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Institute of Genetics and Animal Breeding, Jastrzębiec, Poland

Effect of pre-slaughter housing of different cattle categories on beef quality

Andrzej Węglarz

Department of Cattle Breeding, University of Agriculture in Cracow,
Mickiewicza 24/28, 30-059 Kraków, Poland

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The aim of the study was to determine optimal pre-slaughter handling procedures (individual or group housing) for various slaughter cattle categories. Subjects were 842 Black-and-White Polish Holstein-Friesian slaughter cattle, classified into four EUROP categories – bulls up to 24 months of age (A), bulls older than 24 months (B), cows which had had offspring before (D), and heifers (E). Slaughter value, colour and pH characteristics of beef from these cattle categories were studied. Housing method had no significant effect on carcass composition. The pH_{48} of meat from group-housed young bulls (A) and older bulls (B) was higher and the colour parameters were significantly lower compared to meat from individually housed animals of the two categories. No effect of pre-slaughter housing on the pH_{48} and colour parameters of meat was found for cows (D) and heifers (E). Abnormally high pH (>5.8) was much more frequent (over 63%) for meat from group-housed A and B animals than for meat from individually-housed animals (about 30%). Correlation coefficients show that pH_{48} was negatively correlated at P≤0.001 with colour coordinates L*, a*, b* and C* (-0.39, -0.24, -0.22 and -0.25, respectively). It can be concluded that conditions of pre-slaughter housing of cattle in the slaughterhouse significantly affected the quality traits of beef obtained from young bulls (A) and bulls (B). Hence, the pre-slaughter handling should be differentiated according to the sex of animals – it may be more economically justified, despite higher cost, to keep males individually while heifers and cows in groups, prior to slaughter.

KEY WORDS: cattle/ pre-slaughter housing/ *longissimus thoracis muscle* / meat pH and colour

Beef quality depends on many factors, the most important of which are productive type, breed, sex, nutrition and handling procedures related to procurement and slaughter [Hocquette *et al*. 2006, Honkavaara *et al*. 2003, Kögel 2005, Page *et al*. 2001]. Meat parameters include pH, for analysing technological suitability for processing and tenderness, juiciness, and colour which are of great importance for consumers [Abril *et al*. 2001, Resurreccion 2004, Wulf and Page 2000]. Meat quality is also strongly influenced by intramuscular fat content, fatty acid composition and post-mortem aging of meat, which is affected by the action of several proteolytic enzymes and their interaction with specific inhibitors.

An important factor affecting beef quality is animal sex [Page *et al*. 2001, Węglarz 2010b], which differentiates not only the chemical composition of meat but also its physicochemical and sensory properties. Compared to the meat of young bulls, meat of steers and heifers shows higher marbling levels, is more delicate and has better sensory attributes [Wulf and Page 2000, Węglarz 2010b]. Meat of young bulls has darker colour and higher pH which make it less suitable for producing saleable beef. Meat with high pH has dark colour, looks dry (DFD), often has sticky consistency and poorer taste and flavour. In addition, the pH of meat affects its colour and tenderness [Abril *et al*. 2001, Daszkiewicz *et al*. 2009, Jeleníková *et al*. 2008, Węglarz 2010a, Wulf and Page 2000]. It is also microbiologically perishable, as a result of which it cannot be subjected to a long-term aging process, characteristic for beef.

The pH_{48} values considered normal, following proper post-mortem metabolism, range from 5.4 to 5.8 [Page *et al*. 2001, Viljoena *et al*. 2002]. It is difficult to obtain these results for meat from all cattle categories, especially if animals are mishandled prior to slaughter [Van Laack 2001, Beltrán *et al*. 1997, Węglarz 2010a]. Proper preparation of animals for handling (appropriate nutrition, protection against injury and stress) is critical to obtain highest grade meat. The mode of transport to the slaughterhouse (duration and conditions in transport vehicles) plays a significant part. Other factors of importance include lairage management system, droving conditions (diffuse lighting, loading ramp angle) and slaughtering process itself [Mounier *et al*. 2006, Van de Water *et al*. 2003]. Observation of these recommendations and recommended slaughter procedures will result in light meat of pH below 5.8.

