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Institute of Genetics and Animal Breeding, Jastrzębiec, Poland

The impact of heat treatment methods on the physical properties and cooking yield of selected muscles from Limousine breed cattle*

Jarosław Wyrwisz[1], Andrzej Półtorak[1], Ewa Poławska[2], Mariusz Pierzchała[2], Artur Jóźwik[2], Magdalena Zalewska[1], Robert Zaremba[1], Agnieszka Wierzbicka[1]**

[1] Faculty of Human Nutrition and Consumer Sciences, Warsaw University of Life Sciences - SGGW, Department of Functional Food and Commodities, Chair of Engineering in Nutrition, Nowoursynowska 159c, Warsaw 02-776, Poland

[2] Polish Academy of Sciences, Institute of Genetics and Animal Breeding, Jastrzębiec, 05-552, Magdalenka, Poland

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The aim of this study was to analyse the impact of heat treatment methods (frying – FR, grilling – GR, roasting – RO 180°C, roasting – RO ΔT) on certain physical properties and the cooking yield of selected muscles of cattle. Used were samples of five muscles from 40 beef carcasses: *m. longissimus lumborum* (LL), *m. semimembranosus* (SEM), *m. semitendinosus* (SET), *m. psoas major* (PSM) and *m. triceps brachii* (TRI). Instrumental texture parameter measurements were performed using universal testing machine (Instron 5965) equipped with Warner-Bratzler attachment. Instrumental measurement of colour components was performed using Minolta CR-400 chromameter in the L*a*b* system. Cooking yield of the applied thermal processes was determined by weighting method and by thermal shrinkage measurement using computer image analysis.

The greatest tenderness characterized the GR samples, especially of PSM, LL, and TRI muscle. Products roasted with the use of ΔT program occurred significantly (P≤0.001) darker and less red,

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**Corresponding author: jaroslaw_wyrwisz@sggw.pl

particularly the LL, SET and TRI muscles. Long-lasting roasting (RO ΔT) resulted in cooking yields comparable (P≥0.05) to RO 180°C and GR. The meat cooking shrinkage (MCS_L, MCS_d, MCS_{SA}) strongly correlated (r>0.6) with processing losses, with the exception of grilled samples.

KEYWORDS: beef / colour / cooking yield / shrinkage / texture

Quality of culinary beef is perceived by many traits, of which the most important are tenderness, colour, juiciness, flavour, nutritive value and marbling [Listrat and Hocquette 2004, Li *et al.* 2008, Li 2010, Sales *et al.* 1999]. The determinants of meat tenderness are both morphological and structural – the structure of muscle fibres, particularly myofibrils, is responsible for contraction and relaxation of the muscle [Maltin *et al.* 2003]. Tenderness of meat is correlated with the amount and quality of collagen and depends on its total content in muscle tissue and the amount, which transforms into soluble form during thermal treatment [Listrat and Hocquette 2004, Chang *et al.* 2010].

Proper cooking methods and setting of temperature-time-humidity parameters, adequate to these processes, are aimed at improving tenderness of beef, and thus reduce its hardness and processing losses [Janz *et al.* 2006]. Heat treatment has a major impact on meat tenderness, as the water and fat binding ability and texture are closely linked with the heating conditions applied during the process [Wharton *et al.* 2008].

There are many culinary techniques that strongly influence physical properties and sensory quality of meat. Analysis of the influence of heat treatment method is based on three main factors: temperature of meat surface, temperature profile throughout the meat sample and heat exchange method (direct contact with heat source or through the air, or steam). The temperature difference between heating medium and meat portion has a significant effect on the rate and extent of protein structure change, whereas heat exchange method has the greatest impact on sensory perception of the final product [Bajerholm and Aaslyng 2003]. Heat treatment conditions (internal temperature) have significant effect on the profile of meat texture parameters, such as cohesiveness, elasticity, chewiness and hardness [Bertram *et al.* 2004].

