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Glycolytic and energetic resources as the determinants of meat quality of Duroc fatteners

Zasoby glikolityczne i energetyczne jako determinanty jakości mięsa tuczników rasy Duroc

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Abstract

The aim of this study was to determine the diagnostic value of glycolityc and energetical quantities on selected meat quality characteristics of Duroc fatteners. A total of 40 Duroc porkers were investigated. Among two analysed sets of determinants (R_1 with glycogen and R_1 with lactate) measured in 45 min after slaughter, the best diagnostic value for meat quality characteristics exhibit a set involving R_1 and glycogen that composed determination coefficient (R_C^2) was 0.66 for pH measured in 45 min up to 144 h post mortem. Also, with currently used meat diagnostic methods the most useful one that explains the glycolytic and energetic quantities in the highest degree is method that exploits 5 determinants, i.e. pH_1, pH_{24}, EC_2, EC_{24} and L^*_{24}. Higher composed determination coefficient and canonical correlation (C_R) for this method was obtained for set involving R_1 and lactate – 0.41 and 0.64** respectively.

Keywords: canonical analysis, fatteners, meat quality, pigs

Streszczenie

Celem niniejszej pracy było określenie stopnia oddziaływania zasobów energetycznych i glikolitycznych na wybrane cechy jakościowe mięsa tuczników rasy Duroc. Badaniem objętych zostało 40 tuczników wyżej wymienionej rasy. Z dwóch badanych zbiorów determinant (R_1 i glikogenu oraz R_1 i kwasu mlekowego) mierzonych w 45 min. post mortem wyższą wartością diagnostyczną cechowały się poziom R_1 oraz glikogenu, które w 66 % determinowały stopień zakwaszenia tkanki mięśniowej od 45 min. do 144 godz. po śmierci zwierzęcia. Stwierdzono również, że z wykorzystywanych obecnie metod diagnostycznych jakości mięsa najbardziej przydatną i w największym stopniu objaśniającą stan zasobów glikolityczno-energetycznych jest metoda uwzględniająca 5 parametrów, tj. pH_1, pH_{24}, EC_2, EC_{24}, i L^*_{24}. Dla materiału badawczego uwzględnionego w niniejszej pracy większe

wartości współczynnika korelacji kanonicznej (C_R) oraz złożonego współczynnika determinacji (R_C^2), wynoszące odpowiednio 0,64** i 0,41 odnotowano dla zbioru obejmującego R_1 i kwas mlekowy.

