Variability of Fresh Pork Belly Quality Evaluation Results Depends on Measurement Locations

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Abstract

The increase in pork demand has led to an especially high increase in demand for precisely quality-defined bellies. The aim of the study was to determine the influence of quality measurement location on the pork belly on the results of qualitative evaluation and then to recommend the main measurement locations required to determine the precise quality evaluation of the whole cut. The research material consisted of 92 fresh pork belly samples, each divided on 12 testing locations. The highest pH values were noted for M2 (5.74), M1 (5.70), and D3 (5.69) locations, as well as A4 (5.53; $P \leq 0.05$) generating the most outliers. Location D2 was distinguished by generally obtaining the highest values for parameters L^* , b^* , C^* , and H^* and the lowest for a^* ; this was independent of the measurement side. The highest water holding capacity values were reported for D4 and D3 locations, and the lowest (about 7% lower than the maximal values) were obtained for A4 and A2 locations. The highest values for the cooking loss parameter were noted for D4, D1, and M4 (about 33%) locations, and the lowest values were observed for location M2 (only 22%). In the case of sensory evaluation between the analyzed locations, differences ($P \leq 0.05$) were recorded for all parameters. It is recommended to evaluate belly quality using one location: A1 and M3 are most accurate. The highest position in the ranking for processing quality parameters was occupied by the middle locations: M4, M1, and M3. However, when consumers ranked important quality parameters, the highest positions were given to location A1 and then D3 and M2. From a practical point of view, it is highly recommended to take quality parameters from location A1, which is much easier to obtain, and obtaining samples from this location leads to the least damage to the structure of the whole commercial cut.

Keywords Pork · Belly · Location · Quality · Evaluation

Introduction

Pork is the most widely consumed meat in the world (OECD-FAO 2017); however, the demand for individual primal cuts varies across countries and regions (Uttaro and Zawadski 2010; Font-i-Furnols and Guerrero 2014; Choe et al. 2015). The increase in pork consumption on especially not only Asian but also European markets has led to a high increase in demand for precisely quality-defined fresh pork bellies.

Belly is classified as an element with high fat content, although its market and consumption value have been rising fastest among all primal cuts in the last quarter of a century (Arkfeld et al. 2016; Costa-e-Silva et al. 2017). This is partially

due to the fact that meat content (muscle share) in belly has doubled over the last 40 years (Trusell et al. 2011). Pork bellies are increasingly considered by current consumers as rich in taste and flavor (Choe et al. 2015). This is a consequence of the reduced fat content in “lean” commercial cuts, but fat is after all the main carrier of taste. Until now, the most important feature of the belly was the identification of only the meat and fat level. Presently, due to progress in increasing meat share, the quality evaluation of this element plays a very important role.

The belly presents many difficulties during basic surface measurements, even when using advanced equipment (Berg et al., 2002; Marcoux et al. 2003), and unfortunately, it is not justified rationally to refer general carcass measures to all cuts (Uttaro and Zawadski 2010; Arkfeld et al. 2016). Additionally, it should be emphasized that pork quality evaluation at an early stage of slaughter or just after slaughter is not an easy task and should be based on inexpensive or rapid analysis for subsequent segregation to enable further processing and distribution

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(Flores and Toldrá 2014). Many studies indicate that the basic quality parameters (color, pH, water holding capacity, cooking loss, sensory analysis) meet these requirements and can be extremely useful or directly adapted in meat plants during further segregation and destination of raw material. Quality evaluation of bellies presents serious problems because it is characterized by the most complex structure of tissue composition among all commercial cuts. So, in the case of such evaluation, the location should be precisely selected, especially given that the issue of location is of great importance in research (Soladoye et al. 2017).

Based on the above considerations, there needs to be an evaluation of different locations on pork belly to precisely determine its complexity and variability during the assessment of broad qualitative parameters, while seeking a reference location that could be recommended for the whole cut. In consequence, the aim of the study was to determine the influence of quality measurements location on the pork belly on the results of qualitative evaluation and then to recommend the main measurement locations required to determine the precise quality evaluation of the whole cut.

Materials and Methods

Research Population

The research material consisted of 92 fresh pork belly samples, commercial cuts prepared for direct sales, or processing from mass population of finishers. The animals were slaughtered at the age of 6.5–7 months in a meat plant in Wielkopolska province, using the electric stunning method. Finishers were weighed immediately before slaughter, using an electric scale with accuracy to 500 g and mean body weight was 116.35 ± 3.88 kg. The carcasses were bled, separated along the center line and deprived of tongue, bristle, hooves, genital organs, perirenal fat, kidneys, diaphragm, eyes, middle ear, brain and spinal cord. On such presented carcasses weight was determined with a scale installed on the production line and this was: 90.32 ± 4.66 kg for the study population. Lean meat content evaluation was performed on warm carcasses immediately after slaughter, using the Zwei Punkte (ZP) method and this was: $57.67 \pm 1.94\%$. Slaughter performance was calculated by dividing the carcass weight by the final weight of finishers, expressed as a percentage, and this was $77.62 \pm 1.14\%$.