Typical thermal treatment method for large meat portions is roasting in dry air (160-180°C), whereas smaller pieces should be grilled or fried [Drummond and Sun 2006]. Meat rich in collagen with high degree of crosslinking (meat from old animals) needs longer heat treatment in water (boiling, stewing). Roasting, frying and grilling are more suitable for meat from young animals with low collagen content, but with large proportion of soluble collagen [Maltin *et al.* 2003, Herrera-Mendez *et al.* 2006]. Tenderness of meat changes during heating due to the transformations in connective tissue and myofibrilar proteins. When heated in the presence of water, collagen dissolves, which results in crushing of meat, while myofibrilar proteins denature, which causes the meat increased hardness [Bertram *et al.* 2004] and shrinkage both crosswise and along muscle fibres and connective tissue [Barbera and Tassone 2006].

During heat treatment, meat loses 20-40% of its total initial weight due to fluid leakage with the increasing temperature [Zheng *et al.* 2007]. Cooking loss is strongly

associated with fibres shrinkage and thereby impacts the overall process efficiency and general consumer acceptance of the product. Extent of shrinkage is important for the consumers, because when treating meat with different thermal processes, that cause undesirable changes in meat structure, they can perceive increased shrinkage as an indication of low quality [Barbera and Tassone 2006]. Cooking loss measurement is a rapid and valid method of assessing the impact of heat treatment on meat, because it reflects the degree of its juiciness, as well as certain economic aspects [Bertram *et al.* 2004].

Quality of raw and cooked beef can be evaluated using a number of instrumental methods [Panea *et al.* 2008]. For texture measurement the most frequently used is Warner-Bratzler shear test [Vieira *et al.* 2006, Lorenzen *et al.* 2010], and for colour chromameter, in the L*a*b* system [Liu *et al.* 2003, Mancini and Hunt 2005]. Generally, meat shrinkage is described as the change of linear dimensions, surface and volume due to cooling or heating. Manual shrinkage measurement is time-consuming and variable, because of its subjective nature. Computer image analysis techniques allow more precise and repeatable measurements of meat shrinkage rate [Zheng *et al.* 2006].

The aim of this study was to analyse the impact of heat treatment methods (frying, grilling, roasting) on chosen physical properties and the cooking yield of beef muscles with using computer image analysis.

Material and methods

Animals and meat samples preparation

The following five muscles: *m. longissimus lumborum* (LL), *m. semimembranosus* (SEM), *m. semitendinosus* (SET), *m. psoas major* (PSM) and *m. triceps brachii* (TRI) were separated from 40 Limousine beef carcasses from the local slaughterhouse. The slaughtered cattle (steers) aged 18-21 months and their mean carcass weight was 306±19 kg. The animals were maintained in one intensively fattened herd, fed concentrates, ground cereals and silage. Water was available *ad libitum*.

After 48 h since slaughter the separated muscles were subjected to aging process in a vacuum for the next 5 days. Subsequently, the samples were frozen at -25°C for 2 h using Küppersbusch blast-freezer, and then stored at -18°C. Before the specific tests started, samples were thawed at 2±1°C for 24 h. Muscles intended for frying and grilling were divided into steaks of 7.5 cm x 5 cm x 2.5 cm (sample weight 100-120 g). Samples for roasting were shaped as cuboids of 15 cm x 10 cm x 5 cm (sample weight 600-650 g).

Heat treatment

Samples of muscles examined were subjected to heat treatment according to four methods: grilling (GR), frying (FR), roasting in temperature of 180°C (RO 180°C), and ΔT roasting (RO ΔT). The process of heat treatment was conducted to endpoint temperature of T_i=70°C inside the sample. Temperature was controlled using a NiCr-

NiAl thermocouple type TP-151 equipped with EMT-50-K recorder by CZAKI THERMO PRODUCT.