Słowa kluczowe: analiza kanoniczna, jakość mięsa, świnie, tuczniki

Detailed abstract

Celem niniejszej pracy było określenie stopnia oddziaływania zasobów energetycznych i glikolitycznych na wybrane cechy jakościowe mięsa wieprzowego. Badaniem objętych zostało 40 tuczników rasy Duroc, których uboju dokonano wiosną po 4 godzinnym odpoczynku po przebytym transporcie (300 km) i masie ciała ok. 110 kg (masie tuszy ciepłej 85 kg) z wykorzystaniem automatycznego oszałamiania elektrycznego holenderskiej firmy STORK (system Inarco). Tuczniki wykrwawiano w pozycji leżącej. Mięsność tusz określano bezpośrednio na linii ubojowej aparatem ULTRA-FOM 300 (SFK-Technology), zaś masę tuszy ciepłej ustalano bezpośrednio po pomiarze mięsności na wadze kolejkowej z dokładnością do 0,1 kg. Po wytrzewieniu i oszacowaniu mięsności tusze zostały poddane wstępnemu wychładzaniu w trójfazowym tunelu (temp. -10° C w czasie 24 min.; temp. -15° C w czasie 20 min.; temp. -5° C w czasie 45 min. przy szybkości przepływu powietrza wynoszącej 3 m/s), które następnie przechowywano w chłodni w temperaturze 4° C przez 24 godz.. Oceny jakości mięsa świeżego i schłodzonego dokonano w mięśniu Longissimus lumborum (na wysokości ostatniego żebra) w oparciu o: stopień zakwaszenia tkanki mięśniowej [pH] (45 min., 24, 48, 96 i 144 godz.), przewodność elektryczną [EC] (2 i 24 godz.), stosunek nukleotydów IMP/ATP [R_1], jasność barwy [L*] (24 godz.), zdolności utrzymywania wody własnej [WHC], wyciek naturalny (48, 96 i 144 godz.), wskaźnik wydajności technologicznej mięsa peklowanego w procesie parzenia [TY] oraz skład podstawowy mięsa. W próbach pobranych z mięśnia LL w 45 min. post mortem oznaczono również zawartość glikogenu, kwasu mlekowego i potencjał glikolityczny. Do określenia stopnia powiązania zasobów glikolityczno-energetycznych z cechami fizykochemicznymi mięsa oraz jego przydatnością kulinarną i technologiczną posłużono się analizą kanoniczną. Korelacje kanoniczne wyliczano z uwzględnieniem dwóch zbiorów zmiennych niezależnych (X_1 – R_1 i glikogenu oraz X_2 – R_1 i kwasu mlekowego) z 8 zbiorami zmiennych zależnych (Y_1 – pH_1, pH_{24}; Y_2 – EC_2, EC_{24}; Y_3 – pH_1, pH_{24}, pH_{48}, pH_{96}, pH_{144}; Y_4 – pH_1, pH_{24}, EC_2, EC_{24}, L^*_{24}; Y_5 – DL_{48}, DL_{96}, DL_{144}; Y_6 – EC_2, EC_{24}, L^*_{24}, DL_{48}, DL_{96}, DL_{144}, WHC, zawartość wody; Y_7 – pH_{24}, zawartość tłuszczu śródmięśniowego, zawartość białka, zawartość suchej masy, TY oraz Y_8 – zawartość tłuszczu śródmięśniowego, zawartość białka, zawartość suchej masy, L^*_{24}, DL_{48}, DL_{96}, DL_{144}, TY). Współczynniki korelacji kanonicznej dla przyjętych zespołów cech determinujących (X) i zespołu wszystkich cech charakteryzujących jakość mięsa wieprzowego (Y) kształtowały się na poziomie od 0,27^{NS} do 0,81** ($p \leq 0,001$). Stwierdzono, że zawartość glikogenu i R_1 w największym stopniu (od 53 do 66 %) wyjaśniała zmienność stopnia zakwaszenia tkanki mięśnia LL określanego w różnych terminach (Y_3), przewodności elektrycznej połączonej z wyciekiem naturalnym i WHC (Y_6) oraz składu podstawowego mięśnia wraz z wyciekiem naturalnym i wydajnością technologiczną (Y_8).

Introduction

Pork quality and the product uniformity are one of the major concerns of the pork industry (Hammelman, et. al. 2003). Among contemporary known parameters affecting technological and culinary meat quality the most important ones are genetical and enviromental factors (Koćwin-Podsiadła, 1998a), whereas its variablity is associated with rate and extent of post mortem glycolytic and proteolityc metabolism (Koćwin-Podsiadła, et al., 2004a). For several decades, breeding strategies oriented on the production of lean and fast growing pigs lead also to increase of the glycogen concentration in meat (Lonergan, et. al, 2001; Oksbjerg, et. al. 2004). Initial levels of metabolite in meat are closely related to muscle pH, drip loss and meat colour (Christensen, et. al. 2004; Ryu and Kim, 2006). Currently used methods of evaluating this extent is based on determinants of pork quality measured in storage time (Koćwin-Podsiadła, 1993). Nowadays, the rise in meat consumer demands is also increasing the requirements for fast quality characteristics diagnosis. Contemporary meat industry searches for quick, cheap, precise and non-invasive methods that are possible to implement up to 1 h post mortem.

