POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 31(4): 575–585, Y. 2016

PREDICTING HOT CARCASS WEIGHT AND INSTANTANEOUS BODY WEIGHT IN YOUNG CROSSBRED BULLS AND STEERS*

***Paulina Pogorzelska-Przybyłek*[1], *Zenon Nogalski*[1], *Ireneusz Białobrzewski*[2], *Monika Sobczuk-Szul*[1], *Martyna Momot*[1]**

[1] Department of Cattle Breeding and Milk Evaluation
[2] Department of Systems Engineering
University of Warmia and Mazury in Olsztyn

K e y w o r d s: prediction, hot carcass weight, slaughter value, beef cattle, SVMs.

A b s t r a c t

The aim of this study was to estimate hot carcass weight (HCW) and to determine the accuracy of predicting body weight in young bulls and steers, based on live animal measurements performed at 6 and 12 months of age and before slaughter with the use of Support Vector Machines (SVMs). Among the four analyzed kernel functions, a radial basis function (RBF) in the following form: $K(u,v) = \exp(-\gamma \cdot \| u - v \|^2)$, $\gamma > 0$, where γ is the kernel's parameter, provided the best fit. The most accurate and the least accurate prediction of the body weights was achieved for live animal measurements performed before slaughter and at 6 months of age, respectively. The highest and lowest values of the coefficient of correlation (Pearson's *r*) between experimental and model HCW values were noted for measurements taken on the day of slaughter and at 12 months of age, respectively. Early (6 months of age) prediction of HCW could contribute to optimizing the length of the fattening period in beef cattle, thus helping the animals realize their full production potential.

Address: Paulina Pogorzelska-Przybyłek, University of Warmia and Mazury in Olsztyn, ul. M. Oczapowskiego 5/148, 10-719 Olsztyn, phone: +48(89) 523 38 16, e-mail: paulina.pogorzelska@uwm.edu.pl

* This study was carried out as part of the project entitled: *Optymalizacja produkcji wołowiny w Polsce zgodnie ze strategią »od widelca do zagrody«* (*Optimization of beef production in Poland in accordance with the »fork-to-farm« strategy)* No. PO IG 01.03.01-00-204/ co-financed by the European Union from the European Regional Development Fund within the Innovative Economy Operational Programme 2007–2013

PRZEWIDYWANIE MASY TUSZY (WBC) BUHAJKÓW I WOLCÓW MIESZAŃCÓW MIĘSNYCH ORAZ MASY CIAŁA W MOMENCIE WYKONYWANIA POMIARÓW (CHWILOWEJ MASY CIAŁA)

***Paulina Pogorzelska-Przybyłek*[1], *Zenon Nogalski*[1], *Ireneusz Białobrzewski*[2], *Monika Sobczuk-Szul*[1], *Martyna Momot*[1]**

[1] Katedra Hodowli Bydła i Oceny Mleka
[2] Katedra Inżynierii Systemów
Uniwersytet Warmińsko-Mazurski w Olsztynie

Słowa kluczowe: przewidywanie, waga bita ciepła, wartość rzeźna, bydło mięsne, metoda SVMs.

Abstrakt

Celem badań było oszacowanie masy tuszy (wbc) i dokładności przewidywania masy ciała buhajków i wolców mieszańców mięsnych, pochodzących z krzyżowania krów rasy polskiej holsztyńsko-fryzyjskiej (PHF) i buhajów ras mięsnych (HH, LM, CH), na podstawie pomiarów przyżyciowych zwierząt wykonanych w 6. i 12. miesiącu życia oraz przed ubojem, z wykorzystaniem metody Support Vector Machines (SVMs). Z czterech analizowanych funkcji jądrowych najlepsze dopasowanie uzyskano dla funkcji RBF (radial basis function) w postaci: $K(u,v) = \exp(-\gamma \cdot \| u - v \|^2)$, $\gamma > 0$, gdzie: γ, jest parametrem jądra. Najlepszą możliwość przewidywania masy ciała dają przyżyciowe pomiary wykonane przed ubojem, najgorszą w wieku 6 miesięcy. Najwyższe wartości współczynnika korelacji *r* Pearsona między wbc „eksperymentalną” a wbc „modelową” zaobserwowano dla pomiarów wykonanych w dniu uboju, a najniższe po ukończeniu 12. miesiąca życia. Wczesne (w wieku 6 miesięcy) oszacowanie wbc bydła mogłoby pomóc w zaplanowaniu optymalnej długości opasania zgodnie z predyspozycjami produkcyjnymi zwierząt.

