Linear correlation between pH value of stimulated beef and electrical current intensity

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\textbf{ABSTRACT}

The aim of the present study was to determine mathematical relationships between pH changes in beef 24 h post-slaughter and changes in the intensity of electrical current flowing through bull and heifer carcasses during high-voltage electrical stimulation. The electrical stimulation was applied 40 min postmortem for 120 s. The pH values of \textit{m. longissimus thoracis et lumborum} were analyzed in the function of electrical current intensity changes and its change during electrical stimulation. Mathematical linear correlations of the $y = ax \pm b$ type were demonstrated between pH values at 2, 6, and 24 h postmortem and the initial ($I_i$) and ultimate ($I_u$) electrical current intensity values, the difference between them and the initial pH values determined before electrical stimulation. High multiple correlation coefficients ($R^2 = 0.416, \ a \leq 0.001$) between $I_u$ and pH values 24 h post-slaughter enabled concluding that there is a possibility to predict a pH value of stimulated carcass with high accuracy, and thus also beef quality, based merely on the ultimate electrical current intensity values.

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\textbf{Introduction}

Beef quality is affected by its chemical composition, physical status, and muscle tissue structure, which are related to breed, sex, and age of cattle,\textsuperscript{[1,2]} but also by animals handling prior to slaughter, slaughter technology, and post-slaughter operations.\textsuperscript{[3–5]} The method and type of stunning and exsanguination during the slaughter and such technological operations as electrical stimulation (ES) and cooling after the slaughter are crucial for meat quality.\textsuperscript{[6–8]}

Apart from the unidirectional glycolytic processes, particular electrical processes still proceed in the animals immediately after slaughter. The active electrical phenomena are associated with nervous system functions (sustaining up to 1 h post-slaughter), and also with the energetic resources of the meat tissue. After complete consumption of ATP reserves, the \textit{rigor mortis} starts and electrical phenomena might take place only if the energy is externally delivered. The electrical processes which take place during and after \textit{rigor mortis} are called “passive.”\textsuperscript{[8]} Both, active and passive electrical processes which occur in the muscle tissue after slaughter reflect the changes in electrical and physicochemical, properties of meat. These processes underlie scientific researches aimed at determining and predicting meat quality based on \textit{postmortem} changes in electrical properties of the muscle tissue. In the meat industry, meat quality is determined and predicted based on the ultimate pH values. The ultimate pH value which, depending on meat origin, is measured within 6 h post-slaughter for poultry and 48 h post-slaughter for beef, affects the quality and shelf life of meat and meat products.\textsuperscript{[9–11]}

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The ES is a typical technological process in which electrical energy is delivered from the outside to accelerate the postmortem changes in meat.\(\text{[12]}\) It involves the electrical current flowing through the carcass or half-carcass (muscle tissue) of the animal within the first hour after its slaughter.\(\text{[13]}\) Under industrial conditions, it might be applied before or after exsanguination and evisceration.\(\text{[6]}\) ES duration is closely related to the time when it is applied. The longer the time since slaughter, the longer the ES should be or the higher voltage is required,\(\text{[14]}\) because the effect of the nervous system disappears with time. The energy (voltage) is delivered to carcasses (half-carcasses) through electrodes. One of the electrodes is a grounded conveyor, whereas the type and shape of the second electrode depend on whether the process is conducted on the carcasses covered with skin or on skinned half-carcasses. ES increases tenderness, color, and palatability of meat and prevents it from cold shortening.\(\text{[15]–18]}\) The results of our previous studies\(\text{[8,19]}\) addressing the effect of high-voltage electrical stimulation (HVES) and chilling method (accelerated and fast) of beef carcasses on the rate of pH decline, taking into consideration of cattle breed, sex, age, and the preslaughter stress of the cattle, showed the greatest pH decline (approx. 0.8 of the unit) in \textit{m. longissimus thoracis et lumborum} of heifer carcasses chilled using the accelerated method, within the first 2 h after stunning.