The aim of this study was to determine the diagnostic value of glycolityc and energetical quantities on selected meat quality characteristics of Duroc fatteners.

Materials and Methods

The present study was conducted on 40 Duroc fatteners. All of the animals were free of $RYR1^T$ gene. The maintenance and nutrition condition were the same for all animals throughout rearing (complete feeds, fed according to age). The fatteners were slaughtered at approximately 100 kg live weight during spring, within 4 h after transport (300 km) using an electric stunner (MIDAS, Stork RMS, the Netherlands and INARCO constant voltage system) and bled lying down in accordance with the technology applied at one of the leading meat plants in Mazowsze.

Leanness was determined on-line by ULTRA-FOM 300 (SFK-Technology) with hot carcass weight measured immediately after with accuracy to 0.1 kg. Meat was chilled in a three phase chilling tunel (–10 ºC for 15 min, –15 ºC for 25 min and –5 ºC for 40 min with air velocity of 3 $m*s^{-1}$) and stored in 4 °C up to 24 h post mortem.

The quality of fresh (up to 45 min immediately after bleeding) and cooled (after 24 h chilling) meat was evaluated after slaughter on the m. Longissimus lumborum (LL) (after last rib) on the basis of the following parameters:

- acidity of the muscle tissue (pH) measured directly in the LL muscle 45 min, 24 h, 48 h, 96 h and 144 h post mortem (pH_{45}, pH_{24}, pH_{48}, pH_{96}, pH_{144}, respectively), using a pistol pH-meter MASTER (Draminski, Olsztyn, Poland) calibrated with temperature compensation;
- electrical conductivity (EC) measured with a LF-Star conductometer (Ingenieurburo Matthaus, Noblitz, Germany) 2 h and 24 h post mortem (EC_2, EC_{24});
- colour lightness (L*) of the muscle tissue was assessed 24 h post mortem with a Minolta portable chroma meter (model CR 310, Minolta, Osaka, Japan) using D65 illuminant and 50 mm orifice;

- rate of ATP breakdown, expressed by R1 = IMP/ATP indicator, determined 45 min post mortem on meat samples taken after last rib, according to the method of Honikel and Fischer (1977);
- WHC determined by the filter paper press method (using Whatman 4 filter paper) according to the method of Grau and Hamm (1952) modified by Pohja and Ninivaara (1957), 24 h post mortem;
- drip loss, determined according to Prange, Juggrt, and Scharner (1977), 48 h, 96 h, and 144 h post mortem (storage temperature 4°C);
- meat yield in the curing and thermal processing (72°C) expressed by TY (technological yield) indicator according to Naveau, Pommeret, and Lechaux (1985) as modified by Koćwin-Podsiadła, et al. (2004b). The samples of LL muscle were taken 24 h after slaughter. Meat cubes (1 x 1 x 1 cm) were immersed in a solution containing of 12 % NaCl, 0.07 % $NaNO_2$ and 0.06 % of glucose. After 24 h of curing in 4 °C samples were thermal processed in a water bath (to an internal temperature of 72 °C).

The water, dry matter, total protein and intramuscular fat content (IMF) of LL muscle were determined in accordance with following procedures recommended by the AOAC: water and dry matter – procedure No. 950.46, protein – 968.06, IMF – 991.36 (AOAC, 2000).

The samples cut from LL muscle 45 min post mortem (immediately immersed into tubes with 1 M $HClO_4$ and homogenized to inhibit glycolytic changes) were analyzed for the glycolytic potential (GP) and content of glycogen and lactate. The content of glycogen was determined by the enzymatic method according to Darymple and Hamm (1973) and lactate content according to Bergmeyer (1974). The glycolytic potential was calculated as the sum of: 2 [glycogen] + [lactate] according to Monin and Sellier (1985) and expressed as µmol of lactic acid equivalent per g of fresh muscle.