Introduction

Beef carcass evaluation provides a basis for transactions between livestock producers and meat processing plants. Beef carcasses are assessed based on their weight and conformation/fat cover scores in the EUROP classification system. Therefore, reliable methods supporting early and accurate prediction of hot carcass weight (HCW) are constantly being searched for. Information on HCW and carcass composition can be used to optimize the production process, conduct food research and develop breeding programs. The development of objective carcass appraisal methods, including ultrasound (WILSON 1992, REALINI et al. 2001, LAMBE et al. 2010, SAKAMOTO et al. 2014) and zoometric measurements, has been a priority for decades. Ultrasound evaluations of live animals have attracted the attention of the meat processing industry (NASH et al. 2000, CREWS and KEMP 2001, GREINER et al. 2003, NAVAJAS et al. 2010a, NAVAJAS et al. 2010b), and a strong relationship between body size and slaughter traits has been documented, among others, by TATUM et al. (1982), PAPSTEIN et al. (1992), NOGALSKI et al. (2000), and in our previous studies (POGORZELSKA-PRZYBYŁEK et al. 2014, POGORZELSKA-PRZYBYŁEK et al. 2015), which confirms that zoometric measurements can be used as predictors of body weight and composition in cattle (LAWRENCE and FOWLER 2002, FERNANDES et al. 2010). Visual assessment of muscling in live animals is an easy, cheap and rapid method for evaluating meat performance traits, and it is significantly correlated with carcass dressing percentage and quality (r = 0.82 and r = 0.72, respectively; CONROY et al. 2010).

The objective of this study was to estimate the hot carcass weight (HCW) of young crossbred bulls and steers, the offspring of Polish Holstein-Friesian (PHF) cows and beef bulls (Limousin, Hereford and Charolaise), based on live animal measurements performed at 6 and 12 months of age and before slaughter with the use of Support Vector Machines (SVMs). An attempt was also made to determine the accuracy of predicting the instantaneous body weight of animals based on live measurements.

Materials and Methods

Animals

The experimental materials comprised young crossbred bulls and steers, the offspring of Polish Holstein-Friesian (PHF) cows and beef bulls of the following breeds: Hereford (HH), Limousin (LM) and Charolaise (CH) – Table 1. Calves of known origin, at 2–3 weeks of age, were purchased in north-eastern Poland. One half of the calves were castrated at purchase. Bloodless castration was carried out using a rubber elastrator. The animals were fed milk replacer from automatic feeders. At 2 weeks of age, the calves were transferred to a calf shed with straw bedding, and their milk-based liquid diet was supplemented with solid feeds (concentrate, haylage and hay). The fattening period began at 6 months of age, and the calves were fed a Total Mixed Ration (TMR) provided *ad libitum*. The TMR was composed of wilted grass (first-cut) silage and concentrate (rapeseed meal, ground triticale and mineral supplements). Live body measurements were taken three times: I – at the beginning of fattening (at 6 months of age), II – at 12 months of age, III – on the day of slaughter. The body weights of animals were determined, zoometric measurements (height at sacrum, chest width between shoulder joints, pelvic width, rump length, trunk length, chest girth) and ultrasound measurements (thickness of *m. longissimus dorsi* – MLD, at the level of the 12^{th} – 13^{th} thoracic vertebrae, cross-sectional area of MLD) were carried out, and muscling was assessed. Zoometric measurements were performed by two qualified technicians, and ultrasound measurements were performed by one person with the use of the Mysono 201 scanner (Medison Co., Seoul, Korea), equipped with a 170 mm linear probe (PB-MYL2-5/170 CD), operating in the 2–5 MHz frequency range. A visual appraisal of muscle scoring was performed on a scale of 1 (low lean content) to 10 (very high lean content). "The muscle score describes the shape of cattle independent of the influence of fatness. Muscling is the degree of thickness or convexity of an animal relative to its frame size" (MC KIERNAN 2007). A similar method for evaluating the conformation of animals was applied by CHOROSZY et al. (2010), but it was not identical to that used in our study.

