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Effects of carcass maturity on meat quality characteristics of beef *semitendinosus* muscle for chinese native yellow steers

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This work was designed to study the effects of carcass maturity on meat quality characteristics and intramuscular connective tissue of beef semitendinosus *muscle from Chinese native Yellow steers. Chemical determinations, histological and mechanical measurements were performed on the raw and cooked meat at 4 days* post mortem. *In raw meat, intramuscular fat, collagen solubility, mechanical strength and transition temperature of intramuscular connective tissue increased (*$P < 0.05$*) with carcass maturity before body maturation, whilst moisture, total collagen, fibre diameter decreased after body maturation. Warner-Bratzlar shear force (WBSF) of cooked meat increased with maturity before body maturation due to the muscle atrophy, and thus the decline of moisture content and the increase of cooking losses. After body maturation, the increase of WBSF was neutralised by the increase of intramuscular fat, the decrease of total collagen and the elongation of sarcomere length.*

Keywords: beef, connective tissue, maturity, sarcomere length, tenderness

Introduction

Tenderness is one of the most important meat palatability attributes (tenderness, juiciness, and flavour) and it is influenced by a great many factors, including carcass maturity or animal age. Many studies have shown that meat tenderness decreases with animal age (Judge and Aberle, 1982; Shorthose and Harris, 1990; Moon *et al*., 2006). But different scientists ascribed this increase to different reasons. Shorthose and Harris (1990) reported decreased tenderness of all muscles as animal age increased from 10 to 60 months. They attributed this decrease in tenderness to changes in collagen rather than the myofibrils, with the changes in collagen being muscle-dependent. Bailey (1985) attributed the tougher texture of beef in older cattle to the mature collagen crosslinks and Bosselmann *et al.* (1995) found a high concentration of pyridinole crosslink in tough beef. Moreover other researchers gave proofs that the shrinkage temperature of intramuscular connective tissue (IMCT) increased (Judge and Aberle, 1982) and collagen solubility decreased when meat tenderness decreased (Volpelli *et al*., 2003). Thus intramuscular connective tissue is an important factor to meat tenderness. But other reports did not show any age-related changes in meat tenderness and its related traits (Dikeman *et al*., 1986; Avery *et al*., 1998). Thus, it is still uncertain whether animal age has any effect on meat tenderness.

Carcass maturity has been extensively used as an indictor of animal age for beef grading in the United States, Australia, and recently in China (US Department of Agriculture (USDA), 1997; AUS-MEAT, 1998; China's Ministry of Agriculture (CMA), 2003). China is one of the biggest worldwide nations in beef production and is rich in cattle breeds, but beef cattle are reared by way of feeding roughages at an earlier time, and adding some concentrates just a few months before harvest to increase the energy levels (National Bureau of Statistics of China (NBSC), 2004; China's Academy of Agriculture (CAA), 1986). This production system could lead to a better beef eating quality according to experience from other countries (Sami *et al*., 2004). Meanwhile, few data are available on effects of carcass maturity on meat tenderness for Chinese Yellow cattle.

Therefore, the objective of this study was to investigate the changes of meat quality characteristics and IMCT of beef *semitendinosus* muscle with carcass maturity for Chinese native Yellow steers.

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Material and methods

Sampling

To obtain carcasses with different maturities, 21 approximately 24-month, 42-month and 72-month Luxi ($n = 7$ each group) steers were chosen from a farm. Luxi cattle are a later-mature but marbled yellow breed that does not reach body maturation until 36 to 42 months of age. They are famous for their better growth performance (body weight 644 kg for mature bulls), higher slaughter performance (dressing percentage 58.1% and lean percentage 50.7%, ribeye area 94.2 cm^2) and better palatability (more tender, juicy, and intense flavour) (Chen and Xu, 2004). All the cattle had been fed with enough roughage and forage until 3 months before slaughter. And then they were fattened with concentrate and roughage (concentrate/roughage of 3 : 7). The animals were humanely slaughtered in a commercial meat processing company. Carcasses were hung in a 4°C chiller, and carcass attributes were determined according to the US Department of Agriculture (USDA) beef standards at 24 h *post mortem*. Carcass maturities were USDA A, C and D, and accordingly, backfat thickness was about 1, 6 and 10 mm for 24-, 42- and 72-month groups respectively.