According to Wulf and Page [2000], evaluation of pH and colour is used to sort meat in meat plants and to determine its suitability for saleable beef production. Excessive pH implies that long-term meat aging, which provides meat with characteristics typical of good quality beef (low acidity favours growth of proteolytic bacteria that spoil meat), is not possible.

When evaluating beef, consumers concentrate on its colour depending on the presence of pigments, tissue composition, pH value and muscle structure [Mancini and Hunt 2005]. Many studies have shown a significant relationship between changes in meat pH and colour [Abril *et al*. 2001, Węglarz 2010a, Wulf and Page 2000].

In countries where meat quality traits have long been subject to routine testing, special attention is paid to a significant impact of animal temper on beef quality. Quantitative losses and deterioration in beef quality are unavoidable during the critical pre-slaughter period. The extent of these losses is dependent on stressor intensity and duration. Animal temper and stress affect beef quality both directly and indirectly. Excitable animals are more prone to injuries caused by pre-slaughter handling that result in great losses due to skin or carcass damage (seizure of damaged muscles) [King *et al*. 2006]. Restless behaviour of animals prior to slaughter is related to heavy muscular work that influences glycogen content, on which final meat pH depends. Lower glycogen amounts result in production of small amounts of lactic acid and thus high pH. Additionally, during pre-slaughter housing stressed animals are less resistant to endogenous infections derived from the digestive tract. Results reported by many authors indicate that conditions of transport and housing of bulls in the slaughterhouse affect the quality of their meat [Franc *et al*. 1990, Pipek *et al*. 2003, Jeleníková *et al*. 2008].

The current study aimed at the determination of pre-slaughter handling procedures that ensure proper values of pH and colour parameters of beef obtained from various slaughter cattle categories: young bulls, bulls, cows and heifers.

Material and methods

Subjects were 842 Black-and-White Polish Holstein-Friesian slaughter cattle divided into four categories based on the EUROP system of beef carcass grading. The following categories were distinguished: young bulls up to 24 months of age (A); bulls older than 24 months; cows with offspring (D); heifers without offspring (E). Each cattle category included two groups depending on pre-slaughter handling procedures (during and in the lairage). Group I comprised housed animals (G) and group II tethered animals (I). Number of animals in each cattle category as divided into pre-slaughter housing methods is presented in Table 1. Transport of cattle from the farms to the slaughterhouse took 4 to 6 h. The animals were transported by car. The average space provided for animal was approx. 1.4 m^2. On arrival, all animals were held in lairage for 8 to 12 h. Animals had free access to water and stayed in straw-bedded facilities. In the group-housing the number of animals in pen was 12-15 and the average space per animal was 3.5 m^2.

Table 1. Number of animals in each cattle category depending on pre-slaughter housing method

Pre-slaughter housing	Cattle category				Total
	A	B	D	E	
Group (G)	103	98	121	88	410
Individual (I)	108	94	133	97	432

A – young bulls, B – bulls, D – cows, E – heifers.

After the slaughter and post-slaughter treatment, carcasses were scored for quality (conformation and degree of fat cover according to the EUROP system) and weighed. The pH of *m. longissimus thoracis* (LT) was measured twice (within 45 min post-mortem – pH_0; after 48-h chilling – pH_{48}) between 11th and 13th thoracic vertebrae using a pH STAR CPU device (Matthäus, Germany) with a spearhead pH electrode. The pH meter was calibrated in buffers of pH 4.6 and 7.0. The device automatically corrected pH values for muscle temperature.