The genomic DNA was isolated from white blood cells according to Kawasaki (1990) and Coppieters, van Zeveren, van de Weghe, Peelman, and Bouquet (1992). The RYR1 C1843T polymorphic site was analyzed with DNA test using the PCR/RFLP method, according to Fujii, et al. (1991).

The estimation of the usefulness of glycolytic and energetical resources expressed by glycogen, lactate content and R_1 indicator (IMP to ATP ratio) for the determination of pork meat quality was performed on the basis of coefficients of canonical correlation (C_R) and composed determination coefficients (R_C^2) (respective squared value) (Zaremba, et al. 1989).

Results and Discussion

In calculations independent variables (glycolytic and energetical quantities) were grouped in 2 sets: R_1 and glycogen (X_1) and R_1 and lactate (X_2) and dependent variables (meat quality traits) were grouped in 8 sets as follows: pH measured in 1 h and 24 h post mortem (Y_1 – pH_1, pH_{24}), electrical conductivity in 2 h and 24 h post mortem (Y_2 – EC_2, EC_{24}), pH in 1 h, 24 h, 48 h, 96 h, 144 h post mortem (Y_3 – pH_1, pH_{24}, pH_{48}, pH_{96}, pH_{144}), pH in 1 h, 24 h, electrical conductivity measured in 2 h and 24 h and colour lightness in 24 h post mortem (Y_4 – pH_1, pH_{24}, EC_2, EC_{24}, L^*_{24}), drip

loss in 48 h, 96 h and 144 h post mortem (Y_5 – DL_{48}, DL_{96}, DL_{144}), electrical conductivity in 2 h and 24 h, colour lightness in 24 h, drip loss in 48 h, 96 h and 144 h post mortem and water holding capacity and water content (Y_6 – EC_2, EC_{24}, L^*_{24}, DL_{48}, DL_{96}, DL_{144},WHC, water content), pH in 24 h post mortem, intramuscular fat content, protein content, dry matter content and technological yield in curing and thermal processing (72 °C) (Y_7 – pH_{24}, IMF, protein content, dry matter content, TY) and intramuscular fat content, protein content, dry matter content, colour lightness in 24 h, drip loss in 48 h, 96 h and 144 h post mortem and technological yield in curing and thermal processing (72 °C) (Y_8 – IMF, protein content, dry matter content, L^*_{24}, DL_{48}, DL_{96}, DL_{144}, TY).

Lean meat content, hot carcass weight, glycolytic potential (GP) and its components, i.e. content of glycogen and lactate, approximate composition and analysed meat quality traits of Duroc fatteners were shown in table 1.

The analysed porkers were characterised by mean lean meat content by 3 percentage points and hot carcass weight by 6 kg higher than mass population (Lisiak and Borzuta, 2009). In comparison to results achieved by Terlouw and Rybarczyk (2008) hot carcass weight obtained in this study was also higher by 13,5 kg.

Glycolytic potential and its components was at similar level to results achieved by Fernandez, et al. (2002), but higher than values obtained by Terlouw and Rybarczyk (2008) and Lonergan, et. al. (2001) by 20 and 27 $\mu mol*g^{-1}$ respectively.

Physico-chemical parameters of analysed porkers was typical for normal meat (Koćwin-Podsiadła, 2004a) except intamuscular fat content, which level was 1.1 % lower than that achieved by Florowski, et al. (2006). Duroc fatteners are considered as meat quality model which is used widely in breeding programs in majority of European countries (Koćwin-Podsiadła, et al., 1998b), although its usage should not be higher than 25 – 50 % on the grounds of above-mentioned high intramuscular fat content (5 – 8 %) in Longissimus dorsi. On the other hand, the ivestigations of Wood, et al. (1994, 1996) have proved that Danish population of Duroc was characterised by noticeably lower level of this trait, i.e. 2,5-3 % in LD, that is however still higher than value achieved in this paper.

Technological yield in curing and thermal processing (72 °C) expressed by TY indicator was silimilar to that obtained by Lundström, et al. (1996) from RN^--gene free fatteners.