This study was designed to focus on the effects of intramuscular connective tissue on beef shear force values. Therefore, *semitendinosus* muscle, which contains higher connective tissue, was used for analyses. At 4 days *post mortem*, two 2.54-cm-thick *semitendinosus* steaks were removed at the interface of 12/13th ribs of the right side. Of the two steaks from each carcass, one was directly used for chemical, thermal, histological, and IMCTs mechnical analyses. The other was used for Warner-Bratzlar shear force (WBSF) measurement (Li *et al*., 2006). Briefly, The steaks were individually placed inside polyethylene bags and cooked in a water bath at 80°C until an internal temperature of 70 C was reached. During cooking, the internal temperature was tracked by the above portable needle-tipped thermometer. The cooked steaks were cooled at 4 C for 16 h (overnight), taken from the bags, dried with filter paper and then weighed. The cooking loss was expressed as the percentage change of weight before and after cooking. After measurements of cooking loss, the same steaks were used for determination of shear force. About six to eight 1.27-cm-diameter cylindrical cores were removed from each steak parallel to the muscle fibre orientation. A single, peak shear force measurement was obtained for each core using a Warner-Bratzler meat shear machine (Salter 235, Manhattan Kansas, USA) and an average WBSF was calculated and recorded for each steak. After shearing, each core was used for chemical determination and histological observation.

Chemical analysis

Determinations of moisture, crude fat, total and insoluble collagen of raw meat was based on the whole steak, whereas those of cooked meat were determined on the basis of cores. Moisture was determined using the method of freeze-drying. About 5.0 g of samples were freezing-dried under the vacuum in a desiccator (alpha2, Christ, Germany) for approximately 24 h until the sample weight was constant. Crude fat in dried samples was extracted in the ether solution for 15 h. Collagen content and its solubility were determined according to the procedures of Hill (1966) and Bergman and Loxley (1963).

Differential scanning calorimetry (DSC)

The perimysium and the endomysium were extracted according to the procedures of Light and Champion (1984). The purified perimysial and endomysial portions were concentrated by the method of freeze-drying and then used for the analysis of DSC. The endothermal transition temperature of perimysial and endomysial portions was measured using a calorimeter (DSC 7, Perkin Elmer, USA). Temperature calibration was run using the Indium thermogram. The samples (20 mg) were accurately weighed into aluminum pans and sealed. The samples were scanned at 10°C/min over the range of 20 to 90°C using liquid nitrogen as the cooling medium. Maximum transition temperature was estimated from the thermogram using the software Pyris Manager Series (DSC 7, Perkin Elmer, USA).

Sarcomere length

Sarcomere length was measured according to the method of Cross *et al.* (1981) with some modifications. Briefly, approximately 5 g of meat sample was cut into 0.5 cm × 0.5 cm × 0.5 cm cubes and homogenized in 30 ml of cold 0.25 mol/l sucrose for 60 s at a low speed (5000 r.p.m.). A drop of homogenate was observed with the oil objective using a phase-contrast microscopy (BX41, Olympus, Japan), and 25 single muscle fibres were photographed by a digital camera (Olympus, Japan). Different from Cross *et al.* (1981), all the images were analysed by the software Image-Pro Plus 5.1 (Media Cybernetics, USA). Five measurements of sarcomere length were performed on the same image. Finally, the average of 125 measurements (25 × 5) was designated as the sarcomere length of each steak.

Histological observations

Several 0.5 cm × 0.5 cm × 0.5 cm cubes were removed from both raw and cooked steaks. The cubes were rapidly frozen in nitrogen for 3 to 4 h, and cut into 10 μm sections, perpendicular to the orientation of muscle fibres, using a cryostat (1850, Leica, Germany). The sections were stained according to Flint and Pickering (1984). Slides were examined under bright-field illumination with a 10 × objective using a light microscope (BX41, Olympus, Japan). Fifteen photographs were taken using a digital camera (Olympus, Japan), affixed to the microscope, from different visual fields of each slide for measurements of the perimysial thickness and the fibre diameter.