Our earlier studies\(\text{[8,19,20]}\) demonstrated mathematical correlations between pH values measured 2, 6, and 24 h post-slaughter and pH values measured before ES (approx. 40 min after stunning), initial value of current intensity measured approx. 5 s after the beginning of the ES, and ultimate values measured approx. 3 s before the end of ES, and the difference between them. These correlations enable determining pH values in the above mentioned sampling times, immediately after the ES. Therefore, we concluded that low intensity of the electrical current passing through beef carcass during ES, and high values of muscle pH\(_0\) (determined directly before ES) indicate that the ultimate pH of meat (24 h post-slaughter) would be low and the post-slaughter changes would proceed with the optimal rate indicating the beneficial effects of HVES on beef tenderness. However, our earlier studies were performed solely on bull carcasses. Bulls and heifers differ in the rate of post-slaughter pH decline between individuals; a higher variability in muscle pH decline between individuals is observed in the group of bulls, whereas lesser variability occurs in the group of heifers. Moreover, the range of pH changes (between the initial and ultimate pH values) in heifer meat is wider than in bulls.\(\text{[8,19,21]}\) These differences have become the basis of a further study aimed at determining mathematical correlations between changes in pH values in beef 24 h post-slaughter and changes in the electrical current intensity flowing through bull and heifer carcasses during high voltage ES.

## Materials and methods

### Material and parameters of ES

The study was performed on carcasses of bulls \((n = 81)\) and heifers \((n = 28)\) of Polish Holstein-Friesian breed, Black, and White variety, approx. 18 months old. They were selected for the study at random; 9 to 11 animals were picked from each lot of 109 animals. The selected animals were slaughtered after 1 h rest in the lairage. Slaughter and post-slaughter processing were carried out in accordance with Council Regulation (EC) No. 1099/2009 of 24 September 2009\(\text{[22]}\) on the protection of animals at the time of killing.

The HVES was proceeded using the device of our own construction,\(\text{[23]}\) which has been implemented at Ostrołęka S.A. meat plant in Ostrołęka, Poland. The device was awarded the bronze medal at the 45th International Exhibition of Inventions and Innovations “Brussels Eureka 96”. HVES was carried out 40 min after captive bolt stunning. The alternating electrical current was applied with the max voltage (amplitude) of 330 V, frequency of 17 Hz (according to literature data fitting within the optimal range – Polidori et al.\(\text{[16]}\)), rectangular shape of impulses, pulse-duty factor of 0.9, width of the pulse of 26.5 ms, and ES time was 120 s. ES-treated beef half-carcasses were chilled using the accelerated method at air temperature of approx. 2°C and humidity of approx. 95%. The method is
protected by patent rights. The ES parameters were set based on the results of our previous studies, which have shown that the optimum postmortem rate of pH decline (pH between 6.0 and 6.1 in the third hour after slaughter) and meat tenderness improvement up to 60%, were obtained using the electric current with the parameters given above, 40 min post-slaughter and with ES duration of 120 s.

**pH value measurements**

The values of pH were measured in three different locations of *m. longissimus thoracis et lumborum* (between 5th and 6th rib) directly before ES (approx. 40 min after stunning) (pH₀), and 2, 6, 24, and 48 h after stunning, with an HI 8314C type pH-meter equipped with an FC 200 stiletto electrode (Hanna Instruments Polska, Olsztyn, Poland). The pH-meter was calibrated using pH 5, 7, and 10 buffers at approx. 20°C. Due to the fact that statistical analysis revealed no significant differences between the mean pH values measured 24 h (pH₂₄) and 48 h (pH₄₈) after stunning, pH₂₄ was regarded as the ultimate pH value and reported in tables.

**Electrical current parameters**

The voltage (U) on the electrodes was measured approx. 20 s after the beginning of ES, using an LE-3 type laboratory voltameter (eraGost, Gostynin, Poland). The intensity (I) of electrical current flowing through the beef carcasses was measured approx. 5 s after the beginning of the ES (the initial value Iᵢ) and approx. 3 s before the end of ES (the ultimate value Iᵤ) using an LE-3P type laboratory ammeter (eraGost, Gostynin, Poland). The above electrical values were measured at the average temperature of carcasses of 39.5°C.

**Statistical analysis**

The statistical analysis of the results was carried out according to the variance analysis for 1-, 2-, and 3-factor cross, orthogonal, and non-orthogonal experiments. Correlation and simple linear regression as well as correlation and multiple regression were calculated to determine the relation between the electrical current parameters (Iᵢ, Iᵤ, ΔI) and the pH values before ES (pH₀) and after ES (pHₜ(2, 6, 24)).

