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Author	Pil-Nam Seong[1], Hyun-Wook Kim[1], Dong-Gun Kim[1], Kyung Jo[2], Samooel Jung[2], and Van-Ba Hoa1*
Affiliation	[1] Animal Resources Food Tech Division, National Institute of Animal Science, RDA, Wanju 55365, Republic of Korea [2] Department of Animal Science and Biotechnology, Chungnam National University, Daejeon 34134, Republic of Korea
Special remarks – if authors have additional information to inform the editorial office	
ORCID (All authors must have ORCID) https://orcid.org	Pil-Nam Seong (https://orcid.org/0000-0003-2915-1059 Van-Ba Hoa (https://orcid.org/0000-0001-8725-1504) Hyun-Wook Kim (https://orcid.org/0000-0002-2979-345X) Dong Gyun Kim (https://(orcid.org/0000-0002-8416-0436) Jung Samooel https://orcid.org/0000-0002-8116-188X Kyung Jo https://orcid.org/0000-0002-3006-5396
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CORRESPONDING AUTHOR CONTACT INFORMATION

For the corresponding author (responsible for correspondence, proofreading, and reprints)	**Fill in information in each box below**
First name, middle initial, last name	Hoa Van Ba
Email address – this is where your proofs will be sent	bacbnu1981@gmail.com
Secondary Email address	
Postal address	55365
Cell phone number	010-3034-2557
Office phone number	+82-63-238-7351
Fax number	+82-63-2387397

Abstract

Recently, consumers have complained about being served over-fat pork belly on social forums; therefore, providing information about the excess fat of belly slices is necessary for meat traders and consumers. Wholesale-ready bellies of commercial pigs (66 gilts and 41 barrows) including quality grade 1^+ (n=55), quality grade 1 (n=24), and quality grade 2 (n=28) were used to evaluate the fat level and trimmed excessive fat of retail-ready pork belly slices by the quality grade. Each belly was prepared into 18 slices corresponding to 12 thoracic vertebrae (5^{th}-16^{th}thoracic vertebrae) and 6 lumbar vertebrae (1^{st}-6^{th}lumbar vertebrae). The excessive fat in slices was trimmed following the government's guidelines, and expressed as a trimming loss percentage. The fat level in each slice was analyzed using a FoodScan. When gender factor was ignored, no differences in fat level were found among the quality grade categories for all slices. When gender was considered an influencing factor, the fat level in almost barrow belly slices was higher (by 5-6%) than in gilts, especially in the quality grade 1 and quality grade 2 (p<0.05). In all quality grades, the highest excessive fat was found in slices at 12^{th}-14^{th} thoracic vertebrae (7.28-11.55%), and the lowest (0.59-5.25%) was found at the lumbar vertebras. Most of the barrow belly slices had a significantly (p<0.05) higher trimming loss than gilts in all 3 quality grades. These findings suggest that an adjustment of belly wholesale prices or following the government's cutting guidelines to ensure the interests of both traders and consumers is needed.

Keywords: Excessive fat, pork belly, fat level, quality grade, gender

Introduction

Pork belly is the most preferred part by many consumers worldwide, especially in Asian countries such as Korea and China (Choe et al., 2015; Oh and Lee, 2012). This pork cut is mostly used in dishes such as grilling, a favorite dish in recent consumption trends in this region. (Kang et al., 2024). In Europe, pork belly is an essential ingredient for making famous commercial products such as bacon (Soladoye et al., 2015). With such a high consumption demand, pork belly is ranked as the most valuable part compared to other parts, such as loin and ham in the pork carcass (Lim et al., 2025). However, in each pork carcass, the belly cut only accounts for a moderate proportion (around 15%), lower than other lower-value parts such as ham (18%) (Hoa et al., 2025). The belly cut usually has a high-fat content, making it juicier, tastier, and more flavorful, that is why consumers prefer this part over the other parts in the carcass (Lee et al., 2021). However, bellies containing too much fat level are often rejected by consumers (Lim et al., 2025). Therefore, a lot of studies have recently been conducted to investigate the factors affecting the quality of this cut (Lee et al., 2018; Lee et al., 2023). In addition, many studies have been conducted to improve its economic traits and consumer's preference through breeding and feeding regimen adjustment (Hoa et al., 2025; Lee and Kim, 2023).

In recent years, due to its continuous increase in consumption demand and price, pork belly has become a concern for producer, suppliers, and consumers. In particular, consumers have complained to many meat retail outlets and restaurants on social forums about being served pork belly containing excessive fat (Jeong, 2024; Lee, 2024). Although its impact has not been accurately assessed, this problem has negatively affected the business operations of domestic pork belly brands and suppliers. Until now, a guideline on the cutting specifications of pork belly has been issued by the Ministry of Food, Agriculture, and Rural Affairs

(MFARA, 2023); it is not often referred to because of business profits. The excessive fat layers on belly slices are usually not consumed and removed, leading to waste and more disadvantages for consumers. To solve this problem, in other words, to ensure fairness in trading and consumer interests, an estimate of the amount of excessive fat that needs to be removed from pork belly is necessary.

As we know, the pork belly comprises many fat and lean layers and has a complex structure. Subcutaneous and intermuscular fat is the primary source of fat in the belly (Choe et al., 2015). Depending on pre-harvest factors such as gender and age etc., the fat level can vary greatly (Hoa et al., 2021a; Hoa et al., 2023). However, except for these factors, there are still significant variations in the fat content between anatomical locations within the belly (Knecht et al., 2018). In Korea, after slaughter, pork carcasses are classified into quality grades (QG) based on grading system by Korea Institute of Animal Products Quality Evaluation (KAPE, 2018), resulting in four main QG categories, including $QG1^{+}$, 1, 2, and off-grade. The criteria (e.g., carcass weight, backfat thickness, meat and fat color etc.,) used to grade pork carcasses are described in detail in previous studies (Hoa et al., 2021b; Seong et al., 2024). After grading, the wholesale prices of pork carcasses are also determined for the corresponding QGs. In our earlier studies or those of other authors, the fat level and meat quality characteristics of the belly differed depending on the sampling locations (Knecht et al., 2018; Seong et al., 2024). However, the limitation of these previous studies is that the sampling was only taken at one or several locations to evaluate the influence of QG or other factors on the fat content of the entire belly cut. This sampling method seems to be inappropriate and cannot reflect the fat content in over locations (slices) as they are usually cut for retail sales. A recent study by Lim et al. (2025) sampled 10 different locations of belly cut to determine the relationship between the fat level measured by the VCS2000 device and consumer preferences; however, this sampling method still cannot reflect the fat level in the remaining locations of the pork belly.

