CHAPTER 3

RESULTS AND DISCUSSION

1. Effect of age and rearing systems on quality characteristics and microstructure of Thai indigenous chicken muscles

1.1 Proximate compositions

The effect of age and rearing system on proximate composition of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles are presented in Table 3. In both rearing system, the decrease in moisture (p<0.05) but increase in protein and fat content (p<0.05) in chicken muscles were observed when the age increased from 16 weeks to 20 weeks. The significant increase in ash content with the age was found only in *biceps femoris* muscle (p<0.05). Rearing chicken with intensive system affected more fat content (p<0.05) in muscles than rearing with extensive system. In addition, the later system caused lower moisture and ash content (p<0.05) in *biceps femoris* muscle. This is probably due to the difference in exercise of chicken and feeding method between the systems. Since the former system limited the area in chicken's house and provided concentrated feeds unlimited for the chicken while chickens in the later system were allowed to scavenge on natural food around the homestead (18 meter squares) during the day and supplemented with concentrated feeds in the evening. There was no significant interaction between age and rearing system on proximate composition of the chicken muscles except for fat content. As compared between muscles, the higher protein and fat content were obtained in *pectoralis major* muscle while *biceps femoris* muscle contained more moisture content. The proximate composition of Thai indigenous chicken muscles found in this study was in accordance with Sanchai *et al*. (2003) and Wattanachant and Wattanachant (2007) who studied on Thai indigenous chicken breed in Northern and Southern part of Thailand, respectively. Those researchers reported that no significant effect of live weights (1.3-1.8 kg within the age range 16-24 weeks) on composition of Thai indigenous chicken reared under extensive system. Lawrie (1991) reported the age of animal can influence chemical composition. Generally, moisture and protein content of muscle decrease as increase animal age while fat content increase. Difference proximate compositions in chicken muscles were governed by many factors including age, species, breeds and growth stage (Karakoltsidis *et al*., 1998).

Table 3 Effect of age and rearing system on proximate compositions of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles

Composition	System	Age (weeks)		
		16	18	20
Pectoralis m.				
Moisture (%)	Intensive	74.39 ± 0.41^{a,A}	73.46 ± 1.15^{a,A}	72.81 ± 1.18^{a,A}
	Extensive	74.43 ± 0.77^{a,A}	72.57 ± 1.25^{b,A}	73.63 ± 1.08^{ab,A}
Protein (%)	Intensive	23.05 ± 0.21^{c,A}	23.85 ± 0.35^{a,A}	23.85 ± 0.07^{a,A}
	Extensive	23.65 ± 0.07^{a,A}	23.65 ± 0.21^{a,A}	23.95 ± 0.21^{a,A}
Fat (%)	Intensive	2.88 ± 0.26^{a,A}	3.09 ± 0.26^{a,A}	2.89 ± 0.41^{a,A}
	Extensive	1.99 ± 0.15^{b,B}	2.27 ± 0.54^{b,B}	3.73 ± 0.45^{a,B}
Ash (%)	Intensive	4.60 ± 0.65^{ns}	4.86 ± 0.32^{ns}	4.55 ± 0.22^{ns}
	Extensive	4.65 ± 0.29^{ns}	4.43 ± 0.33^{ns}	4.44 ± 0.17^{ns}
Biceps femoris m.				
Moisture (%)	Intensive	80.82 ± 0.71^{a,A}	79.27 ± 0.33^{c,A}	80.02 ± 0.63^{b,A}
	Extensive	78.93 ± 1.68^{a,A}	79.15 ± 0.15^{a,A}	78.50 ± 0.45^{a,A}
Protein (%)	Intensive	17.43 ± 0.44^{a,A}	17.81 ± 1.13^{a,A}	18.70 ± 0.53^{a,B}
	Extensive	16.80 ± 0.51^{c,A}	18.44 ± 0.57^{b,A}	20.28 ± 0.54^{a,A}
Fat (%)	Intensive	1.14 ± 0.47^{a,A}	1.55 ± 0.78^{a,A}	1.81 ± 0.52^{a,A}
	Extensive	0.65 ± 0.09^{b,A}	1.12 ± 0.04^{a,A}	1.08 ± 0.26^{a,A}
Ash (%)	Intensive	0.75 ± 0.03^{b,A}	0.95 ± 0.06^{a,A}	1.01 ± 0.02^{a,A}
	Extensive	0.84 ± 0.04^{a,A}	0.78 ± 0.01^{b,B}	0.87 ± 0.01^{a,B}

Data are presented as mean ± SD; n = 15 (5 birds x 3 determinations).

$^{a\text{-}b}$ Means with differing superscripts in the same row under the same type of muscles are significant difference (p<0.05).

$^{A\text{-}B}$ Means with differing superscripts in the same column under the same type of muscles are significant difference (p< 0.05).

^{ns} = non significant difference (p≥0.05).