Frying (FR) was performed using electric frying pan (model OEP 500, KÜPPERSBUSCH Großküchentechnik, Gelsenkirchen, Germany), with plate surface temperature of 200°C. The steaks were turned every 2 min until the target endpoint inner temperature was reached. **Grilling (GR**) was carried out in an electric contact grill (model Silex S-165 K, ELEKTROGERÄTE GmbH 59757 Arnsberg, Germany) with bottom and upper grooved surface; bottom plate temperature 221°C, upper 191°C.

Roasting (RO) process was conducted in a convection-steam oven (model CPE-110, KÜPPERSBUSCH Großküchentechnik, Gelsenkirchen, Germany) in constant temperature of 180°C **(RO 180°C).** ΔT roasting **(RO ΔT)** was performed in Küppersbusch convection-steam oven, maintaining constant temperature difference between the core of the product and interior of the oven: ΔT=60 (Fig. 1).

Instrumental measurement of shear force (WBSF)

Shear test was performed using INSTRON 5965 with Warner-Bratzler attachment. WBSF [N] was determined for all the samples. Six cylindrical samples, with the diameter of 1.27 cm and height of 2.5±0.3 cm, were shear using a "V" shaped knife. The direction of cutting force was perpendicular to the muscle fibres orientation. The test was conducted with constant head speed (cell capacity – 500 N) – 200 mm/min, at standardized temperature of the samples (2±1°C).

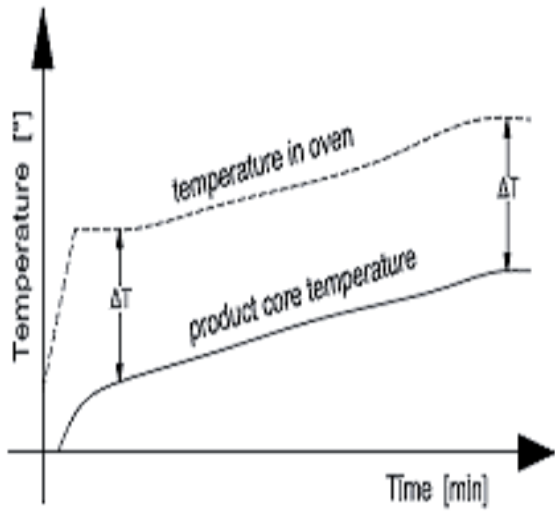

Fig. 1. Roasting process according to Δ T program.

Instrumental measurement of colour components

Colour components were measured using MINOLTA CR-400 chromameter in the L*a*b* system. Following settings were used: illuminate D65, a standard observation of 2°, the aperture 8 mm. The device was calibrated before measuring started to white standard (L*= 98.45, a*= -0.10, b*= -0.13). The values of colour parameters L* (lightness), a* colour axis ranged from greenness (-a*) to redness (+a*) and b* (colour axis ranged from blueness (-b*) to yellowness (+b*) were measured on the cros s-section of the steak, which was cut perpendicularly to the fibres orientation in

the middle of its height. Five measurements were taken for each sample (steak) in the central part of the sample.

Measurement of the shrinkage

Measurement of the shrinkage consisted on archiving the image of raw and cooked meat samples (after cooling to ambient temperature). Pictures were taken using digital camera (QIMAGING, Micro Publisher 5.0 RTV) at a resolution of 2560x1920 pixels, with a linear polarizing filter (Keiser, 46 mm), lighting system (Kaiser RB-5004-HF) with 4 fluorescent lamps (OSRAM DULUX L 36W/954, AC 230V/50Hz) with a colour temperature of 5400K and with polarization filter (Kaiser Polarisationsfilter 5594). The digital camera was connected to a PC with Image Pro Plus 7.0 software, (MEDIA CYBERNETICS).

Major axis length (L), minor axis length (d) and surface area (SA) were examined before ($_i$) and after thermal treatment ($_f$). After acquisition (Fig. 2a) the colour image was converted to monochrome image, then meat sample image was separated form the background through thresholding (Fig. 2b). The selected image was used for determining the length of major and minor axis (Fig. 2c) and the area of the object (Fig. 2d).

