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# USABILITY OF BEEF CONDUCTIVITY PROPERTIES FOR ASSESSMENT AND CONTROL OF ITS RIPENESS

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Key words: conductivity properties, beef, ripeness assessment and control

The aim of the study was to take an attempt to use conductivity properties of fresh and stored in chilling conditions beef for assessment and control of its ripeness.

The experimental material was *longissimus dorsi* muscle of heifers black-white breed. Left half carcasses were applied to high-voltage electrical stimulation, with own-construction device. Right half carcasses were the control samples. Muscles trimmed 1, 24, and 72 h after slaughter as well as those trimmed 24 h after slaughter and stored (2°C, 14 days) were subjected to the following measurements: impedance, resistance and reactance with an HP 4263B meter (250 mV, 100 Hz – 100 kHz). The differences between impedance and resistance values measured at 100 Hz and 10 kHz were the basis to define the ripeness indicators ($Q_{RZ}$, $Q_{RR}$) of meat trimmed in different time after slaughter. Then, using the triangle resistance graph, cos φ and sin φ coefficients for meat stored in chilling conditions were calculated.

The research revealed that non stimulated meat trimmed 1 h after slaughter was characterised with the lowest ripeness indicator, whereas the stimulated one trimmed 72 h after slaughter with the highest ripeness indicator. The results of cos φ and sin φ studies showed that changes of conductivity properties for stimulated meat were stabilized already about 24 h after slaughter, whereas for the non stimulated one after about 14 days of cooling storage, which is in accordance with the time of achievement of full ripeness for stimulated and non stimulated beef.

The study indicates possibilities to develop a method of fast assessment and control of ripeness of beef on the basis of conductivity properties.

## INTRODUCTION

Progress in numerous areas of sciences resulted in appearance of new techniques and technologies for meat quality formation, which caused an increased interest in the methods that allow fast, accurate and repeatable raw material quality assessment and control already on the slaughter line.

The measurement of pH is the best known and commonly applied method of assessing the rate of post-slaughter changes in meat. Technical problems encountered both before and during measurement and increasingly frequent defects of meat resulted in gradual loss of importance of that measurement, particularly once performed immediately after slaughter [Pospiech, 2000]. Methods based on electrical properties of muscular tissue such as impedance, resistance and electric conductivity measurements [Blicharski *et al.,* 1995; Lepetit & Hamel, 1998; Pliquett *et al.,* 2003; Banach & Żywica, 2004] are a supplement or even an alternative to pH measurement. Application of that type of methods is possible as a consequence of the specific muscle structure, which shows conductivity features (intercellular juice, concentration and mobility of $Cl^-$, $K^+$ and $Na^+$ ions) on one hand and features of dielectric material (non-conductive cellular membrane, intracellular fat) on the other. For those and other reasons and as a consequence of a wider measurement range as compared to measurement of electric conductivity, impedance was chosen as the appropriate electrical parameter for characterizing changes in muscle tissue cellular membrane properties as well as changes occurring in extracellular area which is the sum of ohm and capacity resistance [Lepetit *et al.,* 2002; Pliquett *et al.,* 2003].

Studies on the application of measurements of impedance and other electric values for assessment of beef quality features have been carried out for many years. Pliguett *et al*. [1995] and Swatland [1997] established that if changes in muscle tissue electric properties are coupled with structural changes occurring in the raw material during post-slaughter changes (ripening) then they can be used for meat quality assessment. Lepetit & Hamel [1998] on the other hand showed that depending on treatment applied before *rigor mortis* (*e.g.* electric stimulation), meat ripeness could be determined using muscle fibers resistance already 1 day after slaughter. It was also confirmed by a significant correlation obtained by the authors at that time between impedance values and values of the maximum shear force that in instrumental assessment is considered the indicator of meat tenderness [Spadaro *et al.,* 2002]. Lepetit *et al*. [2002] also indicated the possibility of using electric meat properties for control of the meat tenderness degree during its storage. Schöeberlein *et al*. [1999] and Byrne *et al*. [2000] believe, in turn, that early post slaughter measurement of beef electric properties is unsuitable for quality determination in that type of meat as a consequence of too slow rate of biochemical changes.

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Contradictory literature data concerning electric properties of meat indicate that they are not fully known and, as a consequence, such data offers no clear indication concerning the potential for using electric properties for beef ripeness assessment and control.

As a consequence of the above, the studies were undertaken aiming at using the conductivity properties of fresh and stored beef under cooling conditions for its ripeness assessment and control.