The secondary perimysial thickness and the fibre diameter were measured by the software Image-Pro Plus 5.1 (Media Cybernetics, USA). Fifteen points were randomly

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selected from each picture. The secondary perimysial thickness was designated as the shortest distance between the two edges of the membrane, and the fibre diameter was designated as the shortest diameter of a single muscle fibre. Finally, the secondary perimysial thickness and the fibre diameter for each sample were recorded as the averages of 225 measurements (15 × 15).

Mechanical strength of IMCT

IMCT preparation was prepared according to the procedures of Nishimura *et al.* (1999). The shear force value of IMCT preparations embedded in acrylamide gels was measured using a texture analyser (TA-XT2i, Godalming, England) with a 7-mm thick V-type blade (HDP/BSW).

Statistical analyses

The effects of carcass maturity on WBSF, moisture, crude fat, collagen content and its solubility, the secondary perimysial thickness, transition temperature, mechanical strength of IMCT, sarcomere length and fibre diameter were evaluated by one-way analysis of variance (ANOVA) techniques where these measurements were as dependent variables and maturity group as an independent variable. Means of the measurements of different maturity groups were compared using the Duncan's multiple-range test at the significance level of 0.05. Correlation coefficients among all the variables were evaluated by descriptive analysis of correlations. All statistical analyses were performed by SAS 8.12 (Statistical Analysis Systems Institute, 2001).

Results and discussion

Changes of chemical, histological measurements of raw meat with carcass maturity

Table 1 lists the means and standard errors of chemical composition, mechanical strength of IMCT, fibre diameter, and sarcomere length of raw beef *semitendinosus* steaks with different carcass maturities.

The moisture content in raw meat decreased ($P < 0.05$) with the advanced maturity, which is due to the potential increase of intramuscular fat and also the decrease of fibre diameter (see below). Although the backfat thickness differed significantly among three maturity groups (see **Material and methods**), no significant differences existed ($P > 0.05$) in the content of intramuscular fat. This is mainly attributed to a great variability for individuals within the same maturity group (CVs are 24.9%, 20.6%, 18.3% for maturities A, C, D, respectively). However, intramuscular fat still had a trend to increase with maturity and its variability within the same group decrease as maturity increased. Gerhardy (1995) also observed that the intramuscular fat content in beef *semitendinosus* from older female cattle was higher than from younger females, and the order of categories was reversed when ranking by moisture. Similarly, Nishimura *et al.* (1999) found an age-related increase in the intramuscular fat in both beef *m. longissimus* and *m. semitendinosus.* The lack of significant difference in intramuscular fat content in *m. semitendinosus*, herein, could result from its highly intensive movement because most of Chinese Yellow cattle are grazed and therefore intramuscular fat in the leg muscles is fueled during movement.

The total collagen content in A- and C-maturities muscles was slightly higher ($P < 0.05$) than that D- maturity muscle. This indicates that total collagen content has a trend to decrease with increasing maturity after body maturation. The decrease in collagen content could be a dilution effect as the potentially increasing intramuscular fat. Nishimura *et al.* (1999) observed a decrease in collagen content with animal age ranged from 8 months to 32 months. Gerhardy (1995) observed that the collagen contents in young heifers (13 months) were higher than for

Table 1 *Chemical composition, mechanical strength, fibre diameter and sarcomere length of raw beef steaks (n = 7 each group)*[†]

	Carcass maturity grades					
	USDA A		USDA C		USDA D	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Moisture (g/kg)	717.20[a]	21.69	701.21[a]	22.83	649.04[b]	42.86
Intramuscular fat (g/kg)	85.55[a]	16.22	96.05[a]	16.01	101.82[a]	14.58
Collagen						
Total collagen (g/kg)	4.58[a]	0.36	4.66[a]	0.42	3.95[b]	0.40
Insoluble collagen (g/kg)	3.67[a]	0.18	3.04[b]	0.30	3.43[ab]	0.31
Solubility (%)	16.59[a]	6.53	23.22[b]	7.82	12.44[a]	2.20
IMCT mechanical strength (Newton)	4.11[a]	0.50	6.24[b]	0.60	4.81[a]	0.61
Fibre diameter (μm)	44.23[a]	2.21	43.20[a]	0.49	41.29[b]	1.61
Sarcomere length (μm)	2.50[a]	0.10	2.71[b]	0.10	2.72[b]	0.10
Transition temperature (°C)						
Perimysium	62.30[a]	0.50	68.80[b]	0.81	67.70[b]	0.82
Endomysium	56.72[a]	0.62	58.70[b]	0.61	58.40[b]	0.60

[a,b] Means with different superscript letters differ significantly ($P < 0.05$).
[†] Maturity A corresponds to chronological age of 9 to 30 months, C to 42 to 72 months and D to 72 to 96 months. IMCT, intramuscular connective tissue.