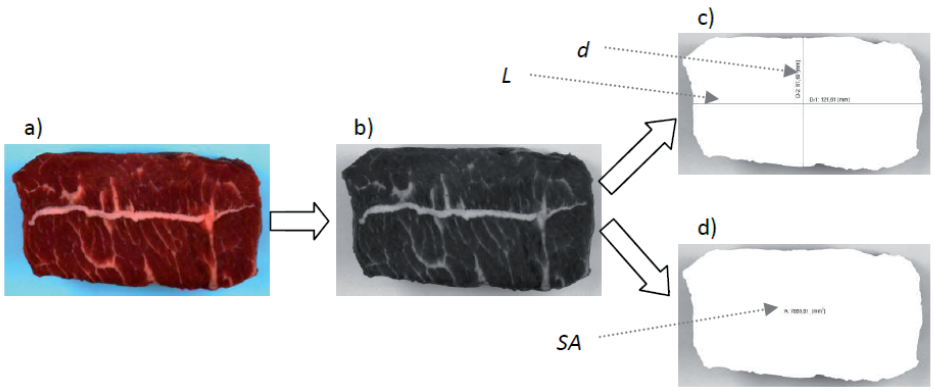

Fig. 2. Determining parameters of shrinkage in meat.

The extent of meat shrinkage (MCS) was defined by the equation (1), (2), (3):

$$MSC_L = \frac{L_i - L_f}{L_i} \times 100\% \quad (1)$$

$$MSC_d = \frac{d_i - d_f}{d_i} \times 100\% \quad (2)$$

$$MSC_{SA} = \frac{SA_i - SA_f}{SA_i} \times 100\% \quad (3)$$

Cooking yield

Cooking yield (CY) was determined by measuring sample weight before (M_i) and after heat treatment, after cooling to ambient temperature (M_f). Cooking yield was calculated from equation (4), and cooking losses (CL) from formula (5):

$$CY = \frac{M_i}{M_f} \times 100\% \quad (4)$$

$$CL = 1 - \frac{M_i}{M_f} \times 100\% \quad (5)$$

Statistical analysis

Statistical analysis of results was performed using StatSoft`s Statistica 9.0 program. Verification of differences' significance for measured parameters was used for individual muscles applying LSD Fisher's test) – the least significant difference at P≤0.05 and P≤0.001. Correlation between shrinkage parameters of the examined muscles and cooking loss for each treatment method was evaluated using Pearson's linear correlation at the significance level of P≤0.05.

Results and discussion

The impact of heat treatment method on changes in specific physical parameters of muscles.

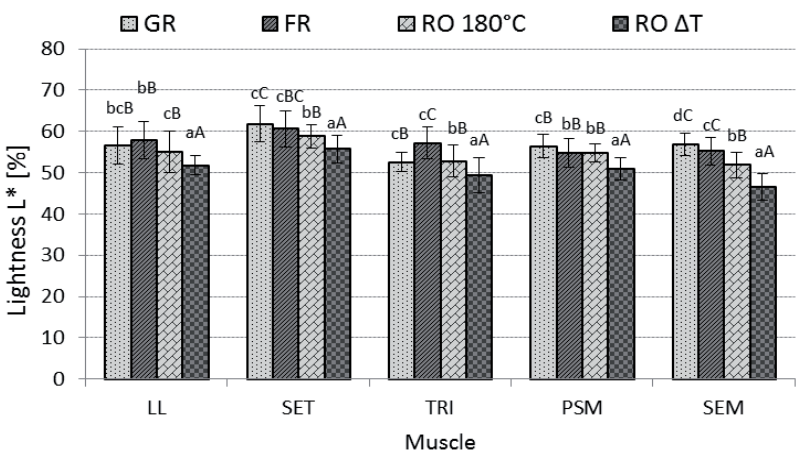

Fig. 3. Lightness L* (%) changes of beef muscles as a result of different cookery methods (mean with different letters within the muscle differ significantly (LSD test: a, b – P≤0.05; A, B – P≤0.001).