## MATERIAL AND METHODS

The experimental material was the *longissimus dorsi* muscle from half carcasses of black-white heifers (n = 8) aged *ca.* 18 months. Left half-carcasses were subjected to electrical high voltage stimulation using a device of own design [Żywica *et al.,* 1997]. The device was implemented at the "Ostrołęka S.A." Meat Plant in Ostrołęka, and was awarded the bronze medal at the 45th International Exhibition of Inventions and Innovations "Brussels Eureka 96".

Right half carcasses were the controls. The pH and electric parameters measurements were taken from muscles trimmed *ca.* 1, 24 and 72 h after slaughter and those trimmed 24 h after slaughter and stored under cooling conditions (air temperature *ca.* 4°C) for 14 days. Measurements of pH in stimulated and control muscles were taken, independent of the trimmed time, 24 h after slaughter using an HI 8314C type pH meter equipped with an FC 200 stiletto electrode. The average pH values were 5.56 and 5.58, respectively. No significant pH changes in the examined muscles were observed during storage. For the purpose of electric parameters measurement the muscles were divided into segments of *ca.* 500 g each close to 150 × 80 × 60 mm in size, placed in glass tanks 115 × 70 × 100 mm equipped with plate electrodes of acid resistant steel mounted in contact with two opposite walls (smaller in area) of the container, covered with plates made of insulating material and placed in the cooling chamber (Memmert) at air temperature of 4±0.1°C. Before and during storage (the initial 3 measurements at 12-h interval, following measurements at 24-h interval) measurements of the following electric parameters were taken: impedance (Z), resistance (R) and capacity reactance ($X_c$), using the HP 4263B type (Hewlett Packard, USA) device at 250 mV and frequency (*f*) from 100 Hz to 100 kHz, in 4 repetitions. On the basis of the difference between impedance and resistance values measured at 100 Hz and 10 kHz the ripeness indexes ($Q_{RZ}$ and $Q_{RR}$) were determined for meat trimmed at different times after slaughter.

$$Q_{RZ} = 1 - (Z_{100Hz} - Z_{10kHz} / Z_{100Hz}) \times 100\% \quad (1)$$

$$Q_{RR} = 1 - (R_{100Hz} - R_{10kHz} / R_{100Hz}) \times 100\% \quad (2)$$

where: $Q_{RZ}$ – ripeness index calculated on the basis of impedance value, $Q_{RR}$ – ripeness index calculated on the basis of resistance value, $Z_{100\,Hz}$ – impedance measured at 100 Hz, $Z_{10kHz}$ – impedance measured at 10 kHz, $R_{100\,Hz}$ – resistance measured at 100 Hz, and $R_{10\,kHz}$ – resistance measured at 10 kHz.

Next the values of cos φ and sin φ, *i.e.* value of resistance (R) and reactance ($X_c$) in the total impedance value (Z) of meat trimmed 24 h after slaughter and stored under cooling conditions were calculated on the basis of formulas (3 – 4) resulting from the graph of indicators in resistance triangle (Figure 1). The calculations were taken on the basis of electric parameters measured at frequency of 10 kHz.

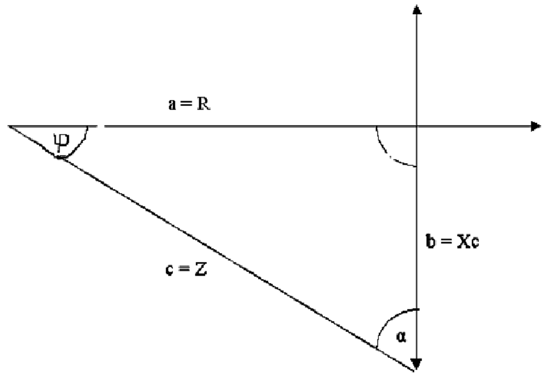


FIGURE 1. Graph of indicators in resistance triangle.

$$\sin \varphi = b / c = X_c / Z => X_c = Z \sin \varphi \quad (3)$$

$$\cos \varphi = a / c = R / Z => R = Z \cos \varphi \quad (4)$$

A statistical analysis of the results obtained was carried out on the basis of analysis of variance.

## RESULTS AND DISCUSSION

Results of impedance measurements and calculations based on them showed that ripeness index values ($Q_{RZ}$) for fresh stimulated meat trimmed 1, 24 and 72 h after slaughter were 46.80, 75.63 and 83.85% while for the non-stimulated meat they were 42.51, 67.30 and 77.26%, respectively. The values of $Q_{RR}$ index for stimulated and non-stimulated meat were lower at 34.30, 72.06 and 83.36% and 32.72, 61.61 and 75.12%, respectively (Table 1). The above values of $Q_{RZ}$ and $Q_{RR}$ indexes clearly indicate favorable influence of electric stimulation on post-slaughter change processes and confirm literature reports that stimulated meat ripening process occurs much faster than in the non-stimulated meat. This is linked to destruction of muscle tissue structure and spillage of cellular liquid outside the cell, increase in the total conductive diameter and faster, as compared to non-stimulated meat, increase of electric conductivity [Eilers *et al.,* 1996; Polidori *et al.,* 1996; Żywica 1999; Lepetit *et al.,* 2002].

