were shipped to Texas A&M University, where one was randomly assigned for fabrication. Selected sides were fabricated to four lean cuts (ham, loin, Boston butt, and picnic shoulder) then fabricated progressively into bone-in (BI) and boneless (BL) four lean cuts (FLC) trimmed to .64, .32, and 0 cm of s.c. fat, and BL 0 cm trim, seam fat removed, four lean cuts (BLS-0FLC). Total dissected carcass lean was used to calculate the percentage of total carcass lean (PLEAN). Lean tissue subsamples were collected for chemical fat-free analysis and percentage carcass fat-free lean (FFLEAN) was determined. Longissimus muscle area and fat depth also were collected at the 10th and 11th rib interface during fabrication. Regression equations were developed from linear carcass and OGP measurements predicting FLC of each fabrication point. Loin muscle and fat depths from the OPG obtained on warm, prerigor carcasses at the TH interface were more accurate predictors of fabrication end points than warm carcass probe depth obtained at the last rib or either of the chilled carcass probe sites (probed at TH or LR). Fat and loin muscle depth obtained via OGP explained 46.7, 52.6, and 57.1% (residual mean square error [RMSE] = 3.30, 3.19, and 3.04%) of the variation in the percentage of BI-FLC trimmed to .64, .32, and 0 cm of s.c. fat, respectively, and 49.0, 53.9, and 60.7% (RMSE = 2.91, 2.81, and 2.69%) of the variation in the percentage of BL-FLC trimmed to .64, .32, and 0 cm of s.c. fat, respectively. Fat and loin muscle depth from warm carcass OGP probes at the TH interface accounted for 62.4 and 63.5% (RMSE = 3.38 and 3.27%) of the variation in PLEAN and FFLEAN, respectively. These equations provide an opportunity to estimate pork carcass yield for a variety of procurement end point equations using existing on-line techniques.

Key Words: Pigmeat, Carcass Yield, Probes

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Introduction

Signals from consumers reveal that they prefer to purchase meat products that have little or no trimmable fat (Savell et al., 1989). The retail food industry is responding to these demands by presenting products to its customers that are trimmed of excess fat and in many cases boneless. Pork carcass pricing grids based on proportional yield of lean meat have been established to provide monetary incentive to produce leaner hogs. Boland (unpublished data) reported that 41% of U.S. packers use a last rib backfat thickness as a single-point variable to estimate lean carcass yield. Another 48% use an optical grading probe inserted between the 3rd and 4th vertebrae from the last

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thoracic vertebra to obtain a fat and loin muscle tissue depth to estimate carcass lean yield.

Currently, processors and retailers are selling pork primals, subprimals, and retail cuts, bone-in or boneless, that have been trimmed to .64, .32, or 0 cm of external fat. The objective of this study was to develop prediction equations that would provide pork processors the ability to estimate proportional carcass yield at a variety of external trim levels and bone-in and boneless status.

Materials and Methods

Carcass Selection

Two hundred pork carcasses were selected at the following processing plants: Excell (Ottumwa, IA and Beardstown, IL); Monfort (Marshalltown, IA); IBP Inc. (Perry, IA); Hatfield Quality Meats (Hatfield, PA); and Sioux Preme Packers (Sioux Center, IA). Carcasses were selected to represent the national USDA carcass grade distribution (25% USDA #1; 36% USDA #2; 25% USDA #3; and 14% USDA #4). Warm, prerigor carcasses were preselected based on last rib backfat thickness and tagged for identification before entry into the chiller. Once in the chiller, last rib (**LR**) backfat thickness and subjective muscle score for degree of carcass muscling was determined by a trained USDA grader. The USDA grader's data were used for assigning an official USDA carcass grade according to USDA (1984).

Optical Grading Probe Measurement

A Hennessy optical grading probe (**OGP**; Hennessy Grading Systems, Auckland, New Zealand) was used to determine fat (**OGPFAT**) and loin muscle tissue depths (**OGPLOIN**) adjacent to the LR and at the interface of the third and fourth vertebrae from the last rib (**TH**), 7 cm lateral to the split medial plane. Warm, prerigor tissue depths were obtained within 1 h after entry into the chiller and again after a 24-h chill at 4°C. The OGP was operated by two trained operators. Carcasses were probed first at the LR and then at the TH interface. Operators and carcass sides were randomized for probing to reduce carcass side-to-side variation and operator error.