The following Figures present mean values for lightness L* (Fig. 3) and redness a* (Fig. 4) of *m. longissimus lumborum* (LL), *m. semimembranosus* (SEM), *m. semitendinosus* (SET), *m. psoas major* (PSM) and *m. triceps brachii* (TRI), exposed to different heat treatments: grilling (GR), frying (FR), roasting (RO 180°C) and ΔT roasting (RO ΔT).

Higher lightness values were observed after grilling and frying of SET, PSM, and SEM. Roasted products in the ΔT program had significantly darker colour of the cross-section, regardless of the muscle type, compared to products processed by other heat treatment methods.

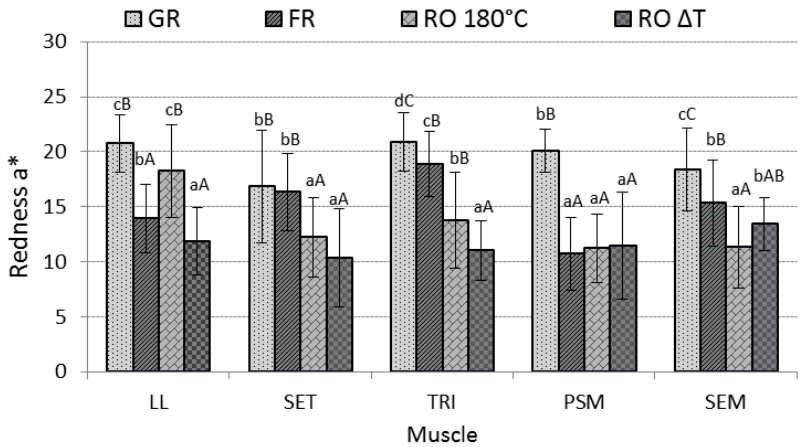

Fig. 4. Redness a* changes of beef muscles as a result of different cookery methods (mean with different letters within the muscle differ significantly (LSD test: a, b – P≤0.05; A, B – P≤0.001).

Grilling resulted in products with the highest redness a* level in all of the muscle samples examined (Fig. 4). On the contrary, roasting, both at 180°C and in the ΔT program, caused significant reduction (P≤0.05) in red colour saturation of PSM, SET, TRI and SEM muscles when compared to grilled samples.

Myoglobin denaturation rose with higher heating temperature [Gašperlin *et al.* 2001]. Sen *et al.* [2011] found, that increase in final core temperature of heating meat products intensifies the lightness L* on the cross-section, and decreases the redness a*. However, the heating rate of meat products is also a factor creating the colour on the cross-section. Slow heat supply to the muscle sample, like in roasting ΔT (42-65 min), caused darker and less red colour of the cross-section as compared to grilled and fried samples (Tab. 1).

In products slowly heated to core temperature of 71°C (0.2°C/s) Ryan *et al.* [2006] found lower brightness and redness of cross-sections, when compared to the samples heated rapidly (1°C/s). Roasting with the ΔT program enables longer action of higher temperature on myoglobin, which results in higher protein denaturation. This corresponds with the report of Ryan *et al*. [2006], who observed 90.4%

myoglobin denaturation during slow heat treatment (to T_i=71°C) and 72.1% during rapid cooking.