Table 1

Experimental material

Gender category	Bulls			Steers		
Number of heads	96			96		
Breed	PHF x HH	PHF x LM	PHF x CH	PHF x HH	PHF x LM	PHF x CH
Number of heads	32	32	32	32	32	32
Number of heads	192					

Statistical Analysis

Support Vector Machines (SVMs) are learning models used for regression analysis, which were originally developed for discriminating between sets. The recent algorithms associated with SVMs allow to construct regression models in the form of a linear function. Nonlinearity can be achieved by mapping sets of elements into a new larger space with the use of nonlinear transformation ϕ. A formal representation of a set assumes the following form: $\{(x_1, y_N), ..., (x_N, y_N)\}$ where $x_i \in \Re^d$ and $y_i \in \Re$ for $i = 1, ..., N$ and nonlinear transformation $\phi: \Re^d \rightarrow Z$, where Z is a feature space. In regression and classification tasks, SVMs construct an optimal hyperplane without the need to separate feature classes for discrimination, but based on the assumption that the points of a newly-created (by transformation) set located at distance $\varepsilon > 0$ form the hyperplane. VAPNIK (1998) proposed the following function as a measure of fit:

$$L^{\varepsilon}(y, f(x, \beta)) = \begin{Bmatrix} 0, & \text{if } |y - f(x,\beta)| \leq \varepsilon \\ |y - f(x,\beta)| - \varepsilon, & \text{if } |y - f(x,\beta)| > \varepsilon \end{Bmatrix} \tag{1}$$

where:

$f(x,\beta) = \beta \cdot \phi(x) + \beta_0$.

Sets of measurement data are burdened with various errors, and outliers that lie beyond (ε) the optimal hyperplane are often encountered. Therefore, additional variables $\xi_1,..., \xi_N, \xi_1^*,..., \xi_N^* \geq 0$ were introduced in SVMs, which enabled to rewrite the optimization problem, aimed at finding the optimal hyperplane, in the following way:

$$\begin{cases} \min_{\beta,\beta_0\xi} \frac{1}{2} \|\beta\|^2 + C \sum_{i=1}^{N} (\xi_i + \xi_i^*), \\ y_i - (\beta \cdot \phi(x_i) \leq \varepsilon + \xi_i, \qquad i = 1, ..., N, \\ -y_i + (\beta \cdot \phi(x_i) \leq \varepsilon + \xi_i^* \qquad i, = 1, ..., N, \\ \xi_i, \xi_i^* \geq 0. \end{cases} \tag{2}$$

In SVMs, there is no need to directly define the transformation (ϕ). It is enough to calculate the dot products of certain functions in a larger space, with the use of a kernel function in the following form: $K(u,v) = \phi(u) \cdot \phi(v)$. The accuracy of a regression model developed using SVMs is primarily determined by nonlinear transformation ϕ and the value of parameter C which gives a tradeoff between model complexity and training error. The *libsvm* library (CHANG and LIN 2011) cooperating with Matlab 2014a environment (Statistics Toolbox 2014) was used in the present study *libsvm* algorithms enabled to test many forms of a kernel function, including:
– linear function: $K(u,v) = u^T \cdot v$,
– polynomial function: $K(u,v) = (\gamma \cdot u^T \cdot v + t)^d$, $\gamma > 0$,
– sigmoid function: $K(u,v) = \tanh(\gamma \cdot u^T \cdot v + t)$,
– radial basis function (RBF): $K(u,v) = \exp(-\gamma \cdot \| u - v \|^2)$, $\gamma > 0$,
where γ, d, t are kernel parameters.

Parameters for the above four forms of the kernel function were determined based on optimization procedures using genetic algorithms. The criterion adopted in the study was the maximum value of the linear correlation coefficient (Pearson's r) between the model and experimental values of a validation set (HCW values). The training set and the validation set were generated by bootstrapping. This method relies on random sampling with replacement, and it creates a training set where the number of elements is equal to the number of elements in the existing set of empirical data. The validation set represents the difference between the empirical set and the set of elements that were never sampled for the training set. The training set was used to determine the parameters of the kernel function. The values of zoometric variables from the validation set were input into the created model to determine the model values of HCW. The bootstrapping procedure was repeated 50 times, and the goodness-of-fit was the mean value from all iterations.