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heifers (23 months) and once-bred heifers (33 months). In those studies, the decrease in collagen content could be a dilution effect as muscle fibres grow, but this effect did not occur in the present study (the fibre diameter declined, see below). The insoluble collagen content decreased ($P < 0.05$) as the carcass maturity increased from A to C, but it slightly increased ($P > 0.05$) with a further increase of carcass maturity. Correspondingly, the collagen solubility showed an increase ($P < 0.05$) from maturities A to C, and then decreased ($P < 0.05$) from C to D. This is different from other studies, which indicates no or negatively age-related changes in the insoluble or soluble collagen content, or in the collagen solubility (Miller *et al.*, 1983; Volpelli *et al.*, 2003). The differences in collagen between the present study and others could be explained by breed and feeding regimes. As mentioned previously, Luxi cattle are a later-mature breed, which need a longer time to reach maturity compared with other breeds such as Simmental, Limousin and Hereford (China's Academy of Agriculture (CAA), 1986). Thus, the fattening period, which produces a compensatory growth, is associated with an increment of neo-formed-soluble collagen, but the older animals could have a lower value.

In contrast to the collagen solubility, shear force value of intramuscular connective tissue increased ($P < 0.05$) from maturities A to C and then decreased ($P < 0.05$) from C to D. This is due to the liability of immature IMCT of young animals to breakdown in a high concentration of NaOH solution (10 mol/l) during sample treatment. On the other hand, the structure of IMCT from the oldest animals was more liable to be destroyed because of dissolution of intramuscular fat. Nishimura *et al.* (1999) observed a similar trend in changes of mechanical strength of IMCT for *m. semitendinosus* from Japanese Black cattle, but the peak age point of mechanical strength they reported was 24 months, whereas the age at peak mechanical strength in the present study was older than 30 months. Meanwhile, the values of mechanical strength they reported (lower than 0.2 N) were far lower than those in the present study (greater than 3.0 N), which may be due to the different thickness of shearing blade (7 mm herein *v.* 0.35 mm therein).

The fibre diameter had a slight but significant decline ($P < 0.05$) from maturities C to D, which could result from a lower absorption of nutrients for D-maturity cattle, allowing some muscle atrophy to occur (Sheffield-Moore and Urban, 2004). The sarcomere length rose ($P < 0.05$) as carcass maturity increased from A to C, but varied little afterwards ($P > 0.05$). This could be because older animals had thicker fat cover, which could, to a large extent, avoid or lessen cold shortening during post-mortem chilling.

The transition temperatures of the perimysia and the endomysia increased ($P < 0.05$) from maturities A to C, indicating that more mature collagen crosslink formed during body maturation (Smith and Judge, 1991). The increase in transition temperature accounts for the rise in the mechanical strength of IMCT from young to mature animals.

Changes of chemical and histological measurements of cooked meat with carcass maturity

According to Wheeler *et al.* (2002), analyses of chemical traits on the cooked cores used for WBSF determination could explain more of the variation of tenderness measurements than analyses performed on raw samples, therefore, the authors chose to perform the analyses of moisture, crude fat, collagen and fibre diameter and perimysial thickness on the cooked cores.

Table 2 shows means and standard errors of cooking losses, WBSF, chemical composition, fibre diameter, secondary perimysial thickness and sarcomere length of cooked beef *semitendinosus* with different carcass maturities.