Table 1. Means of heat treatment time of five beef muscles: LL, SET, TRI, PSM, SEM

Muscle	Cockery metod (Ti = 70°C)			
	GR (min)	FR (min)	RO 180°C (min)	RO ΔT (min)
LL (n=10)	6.14±0.15	12.65±0.24	23.22±0.23	53.82±0.18
SET (n=10)	5.97±0.19	10.65±0.30	25.34±0.17	60.44±0.14
TRI (n=10)	6.57±0.24	13.72±0.16	29.54±0.33	65.23±0.28
PSM (n=10)	5.64±0.09	9.54±0.14	18.53±0.26	42.12±0.22
SEM (n=10)	6.34±0.21	10.23±0.27	29.23±0.13	64.28±0.32

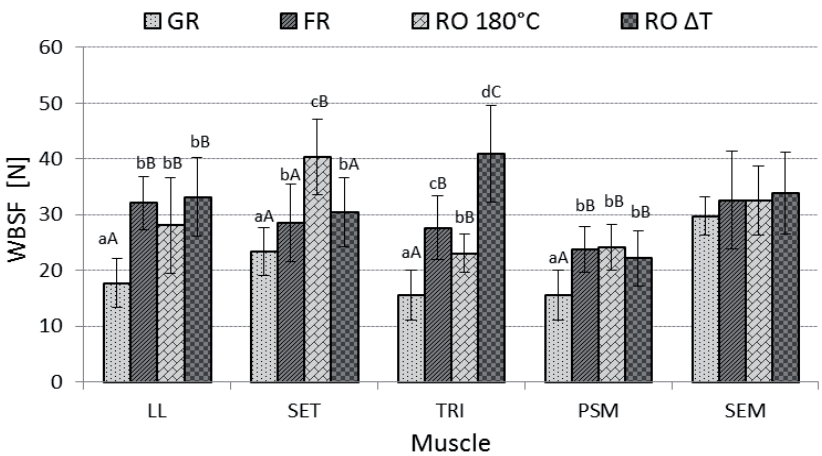

Fig. 5. Changes in WBSF [N] of beef muscle as a result of different cookery methods (mean with different letters within the muscle differ significantly (LSD test: a, b – P≤0.05; A, B – P≤0.001).

The highest tenderness characterized the GR products (P≤0.05), regardless of the type of muscle (Fig. 5). Whereas, PSM muscle showed the highest tenderness (15.56-24.14 N) regardless of heat treatment method. Prolonged treatment (RO ΔT and RO 180°C) caused tenderness loss in the products of TRI, SET and SEM muscles. This can be explained by significant content (of connective tissue in the muscle [Li *et al.* 2010]. High temperature (above 75°C) and prolonged heating affect the tissue, which in turn influences hardness of the product, since changes in the cutting force are closely related to the myofibrils contraction and degree of collagen denaturation [García-Segovia *et al.* 2007].

Similar conclusions were presented by Obuz *et al.* [2004], who reported that in beef steaks of LL muscle, WBSF value after grilling was lower than that recorded after heating in water medium.

Yencey *et al.* [2011] obtained higher WBSF values after applying cookery methods with heat transfer based on conduction (contact grill), compared to the meat samples heated through convection (convection-steam oven).

Walsh *et al.* [2010] showed no significant differences in WBSF values of the *triceps brachii caput longum* exposed to roasting at constant temperature and using ΔT roasting (ΔT=10).

Significant differences (P≤0.05) in cooking yield were reported after applying grilling process as compared to other cookery methods (Fig. 6). However, comparable cooking yield was observed in LL, SET and TRI muscles after frying (FR), roasting in constant temperature (RO 180°C) and roasting in the ΔT program (RO ΔT).