In practice, at retail outlets and barbecue restaurants, pork belly is often cut into moderately thin slices according to dorsal to ventral direction for the convenience of consumers. According to the guidelines for pork belly cutting by the MFARA (2023), the excess fat (at the dorsal area) should be removed, leaving only about 1cm of subcutaneous fat thickness to the muscle layer. In the context of controversy and disagreement between belly traders and consumers, as mentioned above, providing information on the fat level and the percentage of excessive fat that must be cut off from each slice over the belly cut is necessary to re-adjust the wholesale price to ensure the interests of both traders and consumers. Thus, this study aimed to evaluate the fat level and percentage of trimmed excessive fat of retail-ready pork belly slices among the quality grades.

Materials and method

Sample collection

One hundred and seven growing-finishing pigs ([Landrace × Yorkshire]♀ × Duroc ♂), LYD: 41 barrows and 66 gilts) collected from a commercial meat supplier (Tae Heung Korea Pork, Iksan-si, Jeollabuk-do, Korea) were used in this study. The pigs were slaughtered from March to September of the year 2024 (each slaughter batch/month was collected). All pigs were slaughtered following the industrial process at a commercial slaughter of the supplier. After slaughter, the carcasses were evaluated for quality grades by an official grader according to the Korean pork carcass grading system (KAPE, 2018) as detailed in our previous studies (Hoa et al., 2021b; Seong et al., 2024). The carcasses were classified into: QG1^{+} (n=55: 39 gilts and 16 barrows), QG1 (n=24: 14 gilts and 10 barrows), and QG2 (n=28: 13 gilts and 15 barrows). Measured carcass traits, such as carcass weight, backfat thickness (BFT), backfat area (BFA), loin surface area, and meat and fat color etc. of all carcasses were collected from the grader. In this study, besides the grading BFT (measured at two locations: between the last rib and the first LV, and between the 11th and 12th ribs) (KAPE, 2018), it was additionally measured at 4 different locations: at 5th, 9th, 13th thoracic vertebrae (TV) and 6th lumbar vertebrae (LV) (Fig 1A) to examine its correlation with the belly fat level. The pork carcasses were then fabricated into primal cuts, deboned, and skinned according to the current industry process. The belly cuts (in the wholesale-ready form, from 5thTV to the last LV) from left carcass side were vacuum-packaged, placed in Styrofoam boxes, and shipped to the meat laboratory. The weights of all the bellies were recorded and provided by the supplier.

Preparation of retail-ready belly slices

Each belly was manually prepared into slices 12 slices corresponding to the 12 TVs (5-16thTV) and 6 slices corresponding to the 6 LVs (1-6th LV), as shown in Fig 1B. The cutting was performed by making a straight cut from the dorsal to the ventral direction, similar to the cutting manner used at retail outlets. Each slice was labeled with its QG, gender, and weight.

Excessive fat removal and trimming loss measurement

To determine the amount of excess fat that needs to be removed (known as trimming loss) in each belly slice, the subcutaneous fat layer (at the dorsal area) was removed, leaving only 1 cm thickness to the muscle layer according to the cutting manual of the MFARA (2023) (Fig 1C). The weight of the trimmed fat was recorded, and trimming loss was calculated and expressed as a percentage of the trimmed fat weight to the initial weight of the belly slice (before removing the excessive fat) multiplied by 100. Finally, the trimmed excess fat was placed back into its corresponding slice for fat content analysis.

Fat content determination

In this study, the fat content of each belly slice was analyzed using a Food Scan (model: Lab 78810, Foss Tecator Co., Ltd., Denmark). This device has been designed with the Foss artificial neural network calibration model, specialized for determining the protein, fat, and moisture content in animal-derived foods such as meat. In particular, the device has a calibrated database with a wide range of fat content from 0.1-86%, allowing the analysis of food samples such as meat with different fat levels. The determination of fat content using the Food Scan was performed according to the AOAC official method 2007.04, as described by Anderson (2007). For analysis, each belly slice (trimmed excessive fat included) was cut into small pieces and then ground with a blender (Hanil Electric Co., Ltd., Seoul, Korea). After mixing thoroughly, about 100 g of the sample was placed on a 110 mm round dish and manually spread evenly over the entire dish. The sample dish was then placed into the sample chamber and proceeded to the analysis. The analysis results displayed as a percentage (g/100g) were collected and used for statistical analysis.

Statistical analysis

Different batches of statistical analysis were carried out in this study using SAS software (version 7.1; SAS Institute, Inc., Cary, NY, USA)**.** A preliminary statistical analysis was performed to determine the correlation between carcass traits (such as grading backfat thickness, backfat surface area, carcass weight, meat and fat color etc.) with fat level and excessive fat (trimming loss percentage) in each belly slice using Pearson correlation coefficients (Pearson's *r*). However, some carcass traits (e.g., meat and fat color, and grading

BFT) with very low correlation coefficient values ($r < 0.1$) were not used for further statistical analysis. The General Linear Model (GLM) was used to determine the effects of QG/or gender (set as fixed factors) on the carcass traits and belly slice fat content (set as variables). The same procedure was used for analysis of excessive fat percentage from the belly slices. Mean differences were determined using Duncan's multiple range test, and a p-value of < 0.05 was considered significant. Additionally, linear regression analyses were carried out to determine the coefficient of determination (R^2) and root mean square error (RMSE) for predicting the excessive fat percentage (trimming loss) from the bellies. For this linear regression analysis, the carcass traits were set as independent variables and trimming loss as dependent variable.

Results and Discussion

Carcass traits and fat level of belly slices by QG

In this study, the values of carcass traits were collected from the grader and statistically analyzed to assess the QG effect. Some traits (e.g., grading BFT, meat or fat color, etc.) showing no differences among the QG categories or weak correlation with the belly fat content (data not shown) were not presented. The mean values for some selected pork carcass traits of the 3 QG categories are presented in Table 1. Results showed that the BFT measured with or without skin showed significant differences among the three QGs. Notably, $QG1^+$ carcasses showed a significantly ($p< 0.05$) lower BFT than those of QG1 and QG2, even though the carcass weight were similar for all the QGs. Similarly, BFA values measured at the 5^{th} and 7^{th}TV were also lower in the $QG1^+$ than in the other QGs ($p< 0.05$)**.** This means that the subcutaneous fat deposition was lower in the $QG1^+$ carcasses than in the QG1 and QG2 carcasses. Compared to studies on beef, the influence of QG on pork carcass traits has received lesser attention. Although a few studies have reported some carcass traits, such as BFT among the QG categories (Hoa et al., 2021b; Hoa et al., 2025), however, the BFT reported in these studies was measured at only a few representative locations, which may lead to inaccuracies in assessing its relationship with other quality traits. To date, the BFT is considered an essential factor in predicting pork yield and quality (Hoa et al., 2021c; Li et al., 2018).