**Results and discussion**

The analysis of our earlier results and available literature data showed that the choice of ES type is related to the place of ES device installation on a slaughter line. Under industrial conditions, the time between the stunning and the start of the chilling process is about 1 h, hence if the extra low and low voltage ES is applied approx. 10 min after stunning, the temperature of half-carcasses is above 38°C during their stay in the slaughter hall (at a temperature of approx. 20°C) for about 50 min. Conducting ES about 40 min after slaughter reduces the time the carcasses stay in the slaughter hall to about 20 min, thus allows decreasing the rate of pH change and achieving its higher value (approx. 6.1), measured approx. 2 h after the slaughter.

The correlation analysis of *m. longissimus thoracis et lumborum* pH values in a function of changes in the intensity of electric current passing through beef carcasses and its change during ES, revealed a significant correlation (P ≤ 0.001) between pH values measured 2, 6, and 24 h after stunning (pHₜ(2, 6, 24)) and the ultimate electrical current intensity (Iᵤ) (Table 1). The multiple correlation coefficients, ranging from 0.213 to 0.416, indicated clearly that there are relationships between the above-mentioned parameters, however suggested that other factors, such as fatigue and stress, also affected the pH value of meat. Based on these results, a similar way of data analysis as previously described was applied.

It was assumed that the most important factors which affect post-slaughter changes in meat and also changes in its pH value are the diversity and variability of the physicochemical status of muscles.
of individual animals (heifers and bulls). Then, it was assumed that, due to fatigue and stress, a great part of glycogen is converted into lactic acid in the animal body, which results in muscle tissue pH decrease after the slaughter. Therefore the animals differ in pH values of their muscles, which in turn affects electric (ionic) conductivity of beef carcass. The correlation might be presented as the following Eq. (1) (Table 1):

\[
\text{pH}_{h(2,6,24)} = b I_u + d
\]  

(1)

The value of muscle pH during postmortem changes is affected by two factors: meat pH immediately after the slaughter (pH\text{0}) and ultimate electrical current intensity (I_u), according to the Eq. (2) (Table 1).

\[
\text{pH}_{h(2,6,24)} = a \text{pH}_0 + b I_u + d
\]  

(2)

The third factor, i.e., initial electrical current intensity (I_i) was additionally considered, according to Eq. (3) (Table 1).

\[
\text{pH}_{h(2,6,24)} = a \text{pH}_0 + b I_u + c I_i + d
\]  

(3)

To determine which factor, the absolute electrical current intensity values (I_u and I_i) or the difference between them (ΔI), affects to a greater extent pH\text{h(2, 6, 24)} values, and to attempt to explain the reason behind the above-mentioned dependence, the correlation described by the following Eq. (4) (Table 1) was studied as well:

\[
\text{pH}_{h(2,6,24)} = a \text{pH}_0 + b \Delta I + d
\]  

(4)

Knowing the ultimate intensity of electrical current (I_u) flowing through bull and heifer carcasses during ES, it is possible to calculate, directly after its termination, the pH values of meat in the 2nd, 6th and 24th h after the slaughter using Eq. 1 (Table 1) with much higher accuracy than reported in our earlier study. Knowing the values of pH\text{0}, I_i, I_u, and ΔI, and using Eqs. (2)–(4), presented in Table 1, it is possible to calculate meat pH in the 24th h after the slaughter with the same accuracy, and also pH values of meat after 2 and 6 h with a slightly lesser accuracy than that presented in the previous study.
Tables 2–4 present the values of $\text{pH}_{h(2, 6, 24)}$ calculated using the equations shown in Table 1 based on the lowest, mean, and the highest values of $\text{pH}_0$, $I_i$, $I_u$, and $\Delta I$. The results of calculations (Table 2) indicate that the highest value of $\text{pH}_0 = 7.00$ corresponds the lowest and the same values of $I_i$ and $I_u$ 1.30 A (at $\Delta I = 0$), which in turn allows predicting the lowest $\text{pH}_{h(2, 6, 24)}$ values. The lowest and the most similar to each other pH values, 5.937 and 5.940 in the 2nd h after the slaughter ($\text{pH}_2$), 5.688 and 5.685 in the 6th h after the slaughter ($\text{pH}_6$), and 5.481 and 5.478 in the 24th h after the slaughter ($\text{pH}_{24}$), were obtained from Eqs. (2) and (3), presented in Table 1, that offered the highest correlation coefficient values. Slightly higher pH values: 6.025, 5.798, and 5.611 in the 2nd, 6th, and 24th h post-slaughter, respectively, were obtained with the use of Eq. (1) (Table 1), that offered the lowest multiple correlation coefficients.