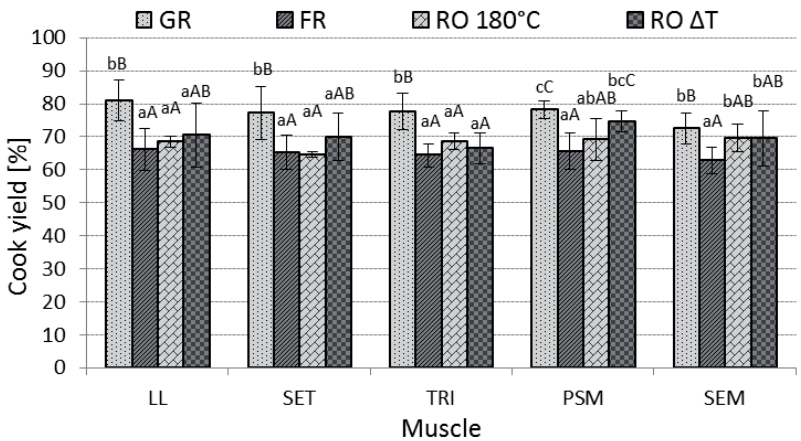

Fig. 6. Changes in cooking yield [%] of beef muscles as a result of different cookery methods (mean with different letters within the muscle differ significantly (LSD test: a, b – P≤0.05; A, B – P≤0.001).

These results are in accordance with studies of Walsh *et al.* [2010], who observed insignificant difference in cooking beef yield between slow heating process (roasting ΔT=10) and conventional roasting. However, this is in contradiction to Boles and Swan [2002], who found that rapid roasting at constant temperature, resulted in higher cooking yield, compared to slow roasting method of ΔT. This may be caused by different temperature changes during these cooking methods, and thus the rate of heat supply to the product, and partly by differences in weight and dimensions of the samples [Boles and Swan 2002].

Greater shrinkage was observed during frying process, both along the L and d axis (Tab. 2) compared to grilled samples, which was reflected by the size of changes in surface area of the fried steaks. Cooking losses (CL) in frying process strongly correlated with meat shrinkage, both along L (r = 0.802) and d (r = 0.883) axis, as well as with surface area (SA): r = 0.879 (Fig. 7). However, the correlation between cooking losses and shrinkage of grilled steaks was found distinct (MCS_d= 0.324; MCS_{SA}= 0.275) or significant (MCS_L= 0.671). This effect can be explained by the

Table 2. Means for beef muscle shrinkage (MCS) as a change in major axis length (L), minor axis (d) and surface area (SA) using various cookery methods (GR-grilling, FR - frying, RO 180°C - roasting at constant temperature, RO ΔT - roasting with the ΔT program)

Cookery method	MCSL (%)	MCSd (%)	MCSSA (%)
GR (n=25)	9.9±2.0	4.7±1.1	10.3±1.7
FR (n=25)	19.7±1.5	15.8±1.6	18.7±1.8
RO 180°C (n=25)	16.8±2.0	13.5±1.3	23.3±3.5
RO ΔT (n=25)	11.9±2.6	9.5±2.0	19.4±2.5

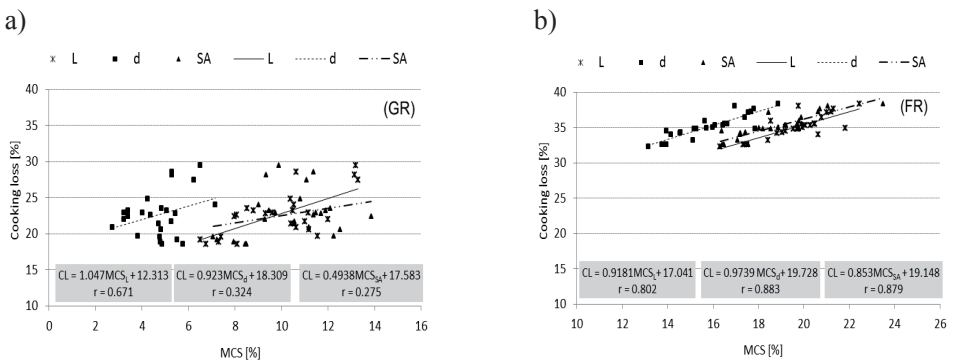

Fig. 7. Correlation coefficients between cooking losses (CL) [%] and cooking shrinkage MCS (%) defined as the change in length of major axis (L), minor axis (d) and surface area (SA) during grilling (GR) and frying (FR) of selected beef muscles.

specificity of contact grilling, which involves heating the meat between two hot plates, with the upper plate freely presses down the steaks. This results in less shrinkage in the horizontal plane, but a greater change in the height of the steak.

