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Abstract

Currently, in pork auctions in Korea, only carcass weight and backfat thickness provide information on meat quantity, while the production volume of primal cuts and fat contents remains largely unknown. This study aims to predict the production of primal cuts in pigs and investigate how these carcass traits affect pricing. Using the VS2000, the production of shoulder blade, loin, belly, shoulder picnic, and ham was measured for gilts (17,257 pigs) and barrows (16,365 pigs) of LYD (Landrace × Yorkshire × Duroc) pigs. Single and multiple regression analysis were conducted to analyze the relationship between the primal cuts and carcass weight. The study also examined the correlation between each primal cut, backfat thickness (1st thoracic vertebra backfat thickness, grading backfat thickness, and Multi-brached muscle middle backfat thickness), pork belly fat percentage, total fat yield, and auction price. A multiple regression analysis was conducted between the carcass traits that showed a high correlation and the auction price. After conducting a single regression analysis on the primal cuts of gilt and barrow, all coefficients of determination (R^2) were 0.77 or higher. In the multiple regression analysis, the R^2 value was 0.98 or higher. The correlation coefficient between the carcass weights and the auction price exceeded 0.70, while the correlation coefficients between the primal cuts and the auction prices were above 0.65. In terms of fat content, the backfat thickness of gilt exhibited a correlation coefficient of 0.70, and all other items had a correlation coefficient of 0.47 or higher. The correlation coefficients between the Forequarter, Middle, and Hindquarter and the auction price were 0.62 or higher. The R^2 values of the multiple regression analysis between carcass traits and auction price were 0.5 or higher for gilts and 0.4 or higher for barrows. The regression equations between carcass weight and primal cuts derived in this study exhibited high determination coefficients, suggesting that they could serve as reliable means to predict primal cut production from pig carcasses. Elucidating the correlation between primal cuts, fat contents and auction prices can provide economic indicators for pork and assist in guiding the direction of pig farming.

Keywords (3 to 6): LYD pig, Carcass traits, regression analysis, Correlation coefficient, Auction price, VCS2000

Introduction

The per capita consumption of livestock products in the Republic of Korea increased from 40.6 kg in 2010 to 56.1 kg in 2021, marking a growth of 15.5 kg. Among the different types of meat, pork consumption was the highest from 1985 to 2021. Consequently, the number of pigs raised in South Korea also increased, rising from 8.2 million pigs in 2011 to around 11.2 million pigs in 2021, an increase of approximately 3 million pigs [1]. Thus, the Korean government is increasing the processing speed of slaughterhouses by designating centralized slaughterhouses equipped with modern facilities. In 2016, as a pilot project, the government introduced the VCS2000, an automated grading machine, to improve the accuracy of pork grading and reduce the need for additional labor [2]. As of November 2022, VCS2000 equipment has been installed in 11 domestic slaughterhouses [3].

The VCS2000 device is non- invasive carcass measurement equipment that analyzes images of pigs captured using a monochromatic camera and two-color cameras during the pig slaughtering process. Through this, it is possible to measure the production quantity of primal cuts, such as shoulder picnic, ham, shoulder blade, ribs, belly, and loin, as well as the backfat thickness, total fat yield, and belly fat percentage of the pig [2, 3, 4, 5]

As of 2021, among the pigs sent to market in South Korea, gilts accounted for 50.5%, while barrows, which are castrated pigs, accounted for 49.0% [6]. Furthermore, the castration rate of male pigs increased from 98.1% in 2010 to 99.1% in 2021 [6]. Barrows are pigs in which the testes have been removed to eliminate reproductive functions [7, 8]. Females and castrated males exhibit differences in feed intake and feed efficiency during the rearing and fattening periods [9, 10]. Previous studies showed differences in carcass characteristics, including weight, the quantity of pork cuts produced, fat content, and back fat thickness, between females and castrated males [10, 11, 12, 13].