High $Q_{RZ}$ and $Q_{RR}$ values for stimulated (46.80 and 34.30%) and non-stimulated (42.51 and 32.72%) meat trimmed 1 h af-

TABLE 1. Beef ripeness indexes depending on the trimming time.

| Trimming time (h) | $Q_{RZ}$ (%) | | $Q_{RR}$ (%) | |
|---|---|---|---|---|
| | S | K | S | K |
| 1 | 46.80 | 42.51 | 34.30 | 32.72 |
| 24 | 75.63 | 67.30 | 72.06 | 61.61 |
| 72 | 83.85 | 77.26 | 83.36 | 75.12 |

S – stimulated muscles, K – non-stimulated muscles

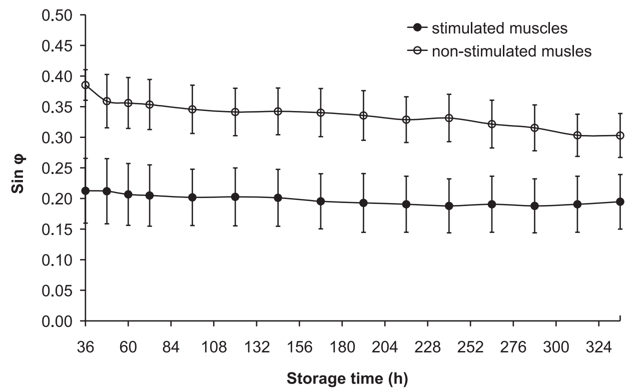


FIGURE 2. Changes of sin φ of stimulated and non-stimulated *longissimus dorsi* muscles during cooling storage.

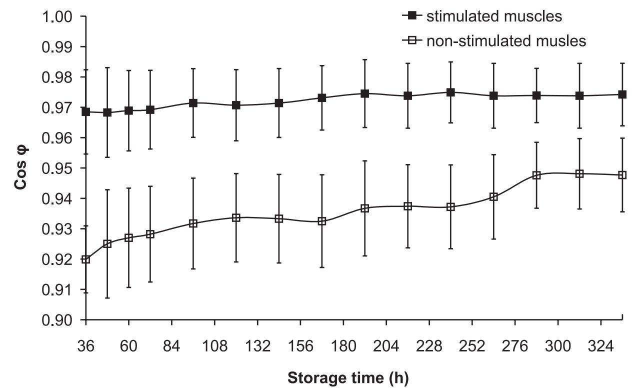


FIGURE 3. Changes of cos φ of stimulated and non-stimulated *longissimus dorsi* muscles during cooling storage.

ter slaughter result from the long-lasting total meat transport and preparation for studies time of *ca.* 6 h and its high temperature (on average *ca.* 28°C).

A much lesser influence of time and transport conditions was found through resistance measurements at $f$ = 10 kHz. That is reflected in the calculated meat ripeness indexes ($Q_{RR}$), which for control meat trimmed 1, 24 and 72h after slaughter were 32.72, 61.61 and 75.12% and for stimulated meat 34.30, 72.06 and 83.36%, respectively (Table 1). It means that resistance measurements, although more difficult to take than impedance measurements, might be more reliable in the assessment of stimulated and non-stimulated beef ripeness. Also Lepetit & Hamel [1998] propose using meat fibers resistance for assessment of beef ripeness.

The formulas presented as equations (1) and (2) allow determining beef ripeness index depending on the time of trimming but do not allow determining the time of achievement of full ripeness during storage on the basis of impedance and resistance measured at 100 Hz and 10 kHz. That is why further analysis of electric parameters values measured, from the point of possible use for assessing and predicting beef quality, was carried out on the basis of calculated sin φ and cos φ values.

It was shown that the share of reactance in the total impedance value (sin φ) of stimulated muscles was much lower than the share of control muscles reactance. Besides, during storage, the sin φ values for stimulated muscles remained at a fixed level of *ca.* 0.2 while the sin φ value for control muscles decreased from 0.3854 to 0.3038. The average difference between the initial and final values was *ca.* 0.08 (Figure 2).

The share of resistance in the total impedance value (cos φ) was much larger in stimulated than non-stimulated muscles. Its value during cooling storage for 336 h was at a fixed level of *ca.* 0.97 and showed no significant differences. Values of cos φ for control muscles increased with storage time from 0.92 to 0.95 (Figure 3).