Previous studies have reported a significant effect of gender on pork quality (Lee et al., 2019; Kim et al., 2020). In this study, gender was also considered an influencing factor to assess whether it affects the carcass traits within each QG, and the results are presented in Table 2. As expected, the QG significantly affected the BFT (except for the BFT at 6^{th}LV), with a lower value for both genders of the $QG1^{+}$ ($p< 0.05$)**.** Notably, a significantly higher BFT value was found in barrows than in gilts in almost all the QG categories, indicating a higher subcutaneous fat deposition in the barrows than in the gilts. In line with our results, Serrano et al. (2008) and Muhlisin et al. (2014) reported higher BFT in castrated pigs than in intact female pigs.

For many meat markets, the belly becomes the most favorite part with the highest economic value compared to the rest of the pork carcass (Choe et al., 2015; Lee et al., 2021). Its chemical composition, especially its fat content, become of the utmost concern to producers and consumers. The reason is that the fat content positively impacts the eating quality by increasing the tenderness, juiciness and flavor of the meat (Schumacher et al., 2022). Studies have shown that pork bellies with a moderate fat content to improve its eating quality is positively perceived by consumers, whereas over-fat bellies are often perceived negatively and rejected by consumers (Lim et al., 2025; Lee et al., 2021). Furthermore, with the current living trend of small households with few members, they often prefer to buy ready-to-grill belly slices (about ~200 g each) for convenience and culinary versatility

(Magqupu et al., 2024). The results of the fat level of 18 belly slices corresponding to 18 vertebrae (both genders) are presented in Table 3. It was observed that there was a large variation in fat level among these slices in all QG categories. Particularly, the fat level tended to increase gradually in slices from the 5th to the 9thTV and then decreased gradually to the last LV for the QG1^{+} and QG1 (Fig 2A). The belly slices in the QG2 also showed the same variation trend as those of QG1^{+} and QG1. However, the fat level of slices in the GQ2 increased from the 5th to 9thTV and remained high until the 12thTV. The lowest fat level was found at the last 6thLV (10.27, 8.30, and 11.14% in QG1^{+}, QG1, and QG2, respectively), while the highest fat content was found at 10thTV (40.17 and 39.17% in QG1^{+} and QG1, respectively), and at 12thTV (40.52%) in QG2. However, no statistical differences in the fat level were found among the QG categories for all the slices ($p>0.05$). This finding was different from results of previous studies (Hoa et al., 2019; Hoa et al. 2021b). These authors reported a significant higher fat level in pork (belly, shoulder butt and loin) of higher QG category. The discrepancy in results may be due to the difference in sampling methods used between studies.

When gender was considered an influencing factor within each QG, the fat level of belly slices was compared between barrows and gilts. The results (Table 4) showed that QG also showed no effect on the fat level of all belly slices of barrows or gilts, except for a few slices at 14thTV, 4thLV, and 5thLV. The fat levels of barrow and gilt belly slices increased gradually from 5thTV to 9thTV, then decreased gradually to the last LV (Fig 2B & 2C). Gender affected the fat level of almost all slices, especially in the QG1 and QG2. The variation in fat levels between the two genders also depended on the anatomical locations; for example, at the 9th and 13thTV, and 5thLV, the barrows had a higher level (by about 8-9%) than the gilts. On average, the barrow bellies had a significantly ($p< 0.05$) higher fat level (by about 6%) than that of gilts. In line with the results of this study, previous studies also reported the gender effect on fat content in pork cuts. Alonso et al. (2009) and Muhlisin et al. (2014) reported that the pork (*longissimus dorsi*, LD) of barrows had a higher fat level than that of gilts. In contrast, Razmaite et al. (2021) reported no gender effect on the fat level of pork LD and *semimembranosus* muscles. For the first time, in this study, the fat levels of pork bellies were compared between the two genders, and the results indicating the higher level in barrow bellies imply a stronger fat deposition in this sex type than in gilts. The researchers showed that male (non-castrated) pigs can deposit fat faster than the females due to the influence of gut microbiota and short-chain fatty acid composition (Yao et al., 2024). Castrated pigs (barrows) also exhibit a significantly higher carcass fat level than entire male or female pigs at 70, 100, or 120 kg body weight (Zomeno et al., 2023). Studies on livestock have shown that castration alters the metabolic state due to sexual hormone change, leading to increased synthesis and accumulation of fat in the carcasses (Anaruma et al., 2020; Hoa et al., 2022).

The Pearson's correlation analysis was performed to determine the relationship between BFT and BFA with belly fat level in barrows and gilts. As shown in Table 5, the BFT (with or without skin) at 7th, 13thTV and 6thLV had high *r*- values (*r* = 0.348-0.417) with the fat level of barrow belly. Meanwhile, the BFT (with or without skin) at 9th and 13thTV had higher *r*- values (*r* = 0.328-0.515) with the fat level of gilt belly. Thus, a positive correlation was observed between the BFT and pork belly fat content; however, these correlation coefficients (*r*- values) were relatively low. This could be partly attributed to the wide variations in fat content among the bellies or the fact that the sample sizes were not sufficiently large.

Trimming loss of belly slices

In recent times, consumers have complained about being served pork belly slices with too much excess fat, which negatively affected the domestic pork belly trading (Jeong, 2024;

Lee, 2024). The trimmed excessive fat percentage of belly slices at each vertebra could be valuable information to meat retailers and consumers; however, no study has addressed this issue to date. In this study, belly slices were prepared and the excessive fat was removed following the cutting manual of MAF (2023), and results are presented in Table 6. The trimming loss increased in slices from the 5th to the 13thTV and then decreased towards the last vertebra in all the 3 QG categories (Fig 3). The highest trimming loss was found in the slices at the 12th - 14th TV (7.28-11.55%), and the lowest (0.59-5.25%) was found in slices at the LVs. It is noteworthy that the QG did not affect the fat levels (Table 3), but it did affect the trimming loss of almost all the belly slices. In these slices, the QG2 had a significantly (p**<0.05)** higher trimming loss than the QG1^{+} and QG1 (p>0.05). The average trimming loss in the whole belly cut (all slices) was about 4.50, 4.50, and 5.70% in the QG1+, QG1, and QG2, respectively. The difference in excess fat level among QGs, while their fat content was similar, could be due to the difference in fat deposition pattern as follows: In the higher QG categories (e.g., QG1^{+} or QG1), most of the fat may be accumulated in the form of intermuscular and intramuscular fat, while in the lower QG (e.g., QG2), the fat may mainly be accumulated in the form of subcutaneous fat, especially in the dorsal area at the 12th -14th TV (Fig 1C). This may be the main reason for the higher excess fat level in the pork belly slices in the lower QG category.