In South Korea, pig auctions are conducted for wholesale buyers, including trading participant and auction participants, who bid on graded meat [14]. During the auction, the half carcass, as well as its gender, carcass weight, grade, and breed, is displayed on electronic boards [15]. Pig grading is based on the Ministry of Agriculture, Food, and Rural Affairs Notice No. 2020-112 (MAFRA. 2020. 12. 29) detailed standards for livestock product grading. The grading consists of a first grading, which measures carcass weight and backfat thickness, and a second grading of appearance and meat quality. In pork auctions, bidding is based solely on the visual appearance of the half carcass and the grading results without considering the actual primal cut quantity. Therefore, until now, meat quantity could only be inferred based on the carcass weight and back fat thickness, and the weight of specific pork cuts could only be determined after the auction when the pig carcass was processed into primal cuts.

Currently, the auction price of pork is determined through primary and secondary grading, and some data, such as carcass traits and lean meat yield predictions made by the VCS 2000, are only minimally used as reference data in some slaughterhouses [3]. This study utilized the VCS 2000 to investigate the differences in production quantity of each primal cut between gilts and barrows and established a means to predict primal cut production quantity. Additionally, by clarifying the correlation between primal cuts and the backfat of pigs with auction prices, this research aimed to provide important economic indicators for pork production in the swine industry.

Materials and Methods

Animals

Pigs were selected from a total of 33,622 individuals, consisting of 17,257 female LYD (Landrace × Yorkshire × Duroc) pigs and 16,365 castrated male pigs, that were slaughtered from June 2 to July 29, 2022, in the Bukyeong Livestock Auction Market in Juchon-myeon, Gimhae-si, Gyeongsangnam-do. All pigs were slaughtered according to the Livestock Products Sanitation Control Act (Livestock Sanitation Control Act, 2021 revision).

VCS2000 equipment

The VCS2000 equipment (E+V Technology GmbH, Germany) consists of a monochromatic camera, color camera, lighting device, background device, carcass guide, carcass holder, control box, vision program, computer, and spare parts.

The measurements were taken after dividing the pig carcass into two parts during the slaughtering process, where the half carcass was fixed on the carcass holder, and the rear portion of the half carcass was captured using a monochromatic camera. After that, two color cameras were used to photograph the upper and lower surfaces of the half carcass front, respectively, and then these images were input into a computer for analysis. The accuracy of the VCS2000 equipment was demonstrated by Park et al. [16].

The following measurements were obtained for pigs using the VCS2000: production quantity of five primal cuts (shoulder picnic, ham, loin, belly, and shoulder blade), backfat thickness at the first thoracic vertebra, backfat thickness used for grading (average thickness between the last rib and the first lumbar vertebra, and the thickness between the 11th and 12th ribs), multi-branched muscle middle backfat thickness, pork belly fat percentage, and total fat yield, as well as the quantity of forequarter, middle, and hindquarter produced.

Statistical analysis

Descriptive statistics (mean, standard deviation) were calculated to compare the VCS2000 measurements between gilts and barrows, and t-tests were conducted for the mean and standard deviation. Through One-way ANOVA, we confirmed the significance tests for the five primal cuts and three backfat thickness, and post hoc tests were conducted using the Duncan test. the VCS2000 measurements between female pigs and castrated male pigs, and t-tests were conducted for the mean and standard deviation. A simple regression analysis was performed to analyze the relationship between primal cuts and carcass weight in gilts and barrows, with carcass weight as the dependent variable and primal cut production quantity as the independent variable. Pearson's correlation coefficients were calculated to analyze the correlation between VCS2000 measurements and auction prices for gits and barrows. A multiple regression analysis was also conducted, with carcass weight as the dependent variable and the production quantity of all primal cuts as the independent variable. All statistical analyses were performed using SPSS software, version 25.0 (SPSS Inc., Chicago, IL, USA).