Slight differences between pH values calculated using different equations from Table 1, confirm the assumptions that the predominant factor affecting the post-slaughter changes in meat and the same changes in meat pH after slaughter, was the diversity and variability of physicochemical status of muscles of individual animals. Fatigue and stress in the body of a living animal cause the conversion of a significant part of glycogen into lactic acid, which results in pH decrease before slaughter. Therefore, the animals differ in muscle pH, which affects the electrical conductivity of beef carcass.\textsuperscript{8,20}

The results of the calculations (Table 2) made based on the equations from Table 1, allow predicting the optimal rate of post-slaughter changes, which according to the literature\textsuperscript{24,29,30} should result in pH values ranging from 5.9 to 6.3 between the 1.5 and 3 h post-slaughter. The calculations made for mean values: $\text{pH}_0 = 6.896$, $I_i = 1.786$, $I_u = 1.731$, and $\Delta I = 0.055$, shown in Table 3, demonstrated insignificant differences in the predicted $\text{pH}_{h(2, 6, 24)}$ values calculated from the equations presented in Table 1. Moreover, the $\text{pH}_{24}$ values: 6.029, 6.032, 6.032, and 6.028, calculated from Eqs. (1)–(4), respectively (Table 1) are lower, by approx. 0.17 of the unit, than the

| Table 2. Results of calculations of expected pH values after a slaughter ($\text{pH}_{h(2, 6, 24)}$) based on regression functions in case of the highest $\text{pH}_0$ value and the lowest values of electrical current parameters (Table 1). |
|---|---|---|---|---|
| Measured values | Source of the regression functions | Calculated $\text{pH}_{h(2, 6, 24)}$ values |
| $\text{pH}_0$ | 7.00 | $I_u$ | $\text{pH}_0$, $I_u$ | $\text{pH}_0$, $I_u$, $I_u$ | $\text{pH}_0$, $I_u$, $I_u$, $\Delta I$ |
| $I_i$ (A) | 1.30 | (Eq. (1)) | (Eq. (2)) | (Eq. (3)) | (Eq. (4)) |
| $I_u$ (A) | 1.30 | 6.025 | 5.937 | 5.940 | 5.974 |
| $\Delta I$ (A) | 0.00 | 5.798 | 5.688 | 5.685 | 5.763 |
| $\text{pH}_2$ | 5.611 | 5.481 | 5.478 | 5.582 |
| $\text{pH}_6$ | 5.582 |
| $\text{pH}_{24}$ | 5.582 |

$pH_0$: value measured directly before electrical stimulation; $I_i$ and $I_u$: initial and ultimate values of intensity of electrical current; $\Delta I$: changes of intensity of electrical current flowing through carcasses of young bulls and heifers during electrical stimulation.

| Table 3. Results of calculations of expected pH values after slaughter ($\text{pH}_{h(2, 6, 24)}$) based on regression functions in case of the mean $\text{pH}_0$ value and the mean values of electrical current parameters (Table 1). |
|---|---|---|---|---|
| Measured values | Source of the regression functions | Calculated $\text{pH}_{h(2, 6, 24)}$ values |
| $\text{pH}_0$ | 6.896 | $I_u$ | $\text{pH}_0$, $I_u$ | $\text{pH}_0$, $I_u$, $I_u$ | $\text{pH}_0$, $I_u$, $I_u$, $\Delta I$ |
| $I_i$ (A) | 1.786 | (Eq. (1)) | (Eq. (2)) | (Eq. (3)) | (Eq. (4)) |
| $I_u$ (A) | 1.731 | 6.234 | 6.234 | 6.233 | 6.240 |
| $\Delta I$ (A) | 0.055 | 6.113 | 6.112 | 6.111 | 6.113 |
| $\text{pH}_2$ | 6.029 | 6.032 | 6.032 | 6.028 |
| $\text{pH}_6$ | 6.032 |
| $\text{pH}_{24}$ | 6.032 |