When gender was considered an influencing factor within each QG, the trimming loss was compared between two genders. As shown in Table 7, the belly slices of barrows had a significantly (p< 0.05) higher trimming loss than those of gilts in all three QG categories. Especially for the 12-13th TV slices, the trimming loss of barrows in all the QG categories was about 4-5% higher than that of gilts. It is well known that belly fat content consists of subcutaneous and intermuscular fat (Choe et al., 2015). Animals, after castration, often have an increased fat accumulation level in the body (Anaruma et al., 2020; Hoa et al., 2022), and this could be the main reason leading to increased excessive fat over the belly cut, especially at the 12-14th TV of this sex type. With these findings, it may be seen that there are still many shortcomings in the domestic pork belly trading sector. An appropriate adjustment in price is necessary to ensure the interests of producers, suppliers, and consumers. For example, for the lower QG category and barrows that are often associated with high excess fat levels, lowering the wholesale price of the pork carcasses may be necessary. In this case, retailers need to comply with the government's cutting guideline (MFARA, 2023) when preparing pork belly slices for consumers. In the case that adjusting the wholesale price is impossible, retailers can prepare belly slices according to the current specifications, but the retail price needs to be adjusted appropriately for each anatomical location (e.g., lowering the price for the belly slices with too much excess fat).

In an attempt to find the relationship between trimming loss and carcass traits, Pearson correlation analysis was performed, and the results are shown in Table 8. Trimming loss had a higher *r* value with BFT at 13th TV (r = 0.532), followed by BFT at 9thTV (r = 0.521) and BFT at 5thTV (r= 0.519). With these *r* values, it can be said that the BFT only had a moderate positive correlation with the trimming loss of belly cut. To date, some studies have reported a correlation between BFT and the level of fat accumulation in pork carcasses. According to Hoa et al. (2021c), total trimmed fat amount of pork carcasses has a positive correlation (r = 0.686) with BFT. Lim et al. (2025) reported a correlation coefficient value (r = 0.52) between BFT and belly fat weight. From our results and those of previous studies, it can be said that BFT was positively correlated with the level of fat accumulation in pork carcasses; however, this correlation was not very strong.

The regression model was applied to predict the trimming loss in whole belly cut (all slices) of all three QGs. In this model, the BFT values measured at all locations were set as dependent variables and trimming loss as independent variable, and the results are presented in Table 9. The R^2 values for the regression equations between BFT 5^{th}TV, BFT 5^{th}TV with skin, BFT 9^{th}TV, BFT 9^{th}TV with skin, BFT 13^{th}TV, BFT 13^{th}TV with skin, BFT 6^{th} LV, BFT 6^{th}LV with skin were 0.27, 0.195, 0.271, 0.259, 0.289, 0.293, 0.116 and 0.113, respectively. Amongst, the regression equation between the BFT at 13^{th}TV with or without skin with the trimming loss gave the highest R^2 value compared to the other remaining regression equations. However, the R^2 values of all these equations were generally low, implying that the carcass traits, such as BFT, was not highly effective in predicting the trimming loss of pork belly. In alignment with our results, Lim et al. (2025) reported an R^2 value of 0.06 for the regression equation between the pork belly fat level measured by the VCS2000 device and the number of pork bellies rejected by consumers. These authors also suggested that the belly fat level measured by this device was ineffective in predicting the consumer rejection. In a study by Ko et al. (2023), the amount of pork belly (kg) measured by AutoForm III device, the regression equation between carcass weight and belly amount was applied, and these authors reported high R^2 values (0.637-0.867). However, we assume that using the regression equations for predicting the yield of pork belly by carcass weight is more feasible and accurate than predicting fat content or trimming loss by using the carcass traits (e.g., BFT). The main reason may be that the weights range of pork carcasses or bellies within each QG are not highly variable (KAPE, 2018)**.** On the contrary, the amount of trimmed excessive fat often varies widely among bellies and QGs, leading to low R^2 values, as shown in our studies and others, as mentioned above. Recent findings and applications on beef have shown that using ultrasound instruments can quickly predict the fat content in this meat type with an accuracy of over 98% (Kim, 2021). An automated prediction network of fat content in beef developed by Lee et al. (2022) has shown high accuracy. Therefore, the application of these devices or the development of new methods more suitable for quickly and accurately predicting the excessive fat level in pork belly after slaughter is necessary for adjusting wholesale prices appropriately for each QG and gender.

Conclusion

For the first time, this study prepared the pork bellies into retail-ready slices corresponding to 12 thoracic vertebrae and 6 lumbar vertebrae according to the cutting manner commonly used at retail outlets to assess the effect of QG on the fat content. In addition, the belly slices were trimmed to remove excess fat according to the government's cutting manual. Based on the obtained results it may be said that QG had no effect on the belly fat content. Gender exhibited a greater influence on fat content in pork bellies, with a significantly higher level in barrows than in gilts. The trimming loss in most belly slices was affected by QG, with significantly higher level in lower QG category, such as QG2. In addition, trimming loss in almost all belly slices, regardless of the QG, was higher in barrows than in gilts. When the R2 values of the regression equations were low, the carcass traits, such as BFT, can only be used as an additional referencing factor to predict the excess fat content in pork belly. From the finding of this study, it may be recommended that wholesale price adjustment for barrow and gilt bellies due to the trimmed excessive fat is necessary to ensure the interests of meat traders. At retail meat outlets (e.g., meat shops and restaurants), the preparation of belly slices should follow the government's cutting specification to ensure fairness in meat trading and consumer interests. Further studies using larger sample sizes from various commercial pig breeds and suppliers are needed to understand better the variations in fat content and excess fat levels by QG and gender. Additionally, the use of other devices (e.g., ultrasound) or the development of new devices and methods is needed to rapidly and accurately predict excess fat content in pork belly to support its wholesale pricing after slaughter.