Carcass Preparation for Shipping

Chilled carcasses were weighed, wrapped in moisture-barrier plastic, and shipped to the Rosenthal Meat Science and Technology Center at Texas A&M University under refrigeration (< 10°C) for carcass fabrication. Upon arrival, each carcass side was assigned randomly for fabrication to either regular trimmed, bone-in four lean cuts (**FLC**) and belly according to the fabrication protocol of Cross et al. (1975). Weights were collected. The alternate side was frozen, and stored at –40°C until fabrication, at which time carcass sides were further fabricated into specified cuts, trim levels, and separable fat, lean, and bone as described below.

Carcass Side Fabrication

One carcass side per animal was standardized to a constant side weight according to Cross et al. (1975) by removing the jowl, tail (between first and second coccygeal vertebrae), pillar of the diaphragm, wing of the diaphragm membrane, and spinal cord. Loin muscle area was measured at the 10th rib using a grid on the transverse surface of the loin muscle, which was cut perpendicular to the vertebral column. A fat depth measurement adjacent to the 10th rib was taken at a point 3/4 the distance of the longissimus muscle from the split surface of the chine bone, which included the skin thickness in the measurement.

Regular Trimmed Ham. The rough ham was removed by making a cut at a point half the distance between the anterior edge of the aitch bone and the posterior edge of the last lumbar vertebra, perpendicular to the outer skin surface, and to a line that is parallel to the shank. Once through the butt face, a bootjack was formed in the belly by making a cut that turned at a 20° angle toward the anterior edge of the belly. The foot was removed perpendicular to the length of the shank 1.27 cm below the tuber calcis. Pelvic fat, rectus abdominus (flank muscle), lymph glands, and associated fat were removed. The ham was faced by removing a well-rounded skin collar 6.35 cm inward from the stifle joint. Collar fat exceeding 1.27 cm was removed. The rough ham was partially skinned, leaving a collar measured from the posterior end, whose length along a line down the center of the ham was 50% of the overall length of the ham. The collar line also slanted at an angle of 15 to 18° so that the skin collar was 2.54 cm longer on the flank edge than on the cushion side. Subcutaneous fat remaining on the skinned surface was beveled to a depth of 1.27 cm from the exposed collar edge to a 3.81-cm anterior point. Subcutaneous fat was beveled at a 45° angle under the butt face.

Regular Trimmed Shoulder. The rough shoulder was separated from the side by splitting the second rib along a straight line perpendicular to both the length of the loin and the outer skin surface, leaving one and one-half ribs remaining on the shoulder. The jowl was removed by a straight cut parallel to the shoulder/loin separation leaving not more than 2.54 cm of jowl anterior to the ear dip. The front foot was removed by a cut 1.27 cm above the knee joint perpendicular to the shank. Neck bones, ribs and related cartilage, intercostal meat, bloody discoloration, and loose ends and pieces were removed.

The Boston butt (**BB**) and picnic shoulder (**PS**) were separated by a cut 2.54 cm ventral to the exposed edge of the scapula on a line perpendicular to the outer skin surface and parallel to the breast side of the shoulder. The remaining portion of the jowl was removed by a cut adjacent to the Pectorales perfundus muscle. Fat and skin were removed and beveled to .64 cm on both cut lean surfaces of the picnic shoulder. The breast flap (superficial pectoral) was removed. The Boston butt was trimmed of all skin and fat in excess of .64 cm, exposing all false lean (trapezius). Fat was beveled to meet the lean on all four sides of the Boston butt.

Regular Trimmed Loin. The loin was separated from the belly along a line perpendicular to the outside skin surface, extending in a straight line from a point on the most anterior rib, which was 3.81 cm from the junction of the rib and the thoracic vertebra to a point on the ham end, which was immediately adjacent to the ventral edge of the psoas major. Skin and fat in excess of .64 cm were removed from the entire loin except in the hip bone area (5.08 cm either side of the hip pocket). False lean on the blade end was exposed lengthwise for 10.16 cm. Fat ventral to the longissimus was removed to form a bevel to the outside edge of the ribs at the ribends and continued in the same plane through the remaining length of the loin. The external fat at the ham end was beveled to practically meet the lean on the exposed face. Lumbar and pelvic fat were removed. Spareribs, sternum, and lumbar and pelvic fat were removed from the rough belly and weighed separately.