The D-maturity samples had greater ($P < 0.05$) quantities of cooking losses than A- and C- maturities samples. The cooking losses of the A- and C- maturity steaks were

Table 2 *Cooking losses, WBSF, chemical composition, fibre diameter, perimysial thickness and sarcomere length of cooked beef steaks ($n = 7$ each group)*[†]

	Carcass maturity grades					
	USDA A		USDA C		USDA D	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Cooking losses (%)	17.61[a]	0.51	17.22[a]	0.63	20.84[b]	0.60
WBSF (N)	50.29[a]	2.41	68.92[b]	4.81	63.40[b]	3.00
Moisture (g/kg)	636.93[a]	6.73	603.64[b]	6.72	603.30[b]	7.11
Crude fat (g/kg)	104.74[a]	9.31	138.90[b]	10.77	134.29[b]	10.01
Collagen						
Total collagen (g/kg)	4.40[a]	0.12	4.68[a]	0.23	4.43[a]	0.21
Insoluble collagen (g/kg)	4.30[a]	0.11	4.21[a]	0.20	4.59[a]	0.21
Fibre diameter (μm)	26.32[a]	0.43	29.94[b]	0.41	30.11[b]	0.28
Sarcomere length (μm)	1.91[a]	0.10	1.91[a]	0.10	1.83[a]	0.10
Perimysial thickness (μm)	48.83[a]	7.22	46.89[a]	4.73	49.42[a]	5.51

[a,b] Means with different superscript letters differ significantly ($P < 0.05$).
[†] Maturity A corresponds to chronological age of 9 to 30 months, C to 42 to 72 months and D to 72 to 96 months. WBSF, Warner-Bratzlar shear force.

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similar ($P > 0.05$). The increase in cooking losses from the C-maturity to the D maturity could be due to the decline of water-holding capacity for muscle fibre, concomitant with the previously mentioned muscle atrophy (Sheffield-Moore and Urban, 2004). Meanwhile, the cooking time to a get to a determinate temperature could be another factor in the differences in cooking losses among the three maturity groups. Slightly more intramuscular fat (maturity C and D group) would lead to slower heat transfer, more time to get a certain core temperature, and thus more losses (Oroszvári *et al*., 2006). Obuz *et al.* (2004) also reported a significant relationship between cooking time and cooking losses. In the present study, the cooking times were 22 min, 22.5 min and 25 min respectively, for maturities A, C, D steaks.

For cooked meat, moisture content of A-maturity samples was higher ($P < 0.05$), corresponding with a lower ($P < 0.05$) intramuscular fat, than that of C- or D-maturity samples. But there was no significant difference in moisture and intramuscular fat content between C- and D-maturities samples ($P > 0.05$). Corresponding to raw meat, cooked meat did not differ ($P > 0.05$) in total collagen content for all maturity groups. Veiseth *et al.* (2004) also noted that lamb *longissimus* collagen concentration, in either raw or cooked sample, did not change with age.

In contrast to raw meat, fibre diameter of cooked meat increased ($P < 0.05$) before body maturation (from maturities A to C), indicating that heat allowed muscle fibres from younger animals to be more liable to transverse shrinkage (40.40% *v.* 30.90% for A- and C-maturities, respectively). However, changes of sarcomere length showed that muscle fibres from older animals were more liable to heat-induced, longitudinal shrinkage (27.44% *v.* 32.46% for C- and D-maturities, individually). No significant age-related change ($P > 0.05$) was observed for perimysial thickness.

Changes of WBSF with carcass maturity

The C-maturity group had a higher ($P < 0.05$) WBSF value than the A-maturity group, but there was no significant difference ($P > 0.05$) between C- and D-maturity groups. This indicates that WBSF increases with maturity only before body maturation. Cross *et al.* (1984) also showed a stepwise change over the range from 12 to 18 months. But they found that WBSF of steers decreased with age within that range. The difference between the quoted literature and the present study could result from the difference of animal age scope and feeding regimes. According to Perry and Thompson (2005), increased growth rate during finishing would result in more tender meat. Obviously, the young animals had a higher growth rate than older animals. The lack of significant difference in WBSF values between C and D needs further study.