Design of the Study

Bellies intended for further analysis were cut from right carcasses after 24 h cooling, according to the production methodology of the slaughterhouse. Belly with ribs was cut off from the half-carcass along with the lower ends of the ribs

(from fifth to last) and part of the halved sternum with rib cartilages and the cutting lines were as follows: (1) top—in the half of all ribs length, (2) front—lines after cutting shoulder and to ventral part of belly, and (3) down—lines after cutting fat belt connecting belly and to ventral part of belly and rindless. During supplementary cutting, ribs, milk glands, and rest of the ventral part of belly were removed. The belly was profiled in a rectangular shape, and from the dorsal part, the overgrowth of meat was about two thirds of its length. The main muscles were as follows: *external* and *internal oblique*, *transversus abdominis*, and intercostal muscles. The samples for testing were vacuum-packed and transported in stable cooling conditions directly to the meat evaluation laboratory at the Institute of Animal Science, Wroclaw University of Environmental and Life Sciences, where they were then subjected to further analysis.

Measurement locations for evaluation of quality parameters were determined by their anatomical position in the longitudinal section (from cranial to caudal end in three plains: dorsal, central, ventral) and transverse on four plains (from dorsal to abdominal). Overall from each belly, 12 locations were tested, and this is presented in Fig. 1.

The characteristics of length, height, and width of selected locations in the study material are presented in Table 1.

Basic Measurements of Bellies

Overall belly length and width were measured in three rows (back, middle, and front end) from caudal to cranial and are presented as averages. All linear measurements were made using calipers.

Fat quality score (FQS) represented belly fat scoring and was made according to the scale and methodology included by Seman et al. (2013). The score was based on a five-point visual and tactile response scale: 1 = white, firm fat; 2 = white, soft fat; 3 = soft spongy fat, finger depressions remain; 4 = grainy appearance, soft, spongy fat, finger depressions remain; and 5 = grainy appearance, soft spongy fat, finger depressions remain, oily.

Fig. 1 Division and location of research samples on fresh pork belly (cut line)

Belly firmness was determined by suspending the longitudinal midpoint of the belly across a stainless steel rod and measuring the distance in centimeters between the ham and shoulder end, lean side down (flop-method) using the Thiel-Cooper et al. (2001) methodology.

Each belly was weighed individually using an electronic scale.

Meat Quality Assessment

pH measurements were conducted with a Testo 205 pH device (Testo Sp. z o. o., Warsaw, Poland) for each ham location immediately after cross-division of the element.

Simultaneously and on the same cross section and locations, instrumental color evaluations were performed with a Minolta Chroma CR 400 device with an 11 mm diameter aperture, D65 illuminant, calibrated against a white tile (Osaka, Japan). The measurements were made on both sites: internal (ribs removed site) and external (skinned site). During instrumental color assessment, the following parameters were determined: CIE L^* , a^* , and b^* values representing lightness, redness, and yellowness, respectively. Additionally determined were chroma (C^*) and hue angle (H^*) indicators. Chroma described the color saturation in space CIE $L^*a^*b^*$ and was calculated according to $C^* = (a^{*2} + b^{*2})^{1/2}$. Hue angle determined the immaculateness of color and was calculated as follows: $H^* = (\tan^{-1} b^*/a^*)$ (Minolta, 2007). Each measurement was repeated three times in the same place, after 5 min bloom time.

Water holding capacity (WHC) was evaluated using the Grau and Hamm (1952) method with the modification of Pohja and Niinivaara (1957). Cooking losses (CL) were determined by heating to a temperature of 70 °C inside the muscle, and the result was the difference between the mass before and after cooking.

Sensory evaluation of samples was conducted by five trained person (judging team) on a five-point scale, and this included flavor, taste, juiciness, chewiness, palatability, and overall score (Barylko-Pikielna and Matuszewska 2014). The heating process was carried out until the internal temperature of the muscle was 72 °C, and then the samples were kept under cover to obtain 75 °C. After cooling, the meat samples were cut into pieces of equal size and weight and placed in plastic disposable boxes, which were covered with lids. All samples were coded individually with three-digit codes and were given in random order to avoid the impact of the previous sample on the next sample. The order of analysis of the parameters was consistent with the natural order of sensory perception. The scales for flavor, taste, and palatability were 1—unacceptable, 5—very desirable; juiciness 1—very dry, 5—very juicy; and chewiness 1—very tender, 5—very chewy.