Meat colour was registered 48 h after slaughter on a fresh cross-section area of *m. longissimus thoracis* (LT), between the last thoracic vertebra and the first lumbar vertebra, using a CR-310 chromameter (Minolta Co., Ltd., Japan) equipped with a 50 mm measuring head, and quantified in the CIE L*a*b* colour space, where L* is the lightness of colour whose value ranges from 0 for black to 100 for perfect white, whereas a* and b* are colour coordinates: +a* – red, -a* – green, +b* – yellow, -b* – blue. The chromameter was calibrated with a white tile (Y=93.8, x=0.3136, y=0.3192). Based on a* (red) and b* (yellow) coordinate values, C* (colour saturation) was calculated as

$$(C^* = \sqrt{(a^*)^2 + (b^*)^2}) \text{ and } h^* \text{ index as } (h^* = \arctan(\frac{b^*}{a^*})).$$

Data were analysed in terms of cattle category and pre-slaughter housing method. Statistical calculations were made with two-way analysis of variance with interaction, using SAS statistical package (SAS Institute, Cary, NC).

Differences between the means for the analysed groups were assessed with the Scheffe test. Estimated were also correlations between slaughter value and meat pH and colour parameters.

Results and discussion

Table 2 presents data on slaughter value parameters of beef carcasses according to cattle category and pre-slaughter housing procedure. The effects of pre-slaughter housing and the interaction between cattle category and housing on the analysed traits proved to be non-significant. Individual categories differed considerably in pre-slaughter body weight and carcass weight. Regardless of pre-slaughter housing procedure, bulls had the highest dressing percentage of 53.6 for group housing and 53.3 for individual housing. Bulls (B) were differed significantly from other categories except heifers, which were characterized by higher performance compared to young bulls and cows ($P \leq 0.05$). There were differences between cattle categories in carcass conformation scoring. The highest values were found for heifers and bulls (1.90 to 2.06). The B and E categories differed significantly in relation to young bulls and cows, whose conformation averaged from 1.57 to 1.65. Likewise, better degree of carcass fatness was characteristic of heifers and bulls compared to young bulls and cows, but statistically significant differences were only confirmed between heifer carcasses and those of young bulls and cows. Better conformation of carcasses from heifers and bulls compared to young bulls suggests that for the latter cattle category pre-slaughter body weight was too low (525 and 531 kg on average). The much lower fatness of carcasses is also evidence that young bulls were not yet ready for slaughter. Litwińczuk *et al*. [2006] reported that the increase in slaughter weight of heifers and bulls is paralleled by improvements in the degree of carcass muscling and higher dressing percentage, which was also confirmed in the present study. Similar relationships were found by Węglarz [2010c], who reported Holstein-Friesian bulls slaughtered at 650 kg body weight to show better slaughter parameters compared with the bulls slaughtered at lower body weights.

Table 2. Parameters of slaughter value depending on cattle category and pre-slaughter housing

Trait		Pre-slaughter housing							
		Group				Individual			
		cattle category				cattle category			
		A	B	D	E	A	B	D	E
Body weight at slaughter (kg)	mean	524.7^{AB}	663.1^{ACD}	517.4^{Ca}	463.1^{BDa}	531.2^{AB}	655.4^{ACD}	510.3^{Ca}	468.1^{BDa}
	SD	114.2	110.8	95.1	67.5	98.2	133.6	92.9	59.4
Hot carcass weight (kg)	mean	274.5^{AD}	355.0^{BDE}	269.2^{CE}	$244.^{8ABC}$	278.5^{AB}	349.2^{ACD}	265.9^{CE}	248.0^{BDE}
	SD	54.1	56.2	78.8	35.8	49.4	66.8	72.5	43.2
Hot dressing percentage (%)	mean	52.3^{Aa}	53.6^{ABb}	52.0^{BC}	52.9^{Cab}	52.4^{a}	53.3^{Aab}	52.1^{Ac}	53.0^{bc}
	SD	0.7	0.8	0.7	0.7	0.9	0.8	0.9	0.7
Conformation score (EUROP)	mean	1.57^{Aa}	1.90^{ab}	1.57^{Bb}	1.98^{AB}	1.59^{Ab}	2.06^{bc}	1.65^{ac}	2.04^{Aa}
	SD	0.49	0.35	0.51	0.35	0.61	0.72	0.61	0.66
Fatness score (1-5)	mean	2.15^{a}	2.52	2.32^{b}	2.67^{ab}	2.21^{a}	2.58	2.28^{b}	2.71^{ab}
	SD	0.72	0.83	0.75	0.69	0.71	0.72	0.93	0.91