Further Processing of the FLC

Ham Fabrication. The regular trimmed ham was progressively fabricated with weights obtained at each stage of fabrication. The ham was separated into boneless cuts by separating the inside ham (semimembranosus, gracillis, and adductor), the outside ham (semitendinosus and biceps femoris), the knuckle or cushion (vastus intermedius, vastus lateralis, tensor fasciae, and vastus medialis), the tip (psoas major), bone, lean trim, and shank lean (including the heel portion). Each cut was progressively trimmed to .64, .32, and 0 cm s.c. fat and weighed. Total seam fat and other separable lean were weighed separately.

Shoulder Fabrication. The BB was trimmed to .64, .64 to .32, and .32 to 0 cm of exterior fat and further segmented into total seam fat, bone, connective tissue, and separable lean. Weights were recorded for each respective component. The skin was removed from the PS and the exterior fat was trimmed to .64, .64 to .32, and .32 to 0 cm, respectively. The remaining portion of the PS was segmented into seam fat, bone, connective tissue, separable lean, and cushion (triceps brachii). Weights were recorded for all component parts.

Loin Fabrication. Fat-back in an excess of .64, .32, and 0 cm was progressively trimmed over the length of the loin. The bevel was reduced as external loin fat was removed from .64 to.32 and .32 to 0 cm. Weights were recorded. The hanging tender was removed, weighed, and then trimmed of all remaining external fat. The subsequent trimmed hanging tender and separable fat were weighed. Back ribs were removed from the loin section. The chine bones and feather bones were removed at the ventral base of the vertebral-rib juncture. The back ribs were dissected into separable fat, lean, and bone. Chine bones and feather bones were trimmed of all separable fat and bone. All weights were recorded.

Belly Fabrication. Leaf fat and pizzle were removed from the rough belly and weighed. The rough belly was separated into the sparerib and trimmed belly sections and each component was weighed. The sternum, diaphragm, and leaf fat were removed from the sparerib section. The spareribs were dissected into separable lean, fat, and bone. All weights were recorded separately. The trimmed belly was skinned and trimmed to .64, .64 to .32, and .32 to 0 cm of external fat then separated into seam fat, lean, and remaining bones and cartilage. All weights were recorded separately.

Collection of Fat-Free Four Lean Cuts

Knife-separable lean (**KSL**) from the BB, PS, trimmed belly, loin, ham, and sparerib was separately ground and subsamples were individually stored in Whirl-Pak bags. Subsamples were then homogenized using a commercial food processor and frozen at –10°C in amber snap-cap vials until fat analysis could be conducted. Percentage moisture was determined with the oven-drying method and percentage fat (**%FAT**) from ether extraction (AOAC, 1990). Fat-free lean weight (**FFLEAN**) was determined for each cut using the following formula: FFL = KSL – (KSL × %FAT), where %FAT = percentage of ether-extractable fat for each primal and(or) subprimal cut. Total FFLEAN for the FLC was determined by adding FFL for the ham, loin, Boston butt, and picnic shoulder and dividing by standardized carcass side weight.

Statistical Analysis

Dependent variables used in the statistical analysis were defined by adding or subtracting sections cut during fabrication expressed as a percentage of warm, prerigor carcass weight. The following nine dependent variables were used: **BI-64FLC** = bone-in FLC trimmed to .64 cm s.c. fat; **BI-32FLC** = bone-in FLC trimmed to .32 cm s.c. fat; **BI-0FLC** = bone-in FLC s.c. fat removed; **BL-64FLC** = boneless FLC trimmed to .64 cm s.c. fat; **BL-32FLC** = boneless FLC trimmed to .32 cm s.c. fat; **BL-0FLC** = boneless FLC s.c. fat removed; **BLS-0FLC** = boneless FLC with seam fat removed and s.c. fat removed; **PLEAN** = percentage of total dissected carcass lean; and **FFLEAN** = percentage of fat-free dissected carcass lean determined by ether extraction.

Table 1. The percentage of carcass as four lean cuts (FLC), bone-in (BI) or boneless (BL) cuts trimmed to .64 cm (64), .32 cm (32), s.c. fat removed (0) or fat-free dissected lean (FFLEAN)

Dependent variable	Mean	Standard deviation	Minimum	Maximum
BI-64FLC, %	58.9	4.49	48.0	82.9
BI-32FLC, %	55.6	4.60	43.8	77.2
BI-0FLC, %	51.4	4.61	39.4	70.8
BL64FLC, %	50.4	3.79	41.5	69.4
BL-32FLC, %	46.8	3.91	37.0	63.2
BL-0FLC, %	42.6	3.94	32.4	56.8
BLS-0FLC, %[a]	35.0	4.80	24.6	56.0
PLEAN, %[a]	42.8	5.48	30.2	63.1
FFLEAN, %	37.5	5.39	25.9	56.5

[a] BLS-0FLC = boneless FLC with seam fat and s.c. fat removed; PLEAN = percentage of total dissected carcass lean.