Statistical Analysis

Numeric materials were analyzed statistically using the Statistica 13.0 software package. The results determined the arithmetic mean ($\bar{x}$) and standard error (SE) or standard deviation (SD). The collected data were checked for normality with the Kolmogorov-Smirnov test with Lilliefors correction. Homogeneity of variances was checked with the Brown-Forsythe test. Statistical analysis included one-way

Table 1 Characteristics of linear measurements of locations used in the study

Location		Mean	SD	Min	Max
D4	Length (cm)	14.13	2.35	11.50	21.50
	Height (cm)	8.78	0.88	7.00	10.00
	Width (cm)	3.50	1.30	2.00	6.50
D3	Length (cm)	13.06	1.69	10.00	16.80
	Height (cm)	9.49	1.37	8.00	12.00
	Width (cm)	2.61	0.54	1.70	3.80
D2	Length (cm)	12.47	1.51	9.50	15.00
	Height (cm)	9.21	1.12	7.60	12.00
	Width (cm)	2.96	0.42	2.20	3.50
D1	Length (cm)	13.64	1.73	11.00	17.00
	Height (cm)	8.78	0.92	7.00	10.50
	Width (cm)	3.64	0.63	2.30	4.50
M4	Length (cm)	15.25	1.88	12.50	21.00
	Height (cm)	9.94	0.94	8.50	12.00
	Width (cm)	3.08	0.79	2.00	4.50
M3	Length (cm)	13.33	1.32	11.50	15.70
	Height (cm)	10.85	1.42	8.00	13.00
	Width (cm)	2.72	0.64	1.50	4.00
M2	Length (cm)	12.84	1.45	11.00	16.00
	Height (cm)	10.05	1.47	8.00	12.50
	Width (cm)	3.12	0.68	2.50	5.00
M1	Length (cm)	14.78	1.66	11.00	16.50
	Height (cm)	10.07	1.63	7.50	13.80
	Width (cm)	3.48	0.75	2.60	5.50
A4	Length (cm)	14.16	1.90	11.50	19.00
	Height (cm)	9.10	1.41	6.50	11.40
	Width (cm)	3.29	0.44	2.60	4.00
A3	Length (cm)	13.54	1.33	11.50	15.50
	Height (cm)	9.71	1.35	6.50	12.00
	Width (cm)	3.46	0.78	1.70	4.80
A2	Length (cm)	13.03	1.31	11.00	15.00
	Height (cm)	9.72	1.49	7.50	12.00
	Width (cm)	3.84	1.09	2.10	5.50
A1	Length (cm)	14.64	1.55	12.50	18.00
	Height (cm)	9.75	2.07	6.50	13.50
	Width (cm)	3.33	1.06	0.60	5.00

SD standard deviation, Min minimal, Max maximal

analysis of variance, which presented the effect of location as the main effect on the measured quality parameters in factorial designs. To indicate the significance of differences between means, Tukey's *post-hoc* test was applied. Levels of significance were given for differences where $0.01 < P \leq 0.05$ and $P \leq 0.01$.

Ranking of locations was based on separate statistical analyses for each of the measurements. Ranking was performed to replace the variable by the calculated rank that was developed with respect to the mean value of the individual measurements for the whole belly cut. The average for the whole element was calculated on the basis of measurements from all locations.

Principle component analysis (PCA) was performed in order to identify the most important directions of variability in the multidimensional data space. This is a multidimensional modeling technique that changes the number (possibly) of correlated variables to (small) the number of non-categorical variables called main components. This presents an interpreted overview of important information with reduced dataset size (number of variables) but preserves most of the original data volatility. The first main component is responsible for the maximum amount of data variability, with each successive component taking into account the greatest variability (Meloun et al. 2005). Thus, to replace the original variables measured in the experiment, a small number of components are used, defined as the linear combination of the measured variables, decreasing their number (Naes et al. 1996). Correlation coefficients between qualitative parameters within each location were calculated using Pearson's *r* correlation.

Results

The basic characteristic of the research material are presented in Table 2. The results covered the average values with standard deviations and min-max values for precise presentation of fresh pork belly samples.

The changes in pH values dependent on belly locations are shown in Fig. 2. The highest pH values were noted for M2 (5.74), M1 (5.70), and D3 (5.69) locations. On the other hand,

most outliers were observed for location A4 (5.53; $P \leq 0.05$). For the whole cut, the average was 5.63.

Color measurements of fresh pork belly depending on the location and internal or external site are presented in Table 3. The spread of results in the case of the L^* parameter regardless of site was large (differences between means $P \leq 0.05$), and extreme values noted for internal sites ranged from 48.46 (D4) to 59.57 (D2) with a mean of 53.24 and for external sites from 63.99 (A4) to 80.35 (D2) with a mean of 70.34. Close results with a low number of statistically significant differences for the a^* parameter were identified on internal sites but on external sites the number of differences were some of the highest. The mean value for this parameter was 16.49 for internal sites and 13.79 for external sites. The reverse situation was demonstrated for b^* , where high differences were reported on internal sites and low on external sites; means were respectively 7.07 and 11.67. For C^* and H^* , means were, respectively, 18.16 and 23.13 for internal sites and 18.50 and 41.02 for external sites. It was characteristic for all color measurements that, in particular for location D2, the highest values were noted for parameters L^* , b^* , C^* , and H^* and the lowest for a^* , and these were independent of the measurement side. Similar precise observations were not made for any of the other locations.