Canonical correlations for selected physico-chemical traits and pork properties (Y) and glycolytic and energetical quantities (X) (shown in table 2) varies from $R_C=0.27^{NS}$ for Y_2 (EC_2, EC_{24}) set to $R_C=0.81^{**}$ ($p \leq 0.001$) for Y_3 set (pH_1, pH_{24}, pH_{48}, pH_{96}, pH_{144}) and were higher than results obtained by Zaremba, et al. (1989) and Koćwin-Podsiadła (1993) in determining usefulness of pH_1 and R_1 and Przybylski (2002) determining influence of lactate and glycolytic potential content on post mortem pork quality diagnostic as well as Koćwin-Podsiadła, et al. (2004c, 2005) determining criteria of culinary and meat processing value of high quality (HQ) pork. Moreover, achieved composed determination coefficient values between X_1 (R_1 and glycogen) and X_2 sets (R_1 and lactate) and Y_3 (pH_1, pH_{24}, pH_{48}, pH_{96}, pH_{144}), i.e. 0.66 and 0.58 respectively was higher than values obtained by van Laack and Kauffman (1999) that proved that GP determines 40 % of differences in LD pHu. In the investigation of Koćwin-Podsiadła, et al. (2009) composed correlation coefficient for glycolytic

potential and pH measured in 45 min, 24 h, 48 h, 96 h and 144 h after slaughter was 0.64.

Table 1. General characteristics of the research material in the lean meat content, hot carcass weight, glycolytic potential and its components, i.e. content of glycogen and lactate, approximate composition and analysed meat quality traits of Duroc fatteners

Tabela 1. Ogólna charakterystyka badanego materiału w zakresie stopnia umięśnienia, potencjału glikolitycznego i jego składowych, tj. glikogenu i kwasu mlekowego, składu podstawowego oraz analizowanych cech jakości mięsa tuczników rasy Duroc

Trait	mean±SD
Leanness [%]	57.71 ± 1.80
Hot carcass weight [kg]	95.10 ± 9.42
Glycolytic potential [µmol*g^{-1}]	128.67 ± 9.41
Glycogen content [µmol*g^{-1}]	44.39 ± 12.21
Lactate content [µmol*g^{-1}]	39.88 ± 7.45
Protein content [%]	22.11 ± 0.45
Water content [%]	74.67 ± 0.49
Dry matter content [%]	25.32 ± 0.49
IMF content [%]	1.85 ± 0.42
pH_1	6.60 ± 0.10
R_1	0.91 ± 0.04
pH_{24}	5.67 ± 0.06
pH_{48}	5.46 ± 0.09
pH_{96}	5.44 ± 0.09
pH_{144}	5.51 ± 0.09
EC_2 [mS*cm^{-1}]	2.62 ± 0.51
EC_{24} [mS*cm^{-1}]	2.96 ± 0.68
L^*_{24}	54.26 ± 2.26
WHC [cm^2]	6.29 ± 1.20
Drip loss at 48th h [%]	4.48 ± 2.10
Drip loss at 96th h [%]	7.53 ± 2.54
Drip loss at 144th h [%]	9.99 ± 2.51
Technological yield in curing and thermal processing (72 °C) – TY (%)	90.44 ± 3.65

Expanding the Y_1 (pH_1, pH_{24},), that composed determination coefficient was 0.24 for X_1 set (R_1 and glycogen) and 0.37 for X_2 set (R_1 and lactate) by additional parameters, i.e. EC_2, EC_{24} and L^*_{24} (Y_4) increases cannonical correlation to 0.53* with X_1 and to 0.64** with X_2, so R_1 and lactate explains variation in Y_4 set in 41 % and R_1 and glycogen in 28 %. Also, in accordance to Przybylski, et al. (2006) glycolytic potential and lactate determines pH_1 and pH_{24} in conjunction with R_1, L^*, WHC and RTN in 90.6 % after slaughter.