Stepwise regression (SAS, 1990) was used to determine the best equation from all independent variables (increased R^2 and reduction in root mean square error [**RMSE**]). The following independent variables were included: **FDTEN** = s.c. fat depth at the 10th thoracic vertebra; **LMA** = loin muscle area at the cut lean surface of the 10th thoracic vertebra; **LRFAT** = s.c. fat thickness recorded adjacent the last thoracic vertebra by a trained USDA grader; **OGPFAT** = s.c. fat depth obtained with the optical grading probe; **OGPLOIN** = loin tissue depth obtained with the optical grading probe; **LR_{hot}** = measure of tissue depth obtained using the OGP on the prerigor carcass last thoracic vertebra; **TH_{hot}** = measure of tissue depth obtained using the OGP on the prerigor carcass between the 3rd and 4th vertebrae from last thoracic vertebra; **LR_{cold}** = measure of tissue depth obtained using the OGP on the chilled carcass at the last thoracic vertebra; and **TH_{cold}** = measure of tissue depth obtained using the OGP on the chilled carcass between the 3rd and 4th vertebrae from the last thoracic vertebra. Additionally, regression equations using independent variables of specific interest were determined. The quadratic variable for each independent variable also was tested to determine whether nonlinear effects would improve the equations predictability. Improved prediction (increase in R^2 and reduction in RMSE) was not reported for nonlinear effects, and, therefore, these equations were not reported. For each equation, the y-intercepts, β-values, R^2, and RMSE were reported. Side weight, hot carcass weight, and cold carcass weight were defined as independent variables, but these independent variables were not reported in regression equations because they either were not selected by stepwise regression or they did not improve the predictability of regression equations when specified in regression models. Selection of equations and criteria for maintaining variables in the equations were based on increased R^2 and reduction in RMSE.

Results and Discussion

Tables and 1 and 2 report sample means, standard deviation, minimum, and maximum values for dependent and independent variables. Boland (unpublished data) reported that 41% of U.S. pork packing plants obtained a backfat thickness measured adjacent the last thoracic vertebra on the carcass split medial plane (**LR**). Thirty-five percent of U.S. pork packers use LR thickness to establish carcass yield as a basis for subsequent carcass procurement. Measurement of LR thickness is a marginal means of estimating pork carcass yield (Table 3). Last rib backfat obtained online by a trained USDA grader was able to explain 37.0, 42.8, and 47.1% of the variation in BL-64FLC, BL-32FLC, and BL-0FLC (RMSE = 3.57, 3.49, and 3.36%, respectively). A slight reduction in the R^2 statistic was noted as the FLC were further processed to boneless product because LR thickness accounted for 28.7, 35.6, and 40.4% of the variation in BI-64FLC, BI-32FLC, and BI-0FLC (RMSE = 3.21, 3.15, and 3.05%, respectively). It is important to note that, although the R^2 statistics were lower at each respective trim level of BL-FLC yield, the RMSE (which is a

Table 2. Means, standard deviation, minimum, and maximum values of the independent variables

Independent variable[a]	Mean	Standard deviation	Minimum	Maximum
SWT, kg	36.8	3.96	25.6	48.2
HCWT, kg	77.9	8.07	54.4	104.8
CWT, kg	77.1	7.94	53.6	103.4
FDTEN, cm	3.13	.93	.89	5.84
LMA, cm	29.00	4.81	15.16	41.93
LRFAT, cm	2.79	.78	.76	4.57
FRFAT, cm	4.08	.85	.51	6.10
OGPFAT-LR_{hot}, cm	2.66	.71	1.00	4.80
OGPLOIN-LR_{hot}, cm	5.17	.72	3.28	7.72
OGPFAT-TH_{hot}, cm	2.70	.71	1.10	4.28
OGPLOIN-TH_{hot}, cm	5.15	.76	3.26	7.36
OGPFAT-LR_{cold}, cm	2.84	.67	.96	4.00
OGPLOIN-LR_{cold}, cm	5.28	.87	3.72	8.60
OGPFAT-TH_{cold}, cm	2.96	.70	.96	4.00
OGPLOIN-TH_{cold}, cm	5.00	.75	4.00	8.12