Conformation score was 5 for class E (good conformation) and 1 for class P (poor conformation).
Fatness score was 5 for very fat carcass and 1 for very lean carcass.
$^{aA...}$Within trait means bearing different superscript differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

Table 3. pH of LT muscle depending on cattle category and pre-slaughter housing

Trait		Pre-slaughter housing							
		Group				Individual			
		cattle category				cattle category			
		A	B	D	E	A	B	D	E
pH_0	mean	6.73	6.83	6.75	6.92	6.80	6.88	7.03	
	SD	0.22	0.27	0.26	0.27	0.23	0.24	0.20	0.24
pH_{48}	mean	5.92^{AabX}	5.88^{aBY}	5.74^{bc}	5.56^{ABc}	5.70^{aX}	5.66^{bY}	5.73^{c}	5.55^{ab}
	SD	0.22	0.27	0.21	0.08	0.21	0.31	0.20	0.17

$^{aA...}$Within trait means bearing different superscript differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

The pH values of LT muscle at slaughter and after 48-h chilling across cattle categories are listed in Table 3. No statistically significant differences for pH_0 of meat were found regardless of pre-slaughter housing or cattle category. The results on meat pH estimated directly after slaughter obtained in the present study confirm the findings of Pipek *et al*. [2003]. They reported that mean pH_{45} values of meat from different cattle categories did not differ considerably and was not affected by different animal housing procedures prior to slaughter.

In the present study, the pH_{48} values of meat from group-housed young bulls and bulls were higher compared to the pH_{48} of meat from individually housed animals of the same two categories. The differences were highly significant. For the other categories of cattle (cows, heifers), pre-slaughter housing procedures had no effect on the final pH_{48} of meat. For pH_{48} the interaction between cattle category and pre-slaughter housing was highly significant. Compared to the current work, Pipek *et al*. [2003] obtained higher pH_{48} values of beef for both group (6.10) and individually housed (5.92) bulls. Meanwhile, Jeleníková *et al*. [2008] reported slightly lower pH values of meat compared to those presented by the above authors, 6.03 for group housed bulls and 5.79 for individually housed bulls, as well as significant differences in pH of meat between group and individually housed cows before slaughter (5.81 and 5.67, respectively). According to Honkavaara *et al*. [2003], shorter duration of animal transport to the slaughterhouse had a greater effect on high pH values of bull meat than when transport exceeded 12 h and animals were fed and watered when muscle glycogen levels were the highest. Meanwhile, Mach *et al*. [2008] found no influence of transport duration on meat quality traits when it was 1 to 16 h long. According to Hartung *et al*. [2004], because heifers are more often affected by energy deficit, especially during long transport, it seems appropriate to feed them during stops. After 14-h transport, animals should rest for at least 3 h to have time for ingesting feed and water. For bulls, transport is less stressful than lairage if they are kept in groups, because fights and attempted mounts are unavoidable. Meanwhile, Villarroel *et al*. [2003] found no effect of transport duration (30 min to 6 h) on pH, but this effect was observed on sensory evaluation of beef.

Jeleníková *et al*. [2008] reported that the effect of pre-slaughter housing on meat quality is less significant for cows and heifers than for bulls, and considered females to be less sensitive to group housing during this period and quicker to re-establish social hierarchy. They did observe differences in the pH of meat from cows induced by housing system, but these were much smaller than in bulls.