To understand the causes to the changes of beef WBSF before and after body maturation, correlation analyses were performed according to the collective data of A- and C-maturity groups, and also those of C- and D-maturity groups. As shown in Table 3, The average WBSF values of cooked steaks were correlated positively with their cooking losses and inversely with their sarcomere length, and also negatively with moisture content in the raw counterparts. This indicates that the trait of muscle fibre is the main contributor to beef WBSF before body maturation because the moisture content reflects intrinsic nature of muscle fibre, whilst the cooking losses and sarcomere length mainly reflects the water-holding capacity of meat sample (especially muscle fibre) during heating. Regression analysis confirmed that moisture content, cooking losses and fibre diameter accounted for 99.1% of total variation of WBSF (Table 4). Okeudo and Moss (2005) also showed a highly positive correlation between cooking losses and WBSF.

After body maturation, WBSF values of cooked cores were correlated with their moisture content, cooking losses and sarcomere length. Meanwhile, WBSF values of cooked cores had a significant relationship with intramuscular fat content, total collagen content and sarcomere length of their raw counterparts ($P < 0.05$, Table 5). That is to say that the increase of intramuscular fat, the decrease of total collagen and the elongation of sarcomere length neutralised

Table 3 *Correlation coefficients among variables based on the collective data of maturities A and C raw steaks (n = 14)*[†‡]

	WBSF (N)	M (g/kg)	IF (g/kg)	TC (g/kg)	IC (%)	CS (%)	MS (N)	FD (μm)	SLR (μm)	SLC (μm)
CL (%)	0.64**	−0.19	−0.52*	0.27	0.30	0.06	0.48*	−0.26	−0.47	−0.52*
WBSF (N)		−0.87***	−0.35	0.35	0.03	0.38	0.15	0.02	−0.35	−0.53*
M (%)			0.15	−0.28	0.15	−0.47	0.10	−0.28	0.21	0.38
IF (%)				−0.32	−0.58*	0.04	−0.01	0.24	0.16	0.47
TC (%)					0.36	0.61*	0.04	−0.19	−0.13	−0.42
IC (%)						−0.48*	−0.06	−0.19	−0.51*	−0.41
CS (%)							0.10	−0.02	0.26	−0.06
MS (N)								0.02	−0.16	−0.06
FD (μm)									−0.30	0.02
SLR (μm)										0.26

[†] The analysis was performed on the measurements of whole steaks, maturity A corresponds to chronological age of 9 to 30 months, C to 42 to 72 months.
[‡] CL: cooking losses; WBSF: Warner-Bratzlar shear force; M: moisture; IF: intramuscular fat; TC: total collagen; IC: insoluble collagen; CS: collagen solubility; MS: mechanical strength of intramuscular connective tissue; FD: fibre diameter; SLR/C: sarcomere length of raw/cooked meat.

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Table 4 *Predictive models for beef WBSF by stepwise regression analysis based on the collective data of maturities A and C raw steaks*[†]

Model	Independent	Coefficients	T	Significance	R Square	s.e. of estimate
1	Constant	19.10	7.98	0.00	0.75	1.03
	Moisture	−0.20	−5.78	0.00		
2	Constant	12.76	16.05	0.00	0.98	0.26
	Moisture	−0.18	−19.85	0.00		
	Cooking losses	0.28	12.55	0.00		
3	Constant	15.16	12.22	0.00	0.99	0.22
	Moisture	−0.18	−23.02	0.00		
	Cooking losses	0.27	13.37	0.00		
	Fibre diameter	−0.04	−2.29	0.04		

[†] Maturity A corresponds to chronological age of 9 to 30 months, C to 42 to 72 months. WBSF, Warner-Bratzlar shear force.

Table 5 *Correlation coefficients among variables based on the collective data of maturities C and D raw steaks (n = 14)*[†‡]

	WBSF (N)	M (%)	IF (%)	TC (%)	IC (%)	CS (%)	MS (N)	FD (μm)	SLR (μm)	SLC (μm)
CL (%)	0.63**	−0.09	−0.40	0.48*	0.66***	−0.17	0.04	0.06	−0.52*	−0.77***
WBSF (N)		−0.82***	−0.59*	0.61*	0.38	0.30	−0.08	0.25	−0.64**	−0.68***
M (%)			0.49*	−0.41	0.06	−0.58*	0.08	−0.25	0.38	0.33
IF (%)				−0.43	−0.32	−0.16	−0.19	0.07	0.28	0.58*
TC (%)					0.69***	0.41	0.10	0.37	−0.42	−0.24
IC (%)						−0.36	0.04	0.19	−0.52*	−0.39
CS (%)							0.10	0.26	0.07	0.15
MS (N)								−0.01	0.04	−0.10
FD (μm)									−0.53*	0.07
SLR (μm)										0.30