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Table 1. Mean values of carcass traits by quality grade (QG)

	QG1^{+}	QG1	QG2
Carcass weight (kg)	88.91±2.11	90.77±4.90	90.21±10.24
Belly weight (kg)	6.48±0.55	6.64±0.57	6.76±0.81
BFT-5thTV (cm)	2.30±0.50^{b}	2.80±0.40^{a}	2.90±0.80^{a}
BFT-5thTV + skin (cm)	3.30±0.60^{b}	3.80±0.50^{a}	3.80±0.90^{a}
BFT-9thTV (cm)	1.80±0.50^{b}	2.10±0.40^{a}	2.30±0.70^{a}
BFT-9thTV + skin (cm)	2.70±0.50^{b}	3.00±0.40^{a}	3.20±0.80^{a}
BFT-13thTV (cm)	1.40±0.40^{b}	1.70±0.40^{a}	1.80±0.70^{a}
BFT-13thTV + skin (cm)	2.20±0.40^{b}	2.50±0.40^{a}	2.60±0.70^{a}
BFT-6thLV (cm)	1.00±0.40	1.10±0.30	1.20±0.50
BFT-6thLV + skin (cm)	1.90±0.50	2.10±0.30	2.10±0.50
FBA-5thTV (cm^{2})	102.86±19.71^{b}	107.54±22.40^{b}	119.64±25.07^{a}
FBA-7thTV (cm^{2})	90.23±15.81^{b}	95.51±20.52^{ab}	103.45±24.23^{a}

$^{a\text{-}c}$ Means with different superscript in the same row significantly differ at $p<0.05$.
TV: thoracic vertebrae; LV: Lumbar vertebrae; BFT: Backfat thickness; BFA: Backfat area

Table 2. Mean values of carcass traits of pork by quality grade (QG) and gender

Items	Gender	QG1^{+}	QG1	QG2
Carcass weight (kg)	Barrow	89.59±2.15	90.33±4.80	90.08±9.32
	Gilt	88.62±2.05	91.08±5.14	90.33±11.31
Belly weight (kg)	Barrow	6.86±0.50^{A}	6.85±0.46	6.93±0.91
	Gilt	6.32±0.49^{B}	6.49±0.61	6.62±0.72
BFT at 5thTV (cm)	Barrow	2.50±0.60^{b}	2.90±0.40^{ab}	3.30±0.60^{aA}
	Gilt	2.30±0.50^{b}	2.70±0.40^{a}	2.40±0.80^{abB}
BFT at 5thTV + skin (cm)	Barrow	3.50±0.50^{b}	3.90±0.60^{b}	4.40±0.70^{aA}
	Gilt	3.30±0.60^{b}	3.80±0.50^{a}	3.30±0.80^{bB}
BFT at 9thTV (cm)	Barrow	2.10±0.50b^{A}	2.30±0.40^{ab}	2.50±0.60^{aA}
	Gilt	1.70±0.40^{B}	2.00±0.40	2.00±0.70^{B}
BFT at 9thTV + skin (cm)	Barrow	2.90±0.60^{b}	3.20±0.40^{ab}	3.60±0.70^{aA}
	Gilt	2.60±0.50	2.90±0.50	2.80±0.70^{B}
BFT at 13thTV (cm)	Barrow	1.60±0.40^{bA}	1.80±0.50^{ab}	2.10±0.50^{aA}
	Gilt	1.30±0.30^{bB}	1.64±0.40^{a}	1.55±0.70^{abB}
BFT at 13thTV + skin (cm)	Barrow	2.30±0.40^{b}	2.60±0.30^{ab}	3.00±0.60^{aA}
	Gilt	2.10±0.40^{b}	2.40±0.40^{a}	2.30±0.70^{abB}
BFT at 6thLV (cm)	Barrow	1.00±0.50	1.00±0.30	1.10±0.40
	Gilt	1.00±0.40	1.20±0.30	1.30±0.60
BFT at 6thLV + skin (cm)	Barrow	1.90±0.50	1.90±0.20^{B}	2.10±0.40
	Gilt	1.90±0.40	2.20±0.30^{A}	2.10±0.50
BFA at 5thTV (cm^{2})	Barrow	114.05±23.58^{abA}	108.59±25.45^{b}	132.89±25.16^{a}
	Gilt	97.88±15.64^{B}	106.90±21.39	107.33±18.28
BFA at 7thTV (cm^{2})	Barrow	94.61±18.42	102.31±25.08	113.35±24.83
	Gilt	88.72±14.81	92.11±18.36	92.45±19.21

$^{A\text{-}C}$ Means with different superscript in the same column significantly differ at $p<0.05$.
$^{a\text{-}c}$ Means with different superscript in the same row significantly differ at $p<0.05$.
TV: thoracic vertebrae; LV: Lumbar vertebrae; BFT: Backfat thickness; BFA: Backfat area

Table 3. Fat content (%) of pork BS by quality grade (QG)

Items	QG1^{+}	QG1	QG2
Belly slice at 5thTV	31.74±6.82	32.42±6.97	33.28±8.19
Belly slice at 6thTV	35.00±4.88	34.27±5.59	35.74±6.51
Belly slice at 7thTV	36.49±4.69	36.12±4.93	36.70±6.29
Belly slice at 8thTV	38.74±5.35	37.70±4.25	39.22±6.99
Belly slice at 9thTV	40.18±4.91	38.81±5.34	40.08±7.71
Belly slice at 10thTV	40.17±5.23	39.17±5.41	40.51±6.59
Belly slice at 11thTV	39.89±5.19	39.16±5.57	40.41±6.51
Belly slice at 12thTV	39.75±5.16	39.11±6.09	40.52±6.52
Belly slice at 13thTV	39.10±5.71	38.62±6.16	39.41±7.15
Belly slice at 14thTV	36.59±5.48	36.26±5.86	37.17±7.64
Belly slice at 15thTV	34.06±5.20	33.80±5.62	34.91±7.14
Belly slice at 16thTV	32.37±5.67	32.34±5.83	32.91±6.84
Belly slice at 1stLV	30.68±5.23	31.11±6.33	32.18±6.61
Belly slice at 2ndLV	29.38±4.64	29.39±5.99	30.95±6.98
Belly slice at 3rdLV	26.54±5.80	26.28±6.56	27.55±7.12
Belly slice at 4thLV	22.41±7.54	23.58±8.14	22.05±8.47
Belly slice at 5thLV	16.79±8.81	14.56±7.38	14.45±8.04
Belly slice at 6thLV	10.27±6.07	8.30±3.77	11.14±5.19
Whole belly cut	32.63±4.78	32.22±5.21	33.43±6.22