Figure 1 shows percentage distribution of meat representing different pH ranges after chilling depending on cattle category and pre-slaughter housing method. The highest percentage of pH values considered normal for beef (below 5.8) was found in meat from heifers (99 and 94%, respectively), and the lowest in meat from young bulls and bulls kept in groups (36.6 and 37%, respectively). The frequency of abnormal pH (>5.8) in meat from young bulls and bulls exceeded 63% for group housing and approximately 30% for individual housing. A relatively high frequency (54.5%) of the 5.8-6.2 pH range was observed in group-housed cows. Likewise, Mach *et al*. [2008] showed that the meat pH >5.8 was more frequent in bulls (above 17%) compared to about 8% in females. According to the same authors, the frequency of meat with abnormal pH values is higher in Holstein-Friesian cattle than in other breeds (17 vs. 12%). Mach *et al*. [2008] reported the highest frequency of meat with pH >5.8 for conformation class P (almost 32%) compared to 11-16% for the other conformation classes. The frequency of meat with abnormal pH (above 42%) was highest among carcasses with poorest fatness.

Table 4 shows the parameters of meat colour. Statistically significant differences were found between the cattle categories in L* values. Lightest colour was characteristic of the meat of heifers regardless pre-slaughter housing, and this category differed from

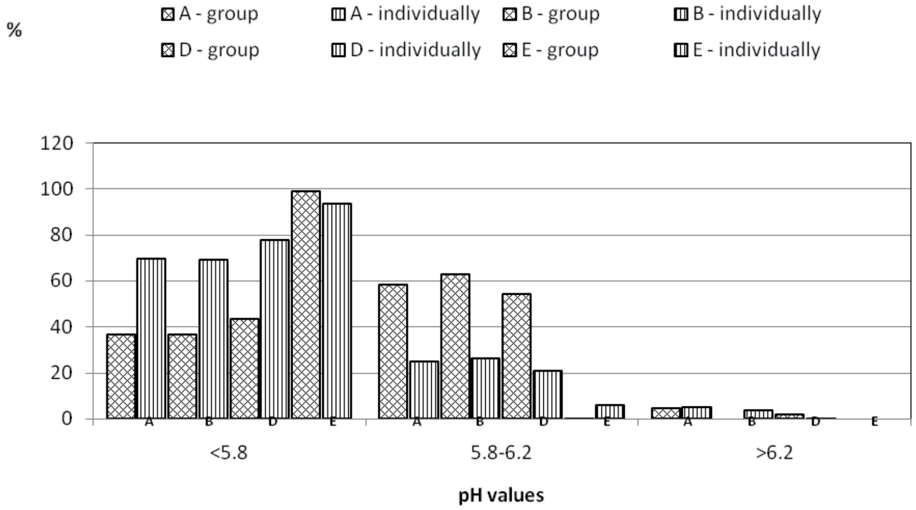

Fig. 1. Percentage distribution of pH values in meat depending on cattle category and pre-slaughter housing.

Table 4. Parameters of colour of LT muscle depending on cattle category and pre-slaughter housing

Trait		Pre-slaughter housing							
		Group				Individual			
		cattle category				cattle category			
		A	B	D	E	A	B	D	E
L*	mean	36.24^{AX}	36.12^{BY}	35.95^{C}	40.75^{ABC}	38.75^{abX}	38.49^{AcY}	36.06^{acd}	40.29^{Abd}
	SD	1.34	1.29	1.84	1.74	1.25	1.49	2.49	2.12
a*	mean	17.16^{ab}	16.18^{ax}	16.94	15.90^{b}	17.7^{Aa}	20.86^{ABCx}	17.25^{B}	16.43^{Ca}
	SD	2.22	2.02	2.76	2.84	2.11	2.46	3.26	3.49
b*	mean	5.24^{ax}	4.85^{bcy}	5.79^{b}	6.82^{ac}	6.35^{ax}	8.21^{ABay}	7.22^{Ab}	5.08^{Bb}
	SD	0.91	1.04	1.34	2.89	1.12	1.65	1.88	2.15
C*	mean	17.95^{abx}	16.90^{acy}	17.93^{bc}	16.87	18.83^{Aax}	22.44^{ABCy}	18.15^{C}	17.23^{Ba}
	SD	2.35	2.20	2.94	3.24	2.21	3.72	3.51	2.54
h	mean	0.30^{ax}	0.29^{Y}	0.33	0.41^{a}	0.34^{ax}	0.37^{Y}	0.40^{ab}	0.30^{b}
	SD	0.03	0.03	0.05	0.06	0.05	0.04	0.08	0.06