Results and Discussion

The analyzed population of crossbred bulls and steers was characterized by satisfactory body dimensions (height at sacrum, chest width between shoulder joints and pelvic width) and muscle score (visual assessment of muscling, thickness of MLD, cross-sectional area of MLD) – Table 2. The live animals measurements performed in this study were selected in view of the fact that trunk length, pelvic length and the thickness of MLD are highly significantly correlated with carcass weight (BLANCO ROA et al. 2003, CONROY et al. 2009). Height at sacrum, included in the prediction model, increases the accuracy of muscle yield prediction (BERGEN et al. 2005). Regardless of the height at sacrum, the width between the processes of the hip bones is correlated with higher live body weight at slaughter and higher values of carcass quality traits (NOGALSKI et al. 2012). TRELA and CHOROSZY (2011) noted highly significant positive correlations between the thickness of MLD, measured behind the 12^{th} rib, and lean meat yield (r = 0.73). Correlations between live ultrasound measurements of subcutaneous adipose tissue and the cross-sectional area of MLD vs. the actual values of those parameters were reported by SMITH et al. (1992), BRETHOUR (2000), MAY et al. (2000) and GREINER et al. (2003).

Table 2

Descriptive statistics

Variables	Measurement I		Measurement II		Measurement III	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
Age on the day of measurement [days]	183.26	3.14	364.15	4.44	557.09	69.03
Independent variables:						
Height at sacrum [cm]	106.58	3.92	124.60	5.51	136.19	5.53
Forechest width [cm]	31.73	3.52	40.75	3.64	49.21	4.05
Pelvic width [cm]	29.60	2.75	40.00	2.97	47.26	3.25
Pelvic length [cm]	35.70	2.14	44.65	2.66	51.13	3.28
Trunk length [cm]	67.68	4.83	83.48	6.13	95.92	8.04
Chest girth [cm]	129.27	7.65	167.03	8.76	194.73	10.51
Thickness of *M. longissimus dorsi* [mm]	43.98	6.26	55.71	6.57	67.26	8.09
Cross-sectional area of *M. longissimus dorsi* [cm]	39.80	7.25	57.41	8.01	84.57	11.89
Intravital muscle score [pts]	5.95	1.41	6.88	1.30	7.75	1.10
Dependent variables:						
Body weight [kg]	193.2	22.0	358.5	46.4	521.9	74.1
Hot carcass weight [kg]	$\bar{x}$			sd		
	288.0			43.4		

All analyses were performed for a normalized dataset in the <0, 1> range. Among the four analyzed kernel functions, a radial basis function (RBF) provided the best fit. The value of parameter C (system of equations (2)) represented the difference between the maximum and the minimum value of variable y for the training set. Due to the size and randomness of the sample, $C \cong 1$. The remaining parameters and the model's goodness-of-fit are presented in Table 3. The highest values of the coefficient of correlation (Pearson's r) between experimental and model HCW values were noted for measurements taken on the day of slaughter. A higher value of the coefficient of correlation between live weight at slaughter and carcass weight (r = 0.94) was reported by MŁYNEK and LITWIŃCZUK (1999). In our previous study, HTC was estimated by stepwise regression based on backward elimination. Live body measurements were performed immediately before slaughter, disregarding weighing results, which confirms the usefulness of HCW estimation on the farm, before the animals are transported to the meat processing plant, assuring a just system of payment for slaughtered animals. The derived equation ($\hat{Y} = 1.507x_1 + 1.103x_2 + 4.043x_3 + 5.53x_4 + 0.379x_5 + 8.076x_6 - 678.93$,
where:
x_1 – height at sacrum [cm]
x_2 – chest girth [cm]
x_3 – pelvic width [cm]
x_4 – pelvic length [cm]
x_5 – thickness of *M. gluteo-biceps* [mm]
x_6 – thickness of MLD (points) overestimated the predicted value by 1.25% (3.9 kg) on average.