$pH_0$: value measured directly before electrical stimulation; $I_i$ and $I_u$: initial and ultimate values of intensity of electrical current; $\Delta I$: changes of intensity of electrical current flowing through carcasses of young bulls and heifers during electrical stimulation.
corresponding values shown in Table 6 in our previous paper\cite{20} and also differ slightly from pH values at 6.234, 6.234, 6.233, and 6.240, respectively, which are approx. 0.12 lower than the corresponding values obtained in our previous study (Table 6 in Ref. \cite{20}). The results indicate and confirm that the highest decrease in pH (to 6.233) will be obtained in the first 2 h after the slaughter using the mean values of electric current flowing through the beef carcass during ES, and mean value of pH \(0\). During further storage, meat pH will decrease slightly to the maximum value of 6.028.

High electric current values \(I_i\), \(I_u\), and \(\Delta I\): 2.30 A, 1.90 A, 0.40, respectively, and low pH \(0\) approx. 6.80 (Table 4) are predictors of high values of pH \(h(2, 6, 24)\) and the lowest pH value decrease (approx. 0.3 unit) obtained in the initial 2 h after the slaughter using the mean values of electric current flowing through the beef carcass during ES, and mean value of pH \(0\). During further storage, meat pH will decrease slightly to the maximum value of 6.028.

High electric current values \(I_i\), \(I_u\), and \(\Delta I\): 2.30 A, 1.90 A, 0.40, respectively, and low pH \(0\) approx. 6.80 (Table 4) are predictors of high values of pH \(h(2, 6, 24)\) and the lowest pH value decrease (approx. 0.3 unit) obtained in the initial 2 h after the slaughter. The highest and closest pH values: 6.478, 6.463, and 6.499 in the 2nd h after the slaughter, 6.436, 6.449, and 6.428 in the 6th h after the slaughter and 6.431 in the 24th h after the slaughter, were obtained from Eqs. (2)–(4), respectively (Table 1), i.e., from the equations characterized by the highest correlation coefficients. Lower, by approx. 0.2 of the unit, pH values: 6.316, 6.237, and 6.192 in the 2nd, 6th, and 24th h after the slaughter, respectively, were obtained using Eq. (1) (Table 1), i.e., the equation calculated at the same significance level and slightly lower correlation coefficients as Eqs. (2)–(4) (Table 1). It might be concluded that the analysis of the pH \(h(2, 6, 24)\) value in the function of pH \(0\) should be based, likewise in the previous study,\cite{29} on the assumption that low values of pH \(0\) are predictors of high values of pH \(24\) in the muscle tissue and of the meat with DFD (Dark, Firm, Dry) defect. Therefore, based on the above-described relationship, it is recommended to measure the pH value in each beef carcass especially in the non-stimulated meat.\cite{29,31}

The results obtained in the present study, such as significantly higher correlation coefficients \((\alpha \leq 0.001)\) between the ultimate values of intensity \((I_u)\) of electric current flowing through beef carcass during ES and values of pH in the 2nd, 6th, and 24th h post-slaughter (Tables 1 and 2) than the correlation coefficients presented in the previous paper (Tables 1 and 5 in Ref. \cite{20}) indicate clearly that the impedance value is directly proportional to the specific resistance, which depends mainly on the physical, physicochemical, and biochemical reactions taking place in the muscle tissue, as well as on the physicochemical status of muscles from stimulated carcasses. This status is related to electrical phenomena occurring in the muscles directly after slaughter; therefore it is affected by active and passive electrical properties of carcass muscle. The direction and extent of these phenomena are mainly influenced by the parameters of electrical current flowing through the beef carcasses during ES. Therefore, ES results in muscle contraction, rapid decrease in pH value, and changes in the structure of muscle tissue, which directly after ES termination are characterized by the shrinkage of sarcomeres and physical damage of myofibril structure. These structural changes consist in disrupting the fibrils’ continuity and loosening their internal structure.\cite{8,13,19} The above-mentioned changes in the structure might be caused by electrical current flow and by muscle shrinkage. The changes caused by the electrical