High values of cos φ and low values of sin φ, indicate resistance-capacity nature of the meat tested while justifying selection of conductivity properties (Z, R, $X_c$) for assessing and predicting meat ripeness [Lepetit & Hamel, 1998; Żywica, 1998; Byrne *et al.,* 2000; Lepetit *et al.,* 2002].

In the case of both sin φ and cos φ changes in non-stimulated meat in storage time function, stability of the values at the levels of *ca.* 0.3 and 0.95 respectively after *ca*. 300 h (*i.e. ca.* 13 days of storage) was observed. That was linked to both stabilization of conductivity and capacity properties of meat and probably reaching full ripeness, which, according to literature data, is reached in non-stimulated meat after *ca.* 14 days of cooling storage [Dransfield *et al.,* 1992].

Stabilization of conductivity and capacity properties of stimulated meat (sin φ ~ 0.2 and cos φ ~ 0.97), indicates, on the other hand, that full ripeness was achieved in that meat already at the beginning of storage process, *i.e. ca.* 36 h after slaughter, and that it was maintained until the end of the experiment [Żywica, 1999].

## CONCLUSIONS

1. Differences between impedance and resistance values at 100 Hz and 10 kHz, determined by conductivity properties of cellular membranes changing over time after slaughter, offer a possibility to develop an index defining the beef ripeness degree in the case of both stimulated and non-stimulated meat.

2. Changes in cos φ and sin φ defining the share of resistance and reactance in the total impedance value during cooling storage coupled with meat ripening process indicate a possibility of developing a method for beef ripeness assessment and for predicting completion of the time of the ripening process.

3. The results obtained justify further studies on the use of $Q_{RZ}$ and $Q_{RR,}$ indexes for determining ripeness of stimulated and non-stimulated beef trimmed at different times after slaughter as well as sin φ and cos φ for predicting the time of reaching full ripeness of meat.


## ACKNOWLEDGEMENTS

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## MOŻLIWOŚCI WYKORZYSTANIA WŁAŚCIWOŚCI PRZEWODNOŚCIOWYCH MIĘSA WOŁOWEGO DO OCENY I KONTROLI JEGO DOJRZAŁOŚCI

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Celem badań było podjęcie próby wykorzystania właściwości przewodnościowych mięsa wołowego świeżego oraz przechowywanego w warunkach chłodniczych do oceny i kontroli jego dojrzałości

Materiał doświadczalny stanowił mięsień najdłuższy grzbietu, pochodzący z półtusz jałówek rasy czarno-białej w wieku ok. 18 miesięcy. Lewe półtusze poddano elektrostymulacji wysokonapięciowej wykorzystując urządzenie własnej konstrukcji (patent PL 173079 B1). Prawe półtusze stanowiły próbę kontrolną. Na mięśniach wykrawanych po ok. 1, 24 i 72 godz. od uboju oraz na mięśniach wykrawanych po 24 godz. od uboju i przechowywanych w warunkach chłodniczych (temperatura powietrza ok. 2°C) przez 14 dni, wykonano pomiary: impedancji, rezystancji oraz reaktancji. Pomiary wykonano miernikiem typu HP 4263B przy napięciu 250 mV i częstotliwości od 100 Hz do 100 kHz. Na podstawie różnic między wartościami impedancji i rezystancji zmierzonych przy częstotliwości 100 Hz i 10 kHz określono wskaźniki dojrzałości ($Q_{DZ}$ i $Q_{DR}$) mięsa wykrawanego w różnym czasie po uboju. Następnie korzystając z wykresów wskazowych trójkąta oporności obliczono współczynniki cos φ i sin φ dla mięsa przechowywanego w warunkach chłodniczych.

Wyniki przeprowadzonych badań wykazały, że najmniejszymi wartościami wskaźnika dojrzałości charakteryzowało się mięso nie stymulowane, wykrawane po 1 h od uboju zaś największymi mięso stymulowane wykrawane po 72 godz. od uboju. Wyniki badań zmian wartości cos φ i sin φ wykazały, że stabilizacje właściwości przewodnościowych mięsa stymulowanego uzyskano już po 24 godz. od uboju, natomiast mięsa nie stymulowanego dopiero po ok. 14 dniach przechowywania chłodniczego, co jest równoznaczne z czasem uzyskania pełnej dojrzałości mięsa wołowego stymulowanego i nie stymulowanego.

Stwierdzono, że uzyskane wyniki uzasadniają celowość prowadzenia dalszych badań nad wykorzystaniem właściwości przewodnościowych do opracowania metod szybkiej oceny i kontroli stopnia dojrzałości mięsa wołowego.