Table 3

Values of model parameters and the coefficient of correlation (Pearson's r) for the hot carcass weight (HCW) and body weights of animals at different ages

Measurement	HCW			Body weight at the moment of performing measurements		
	γ	ε	r	γ	ε	r
I	0.1687	0.2597	0.5162	0.2091	0.2768	0.7907
II	0.0002	0.2513	0.3919	0.0142	0.0570	0.8961
III	0.0832	0.0260	0.9231	0.0672	0.2503	0.9185

The coefficient of determination and the standard error of estimation reached R^2 = 0.892 and Sy = 16.28, respectively (POGORZELSKA-PRZYBYŁEK et al. 2014). The model developed in this study enables to predict, with lower but sufficient accuracy, the HCW of six-month-old bulls and steers slaughtered at 18.5 months of age. Figure 1 shows regression lines for experimental and model HCW values determined based on zoometric measurements performed on three dates. The relationships were obtained for one of the 50 iterations selected randomly from the validation set. The slopes of regression lines indicate that the most and least accurate prediction was achieved based on the measurements taken on date III and date II, respectively. The lower goodness-of-fit noted for HCW estimated based on the measurements performed at 12 months of age can be attributed to the lower weight gains of bulls and steers, resulting from changes in their feeding regime and housing conditions (transfer to a free-stall barn).

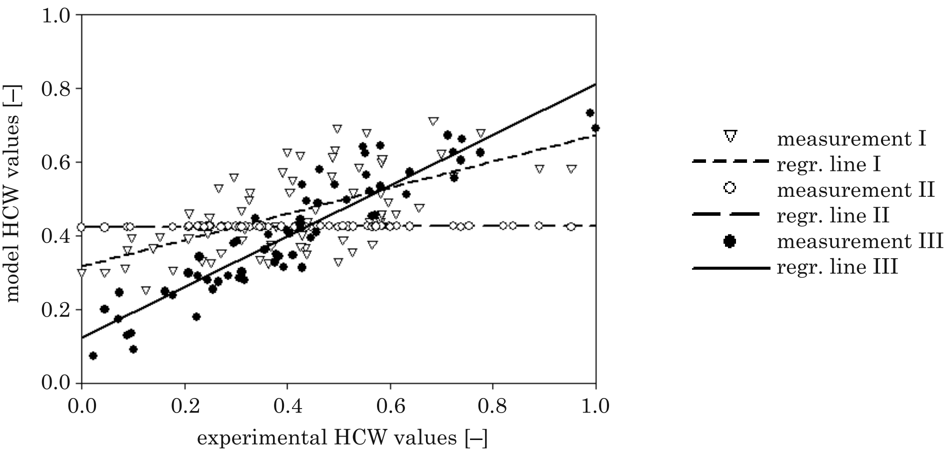

Fig. 1. Regression (RG) lines, with the corresponding points, for experimental and model values of hot carcass weight (HCW), determined based on live measurements performed on three dates; normalized data from the validation set

Selected live measurements allow to predict, with high accuracy, the body weights of animals at the moment of performing zoometric and ultrasound evaluations. The coefficients of correlation between the model-derived and actual body weights increase proportionally to the age of animals subjected to measurements. Figure 2 presents regression lines for experimental and model body weight values determined based on live measurements performed on three dates. The relationships were obtained for one of the 50 iterations selected randomly from the validation set. The slopes of regression lines show that the most and least accurate prediction was achieved based on the measurements taken on date III and date I, respectively. Unlike in Figure 1, the slopes of regression lines in Figure 2 differ slightly. The lower accuracy of estimation observed in younger animals could result from greater variation in their body dimensions. At successive stages of somatic maturation, the analyzed population was characterized by more uniform values of body measurements, and the body parts of individual animals developed more proportionally.

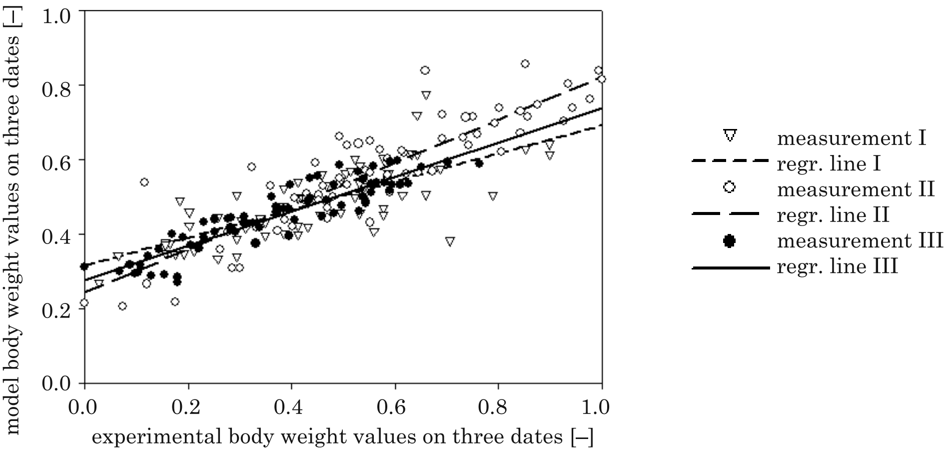

Fig. 2. Regression (RG) lines, with the corresponding points, for experimental and model values of body weight, determined based on live measurements; normalized data (from the validation set) are presented for all three dates when the measurements were performed