| Table 4. Results of calculations of expected pH values after slaughter (pH\(h(2, 6, 24)\)) based on regression functions in case of the lowest pH\(0\) value and the highest values of electrical current parameters (Table 1). |
|---|---|---|---|---|
| Measured values | Source of the regression functions |
| pH\(0\) | 6.80 | \(I_i\) | \(\Delta I\) | \(\text{Calculated pH}_{h(2, 6, 24)}\) values |
| \(I_i\) (A) | 2.30 | \(\text{Eq. (1)}\) | | \(\text{Eq. (4)}\) |
| \(I_u\) (A) | 1.90 | \(\text{Eq. (2)}\) | | \(\text{Eq. (3)}\) |
| \(\Delta I\) | 0.40 | | | |
| pH\(2\) | 6.316 | 6.478 | 6.463 | 6.499 |
| pH\(6\) | 6.237 | 6.436 | 6.449 | 6.428 |
| pH\(24\) | 6.192 | 6.443 | 6.458 | 6.431 |

pH\(0\): value measured directly before electrical stimulation; \(I_i\) and \(I_u\): initial and ultimate values of intensity of electrical current; \(\Delta I\): changes of intensity of electrical current flowing through carcasses of young bulls and heifers during electrical stimulation.
current were due to the fact that the current flows the way with the least resistance and damages the structure of the fibers through which it flows. The structure of the fibers located in their neighborhood might be damaged as a result of the flow of electrical current with significantly lower intensity as well as the shrinkage of muscles caused by electrical irritation of the nervous system. The above considerations may be justified by the fact that only some fibers (about 20%) of *m. longissimus thoracis et lumborum* had damaged cell membranes. The remaining cell membranes did not lose their dielectric properties within such a short time after the slaughter, and constitute an obstacle to the electrical current which when flowing through the muscles can bypass some fibers without damaging them.\cite{8,19,32,33}

High initial and ultimate values of the intensity of electrical current flowing through beef carcasses during ES, as well as the highest differences between them noted at the lowest values of pH\textsubscript{0} (6.80, Table 4) indicate the lowest impedance of the carcasses, which in turn was related with the highest acidity of meat and its best conductivity. It was proved by the lowest values of initial and ultimate electrical current intensity, the lack of differences between them and the highest values of pH\textsubscript{0} (approx. 7.0), regardless the sex of the animals (Table 2). It resulted from the fact that dissociated lactic acid, mainly H\textsuperscript{+} ions characterized by high mobility, influences electrical conductivity of meat. The decrease in the electrical current intensity values during ES is the evidence of deteriorated electrical conductivity of meat as a result of its structure damage. The damage of muscle tissue structure as a result of ES was demonstrated in the previous study, based on ultrastructure images of muscle tissue, along with the findings that about 3 h after stunning the impedance of stimulated muscles was significantly higher than of the non-stimulated ones.\cite{19}

The above observations confirm that the ultimate pH value obtained 24 h after the slaughter is affected by the initial pH value (pH\textsubscript{0}) related to glycogen content in muscles, which in turn depends on the physiological status of animals, their condition and degree of stress prior to slaughter.

**Conclusion**

The method described in the present paper is easily applicable in abattoirs where HVES is used. It involves measuring the parameters of current flowing through the carcass and saving the record in a computer equipped with a program that shows the pH values of the currently stimulated carcass after 2, 6, and 24 h post-slaughter. Using this method for pH prediction will not require employment increase in abattoirs. The method is non-destructive to beef carcass muscles in contrast to online pH measurements done with a pH-meter. The fact that the multiple correlation coefficients (0.213 ≤ R\textsuperscript{2} ≤ 0.416) obtained at much higher significance levels (α ≤ 0.001), between the ultimate values of intensity of the electrical current flowing through the beef carcass during ES (I\textsubscript{u}) and pH values 2, 6, and 24 h after a slaughter were significantly higher than those noted in our previous study\cite{20} (α ≤ 0.05) indicates clearly that it is possible to predict with high accuracy the pH value of meat and also the quality of stimulated beef based on merely the ultimate values of intensity of the electrical current flowing through the beef carcass during high voltage ES. The simplicity of conducting the electrical current intensity measurements and the possibility of predicting the pH value of beef based on ultimate electrical current intensity values, enable the fully automated control of post-slaughter changes with indication of DFD meat directly after the termination of ES. In addition, they allow for eliminating pH measurements of meat which are difficult to proceed during slaughter and chilling. The results presented in the paper form the basis for further studies on the development of a method and a device for predicting the quality and shelf-life of beef based on electrical current intensity values used in HVES, which is increasingly commonly used for quality improvement of beef worldwide.

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