Results and Discussion

Investigation of carcass weight and primal cuts production of gilt and barrow

To investigate the production of gilts and barrows based on primal cuts, the weights of shoulder blade, loin, belly, shoulder picnic, and ham were measured in gilts and barrows using the carcass weight and the VCS2000. There was no difference in carcass weight between gilts and barrows (Table 1). In both gilts and barrows, the highest weight was observed in ham among the five primal cuts, followed by the belly, shoulder picnic, loin, and shoulder blade (p < 0.0001, Table 1). Similar results were reported in a study that investigated the production quantity of seven major primal cuts (ham, belly, shoulder picnic, loin, shoulder blade, spare rib, and tenderloin) in LYD pigs using non-invasive ultrasound equipment [17, 18, 19]. In a study examining the impact of carcass weight on primal cuts, both gilts and barrows showed higher ham production than that of shoulder picnic, belly, loin, and shoulder blade, and shoulder picnic production was higher than that of the shoulder blade

[11]. In a study on the production quantity of primal cuts in Meishan and Yorkshire gilts and barrows, both gilts and barrows showed a higher production of ham compared to loin, shoulder picnic (shoulder), and shoulder blade cuts, with shoulder blades having the lowest production quantity [12]. Another study investigating carcass characteristics based on gender found that the production quantity of ham was higher than that of shoulder picnic (shoulder) [10].

In the comparison of production quantity by primal cut between gilts and barrows, gilts had lower production quantities of shoulder blade, loin, and belly and higher production quantities of shoulder picnic and ham ($p < 0.05$, Table 1). As the backfat thickness of pig carcasses increased, the quantity of shoulder picnic and ham decreased, whereas the quantity of belly cuts increased [20, 21]. Furthermore, in a study on the primal cuts (shoulder picnic, ham, loin, and belly) of pigs by carcass weight, the fat content was highest in the belly, followed by loin, ham, and shoulder picnic cuts [22]. In the comparison of the fat content of different parts (tenderloin, loin, shoulder blade, foreshank, jowls, ham, eye of round, belly, skirt meat, and ribs) in LYD pigs, the belly had the highest fat content, while the shoulder blade had higher fat content compared to tenderloin, loin, foreshank, ham, eye of round, skirt meat, and rib cuts, excluding the belly and jowls ($p < 0.05$) [23]. As the backfat thickness increased, the loin area and the amount of loin meat decreased ($p < 0.01$) [24]. Additionally, when processing primal cuts, a fat thickness of 0.5 cm is typically left, and the remaining backfat and excess fat are trimmed [25]. The data obtained from the VCS2000 used in this experiment included the predictions of primal cut quantities without trimming excessive fat or thick backfat. The untrimmed loin weight of Yorkshire gilts and barrows was higher in barrows than in gilts ($p < 0.05$) [12]. Therefore, due to the thinner backfat and lower overall fat content in gilts, the production quantity of relatively low-fat shoulder picnic and ham was higher in gilts compared to barrows ($p < 0.05$, Tables 1 and 4).

Regression analysis of carcass weight and production of each primal cut yield of gilt and barrow

Simple regression analysis was performed to investigate the relationship between carcass weight and the weights of each primal cut. In the simple regression analysis, the dependent variable y was set as the carcass weight, and the weight of each primal cut was set as the independent variable x to determine the regression equation (Table 2).

It was observed that as the production of each part increased, the slope became small, and the slope increased when production decreased. This trend was observed in both gilts and barrows. The slopes of the gilts and barrows were similar (Table 2). The coefficient of determination (R-squared) was lowest for ham (0.7699) in gilts, while shoulder blade, loin, belly, and shoulder picnic all had R-squared values above 0.8. The coefficients of determination for each regression analysis were similar between gilts and barrows (Table 2). In a study that used 175 pig carcasses and performed regression analysis between carcass weight and the lean meat percentage of the primal cuts using the VCS2000, the coefficients of determination of the the predicted regression equations were 0.90 for shoulder picnic, 0.85 for loin, 0.91 for the belly, and 0.87 for ham, showing similar results to this experiment [5].