The results of WHC and CL depending on belly location are shown in Fig. 3. The highest WHC values were reported for D4 and D3 locations and the lowest (about 7% lower than maximal values) at A4 and A2 locations. The other locations were characterized by a close level of this parameter, oscillating within the range of 18 to 20%. However, a large spread of measurements was observed for location M2.

The highest values for the CL parameter were noted for D4, D1, and M4 (about 33%) locations and the lowest values were observed for location M2 (only 22%). The highest standard deviations were reported for location A1, and this was a consequence of the wide spread of results in this location.

The results of sensory evaluation according to location are shown in Table 4. Statistically significant differences were noted for all parameters between analyzed locations ($P \leq 0.05$). The highest taste evaluations were noted for location M3 and the lowest of 0.75 points for A2. The mean for this parameter was 3.44. The highest flavor rate was shown in central location in dorsal plane (D2), and the lowest was at A3 with a mean of 3.98. Juiciness values were similar between locations, although locations lying next to each other (M2 and M1) achieved the highest and the lowest results. The highest scores among all sensory parameters were reported for chewiness (mean 4.11 points) with the extremes being D4 max and M1 min. The mean palatability score was 3.95 points with the max at D1 and min at M1. The overall score signifying the consumer's perception of the sample was 3.91. The

Table 2 Basic characteristics of the research material

Item	Mean	SD	Min	Max
Width (cm)	28.35	3.05	23.50	32.80
Length (cm)	56.50	2.76	51.00	61.00
FQS	2.16	0.84	1.00	3.00
Firmness (cm)	17.01	2.59	12.00	21.30
Weight (kg)	4.42	0.58	3.99	4.95

SD standard deviation, Min minimal, Max maximal, FQS fat quality score

Fig. 2 The changes in pH values depending on location on fresh pork bellies

a,b,c,d – means with superscript for the same parameter differ significantly at the level of $P \leq 0.05$

highest value was achieved for D1 and the lowest for A3. The most statistically significant differences were found between the means for locations for this parameter.

The ranking of locations depending on the average for the whole belly cut for each quality parameter is shown in Table 5. Based on the established hierarchy of all locations, no distinctive location was observed, which would give the most complete information about the mean quality evaluation for the whole element. The situation was similar in the case of locations furthest from the mean. This proves, first and foremost, the unequivocal translation of the quality measurements of one

location into an estimate for the whole element. However, the overall ranking of the location hierarchy in relation to the mean value allowed location A1 to be selected as the location which was the closest to providing a good estimation of the overall quality and did so slightly better than location M3 (ranked second). Referring to the position in the rank for this position, the average position was 5. Definitely, the most distant position in the ranking was obtained for location A3, with an average position in the hierarchy of 8.26.

Organizing the rankings into qualitative parameters was once very important in the processing process (pH, color,

Table 3 Color measurements depending on the location and measurement site

Location	Internal site					External site				
	L^*	a^*	b^*	C^*	H^*	L^*	a^*	b^*	C^*	H^*
D4	48.46e	16.33bc	3.25f	16.78c	10.95f	69.01def	13.75abcde	12.34b	18.62ab	41.55cde
D3	58.88a	16.24bc	9.57a	18.93abc	31.12ab	77.05ab	11.22def	14.79a	18.94ab	54.55ab
D2	59.57a	15.03c	9.27ab	17.74bc	32.33a	80.35a	10.85ef	14.95a	18.79ab	55.68a
D1	53.13cd	17.61ab	8.45ab	19.61ab	25.75bcd	71.55cd	10.57f	10.84bc	15.69c	47.26bc
M4	53.68bcd	15.97bc	6.09cd	17.25bc	21.20de	66.89def	16.41ab	12.13b	20.45a	36.54def
M3	49.54e	18.96a	6.69cd	20.17a	19.37e	70.69cde	14.25abcd	12.07b	18.87ab	41.32cde
M2	57.09ab	15.95bc	9.54a	18.65abc	30.98ab	74.85bc	12.80def	12.49b	18.03abc	44.84cd
M1	50.43de	17.59ab	7.68bc	19.25ab	23.88cde	70.65cde	13.45bcdef	11.67b	18.22abc	41.07cde
A4	53.95bc	15.50bc	5.70de	16.66c	20.74de	63.99f	15.88abc	9.14c	18.54ab	29.85f
A3	49.34e	17.12abc	4.23ef	17.72bc	13.44f	64.17f	16.74a	9.08c	19.25a	28.67f
A2	50.96cde	15.54bc	5.66de	16.83c	19.54e	68.93def	16.39ab	11.49b	20.34a	35.52ef
A1	53.79bcd	16.04bc	8.66ab	18.28abc	28.26abc	65.91ef	13.17cdef	9.11c	16.28bc	35.33ef
SE	0.28	0.15	0.11	0.16	0.47	0.42	0.22	0.17	0.18	0.67
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means with lowercase letters in the same column differ significantly at the level of $P \leq 0.05$