TV: thoracic vertebrae; LV: Lumbar vertebrae; BS: belly slices

Table 4. Fat content (%) of pork BS by quality grade (QG) and gender

Items	Gender	QG1^{+}	QG1	QG2
Belly slice at 5thTV	Barrow	33.80±6.20	37.58±2.67^{A}	36.50±7.48
	Gilt	30.60±6.98	28.99±6.89^{B}	30.29±7.91
Belly slice at 6thTV	Barrow	37.74±4.64	37.70±4.02^{A}	38.31±5.92^{A}
	Gilt	33.76±4.52	31.90±5.39^{B}	33.51±6.34^{B}
Belly slice at 7thTV	Barrow	38.38±4.49^{A}	38.55±2.94	39.08±5.30
	Gilt	35.66±4.59^{B}	34.44±5.41	34.64±6.53
Belly slice at 8thTV	Barrow	40.06±5.54	40.00±3.13^{A}	42.60±4.93^{A}
	Gilt	38.16±5.24	36.12±4.28^{B}	36.28±7.32^{B}
Belly slice at 9thTV	Barrow	41.03±4.89	41.28±3.78	44.29±4.54A
	Gilt	39.81±4.94	37.09±5.71	36.43±8.14^{B}
Belly slice at 10thTV	Barrow	40.83±5.30	41.68±4.09	44.12±4.04^{A}
	Gilt	39.89±5.24	37.44±5.66	37.38±6.88^{B}
Belly slice at 11thTV	Barrow	40.78±5.30	41.16±3.85	44.04±4.03^{A}
	Gilt	39.50±5.16	37.78±6.27	37.26±6.70^{B}
Belly slice at 12thTV	Barrow	41.23±4.85	42.20±3.98^{A}	44.50±3.44^{A}
	Gilt	39.10±5.22	36.98±6.51^{B}	37.08±6.66^{B}
Belly slice at 13thTV	Barrow	39.81±6.49	41.16±3.85	43.75±4.28^{A}
	Gilt	38.80±5.40	36.87±6.95	35.65±7.09^{B}
Belly slice at 14thTV	Barrow	37.30±5.65^{b}	39.07±4.02^{ab}	41.56±4.37^{aA}
	Gilt	36.29±5.46	34.32±6.26	33.36±7.93^{B}
Belly slice at 15thTV	Barrow	35.19±5.48	36.56±3.85	38.33±4.41^{A}
	Gilt	33.57±5.06	31.89±5.98	31.95±7.84^{B}
Belly slice at 16thTV	Barrow	33.17±5.62	35.17±3.56	36.27±4.13^{A}
	Gilt	32.02±5.73	30.38±6.39	30.00±7.48^{B}
Belly slice at 1stLV	Barrow	31.99±5.53	34.18±3.02	35.19±3.73^{A}
	Gilt	30.11±5.06	28.99±7.22	29.57±7.53^{B}
Belly slice at 2ndLV	Barrow	30.15±4.57	32.79±4.00^{A}	33.84±4.55^{A}
	Gilt	29.04±4.69	27.03±6.12^{B}	28.45±7.85^{B}
Belly slice at 3rdLV	Barrow	27.15±5.83	30.35±3.93^{A}	30.85±5.43^{A}
	Gilt	26.28±5.85	23.47±6.64^{B}	24.69±7.32^{B}
Belly slice at 4thLV	Barrow	20.61±6.20^{b}	27.34±6.66^{a}	25.62±7.68^{abA}
	Gilt	23.19±8.01	20.97±8.27	18.96±8.11^{B}
Belly slice at 5thLV	Barrow	13.97±6.71	17.70±7.53	19.34±8.79^{A}
	Gilt	17.93±9.37^{a}	12.38±6.71^{b}	10.55±4.75^{bB}
Belly slice at 6thLV	Barrow	8.51±4.10	10.33±2.01	13.44±5.29
	Gilt	10.75±6.47	7.48±4.08	7.45±2.04
Whole belly cut	Barrow	33.68±4.84	35.41±3.12^{A}	36.78±3.86^{A}
	Gilt	32.17±4.75	30.01±5.29^{B}	30.53±6.51^{B}

$^{A-C}$ Means with different superscript in the same column significantly differ at $p<0.05$.
$^{a-c}$ Means with different superscript in the same row significantly differ at $p<0.05$.
TV: thoracic vertebrae; LV: Lumbar vertebrae; BS: belly slices

Table 5. Pearson correlation coefficient (*r*) of carcass traits with belly fat content of barrow and gilts

Items	Barrows	Gilts
	Belly fat content	Belly fat content
Carcass weight	0.113	0.194
Belly weight	0.147	0.191
BFT 5thTV	0.348	0.246
BFT 5thTV with skin	0.319	0.363
BFT 9thTV	0.303	0.328
BFT 9thTV with skin	0.301	0.515
BFT 13^{h}TV	0.372	0.350
BFT 13thTV with skin	0.420	0.389
BFT 6thLV	0.417	0.055
BFT-6thLV with skin	0.442	0.249

TV: thoracic vertebrae; LV: lumber vertebrae

Table 6. Trimming loss (%) of pork BS by quality grade (QG)

Items	QG1^{+}	QG1	QG2
Belly slice at 5thTV	4.82±3.49	4.85±2.48	4.93±4.13
Belly slice at 6thTV	4.98±2.47^{ab}	4.07±2.45^{b}	5.51±2.84^{a}
Belly slice at 7thTV	4.29±2.19^{ab}	4.07±2.28^{b}	5.36±2.83^{a}
Belly slice at 8thTV	3.68±1.94	3.52±1.89	4.58±2.33
Belly slice at 9thTV	3.14±1.89^{b}	3.11±1.68^{b}	4.23±2.51^{a}
Belly slice at 10thTV	3.31±2.18	3.75±1.76	4.50±2.81
Belly slice at 11thTV	4.68±3.57	5.52±3.04	6.40±4.04
Belly slice at 12thTV	7.28±4.04	7.92±4.23	9.43±4.85
Belly slice at 13thTV	8.96±3.52^{b}	9.45±3.08^{b}	11.55±4.54^{a}
Belly slice at 14thTV	8.35±2.84^{b}	8.61±2.90^{b}	10.45±3.96^{a}
Belly slice at 15thTV	6.75±4.32	6.80±2.49	8.03±3.70
Belly slice at 16thTV	4.44±2.46^{b}	4.56±2.04^{b}	6.00±3.42^{a}
Belly slice at 1stLV	3.54±4.12	3.25±2.29	5.25±4.85
Belly slice at 2ndLV	2.31±1.76^{b}	2.28±2.05^{b}	3.54±2.39^{a}
Belly slice at 3rdLV	2.70±3.78	1.91±2.12	2.66±1.71
Belly slice at 4thLV	1.94±2.65	2.45±3.10	2.94±3.13
Belly slice at 5thLV	0.93±2.17	0.59±1.63	1.13±2.10
Average loss (%)	4.50±1.98^{b}	4.50±1.81^{b}	5.70±2.52^{a}

$^{a-c}$ Means with different superscript in the same row significantly differ at $p<0.05$.
TV: thoracic vertebrae; LV: Lumbar vertebrae; BS: belly slices

Table 7. Trimming loss (%) of pork BS by gender and quality grade (QG)