Multiple regression analysis was conducted to investigate the relationship between carcass weight and the five primal cuts. In the multiple regression analysis, the dependent variable y was set as the carcass weight, and the independent variable xi was the weight of each primal cut (x1 = shoulder blade, x2 = loin, x3 = belly, x4 = shoulder picnic, x5 = ham). The multiple regression equation and coefficient of determination for carcass weight and the five primal cuts were as follows:

Gilt: $y = 1.09x_1 + 3.06x_2 + 0.07x_3 + 3.01x_4 + 0.33x_5 + 8.37$, $R^2=0.9833$

Barrow: $y = 1.35x_1 + 2.80x_2 + 0.21x_3 + 2.65x_4 + 0.42x_5 + 8.98$, $R^2=0.9832$

In the multiple regression analysis, the relationship between the production quantity of each primal cut and their respective slope was different between gilts and barrows, unlike the simple regression analysis results. However, the coefficients of determination were above 0.98. In a regression analysis using ham, belly, shoulder picnic, loin, shoulder blade, spare rib, and tenderloin as independent variables for Korean pork grading, the coefficients of determination were 0.99 for all grades [17]. When multiple independent variables are considered, higher coefficients of determination are obtained compared to single-variable regression analysis. A coefficient of determination value of 0.73 indicates a reasonable degree of accuracy, while a value of 0.80 or above indicates a high degree of accuracy [5, 26]. In the single regression analysis, both gilts and barrows had coefficients of determination above 0.73 for ham, indicating a reasonable degree of accuracy, and coefficients of determination above 0.80 for the other four primal cuts, indicating a high degree of accuracy (Table 2). Therefore, the single and multiple regression equations obtained in this study could be used to predict the production quantity of each primal cut based on the carcass weight of LYD pigs.

Correlation analysis between carcass weight, production of primal cuts and auction price of gilt and barrow

The correlation between carcass weight, shoulder blade, belly, shoulder picnic, ham, and auction prices for gilts and barrows was analyzed to investigate the impact of carcass weight and individual primal cuts on pork prices. The correlation coefficients for carcass weight were above 0.7 for both gilts and barrows, indicating a strong correlation with auction prices. The correlation of each primal cut with auction prices differed between gilts and barrows. In gilts, shoulder blade, loin, and belly cuts showed higher correlation coefficients with auction prices compared to shoulder picnic and ham (Table 3). In barrows, shoulder blade and loin had higher correlation coefficients with auction prices compared to shoulder picnic and ham, and belly had higher correlation coefficients compared to shoulder picnic (Table 3). Pulkrábek et al. [27] reported a positive association between carcass weight and primal cuts. Korean consumers' preference for the belly, shoulder blade, and loin as favored cuts may be reflected in the auction prices [3]. Correlation coefficients between 0.40 and 0.69 indicate a moderate correlation, while correlation coefficients between 0.70 and 0.89 indicate a strong correlation [28]. Both gilts and barrows showed correlation coefficients above 0.70 for carcass weight, indicating a strong correlation with auction prices. The shoulder blade, loin, belly, shoulder picnic, and ham all had correlation coefficients above 0.60, indicating a moderate correlation with auction prices.

Investigation of fat contents of gilt and barrow

Backfat thickness was highest for the first thoracic vertebra backfat thickness, followed by Backfat thickness used for grading and multi-branched muscle middle backfat thickness (p < 0.0001, Table 4). Backfat thickness tends to decrease from the thoracic vertebrae to the lumbar vertebrae. A study investigating the characteristics of pig carcasses using the VCS2000 yielded similar results, showing that backfat thickness was highest for the first and second thoracic vertebrae, followed by the 11th and 12th thoracic vertebrae, and the 14th thoracic to the first lumbar vertebrae and the seventh branched muscle [18]. When comparing backfat thickness, pork belly fat percentage and the total fat percentage of gilts and barrows, barrows had higher values than gilts (p < 0.0001, Table 4). These results are consistent with the inverse relationship between testosterone concentration in the bloodstream and fat accumulation in the body [29]. As testosterone concentration decreased, muscle mass, strength, and bone density decreased, whereas the proportion of fat tissue increased [30]. When comparing the backfat thickness of barrows and gilts, barrows had thicker backfat due to lower testosterone concentrations caused by castration [10, 11]. Additionally, in a study on fat content in 171-day-old Yorkshire gilts and barrows, barrows had higher fat content than gilts [12].