Fig. 3 WHC (%) and CL (%) parameters depending to location of measurement

WHC, CL) and significant in terms of consumer (sensory analysis) acceptance. The highest ranking position for processing quality parameters was achieved by location M4 (mean position in the hierarchy was 3.69) and this stands out from other top locations in the ranking, i.e., M1 and M3. The lowest positions in the ranking were taken by locations D2 and A3 (mean position 8). In the case of consumer qualities, the A1 position was definitely the highest in the ranking (mean position in the hierarchy 3.83) and then came locations D3 and M2. This is a very interesting observation, since these locations are extreme locations in both longitudinal and

transverse planes. Further positions were obtained for central locations M4 and M1 (mean position 9.17).

As a result, a high ranking for the location was the result of these two divisions. Interestingly, location A1 was ranked first in the hierarchy of quality parameters significant for the consumer, and fourth in the hierarchy of quality processing parameters. On the other hand, location M3 was third in the ranking in terms of quality processing parameters and fourth for consumer quality parameters.

The PCA of quality attributes of fresh pork bellies is presented in Fig. 4. The graph of the load presents a visual

Table 4 Sensory evaluation according to location

Location	Taste	Flavor	Juiciness	Chewiness	Palatability	Overall score
D4	3.56bcd	4.06abc	4.00ab	4.31a	4.00abc	3.99ab
D3	3.75abc	4.19ab	3.88ab	4.25ab	3.94abc	4.00ab
D2	3.88ab	4.25a	3.94ab	4.13ab	4.06abc	4.05ab
D1	3.88ab	4.06abc	3.94ab	4.19ab	4.25a	4.06a
M4	3.94ab	4.06abc	3.94ab	4.13ab	4.13ab	4.04ab
M3	4.00a	3.94bcd	3.75ab	4.00ab	4.06abc	3.95abc
M2	3.69abc	3.81cd	4.06a	4.06ab	4.00abc	3.92abcd
M1	3.75abc	3.81cd	3.68b	3.88b	3.68c	3.76de
A4	3.38cd	3.88cd	3.81ab	4.00ab	3.75bc	3.76de
A3	3.44cd	3.75d	3.75ab	4.00ab	3.81bc	3.75e
A2	3.25d	3.94bcd	3.75ab	4.25ab	3.81bc	3.80cde
A1	3.44cd	4.06abc	3.81ab	4.19ab	3.88abc	3.88bcde
SE	0.04	0.03	0.02	0.03	0.03	0.02
<i>p</i> value	< 0.001	< 0.001	0.21	0.29	0.02	< 0.001

Means with lowercase letters in the same column differ significantly at the level of $P \leq 0.05$

Table 5 Ranking of locations depending on averages for the whole belly cut for each quality parameter

pH	Color		Sensory analysis								Total quality evaluation							
	Internal site	External site	WHC	CL	Sensory analysis													
					Sensory analysis													
					L*	a*	b*	C*	H*	L*		a*	b*	C*	H*	Taste	Flavor	Juiciness
M4	D1	D4	M3	A1	M1	M1	D4	M1	A4	M1	D2	M2	A2	D3	M4	D3	M2	A1
A3	M4	D3	M1	D2	M4	M3	M1	A2	D4	M3	A1	M1	D3	M3	D2	M3	M2	M3
D1	A1	A1	M4	A3	A4	D1	M3	M3	M1	D4	M1	D3	M1	A1	M2	A1	D4	M4
M3	A4	M4	A4	M2	D1	D4	A1	M4	D2	M2	D2	A1	D4	D1	A1	D4	A1	M1
D4	A2	M2	D1	D3	A2	A2	M2	D4	M3	M4	D1	A2	D1	D1	D1	D1	D2	D3
D2	M1	A3	A2	M4	M3	M4	A4	M2	D3	A2	A3	A4	D2	M4	M3	M3	M3	D4
A1	M3	A2	A1	M1	A1	A1	D3	D1	M2	A1	M4	M3	A1	A4	A3	A3	A3	M2
A2	M2	A4	D2	A2	M2	M2	A2	A4	A3	A3	M2	A3	A3	M1	A4	A4	A2	D1
D3	A3	M1	M2	D4	D3	A3	M4	A1	A2	A4	A4	M4	M4	M2	D3	D3	M4	A2
M1	D4	D1	D3	D1	D2	A4	D2	A3	A3	A2	A2	D1	D3	D3	A2	A4	A4	A4
A4	D3	D2	A3	A4	A3	D3	A3	D3	A1	D3	D4	D4	M3	A3	D4	M1	M1	D2
M2	D2	M3	D4	M3	D4	D2	D1	D2	D1	D2	D3	M2	A2	D2	M1	A3	D1	A3

WHC water holding capacity, CL cooking loss

description of the relationship between the different main components, in which the attributes together show a positive correlation. The closer the distance between the features, the more significant the correlation is between them. In contrast, those attributes far from each other show a more negative correlation. The largest horizontal distances were recorded between the parameters H^*_{ES} or L^*_{ES} and a^*_{ES} . In a vertical arrangement, a large distance was noted between C^*_{IS} and taste or palatability. Characteristic of the performed PCA was the large concentration of qualitative attributes of sensory analysis in the same area of the graph. This demonstrates the close relationship between these parameters.