[a] SWT = standardized side weight recorded after transport to Texas A&M; HCWT = prerigor carcass weight recorded in packing plant; CWT = chilled carcass weight recorded in packing plant; FDTEN = s.c. fat depth at the 10th thoracic vertebra; LMA = loin muscle area of the cut lean surface at the interface of the 10th and 11th thoracic vertebrae; LRFAT = s.c. fat thickness recorded adjacent to the last thoracic vertebra on the carcass split medial plane; FRFAT = s.c. fat thickness obtained adjacent the first thoracic vertebra on the carcass split medial plane; OGPFAT = s.c. fat depth obtained with the optical grading probe; OGPLOIN = loin tissue depth obtained with the optical grading probe; LR_{hot} = measure of tissue depth obtained on the prerigor carcass at the last thoracic vertebra; TH_{hot} = measure of tissue depth obtained on the prerigor carcass between the 3rd and 4th vertebrae from last thoracic vertebra; LR_{cold} = measure of tissue depth obtained on the chilled carcass at the last thoracic vertebra; TH_{cold} = measure of tissue depth obtained on the chilled carcass between the 3rd and 4th vertebrae from last thoracic vertebra.

Table 3. Regression equations predicting carcass yield from fat depth recorded in the cooler adjacent the last thoracic vertebra (LRFAT) by a strained carcass grader

Dependent variable^a	Equation no.	R^2	RMSE^b	Intercept	β-values for LRFAT
BI-64FLC, %	1	.370	3.57	70.56	−3.893
BI-32FLC, %	2	.428	3.49	68.40	−4.286
BI-0FLC, %	3	.471	3.36	64.86	−4.503
BL-64FLC, %	4	.287	3.21	59.09	−2.894
BL-32FLC, %	5	.356	3.15	56.73	−3.322
BL-0FLC, %	6	.404	3.05	53.22	−3.566
BLS-0FLC, %	7	.513	3.36	49.67	−4.897
PLEAN, %	8	.536	3.74	59.88	−5.709
FFLEAN, %	9	.529	3.71	54.21	−5.580

[a] FLC = percentage of four lean cuts; BI = bone-in; BL = boneless; 64FLC = FLC trimmed to .64 cm s.c. fat; 32FLC = FLC trimmed to .32 cm s.c. fat; 0FLC = FLC s.c. fat removed; BLS-0FLC = boneless FLC with seam fat and s.c. fat removed; PLEAN = percentage of total dissected carcass lean; FFLEAN = percentage of fat-free dissected carcass lean determined by ether extraction.

[b] Root mean square error.

more reliable indication of statistical accuracy) was lower at each trim level of boneless yield. Last rib fat thickness produced the highest R^2 values for prediction of PLEAN and FFLEAN (R^2 = .536 and .529, respectively) and also the highest RMSE values (RMSE = 3.74 and 3.71%, respectively).

Optical grading probes operate on the principle that white fat will reflect more light than darker lean. The most common single site for probe insertion on pork carcasses in the U.S. is at the interface of the 4th vertebra from last lumbar vertebra (counting from the caudal end). Forty-eight percent of U.S. packers obtain a fat and loin depth measured by OGP (Boland, unpublished data) for use in prediction equations for estimates of carcass lean yield. Packing plants establish a pricing grid based on OGP-derived carcass yield and establish a system of premiums and discounts for carcasses relative to the pricing grid. Forty-one percent of U.S. pork packers use the OGP-estimated carcass yield as the basis for carcass procurement. The high correlation between OGP-derived fat tissue depth and actual fat depth (Kempster et al., 1985; Forrest et al., 1989; Sather et al., 1989; Berg et al., 1994) is the reason OGP are accepted as an applicable tool for assessment of pork carcass grade. The only difference in our equations compared to previous research is the subpopulations of pork carcasses selected for each study. Additionally, we used multiple fat trim end points that have not been previously reported.