Table 2. Values of coefficients of canonical correlation (C_r) and respective composed determination coefficients (R_c^2) revealing relationship between independent sets (X_1 – R_1 and glycogen and X_2 – R_1 and lactate) and dependent variables sets (Y_1 – Y_8)

Tabela 2. Wartości korelacji kanonicznych oraz odpowiadających im złożonych współczynników determinacji między zbiorami zmiennych niezależnych (X_1 – R_1 i glikogenem oraz X_2 – R_1 i kwasem mlekowym) oraz zbiorami zmiennych zależnych (Y_1 – Y_8)

Dependent variables (Y)		Independent variables (X)	
		X_1 – R_1 and glycogen	X_2 – R_1 and lactate
Y_1 – pH_1, pH_{24}	C_R	0.49*	0.61**
	R_C^2	0.24	0.37
Y_2 – EC_2, EC_{24}	C_R	0.27NS	0.23NS
	R_C^2		
Y_3 – pH_1, pH_{24}, pH_{48}, pH_{96}, pH_{144}	C_R	0.81**	0.76**
	R_C^2	0.66	0.58
Y_4 – pH_1, pH_{24}, EC_2, EC_{24}, L^*_{24}	C_R	0.53*	0.64**
	R_C^2	0.28	0.41
Y_5 – DL_{48}, DL_{96}, DL_{144}	C_R	0.68**	0.58*
	R_C^2	0.46	0.34
Y_6 – EC_2, EC_{24}, L^*_{24}, DL_{48}, DL_{96}, DL_{144},WHC, water content	C_R	0.74**	0.67*
	R_C^2	0.54	0.45
Y_7 – pH_{24}, IMF, protein content, dry matter content, TY	C_R	0.54*	0.44NS
	R_C^2	0.29	
Y_8 – IMF, protein content, dry matter content, L^*_{24}, DL_{48}, DL_{96}, DL_{144}, TY	C_R	0.73**	0.69*
	R_C^2	0.53	0.47

* – significant statistically at $p \leq 0.05$

** – significant statistically at $p \leq 0.01$

NS – not statistically significant

Composed determination coefficients values for Y_5 (drip loss measured in 48h, 96h and 144h) and X_1 and X_2 sets, i.e. 0.46 and 0.34 respectively were lower than values obtained by Schäfer, et al. (2002), that proved that glycogen determines drip loss in 60 %, lactate in 80 % and IMP in 71 %.

Furthermore, variation in Y_8 set (IMF, protein content, dry matter content, L^*_{24}, DL_{48}, DL_{96}, DL_{144}, TY) parameters was determined in higher level, i.e. 53 % by R_1 and glycogen and in 47 % by R_1 and lactate than by EC_2 and pH_{24}, i.e. 39 % in accordance to Koćwin-Podsiadła, et al. (2002).

Conclusions

Among currently used meat diagnostic methods, ie. pH_1 and pH_{24} (Y_1), EC_2 and EC_{24} (Y_2) and pH_1, pH_{24}, EC_2, EC_{24} and L^*_{24} (Y_4) the most useful one that explains the glycolytic and energetic quantities in the highest degree is method that exploits 5 determinants (Y_4). Composed determination coefficient and cannonical correlation values) obtained in this study for method and X_2 set (R_1 and lactate) was 0.41 and 64** respectively. Additionally High values of canonical correlation coefficients achieved between X_1 (R_1 and glycogen) and Y_6 (EC_2, EC_{24}, L^*_{24}, DL_{48}, DL_{96}, DL_{144}, WHC, water content) and Y_8 (IMF, protein content, dry matter content, L^*_{24}, DL_{48}, DL_{96}, DL_{144}, TY) sets that equal 0.74** and 0.73** respectively justify developing of quick, cheap and non-invasive methods that are possible to implement up to 1 h post mortem using Raman spectroscopy and laser beams.

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