Correlation coefficients of selected quality parameters according to location on fresh belly are shown in Table 6. The correlation results obtained show ambiguous relationships between the same parameters within the location. The highest number of statistically significant $P \leq 0.05$ strong and moderate correlations (Huff-Lonergan et al., 2002) was noted for location D3. On the other hand, the lowest number of such correlations (Duziński et al., 2015) was observed for four locations: D1, M4, A2, and A1. In general terms, the weakest correlation was demonstrated in the abdominal plane, and the strongest in the dorsal plane. In caudal-cranial layout, the strongest correlations were noted in the third (Bahelka et al., 2011) plane, which was the opposite of the first plane. No distinctive qualitative parameters were observed that would correlate at a similar level for all locations, except for correlations L^* and H^* (from $r = 0.36$ to $r = 0.84$, all $P \leq 0.05$).

Discussion

The results of this research clearly indicate the structural complexity of the belly as a commercial cut. This demonstrates a highly advanced structure that cannot be underestimated. As a consequence, the complexity of the structure also translates into the results of the qualitative evaluation also during division into process-oriented and consumer-oriented parameters.

The quality characteristics of pork are complex features, which make it difficult to correctly estimate specific cuts (Huff-Lonergan et al. 2002). Full evaluation of physical and sensory qualitative feature characteristics and their dependencies can be used to obtain precise processing and consumer information about this element. Unfortunately, bellies from mass populations are currently characterized by differentiation of tissue composition (Duziński et al. 2015). Additionally, the fat and meat distribution in the belly is heterogeneous and highly dependent on the location and also the selection of the population (Fredeen 1980; Brewer et al. 1995; Correa et al. 2006; Trusell et al. 2011). Varying degrees of participation from these two major tissues directly influence the evaluation of quality parameters, although this detailed analysis was performed on muscle tissue. Therefore, in our study, precise

Fig. 4 PCA of analyzed quality parameters of fresh belly independent of location

IS – internal site, ES – external site, WHC – water holding capacity, CL – cooking loss

estimation of the belly quality on the basis of one selected location was difficult, which was manifested in discrepancies in partial results. However, ranking and result-based relations allowed to indicate the leading locations, which were A1 and M3.

As suggested in the study, the division of qualitative measurements into those of particular importance for processing or consumers provided interesting observations. The most precise values of the processing quality parameters in terms of the average value of the whole element were obtained for the middle locations. The middle locations of the belly are characterized as being the most stable in terms of reproducibility of analytical features due to the compact structure of tissue distribution (Trusell et al. 2011; Soladoye et al. 2017). This would explain the value of the abovementioned results of the processing qualitative parameters, especially for the M3 location, as a good overview of the general quality of the belly. Location A1 in our study turned out to be the leading location with the highest quality information for the whole element. This is most likely due to the level and share of muscle tissue in this location. Trusell et al., 2011 observed that extreme abdominal localization in the abdominal region was characterized by the highest proportion of lean meat. It is necessary to reiterate that qualitative assessments were related directly to muscle, not fat tissue. Thus, the values noted from the analyzed parameters provide only approximations to the mean of the whole cut.

The visual perception of the product is primarily based on color, which is a very important determinant of consumer acceptance (Scheier et al. 2015). Rindless belly as a commercial/market cut is very big, in contrast to the pork loin, so its color

rating should be more detailed. This is also due to the presence of visible individual tissues, depending on the location, which is a consequence of the different tissue-to-tissue ratio. This is particularly important for the belly, as it is a highly structured element (Bahelka et al. 2011; Trusell et al. 2011; Duziński et al. 2015). Therefore, measurements on internal and external sites were used. However, the results of the values and correlations were surprisingly different for both the location and the measurement site and were not comparable within them. Some authors state that the a^* parameter and its correlations are very important in the evaluation of color on the slaughter line in meat plants (Dvorak et al. 2001). L^* or H^* measurements in our research population were significantly more stable in the locations and at least moderate. Significant changes in the location of a color evaluation may be due to the complex fat-meat structure of the cut. It has been observed that different layers of fat in the belly differ in their degree of fatty acid saturation (Apple, 2010); this may affect problems of penetration and reflection of light (Seman et al. 2013).