Correlation analysis between fat contents and auction price of gilt and barrow

In the Korean pork grading system, the criterion for grading is the average backfat thickness between the last rib and the first lumbar vertebra, as well as between the 11th and 12th ribs. The correlation coefficients between backfat thickness, belly fat percentage, total fat yield, and auction prices were calculated to investigate the correlation between backfat thickness and auction prices in pigs. The correlation coefficient with the auction price was high in the order of backfat thickness measured according to Korean pork carcass grading, total fat yield, first thoracic vertebra backfat thickness, pork belly fat percentage, and multi-branched muscle middle backfat thickness (Table 5).

The correlation coefficient between backfat thickness and auction prices in gilts was 0.703, indicating a strong correlation, while the correlation coefficients for the other measurements were above 0.40, indicating a moderate correlation. Both the backfat thickness and fat content in gilts were lower than in barrows, and the correlation coefficient between pork fat content and auction prices was higher for gilts than for barrows (Table 5). As backfat thickness increases, the fat yield of pork increases, and the meat yield decreases [24]. Higher backfat thickness results in lower pork carcass grades [31]. Thus, the correlation between backfat thickness and auction prices was found to be higher than that of other factors.

Analysis of production of forequarter, middle and hindquarter of gilt and barrow

The production quantity of the forequarter, middle, and hindquarter was measured for gilts and barrows using the VCS2000, and the production quantity of each part was compared between the two groups. No significant difference in forequarters was observed between gilts and barrows (Table 6).

The forequarter consists of the shoulder blade, spare ribs, and shoulder picnic. The shoulder blade was found to be higher in barrows compared to gilts (p< 0 .05, Table 1). The lack of difference in forequarter production quantities can be attributed to the larger production quantity of spare ribs or shoulder picnic in gilts. In terms of the middle and hindquarter, gilts showed a lower production quantity of the middle and a higher production quantity of the hindquarter compared to barrows ($p < 0.005$, Table 6). The middle consists of the loin, belly, and tenderloin, with the tenderloin occupying a very small proportion in the middle compared to the belly and loin [32]. Since barrows had higher production quantities of loin and belly compared to gilts, it was observed that barrows had a higher production quantity in the middle ($p < 0.05$, Tables 1 and 6). As gilts had a higher production quantity of ham compared to barrows, it was evident that gilts had a higher production quantity in the hindquarter (p< 0.05, Tables 1 and 6).

Correlation analysis between forequarter, middle, and hindquarter of gilt and barrow and auction price

To examine the influence of the production quantities of the Forequarter, middle, and hindquarter on auction prices in pork, The correlation between the production quantity of each division and the auction prices for pork forequarter, middle, and hindquarter was investigated. Both gilts and barrows showed a moderate correlation with auction prices for all three divisions, with correlation coefficients of 0.61 or higher (Table 7). Among the three divisions, the forequarter had the lowest correlation coefficient, whereas the middle had the highest correlation coefficient (Table 7). The middle division showed the highest correlation coefficient, primarily due to the inclusion of the belly, which forms the most expensive cut and has the highest meat production quantity among all the cuts (Table 6) [6]. The higher correlation coefficient for the hindquarter compared to the forequarter is likely due to the important role of the hindquarter in assessing the body condition score (BCS). The body condition score (BCS) evaluation of pigs is based on visual and tactile assessments of the hindquarter area [33, 34]. It assesses the pig's body condition by categorizing it into five levels: Emaciate, Thin, Ideal, Fat, and Overfat [33, 34]. It is used to evaluate the nutritional status and degree of fat deposition in pigs [33, 34]. It is presumed that the correlation with auction prices is higher for the hindquarter than the forequarter because the BCS is evaluated using the hindquarter. As the amount of fat deposition and overall health of pigs can be inferred through the hindquarter, it is presumed that the correlation with auction prices is higher compared to the forequarter.

Multiple regression analysis of gilt and barrow's carcass trait and auction price

To investigate the extent to which auction prices can be predicted through various factors of pig carcass, a multiple regression analysis was conducted between the auction price and several carcass traits that exhibited a relatively high correlation with the auction price.

Gilt: $y = 40.55x_1 + 84.40x_2 + 63.065$, $R^2 = 0.556$

Barrow: $y = 33.65x_1 + 36.87x_2 + 1872.37$, $R^2 = 0.408$

The first multiple regression equations of gilt and barrow were set with the auction price (y) as the dependent variable and body weight (x1) and backfat thickness used for grading (x2) as independent variables, which are used to evaluate the carcass quality of pigs.