Items	Gender	QG1^{+}	QG1	QG2
Belly slice at 5thTV	Barrow	7.23±4.42^{A}	6.17±2.28^{A}	7.71±3.61^{A}
	Gilt	3.75±2.23^{B}	3.82±2.2^{B}	2.16±2.42^{B}
Belly slice at 6thTV	Barrow	6.63±2.42^{A}	4.99±2.84^{A}	6.83±2.32^{A}
	Gilt	4.25±2.10^{B}	3.43±2.02^{B}	4.36±2.82^{B}
Belly slice at 7thTV	Barrow	5.89±2.35^{A}	5.49±2.72^{A}	6.84±2.36^{A}
	Gilt	3.58±1.71^{B}	3.08±1.26^{B}	4.07±2.62^{B}
Belly slice at 8thTV	Barrow	5.02±2.14^{A}	4.54±2.47^{A}	6.05±1.91^{A}
	Gilt	3.09±1.53^{B}	2.81±0.94^{B}	3.30±1.90^{B}
Belly slice at 9thTV	Barrow	4.56±2.32^{A}	4.11±1.98^{A}	5.55±1.43^{A}
	Gilt	2.51±1.25^{B}	2.42±1.02^{B}	3.08±2.71^{B}
Belly slice at 10thTV	Barrow	5.02±2.63^{A}	4.80±1.76^{A}	6.00±1.73^{A}
	Gilt	2.56±1.43^{B}	3.03±1.39^{B}	3.20±2.96^{B}
Belly slice at 11thTV	Barrow	7.78±4.31^{A}	8.13±2.55^{A}	8.02±2.96^{A}
	Gilt	3.38±2.10^{B}	3.72±1.80^{B}	4.99±4.40^{B}
Belly slice at 12thTV	Barrow	10.48±3.91^{A}	11.27±4.59^{A}	11.77±4.06^{A}
	Gilt	5.91±3.21^{B}	5.61±1.75^{B}	7.39±4.65^{B}
Belly slice at 13thTV	Barrow	11.72±2.40^{Ab}	11.07±2.13^{Ab}	14.67±2.60^{Aa}
	Gilt	7.77±3.22^{B}	8.33±3.21^{B}	8.84±4.13^{B}
Belly slice at 14thTV	Barrow	10.10±2.54^{Ab}	9.86±1.59^{b}	12.92±2.99^{Aa}
	Gilt	7.58±2.62^{B}	7.74±3.33	8.31±3.47^{B}
Belly slice at 15thTV	Barrow	8.82±5.93^{A}	8.08±2.13^{A}	10.01±3.32^{A}
	Gilt	5.82±3.04^{B}	5.91±2.39^{B}	6.31±3.17^{B}
Belly slice at 16thTV	Barrow	5.25±2.72^{b}	5.30±1.24^{b}	7.95±2.74^{Aa}
	Gilt	4.07±2.27	4.04±2.36	4.31±3.10B
Belly slice at 1stLV	Barrow	4.04±3.06^{b}	3.71±1.45^{b}	7.76±5.59^{Aa}
	Gilt	3.28±4.47	2.93±2.75	3.08±2.76B
Belly slice at 2ndLV	Barrow	3.02±2.13^{Ab}	2.49±1.60^{ab}	4.46±1.71^{a}
	Gilt	1.98±1.49^{B}	2.13±2.36	2.73±2.65
Belly slice at 3rdLV	Barrow	3.61±3.26	2.74±1.96	3.07±1.67
	Gilt	2.25±3.92	1.33±2.10	2.31±1.72
Belly slice at 4thLV	Barrow	2.32±3.34	3.85±3.26	3.53±3.50
	Gilt	1.74±2.30	1.48±2.71	2.43±2.79
Belly slice at 5thLV	Barrow	0.94±1.90	1.38±2.40	1.99±2.81
	Gilt	0.93±2.29	0.04±0.16	0.44±0.93

$^{A-C}$ Means with different superscript in the same column significantly differ at $p<0.05$.

[a-c] Means with different superscript in the same row significantly differ at $p<0.05$.
TV: thoracic vertebrae; LV: Lumbar vertebrae; BS: belly slices

Table 8. Pearson correlation coefficients (*r*) of carcass traits and trimming loss of pork belly

Items	Trimming loss	BFT 5thTV	BFT 5thTV with skin	BFT 9thTV	BFT 9thTV with skin	BFT 13thTV	BFT 13thTV with skin	BFT 6thLV	BFT 6thLV with skin
Trimming loss	1	0.519	0.442	0.521	0.509	0.532	0.541	0.340	0.365
BFT 5thTV	0.519	1	0.848	0.736	0.660	0.730	0.658	0.420	0.393
BFT 5thTV with skin	0.442	0.848	1	0.585	0.735	0.553	0.663	0.214	0.467
BFT 9thTV	0.521	0.736	0.585	1	0.866	0.890	0.817	0.442	0.377
BFT 9thTV with skin	0.509	0.660	0.735	0.866	1	0.760	0.876	0.243	0.454
BFT 13thTV	0.532	0.730	0.553	0.890	0.760	1	0.867	0.493	0.379
BFT 13thTV with skin	0.541	0.658	0.663	0.817	0.876	0.867	1	0.280	0.467
BFT 6thLV	0.340	0.420	0.214	0.442	0.243	0.493	0.280	1	0.675
BFT 6thLV with skin	0.365	0.393	0.467	0.377	0.454	0.379	0.467	0.675	1

TV: thoracic vertebrae; LV: lumber vertebrae

Table 9. Linear regression models for predicting the trimming loss of pork belly

Items	Observation	R^2	Adjusted R^2	RMSE
BFT 5th TV	107	0.270	0.263	0.546
BFT 5th TV with skin	107	0.195	0.187	0.633
BFT 9th TV	107	0.271	0.264	0.477
BFT 9th TV with skin	107	0.259	0.252	0.551
BFT 13h TV	107	0.286	0.279	0.424
BFT 13th TV with skin	107	0.293	0.287	0.454
BFT 6th LV	107	0.116	0.107	0.401
BFT 6th LV with skin	107	0.133	0.125	0.412