The regression model developed with the use of SVMs enables to estimate the body weights of young crossbred bulls and steers at a selected age, and the accuracy of estimation tends to increase with the animal's age. The model also supports early (at 6 months of age) prediction of the HCW of animals slaughtered at 18.5 months of age on average. The estimation of HCW before or during fattening could contribute to optimizing the length of the fattening period in beef cattle, thus helping the animals realize their full production potential.

Translated by Aleksandra Poprawska

Accepted for print 23.03.2016

References

Bergen R., Miller S.P., Mandell I.B., Robertson W.M. 2005. *Use of live ultrasound, weight and linear measurements to predict carcass composition of young beef bulls*. Can. J. Anim. Sci., 85(1): 23–35.

Blanco Roa N.E., Huba J., Polák P., Hetényi L., Peškovičová D., Bahelka I. 2003. *Comparison of differences in muscle depth and possibilities to predict some parameters of carcass value in bulls by an ultrasonographic method*. Czech J. Anim. Sci., 48: 338–343.

Brethour J.R. 2000. *Using serial ultrasound measures to generate models of marbling and backfat thickness changes in feedlot cattle*. J. Anim. Sci., 78(8): 2055–2061.

Chang C.C., Lin C.J. 2011. LIBSVM. *A library for support vector machines*. ACM Transactions on Intelligent Systems and Technology, 2:27:1–27:27. Software available at http://www.csie.ntu.edu.tw/~cjlin/libsvm, access: 7.12.2015.

Choroszy Z., Choroszy B., Grodzki G., Stachyra M., Szewczyk A. 2010. *Metoda oceny pokroju bydła mięsnego w Polsce*. Rocz. Nauk. Zoot., 37(1): 3–12.

Conroy S.B., Drennan M.J., Kenny D.A., Mc Gee M. 2009. *The relationship of live animal muscular and skeletal scores, ultrasound measurements and carcass classification scores with carcass composition and value in steers*. Animal, 3(11): 1613–1624.

Conroy S.B., Drennan M.J., Kenny D.A., McGee M. 2010. *The relationship of various muscular and skeletal scores and ultrasound measurements in the live animal, carcass classification scores with carcass composition and value of bulls*. Livest. Sci., 127(1): 11–21.

Crews D.H. Jr, Kemp R.A. 2001. *Genetic parameters for ultrasound and carcass measures of yield and quality among replacement and slaughter beef cattle*. J. Anim. Sci., 79(12): 3008–3020.

Fernandes H.J., Tedeschi L.O., Paulino M.F., Paiva L.M. 2010. *Determination of carcass and body fat compositions of grazing crossbred bulls using body measurements*. J. Anim. Sci., 88(4): 1442–1453.

Greiner S.P., Rouse G.H., Wilson D.E., Cundiff L.V., Wheeler T.L. 2003. *Accuracy of predicting weight and percentage of beef carcass retail product using ultrasound and live animal measures*. J. Anim. Sci., 81(2): 466–473.

Lambe N.R., Ross D.W., Navajas E.A., Hyslop J.J., Prieto N., Craigie C., Bünger L., Simm G., Roehe R. 2010. *The prediction of carcass composition and tissue distribution in beef cattle using ultrasound scanning at the start and/or end of the finishing period*. Livest. Sci., 131(2–3): 193–202.

Lawrence T.L.J., Fowler V.R. 2002. *Growth of farm animals*. 2nd ed. CABI Publishng, Wallinhford, Oxon, United Kingdom.

May S.G., Mies W.L., Edwards J.W., Williams F.L., Wise J.W., Morgan J.B., Savell J.W., Cross H.R. 1992. *Beef carcass composition of slaughter cattle differing in frame size, muscle score, and external fitness*. J. Anim. Sci., 70: 2431–2445.