Gilt: $y = 48.70x1 + 98.32x2 + 18.53x3 + 28.52x4 + 78.09x5 + 80.58x6 + 848.32$, $R^2 = 0.560$

Barrow: $y = 97.86x1 + 51.35x2 + 12.72x3 + 3.58x4 + 77.31x5 + 35.14x6 + 2025.39$, $R^2 = 0.411$

The second multiple regression equations of gilt and barrow were set with the auction price(y) as the dependent variable and five primal cuts (shoulder blade = x1, loin = x2, belly = x3, shoulder picnic = x4, ham = x5) and backfat thickness used for grading (x6) as independent variables.

Based on the R^2 values of the first and second multiple regression equations, it can be observed that the R^2 value for Gilt is higher than that for Barrow. This suggests that the correlation between the independent variables used in each equation and the auction price is generally stronger for Gilt compared to Barrow, as indicated in Table 3 and Table 5. Additionally, it can be observed that both Gilt and Barrow show slightly higher R^2 values in the second multiple regression equation compared to the first one. This suggests that the analysis using the five primal cuts measured by VCS2000 provides a better understanding of the auction price than carcass weight alone.
However, the R^2 values for Gilt and Barrow in both equations are not high. The reason for this can be found in the current structure of pig auctions in Korea. As mentioned in the introduction, pig auctions are conducted through a bidding system targeting wholesalers and trading participant [14]. The participants in the bidding may have different preferences for pig carcasses, and furthermore, they may have varying requirements for specific primal cuts or the degree of fat. Due to these reasons, the R^2 values for Gilt and Barrow in the first and second equations did not show a high correlation. However, despite this, it can be sufficiently confirmed through this regression equation the tendency in which auction prices are formed. Therefore, it is deemed usable as a reference material for auction prices.

Conclusion

In this study, we compared the production quantity of primal cuts between LYD gilts and barrows using data measured by the VCS2000 equipment, analyzed the relationship between carcass weight and primal cuts, and investigated their correlation with auction prices. Regression analysis was conducted to derive formulas that predicted the production quantity of primal cuts based on the carcass weight of LYD pigs in Korea. The obtained formulas showed high reliability with determination coefficients ranging from 0.77 to 0.98. The correlation analysis between primal cuts and auction prices found that primal cuts and fat content had a moderate or strong correlation with auction prices. Therefore, this study provides a means to predict the production quantity of primal cuts based on carcass weight and establishes a correlation with auction prices, making it a useful indicator for determining pig specifications in the swine industry.

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Tables

Table 1. Carcass weights and production of primal cut measured by the VCS2000 in gilts and barrows

	Gilts	Barrows
Carcass weight	83.22±7.59	83.18±7.67
Shoulder blade	$5.48±0.55^{\mathbf{bE}}$	$5.53±0.56^{\mathbf{aE}}$
Loin	$9.54±1.04^{\mathbf{bD}}$	$9.6±1.08^{\mathbf{aD}}$
Belly	$16.01±1.97^{\mathbf{bB}}$	$16.1±2.03^{\mathbf{aB}}$
Shoulder picnic	$10.77±1.13^{\mathbf{aC}}$	$10.75±1.14^{\mathbf{bC}}$
Ham	$18.30±1.89^{\mathbf{aA}}$	$18.21±1.86^{\mathbf{bA}}$

Unit: kg, gilts: 17,602 pigs, barrows: 16,579 pigs. Each value is presented as the mean ± standard deviation. $^{A-E}$ Different superscripts in the same column are significantly different from each other ($p < 0.0001$). $^{a-b}$ Different superscripts in the same row are significantly different from each other ($p < 0.05$).

Table 2. Simple regression analysis of carcass weights and production of each primal cut measured by the VCS2000 in gilts and barrows

	Linear regression slope		Intercept		Coefficient of determination (R^2)	
	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows
Shoulder blade	12.86	12.78	12.74	12.46	0.8551	0.8609
Loin	6.85	6.64	17.82	19.38	0.8820	0.8815
Belly	3.35	3.47	26.34	27.18	0.8496	0.8487
Shoulder picnic	6.43	6.42	13.84	17.10	0.9137	0.9089
Ham	3.53	3.66	18.57	16.37	0.7699	0.7901

Gilts: 17,602 pigs, barrows: 16,579 pigs.