Tables 4 and 5 report prediction equations produced from OGP-derived fat and loin tissue depths obtained on warm, prerigor carcasses. Warm carcass probes obtained at TH are more common in the United States

Table 4. Regression equations predicting carcass yield from optical grading probe-derived fat depth (OGPFAT-LR_{hot}) and loin depth (OGPLOIN-LR_{hot}) recorded at last thoracic vertebra on warm, prerigor carcasses

Dependent variable^a	Equation no.	R^2	RMSE^b	Intercept	β-values for OGPFAT-LR_{hot}	β-values for OGPLOIN-LR_{hot}
BI-64FLC, %	10	.425	3.42	70.08	−.4113	−.0046^c
BI-32FLC, %	11	.483	3.33	67.50	−.4487	.0002^c
BI-0FLC, %	12	.529	3.18	63.42	−.4689	.0083^c
BL-64FLC, %	13	.369	3.03	55.82	−.3115	.0559
BL-32FLC, %	14	.441	2.94	53.05	−.3524	.0602
BL-0FLC, %	15	.493	2.82	49.05	−.3746	.0668
BLS-0FLC, %	16	.555	3.22	45.42	−.4928	.0522
PLEAN, %	17	.571	3.61	55.55	−.5726	.0478
FFLEAN, %	18	.579	3.52	49.38	−.5649	.0610

[a] FLC = percentage of four lean cuts; BI = bone-in; BL = boneless; 64FLC = FLC trimmed to .64 cm s.c. fat; 32FLC = FLC trimmed to .32 cm s.c. fat; 0FLC = FLC s.c. fat removed; BLS-0FLC = boneless FLC with seam fat and s.c. fat removed; PLEAN = percentage of total dissected carcass lean; FFLEAN = percentage of fat-free dissected carcass lean determined by ether extraction.

[b] Root mean square error.

[c] Not significant at $P < .1$.

Table 5. Regression equations predicting carcass yield from optical grading probe-derived fat depth (OGPFAT-TH$_{hot}$) and loin depth (OGPLOIN-TH$_{hot}$) obtained between the 3rd and 4th vertebrae from last thoracic vertebra on warm, prerigor carcasses

Dependent variable[a]	Equation no.	R^2	RMSE[b]	Intercept	β-values for OBPFAT-TH$_{hot}$	β-values for OGPLOIN-TH$_{hot}$
BI-64FLC, %	19	.467	3.30	67.97	–.429	.0491
BI-32FLC, %	20	.526	3.19	65.49	–.4665	.0521
BI-0FLC, %	21	.571	3.04	61.71	–.4869	.0549
BL-64FLC, %	22	.418	2.91	54.72	–.3298	.0895
BL-32FLC, %	23	.490	2.81	52.00	–.3705	.0932
BL-0FLC, %	24	.539	2.69	48.27	–.3930	.0948
BLS-0FLC, %	25	.607	3.03	44.11	–.5157	.0938
PLEAN, %	26	.624	3.38	54.01	–.5991	.0964
FFLEAN, %	27	.635	3.27	47.60	–.5909	.1139

[a] FLC = percentage of four lean cuts; BI = bone-in; BL = boneless; 64FLC = FLC trimmed to .64 cm s.c. fat; 32FLC = FLC trimmed to .32 cm s.c. fat; 0FLC = FLC s.c. fat removed; BLS-0FLC = boneless FLC with seam fat and s.c. fat removed; PLEAN = percentage of total dissected carcass lean; FFLEAN = percentage of fat-free dissected carcass lean determined by ether extraction.

[b] Root mean square error.

(Table 5), even though an OGP probing site at the LR can be more conveniently located at rapid line speeds (Table 4). Both probing sites are reported in this article. Fat and loin tissue depths obtained at the TH interface produced more accurate estimates of carcass yield at all levels of fabrication; therefore, the warm carcass TH equations (Eq. 19 to 27) will be the only OGP equations addressed in this section. Optical grading probe fat and loin depth obtained on warm, prerigor carcasses at the TH interface was capable of explaining 46.7, 52.6, and 57.1% of the variation in BI-64FLC, BI-32FLC, and BI-0FLC (RMSE = 3.30, 3.19, and 3.04%, respectively). Similar to the results reported for LR fat depth (Table 3), a reduction in the R^2 statistic was found as the bones were removed from the FLC. Fat and loin depth accounted for 41.8, 49.0, and 53.9% of the variation in BL-64FLC, BL-32FLC, and BL-0FLC (RMSE = 2.91, 2.81, and 2.69%, respectively). As with the LR equations, the R^2 statistics were lower at each trim level of bone-in product, but less prediction error (lower RMSE) was found for each trim level of boneless yield (Table 4). The R^2 values for prediction of PLEAN and FFLEAN were .624 and .635, respectively, although the RMSE values were over 3% (RMSE = 3.38 and 3.27%, respectively).