The pH parameter is an important factor from the point of view of the qualitative evaluation of post-mortem changes, refrigeration maintenance cycle and the overall freshness of the product during storage (Scheier et al. 2015). As shown by the research results presented, the value of this parameter clearly differs between locations. The highest values observed for the vertical plane with numbers 2 and 3 and must be explained by the most compact structure of the element. Values for extreme locations were characterized by the highest variability, which could be due to the uneven tissue distribution of these locations (Trusell et al. 2011).

Table 6 Correlation coefficients of selected quality parameters according to location on fresh belly

Item		D4	D3	D2	D1	M4	M3	M2	M1	A4	A3	A2	A1
pH	<i>L</i> *	−0.23	−0.42*	−0.55*	0.05	−0.29	−0.42*	−0.18	0.09	−0.04	−0.12	−0.50*	−0.27
	<i>a</i> *	−0.13	0.09	0.35	0.35	−0.04	−0.13	−0.30	0.20	0.03	−0.22	−0.03	0.13
	<i>b</i> *	−0.46*	−0.40*	−0.43*	−0.09	−0.10	−0.59*	−0.29	0.05	−0.17	−0.21	−0.43*	−0.13
	<i>C</i> *	−0.27	−0.01	0.26	0.29	−0.07	−0.30	−0.39*	0.20	0.00	−0.23	−0.24	0.05
	<i>H</i> *	−0.43	−0.35*	−0.48*	−0.31	−0.13	−0.58*	−0.07	−0.10	−0.12	−0.16	−0.37*	−0.26
	WHC	−0.24	0.01	0.00	−0.22	−0.02	0.00	−0.08	0.27	0.15	0.11	0.22	0.01
	CL	0.35	0.29	0.28	−0.18	0.23	0.39*	−0.15	−0.40*	−0.40*	−0.09	−0.20	−0.10
<i>L</i> *	<i>a</i> *	−0.53*	−0.39*	−0.75*	−0.04	−0.61*	0.29	−0.15	−0.48*	−0.40*	−0.33	−0.02	0.30
	<i>b</i> *	0.42*	0.41*	0.50*	0.40*	0.22	0.71*	0.57*	0.49*	0.42*	0.40*	0.55*	0.76*
	<i>C</i> *	−0.31	−0.24	−0.67*	0.08	−0.47*	0.50*	0.10	−0.35*	−0.32	−0.22	0.26	0.50*
	<i>H</i> *	0.49*	0.70*	0.84*	0.36*	0.74*	0.63*	0.53*	0.72*	0.48*	0.59*	0.53*	0.70*
	WHC	0.74*	−0.56*	0.20	0.58*	−0.42*	0.09	0.06	0.46*	−0.21	−0.18	−0.03	0.41*
	CL	−0.10	−0.12	−0.22	−0.39*	−0.13	0.16	0.04	−0.11	0.15	−0.20	0.09	0.13
	<i>a</i> *	0.21	0.42*	−0.08	0.23	0.43*	0.27	0.09	0.09	−0.11	0.61*	0.19	0.53*
<i>a</i> *	<i>C</i> *	0.94*	0.98*	0.99*	0.96*	0.98*	0.95*	0.91*	0.98*	0.98*	0.99*	0.89*	0.95*
	<i>H</i> *	0.08	−0.74*	−0.93*	−0.42*	−0.35*	−0.10	−0.54*	−0.67*	−0.57*	0.27	−0.18	−0.13
	WHC	−0.46*	0.40*	−0.16	0.00	0.17	0.57*	−0.31	−0.28	0.35*	−0.33	0.15	0.33
	CL	0.16	0.28	−0.16	−0.17	0.18	0.07	0.35*	0.00	0.21	0.31	−0.37*	0.24
	<i>b</i> *	0.53*	0.61*	0.09	0.50*	0.61*	0.57*	0.48*	0.30	0.11	0.71*	0.61*	0.77*
	<i>H</i> *	0.99*	0.28	0.43*	0.78*	0.67*	0.93*	0.78*	0.67*	0.87*	0.91*	0.92*	0.76*
	WHC	0.67*	−0.02	−0.33	0.43*	−0.23	0.23	−0.37*	0.02	−0.56*	−0.70*	−0.13	0.29
<i>b</i> *	CL	0.13	0.44*	−0.51*	−0.27	0.26	0.07	0.43*	−0.28	0.22	0.18	0.22	0.31
	<i>C</i> *	0.42*	−0.58*	−0.85*	−0.14	−0.14	0.23	−0.16	−0.49*	−0.38*	0.40*	0.28	0.18
	WHC	−0.14	0.34	−0.21	0.13	0.07	0.55*	−0.42*	−0.27	0.20	−0.42*	0.06	0.35*
	CL	0.20	0.34	−0.25	−0.23	0.24	0.10	0.49*	−0.05	0.27	0.30	−0.23	0.30
	<i>H</i> *	0.76*	−0.50*	0.04	0.38*	−0.52*	0.03	−0.09	0.21	−0.69*	−0.65*	−0.18	0.09
	CL	0.12	0.03	−0.02	−0.12	0.14	0.04	0.14	−0.15	0.05	0.06	0.37*	0.17
	WHC	0.11	−0.50*	0.06	−0.06	−0.25	0.13	−0.58*	−0.39*	−0.19	−0.39*	−0.22	−0.38*