The process of roasting at constant temperature of 180°C resulted in greater shrinkage of muscles along the major axis (L), minor axis (d) and surface area (SA) compared to roasting with the ΔT program (Tab. 2).

Very strong or strong correlations were found between cooking losses and muscle shrinkage, both in case of RO 180°C (Fig. 8a) and RO ΔT (Fig. 8b).

Du and Sun [2005] showed a high correlation between cooking losses and changes in surface area (r =0.95) and volume (r =0.91). However, relations to other shrinkage parameters (both axes) were not significant. According to Bertram *et al.* [2004] strong correlation between cooking losses and shrinkage of meat can be explained by the fact, that the shrinkage appearing during cooking causes loss of the meat liquid, which results in mass loss. The process of meat shrinkage has several phases: at approx. 40°C – myosin starts to denaturate and shrinkage across the muscle fibres is observed; at 55-

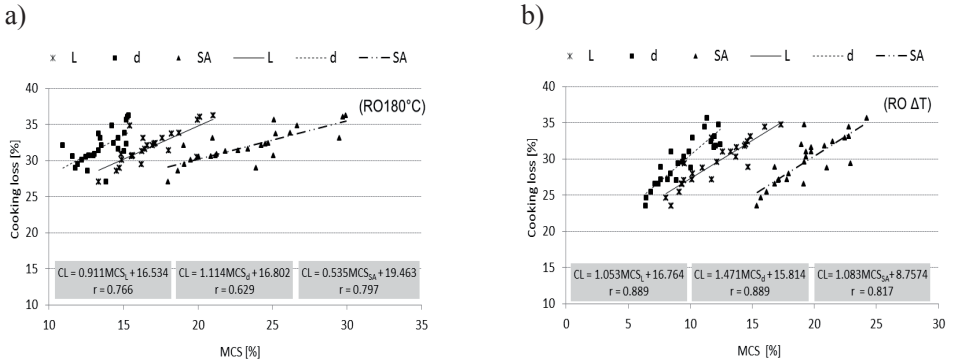

Fig. 8. Correlation coefficients between cooking losses CL (%) and size of the cooking shrinkage MCS (%) defined as the change in length of major axis (L), minor axis (d) and surface area (SA) during: a) roasting at 180°C (RO180°C) b) roasting using the ΔT (RO ΔT) of selected beef muscles.

60°C – collagen shrinkage occurs as a result of denaturation; over 60°C – beginning of the shrinkage takes place along the muscle fibres.

Furthermore, during heat treatment meat composition as well as its physicochemical properties changes significantly. Meat composition, especially its fat content, combined with specific heat treatment methods is among the factors that mostly affect the final quality of meat products [Aflaia *et al.* 2010]. Thermal processes can cause undesirable changes, such as loss of essential fatty acids (FA), mainly due to lipid oxidation, reducing the nutritive value of meat. However, there is a great variability in changes of individual FA caused by the different cooking methods [Badiani *et al.* 2002]. Micronutrients can also flow with the cooking juice, thus reducing the nutritive quality of the final product [Oillic *et al.* 2011].

Summarizing, selection of adequate heating rate during thermal treatment of meat is important for determining the quality of finished product and is particularly significant for improvement in tenderness of culinary elements having high content of connective tissue (blade, eye round, topside). Grilled products characterized by the highest tenderness regardless of muscle type, however fried and roasted products showed comparable tenderness in the case of LL, SEM and PSM muscles. Slow heating (RO ΔT) results in a darker and less red colour of the product on cross section compared to more rapid methods of heat treatment. Rapid, short-term heat treatment (GR) reduces cooking losses, which may be important in maintaining of many valuable nutrients that are lost with the meat juice during the long-term of thermal processes. High temperature heat treatment at constant temperature (RO 180°C) shows comparable level of cooking yield as roasting ΔT. There are correlations between the shrinkage of meat and thermal loss, and their strength depends on heat the cookery method and the shrinkage parameter.

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