Obtaining fat and loin tissue depths for estimation of carcass yield were much more accurate from probes taken on warm carcasses as opposed to chilled ones. Loin tissue depth was not significant ($P < .1$) in many of the equations obtained from chilled carcass probing. It is interesting to note that chilled carcass OGP tissue depths obtained at the LR produced more accurate estimates of carcass yield than those obtained at the TH interface, the opposite of what we found for equations based on measuring warm carcasses. Grading probe equations obtained on chilled carcasses (Tables 6 and 7) were comparable in

Table 6. Regression equations predicting carcass yield from optical grading probe-derived fat depth (OGPFAT-LR$_{cold}$) and loin depth (OGPLOIN-LR$_{cold}$) recorded at the last thoracic vertebra on carcasses after a 24-h chill at 4°C

Dependent variable[a]	Equation no.	R^2	RMSE[b]	Intercept	β-values for OGPFAT-LR$_{cold}$	β-values for OGPLOIN-LR$_{cold}$
BI-64FLC, %	28	.366	3.60	70.98	–.4068	–.0094[c]
BI-32FLC, %	29	.421	3.52	68.57	–.4461	–.0059[c]
BI-0FLC, %	30	.468	3.38	64.89	–.4705	–.0023[c]
BL-64FLC, %	31	.328	3.13	58.24	–.3177	.0231[c]
BL-32FLC, %	32	.397	3.05	55.64	–.3606	.0268[c]
BL-0FLC, %	33	.452	2.93	51.97	–.3875	.0301
BLS-0FLC, %	34	.492	3.44	47.75	–.4959	.0259[c]
PLEAN, %	35	.507	3.87	58.36	–.5777	.0165[c]
FFLEAN, %	36	.509	3.80	51.98	–.5659	.0307

[a] FLC = percentage of four lean cuts; BI = bone-in; BL = boneless; 64FLC = FLC trimmed to .64 cm s.c. fat; 32FLC = FLC trimmed to .32 cm s.c. fat; 0FLC = FLC s.c. fat removed; BLS-0FLC = boneless FLC with seam fat and s.c. fat removed; PLEAN = percentage of total dissected carcass lean; FFLEAN = percentage of fat-free dissected carcass lean determined by ether extraction.

[b] Root mean square error.

[c] Not significant at $P < .1$.

Table 7. Regression equations predicting carcass yield from optical grading probe-derived fat depth ($\text{OGPFAT-TH}_{\text{cold}}$) and loin depth ($\text{OGPLOIN-TH}_{\text{cold}}$) obtained between the 3rd and 4th vertebrae from last thoracic vertebra on carcasses after a 24-h chill at 4°C

Dependent variable[a]	Equation no.	R^2	RMSE[b]	Intercept	β-values for $\text{OGPFAT-TH}_{\text{cold}}$	β-values for $\text{OGPLOIN-TH}_{\text{cold}}$
BI-64FLC, %	37	.310	3.75	73.54	–.3591	–.0799
BI-32FLC, %	38	.361	3.70	71.18	–.3982	–.0765
BI-0FLC, %	39	.407	3.57	67.43	–.4242	–.0699
BL-64FLC, %	40	.242	3.32	58.71	–.2678	–.0071[c]
BL-32FLC, %	41	.307	3.27	56.13	–.3106	–.0029[c]
BL-0FLC, %	42	.361	3.17	52.44	–.3388	.0026[c]
BLS-0FLC, %	43	.415	3.69	48.78	–.4445	–.0124[c]
PLEAN, %	44	.435	4.14	59.59	–.5202	–.0280[c]
FFLEAN, %	45	.440	4.06	52.51	–.5116	.0028[c]

[a] FLC = percentage of four lean cuts; BI = bone-in; BL = boneless; 64FLC = FLC trimmed to .64 cm s.c. fat; 32FLC = FLC trimmed to .32 cm s.c. fat; 0FLC = FLC s.c. fat removed; BLS-0FLC = boneless FLC with seam fat and s.c. fat removed; PLEAN = percentage of total dissected carcass lean; FFLEAN = percentage of fat-free dissected carcass lean determined by ether extraction.

[b] Root mean square error.

[c] Not significant at $P < .1$.

accuracy to LR fat thickness measurements reported in Table 3 and will not be discussed further.