*Correlation statistically significant, with $P \leq 0.05$

The technological value of primal cuts determines their further use (Duziński et al. 2015; Knecht et al. 2016a). Meat content in bellies has a direct impact on their processing and consumer acceptance (Bahelka et al. 2011). The large amount of information obtained at the earliest stage of slaughter or immediately before it is essential for the processing of pork meat (Knecht and Duziński 2016). WHC and CL are indicators that are particularly important in terms of processing, but they are still very rarely used. WHC is also responsible for the color in meat products and can affect the taste characteristics of the meat (Ruiz-Ramírez et al., 2005). However, only indirect correlations were observed in color and, to a lesser extent, sensory analyses. The fat share is an antagonist to drip loss and cooking loss (Suzuki et al., 2005), so it may explain our results for specific locations and correlations. It is best to use the middle locations M4 (with the highest accuracy) or M1, M3 (with slightly lower accuracy) to visualize the overall belly quality, taking into account the processing parameters.

Our earlier studies suggested that differences in quality parameters of pork carcasses can have a pronounced effect on the efficiency of the meat production and it is essential to determine the commercial value (Knecht et al. 2016b). A quick estimation of the belly value allows an immediate determination of the value. The import and export of pork require the adaptation of the batch of products offered for a strictly defined purpose (Duziński et al. 2015). Identifying quality deviations at the processing level often determines significant losses in profitability in the downstream production chain, due to lower processing capacities and a higher percentage of inferior products (Person et al. 2005). It seems that the segregation of raw materials in terms of quality is perhaps unavoidable on modern cutting lines. It seems that there is still no effective system for the segregation of pig carcasses or major cutting elements in terms of the quality characteristics of meat.

Quality evaluation of fresh bellies, for direct sale or processing, is a key task for meat companies resulting from the

expectations of modern consumers. Consumers are the last link in the food chain and meeting their expectations is a key aspect in ensuring an adequate market share (Font-i-Furnols and Guerrero 2014). Consumer reception can be characterized by sensory evaluation as an important point of modern research on meat quality. The consumer accepts or discards the meat according to feelings observed or consumed, evaluating the quality of the sensory food (Rodrigues and Teixeira 2014). An objective method for these measurements is very important, because the individual consumer's assessment differs depending on the continent, country, region, etc. Unfortunately, still little research has been published on the correlation between physical and sensory characteristics of pork meat, although this approach may be important for future consumers (Huff-Lonergan et al. 2002). The presented results indicated that the accuracy of estimating the sensory evaluation of belly as a whole cut may vary from location to location. However, the extreme location of the element A1, followed by D3 and M2, is the most important. This was due to the formation of muscle tissue and the formation of meat-fat relations, as noted earlier (Freedman 1980; Correa et al. 2006). The content of muscle tissue in the A1 location could therefore contribute to a representative evaluation of the whole element, especially for the consumer.

Summing up, the study confirms that fresh pork belly is characterized by a very complex construction structure, which makes it difficult to accurately estimate the quality on the basis of one location. However, by compiling individual results, dependencies and ranking systems, we can now suggest some important recommendations. Therefore, it is recommended that if determination of the quality parameters of fresh pork belly as a whole commercial cut is to be effected using only one location, then A1 and M3 locations are the most accurate. From a practical point of view, it is highly recommended to take more of quality parameters from location A1, which is much easier to obtain and obtaining samples from this location leads to the least damage to the structure of the whole commercial cut. Additionally, when considering quality parameters important for processing and consumers, it was observed that the highest position in the ranking for processing quality parameters were occupied by the middle locations especially M4. However, when consumers ranked important quality parameters, the highest positions were given to location A1.

Based on these observations, it can be noted that due to their complexity of the structure and the size, fresh pork bellies should be evaluated and sorted separately according to intended use. This is related to the acquisition of specific parts of this element, i.e., its division into sub-elements adapted to processing or direct market distribution. The proposed quality evaluation for a particular destination (processing or consumer) and specific location becomes even more precise and exact, which can significantly influence the further efficient use of this cut in meat plants.

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Compliance with Ethical Standards

Conflict of Interest Damian Knecht declares that he has no conflict of interest. Kamil Duziński declares that he has no conflict of interest. Anna Jankowska-Mąkosa declares that she has no conflict of interest.

Ethical Approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. This article does not contain any studies with human participants performed by any of the authors.

Informed Consent Not applicable.

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