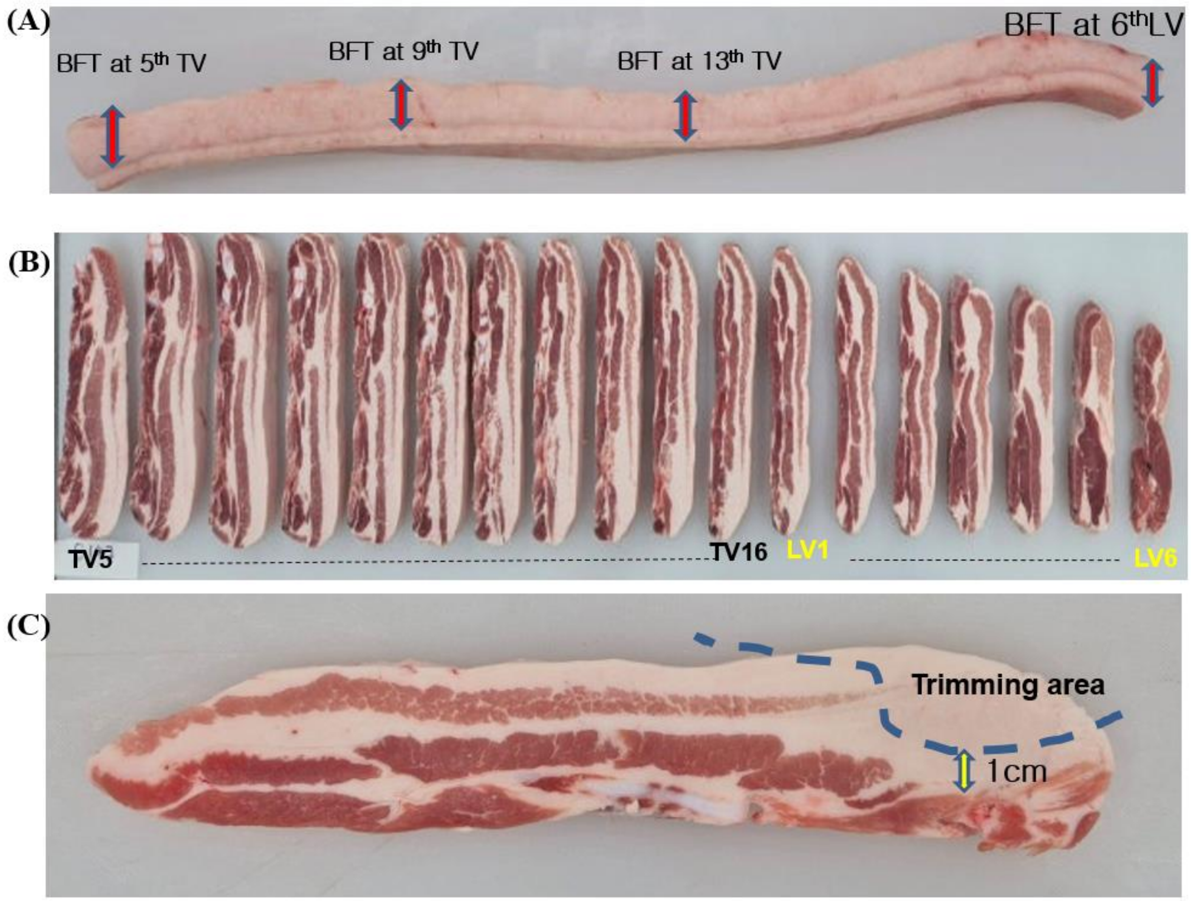

Fig 1. Schematic diagram showing: (A) the locations used for backfat thickness (BFT) measurement, (B) the cutting of retail-ready belly slices at each corresponding thoracic vertebrae (TV) and lumbar vertebrae (LV), and (C) trimming of excessive fat area on each belly slice

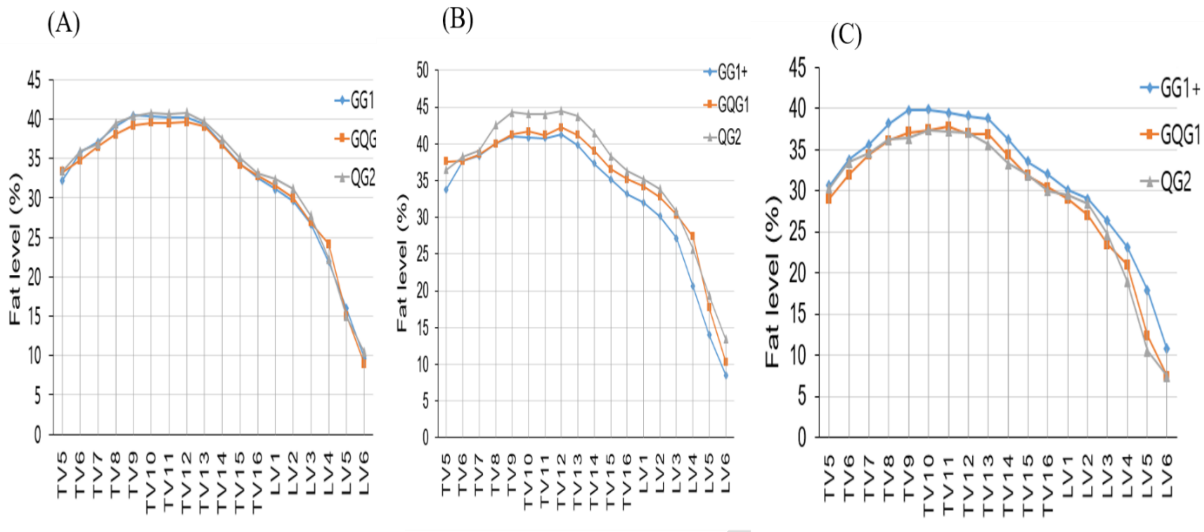

Fig 2. Distribution trend of fat level (%) of pork belly at corresponding thoracic vertebrae (TV) and lumbar vertebrae (LV) by quality grade (QG); A): for both gender, B): for barrows, and C): for gilts.

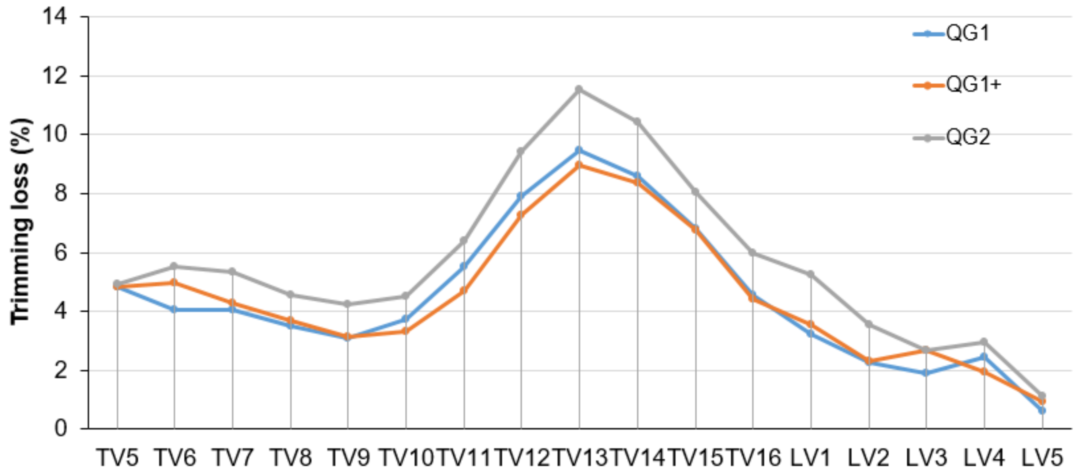

Fig 3. Trend of trimming loss (%) of belly slices at corresponding thoracic vertebrae (TV) and lumbar vertebrae (LV) by quality grade (QG).