Research by Sather et al. (1989) compared different brands of OGP and found no evidence for differential bias between two different probes. Other research has reported statistical differences between brands of OGP (Fortin et al., 1984; Kempster et al., 1985). However, the reported differences were very

Table 8. Regression equations predicting carcass yield from fat depth (FDTEN) and loin muscle area (LMA) recorded at the interface of the 10th and 11th thoracic vertebrae

Dependent variable[a]	Equation no.	R^2	RMSE[b]	Intercept	β-values for FDTEN	β-values for LMA
BI-64FLC, %	46a	.498	3.19	69.55	–3.393	—
	46b	.125	4.22	49.35	—	.330
	46c	.524	3.12	64.33	–3.166	.156
BI-32FLC, %	47a	.555	3.08	67.09	–3.671	—
	47b	.153	4.25	44.74	—	.374
	47c	.590	2.96	60.82	–3.399	.187
BI-0FLC, %	48a	.598	2.93	63.34	–3.813	—
	48b	.173	4.20	39.83	—	.399
	48c	.640	2.78	56.46	–3.5138	.025
BL-64FLC, %	49a	.412	2.92	58.59	–2.603	—
	49b	.200	3.40	40.20	—	.353
	49c	.488	2.73	50.95	–2.271	.228
BL-32FLC, %	50[a]	.481	2.83	55.90	–2.903	—
	50b	.240	3.42	35.23	—	.399
	50c	.575	2.56	47.18	–2.525	.260
BL-0FLC, %	51a	.528	2.72	52.15	–3.064	—
	51b	.266	3.39	30.28	—	.423
	51c	.632	2.40	42.86	–2.661	.277
BLS-0FLC, %	52a	.625	2.95	47.75	–4.063	—
	52b	.230	4.23	21.14	—	.479
	52c	.697	2.66	38.45	–3.659	.277
PLEAN, %	53a	.646	3.27	57.57	–4.711	—
	53b	.217	4.86	27.42	—	.531
	53c	.708	2.98	47.68	–4.282	.295
FFLEAN, %	54a	.638	3.25	51.96	–4.606	—
	54b	.245	4.70	21.43	—	.555
	54c	.716	2.89	40.97	–4.129	.327

[a] FLC = percentage of four lean cuts; BI = bone-in; BL = boneless; 64FLC = FLC trimmed to .64 cm s.c. fat; 32FLC = FLC trimmed to .32 cm s.c. fat; 0FLC = FLC s.c. fat removed; BLS-0FLC = boneless FLC with seam fat and s.c. fat removed; PLEAN = percentage of total dissected carcass lean; FFLEAN = percentage of fat-free dissected carcass lean determined by ether extraction.

[b] Root mean square error.

small, and both groups concluded that differences between probes were not large enough to warrant consideration of one probe over another in an integrated grading system.

Pork carcass yield has long been determined under laboratory and research situations by measurement of s.c. fat tissue depth and loin muscle area at the cut plane between the 10th and 11th thoracic vertebrae (NPPC, 1991). Table 8 reports prediction equations that use 10th rib fat depth (FDTEN), 10th rib loin muscle area (LMA), or a combination of the two variables to estimate proportional carcass yield. From these data, the variables FDTEN and LMA generate the most accurate prediction equations for estimation of all carcass yield end points, possessing RMSE values below 3%. Obtaining FDTEN or LMA in an on-line situation within a packing plant is inconvenient and reduces the value of the loin and belly. However, acquisition and use of these variables is quite common in research and teaching situations; therefore, the equations are reported in this article.

Research studies have been published reporting regression equations predicting pork carcass composition from easily obtained linear measurement in lieu of performing labor-intensive and expensive cutting tests (Cross et al., 1973; Fahey et al., 1977; Edwards et al., 1980; Grisdale et al., 1984; Siemens et al., 1989; Orcutt et al., 1990; Berg et al., 1994). The majority of these equations developed to predict pork carcass composition were generated from a sample of the carcass population that either fit a particular study or was derived from a subpopulation selected to vary in muscling, fatness, and weight. The equations developed in these studies did not take into account a rapidly changing industry that is moving toward a leaner product. Today's pork industry is producing heavier, leaner hogs, and packers are trimming more fat from primal cuts before sending them to the retail market (Orcutt et al., 1990; Buege et al., 1993). These cutting techniques have allowed processors to market products varying in trim level that are boneless or bone-in.

Implications

Accurate estimation of yield could be used to provide economic incentive so that the U.S. pork industry could meet the future demands of consumers by providing the desired trimmed, boneless, fresh pork product at the retail level. Current pork carcass grade and yield marketing strategies estimate yield of lean tissue or percentage of carcass lean. The equations developed in this study provide for estimation of a variety of trim levels and cutting styles that can be used as a means for determination of various carcass yield end points. The use of existing on-line techniques for development of these prediction equations provides the opportunity for estimation of fresh pork carcass yield for a variety of procurement end points.

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