Mc Kiernan B. 2007. *Muscle scoring beef cattle*. NSW Department of Primary Industries, New South Wales, Australia, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/ 103938/muscle-scoring-beef-cattle.pdf, access: 7.12.2015.

Młynek K., Litwińczuk Z. 1999. *Suitability of zoometric measurements and conformation indices for evaluating slaughter value of cattle slaughtered at around 5000 kg body weight*. Zesz. Nauk. Prz. Hod., 44: 343–351.

Nash S.A., Harrison S.N., Packham J.H., Panting R.R., Duckett S.K. 2000. *Case study. Monitoring changes in carcass quality across time-on-feed using real-time ultrasound to optimize marketing endpoints*. The Professional Animal Scientist, 16(3): 202–205.

Navajas E.A., Glasbey C.A., Fisher A.V., Ross D.W., Hyslop J.J., Richardson R.I., Simm G., Roehe R. 2010a. *Assessing beef carcass tissue weights using computed tomography spirals of primal cuts*. Meat Sci., 84(1): 30–38.

Navajas E.A., Richardson R.I., Fisher A.V., Hyslop J.J., Ross D.W., Prieto N., Simm G., Roehe R. 2010b. *Predicting beef carcass composition using tissue weights of a primal cut assessed by computed tomography*. Animal, 4(11): 1810–1817.

Nogalski Z., Kijak Z., Pogorzelska J. 2000. *Wpływ typu budowy na tempo wzrostu i wartość rzeźną buhajków mieszańców mięsnych*. Zesz. Nauk. Prz. Hod., 51: 285–294.

Nogalski Z., Pogorzelska-Przybyłek P., Wronski M., Wielgosz-Groth Z., Purwin C., Sobczuk--Szul M., Mochol M. 2012. *The effect of body conformation on meat performance in young bulls*. J. Anim. Prod. Adv., 2(4): 182–188.

Papstein H.J., Ender K., Pepstein I. 1992. *Wachstumsuntersuchungen an grossrahmigbreiten Bullen des Schwartzbunten Rindes*. Arch. Tierzucht, Dummerstorf, 35: 551–560.

Pogorzelska-Przybyłek P., Nogalski Z., Białobrzewski I., Wielgosz-Groth Z., Sobczuk-Szul 2015. *Prediction of the fattening performance of young slaughter cattle based on selected live animal measurements.* Acta Sci. Pol. Zootechnica, 14(3) 2015, 67–84.

Pogorzelska-Przybyłek P., Nogalski Z., Wielgosz-Groth Z., Winarski R., Sobczuk-Szul M., Łapińska P., Purwin C. 2014. *Prediction of the carcass value of young Holstein-Friesian bulls based on live body measurements*. Ann. Anim. Sci., 14(2), 429–439.

REALINI C.E., WILLIAMS R.E., PRINGLE T.D., BERTRAND J.K. 2001. *Gluteus medius and rump fat depths as additional live animal ultrasound measurements for predicting retail product and trimmable fat in beef carcasses*. J. Anim. Sci., 79(6): 1378–1385.

SAKAMOTO L.S., MERCADANTE M.E.Z., BONILHA S.F.M., BRANCO R.H., BONILHA E.F.M., MAGNANI E. 2014. *Prediction of retail beef yield and fat content from live animal and carcass measurements in Nellore cattle*. J. Anim. Sci., 92(11): 5230–5238.

SMITH M.T., OLTJEN J.W., DOLEZAL H.G., GILL D.R., BEHRENS B.D. 1992. *Evaluation of ultrasound for prediction of carcass fat thickness and longissimus muscle area in feedlot steers*. J. Anim. Sci., 70(1): 29–37.

Statistics Toolbox Matlab R 2014a. 2014. MathWorks, USA.

TATUM J.D., SMITH G.C., MURPHEY C.E., CARPENTER Z.L., SCHAKE L.M. 1982. *Feeder cattle frame size, muscle thickness, and subsequent beef carcass characteristics*. Meat Sci., 6(4): 275–284.

TRELA J., CHOROSZY B. 2011. *The work of the National Research Institute of Animal Production in beef livestock production*. Wiad. Zoot., XLIX, 4: 11–56.

VAPNIK V.N. 1998. *Statistical Learning Theory*. Wiley-Interscience, New York.

WILSON D.E. 1992. *Application of ultrasound for genetic improvement*. J. Anim. Sci., 70(3): 973–983.