Table 3. Correlation coefficient between the carcass weight, production of primal cuts measured by the VCS2000, and auction price in gilts and barrows

	Gilts	Barrows
Carcass weight	0.700^{**}	0.706^{**}
Shoulder blade	0.665^{**}	0.665^{**}
Loin	0.711^{**}	0.683^{**}
Belly	0.693^{**}	0.660^{**}
Shoulder picnic	0.653^{**}	0.653^{**}
Ham	0.653^{**}	0.664^{**}

Gilts: 17,602 pigs, barrows: 16,579 pigs. $^{**}p < 0.01$.

Table 4. Pork backfat thickness, belly fat content, and total fat percentage measured by the VCS2000 in gilts and barrows

	Gilts	Barrows
First thoracic vertebra backfat thickness (mm)	36.73 ± 4.56^{bA}	38.83 ± 4.40^{aA}
Backfat thickness used for grading (mm)[1]	20.87 ± 4.48^{bB}	22.77 ± 4.65^{aB}
Multi-branched muscle middle backfat thickness (mm)	16.28 ± 4.52^{bC}	18.15 ± 4.71^{aC}
Pork belly fat percentage (%)	32.34 ± 6.05^{b}	33.83 ± 6.07^{a}
Total fat yield (%)	26.29 ± 3.52^{b}	27.50 ± 3.58^{a}

Gilts: 17,602 pigs, barrows: 16,579 pigs. [1]Average of two backfat thickness (the backfat thickness between the last rib and the first lumbar vertebra, and the backfat thickness between the 11th and 12th ribs). Each value is presented as the mean ± standard deviation. $^{A\text{-}E}$Different superscripts in the same column are significantly different from each other ($p < 0.0001$). $^{a\text{-}b}$Different superscripts in the same row are significantly different from each other ($p < 0.05$).

Table 5. Correlation between pork backfat thickness, belly fat content, and total fat percentage measured by the VCS2000 and auction price in gilts and barrows

	Gilt	**Barrow**
First thoracic vertebra backfat thickness	0.596**	0.535**
Backfat thickness used for grading[1]	0.703**	0.607**
Multi-branched muscle middle backfat thickness	0.537**	0.476**
Pork belly fat percentage	0.556**	0.519**
Total fat yield	0.680**	0.618**

Gilts: 17,602 pigs, barrows: 16,579 pigs. [1]Average of two backfat thickness (the backfat thickness between the last rib and the first lumbar vertebra, and the backfat thickness between the 11th and 12th ribs). ** $p < 0.01$

Table 6. Forequarter, middle, and hindquarter production measured by the VCS 2000 in gilts and barrows

Items	Gilts	Barrows
Forequarter[1)]	19.81±1.95	19.83±1.98
Middle[2)]	27.11±3.03[b]	27.23±3.14[a]
Hindquarter[3)]	18.29 ±1.88[a]	18.20±1.85[b]

Unit: kg, gilts: 17,602 pigs, barrows: 16,579 pigs. [1)] Forequarter: spare ribs, shoulder blade, and shoulder picnic; [2)] middle: loin, belly, and tenderloin; and [3)] Hindquarter: ham. Each value is presented as the mean ± standard deviation. [a-b] Different superscripts in the same row are significantly different from each other ($p < 0.05$).

Table 7. Correlation coefficient between forequarter, middle, and hindquarter production measured by the VCS 2000 and auction price in gilts and barrows

	Gilts	**Barrows**
Forequarter[1)]	0.615**	0.619**
Middle[2)]	0.697**	0.654**
hindquarter[3)]	0.640**	0.641**

Gilts: 17,602 pigs, barrows: 16,579 pigs. [1)] Forequarter: spare ribs, shoulder blade, and shoulder picnic; [2)] middle: loin, belly, and tenderloin; and [3)] hindquarter: ham. $^{**}p < 0.01$.