L* – lightness, a* – redness, b* – yellowness, C* – chroma, h – hue.
aA...Within trait means bearing different superscript differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

all the other ones. The effect of different housing system on meat colour parameters was noticeable only for the A and B categories of cattle. Meat from young bulls and bulls housed individually before slaughter had higher values of colour parameters compared to those housed in groups. These differences were statistically significant. However, pre-slaughter housing had no effect on the colour parameters of meat from both cows and heifers. The effect of cattle category × pre-slaughter housing interaction proved to be significant for all colour parameters.

Page *et al*. [2001] observed considerable differences in L*, a* and b* between heifers and young bulls, despite the lack of differences in pH of meat from these groups. They suggested that these results could be significantly influenced by the higher content of intramuscular fat in the meat from heifers. Those authors also found significant differences in meat colour parameters (lower L*, a* and b* values) in addition to higher frequency of pH>5.8 in the meat from Holstein-Friesian cattle compared to other breeds.

The relationships of slaughter value indicators with pH and meat colour parameters are given in Table 5. The highest coefficient of correlation (-0.39) was found between pH_{48} and colour lightness (L*). The correlations between ultimate pH of meat and other colour characteristics were also negative (a*=-0.24, b*=-0.22, C*=-0.25). The correlations between ultimate pH and all colour parameters, except h, were highly significant (P≤0.001). Low to moderate correlations (from -0.16 to -0.26) were observed between carcass conformation and the parameters of meat colour except meat colour lightness. Statistically significant relationships were also found between dressing percentage and L*, b* and h* values (0.23, 0.21 and -0.23, respectively). For the other indicators of dressing percentage and meat quality traits, the correlation coefficients suggest that the relationships were small or nonexistent.

Table 5. Correlation between carcass traits with meat pH and colour parameters

Trait	Body weight	Hot dressing percentage	Carcass confor-mation	Carcass fatness	pH_0	pH_{48}
pH_0	-0.09	-0.18	-0.08	-0.04	-	0.08
pH_{48}	0.09	0.06	0.06	-0.11	0.08	-
L*	0.00	0.23^{xx}	0.12	0.09	-0.06	-0.39^{xx}
a*	-0.04	-0.06	-0.22^{xx}	-0.05	0.07	-0.24^{xx}
b*	-0.14	0.21^{xx}	-0.26^{xx}	-0.10	0.19	-0.22^{xx}
C*	-0.06	-0.09	-0.23^{xx}	-0.06	0.11	-0.25^{xx}
H	-0.17	-0.23^{xx}	-0.16^{x}	-0.11	0.18	-0.18

^{x}P≤0.05; ^{xx}P≤0.001.

Similarly negative although higher coefficients of correlation between meat pH and L*, a* and b* colour values (-0.40, -0.58 and -0.56, respectively) were reported by Page et al. [2001] in the study carried out on different breeds and cattle categories. The correlations between meat pH and meat colour characteristics estimated by Kadim et al. [2004] for beef breed of *Bos indicus* cattle were higher than those obtained in the present study but also negative.

Conditions of pre-slaughter housing of cattle in the slaughterhouse significantly affected the evaluated quality traits of beef obtained from young bulls and bulls.

The individual pre-slaughter housing of these cattle categories resulted in lower pH and higher values of colour parameters of beef in comparison with the group pre-slaughter housing. However, the effect of pre-slaughter housing on pH and colour of beef obtained from heifers and cows was not found. Concluding, the pre-slaughter group housing of cows and heifers does not result in the deterioration of beef quality. Contrary, a high quality of beef from bulls and young bulls can be obtained only when they are housed individually which, however, generates higher expenses of such pre-slaughter handling process.

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