[†] The analysis was performed on the measurements of whole steaks, maturity C corresponds to chronological age of 42 to 72 months, C to 72 to 96 months.
[‡] CL: cooking losses; WBSF: Warner-Bratzlar shear force; M: moisture; IF: intramuscular fat; TC: total collagen; IC: insoluble collagen; CS: collagen solubility; MS: mechanical strength of intramuscular connective tissue; FD: fibre diameter; SLR/C: sarcomere length of raw/cooked meat.

the increase of WBSF caused by the decrease of moisture, the heat-induced shrinkage of sarcomere, allowing the cooking losses to increase.

Although Wheeler *et al.* (2002) stated that analyses of chemical traits on the cooked cores used for WBSF determination could explain more of the variation of tenderness measurements than analyses performed on raw samples, all correlation coefficients between WBSF and other variables (except intramuscular fat) of cores were relatively low (Tables 6 and 7). Therefore, it is not feasible to predict beef tenderness of Chinese Yellow steers according to the measurements of cooked cores.

Previous studies showed that the age-related decrease in meat tenderness was associated with increasing collagen fibre diameter and the development of mature cross-links from immature divalent forms (Bosselmann *et al.*, 1995; Nakamura *et al.*, 2003). Cooper *et al.* (1968) observed that the change of meat tenderness with maturity was associated with the perimysial thickness. However, only the total collagen content was related to WBSF of cooked cores in *semitendinosus* muscle after body maturation in the present study, although other traits of IMCT (collagen solubility, mechanical strength, perimysial thickness and transition temperature) also changed with carcass maturity.

Conclusion

Beef *semitendinosus* muscle was observed to vary in moisture content, crude fat content, traits of IMCT, fibre diameter, sarcomere length, cooking losses and WBSF with carcass maturity. WBSF increased with maturity before body maturation due to the decline of moisture content and the increase of cooking losses. After body maturation, the increase of WBSF was neutralised by the increase of intramuscular fat, the decrease of total collagen and the

Table 6 *Correlation coefficients among variables based on the collective data of maturities A and C cooked cores (n = 70)*[†‡]

	M (%)	IF (%)	TC (%)	IC (%)	FD (μm)	PT(μm)
WBSF (N)	0.16	−0.34*	0.27	0.26	0.22	0.14
M (%)		−0.94***	−0.17	−0.08	−0.30	0.26
IF (%)			0.09	0.08	0.28	−0.26
TC (%)				0.65***	−0.03	0.08
IC (%)					−0.11	0.00
FD (μm)						0.05

[†] The analysis was performed on the measurements of individual cores, maturity A corresponds to chronological age of 9 to 30 months, C to 42 to 72 months.
[‡] WBSF: Warner-Bratzlar shear force; M: moisture; IF: intramuscualr fat; TC: total collagen; IC: insoluble collagen; FD: fibre diameter; PT: perimysial thickness

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Table 7 *Correlation coefficients among variables based on the collective data of maturities C and D cooked cores (n = 70)*[†‡]

	M (%)	IF (%)	TC (%)	IC (%)	FD (μm)	PT (μm)
WBSF (N)	0.33	−0.52**	0.32	0.33	0.21	0.33
M (%)		−0.90***	−0.08	−0.14	−0.05	0.15
IF (%)			−0.05	−0.03	0.06	−0.25
TC (%)				0.66***	−.093	0.26
IC (%)					0.02	0.21
FD (μm)						0.15

[†] The analysis was performed on the measurements of individual cores, maturity C corresponds to chronological age of 42 to 72 mo, C to 72 to 96 mo.
[‡] WBSF: Warner-Bratzlar shear force; M: moisture; IF: intramuscualr fat; TC: total collagen; IC: insoluble collagen; FD: fibre diameter; PT: perimysial thickness.

elongation of sarcomere length. Therefore, it could be practical for beef industry to produce desired beef tenderness before body maturity as early as possible.

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