1.2 Total collagen and soluble collagen

Total collagen and soluble collagen content of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles at different age and rearing system are presented in Table 4. The collagen content obtained in this study was in the same range with previous reported (Wattanachant and Wattanachant, 2007; Wattanachant *et al*., 2004). There was no significant difference among ages and rearing system in total collagen and soluble collagen of both muscles (p>0.05). The results showed that age range between 16-20 weeks did not affect the collagen content and its properties. The decrease in soluble collagen content of Thai indigenous chicken *pectoralis major* muscle aged from 6 weeks to 24 weeks was reported by Wattanachant and Wattanachant (2007). However, the non significant difference result between age ranges 16-20 weeks was also obtained. Nakamura *et al*. (1975) also reported that the total collagen was not changed with the chicken age while the soluble collagen was decreased when the chicken age increased. Maran (1999) stated that collagen is the main composition of intramuscular connective tissue which increase with the animal age and will influence on the tenderness of chicken meat. The heat solubility of collagen decreases with increased collagen crosslinking and crosslinking increases as animal ages (Pearson and Young, 1989; Foegeding and Lanier, 1996). Therefore, this study found that the chicken age between 16-20 weeks and rearing system were not influence on the increasing of crosslinked collagen.

1.3 Color

The color (L*, a* and b* value) of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles with different ages and rearing systems are shown in Table 5. No significant differences by age were observed in L*, a* and b* values of *pectoralis major* muscle (p≥0.05) neighter rearing by intensive nor extensive system. Thai indigenous chicken *pectoralis major* muscle reared in the intensive farming system had lower L* and b* values than the extensive farming system (p<0.05). The a* value of muscles was not different by age and rearing system (p≥0.05). This result was not in agreement with Miller (1994) who reported that the content of myoglobin increased with increasing age of poultry meat which could be contributed to increasing a* value of muscle. The *biceps femoris* muscle had no significant difference in L* and a* values related to age or rearing system (p<0.05), while b* value decreased with increasing age

(p<0.05). The *biceps femoris* muscle obtained from indigenous chicken reared in the intensive farming system had lower b* value than the extensive farming system (p<0.05). In this study, rearing system showed more influenced on L* and b* values of the muscles as compared to the effect of chicken age. Since the pH of muscles (in range 5.90-6.06) were not significantly different between the systems. Therefore, the difference in the L* and b* values may be attributed to difference in feeds that chicken selected to eat. The color of chicken muscle was different, depending upon species, muscle type, sex and feeding (Conforth, 1994). *Pectoralis major* muscle had higher L* and b* value but lower in a* value as compared to *biceps femoris* muscle. *Pectoralis major* muscle of indigenous chicken contained higher myoglobin content than *biceps femoris* muscle has been reported (Wattanachant, 2004; Nichida and Nichida, 1985).

Table 4 Effect of age and rearing system on total collagen and soluble collagen of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles

Muscle	**Age (weeks)**	**Total collagen (mg/g muscle)**		**Soluble collagen (% of total collagen)**	
		Intensive	**Extensive**	**Intensive**	**Extensive**
Pectoralis m.	16	7.27 ± 1.14^{ns}	8.31 ± 2.43^{ns}	25.28 ± 0.41^{ns}	23.75 ± 2.81^{ns}
	18	8.75 ± 2.82^{ns}	8.44 ± 1.54^{ns}	24.53 ± 3.92^{ns}	24.91 ± 4.06^{ns}
	20	8.88 ± 1.53^{ns}	8.30 ± 1.70^{ns}	24.50 ± 3.02^{ns}	24.34 ± 3.82^{ns}
Biceps femoris m.	16	10.33 ± 0.98^{ns}	10.33 ± 3.53^{ns}	22.61 ± 0.14^{ns}	24.53 ± 2.18^{ns}
	18	11.02 ± 0.50^{ns}	10.23 ± 1.73^{ns}	23.09 ± 5.43^{ns}	25.31 ± 2.73^{ns}
	20	11.79 ± 0.85^{ns}	10.09 ± 3.32^{ns}	25.53 ± 1.09^{ns}	25.27 ± 4.67^{ns}

Data are presented as mean ± SD; n = 15 (5 birds x 3 determinations).

^{ns} = non significant difference ($p \geq 0.05$).

Table 5 Effect of age and rearing system on colour of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles

Composition	System	Age (weeks)		
		16	18	20
Pectoralis m.				
L*	Intensive	$54.60 \pm 7.26^{a,\ B}$	$53.88 \pm 8.34^{a,B}$	$54.70 \pm 6.68^{a,B}$
	Extensive	$54.51 \pm 5.88^{a,\ A}$	$57.70 \pm 5.95^{a,\ A}$	$57.14 \pm 5.82^{a,\ A}$
a*	Intensive	-0.98 ± 0.56^{ns}	-0.93 ± 0.55^{ns}	-1.20 ± 0.45^{ns}
	Extensive	-0.76 ± 0.40^{ns}	-1.06 ± 0.50^{ns}	-1.18 ± 1.49^{ns}
b*	Intensive	9.27 ± 0.05^{ns}	7.74 ± 0.45^{ns}	8.21 ± 0.85^{ns}
	Extensive	9.11 ± 0.56^{ns}	9.00 ± 0.35^{ns}	8.36 ± 0.37^{ns}
Biceps femoris m.				
L*	Intensive	$50.98 \pm 3.59^{a,A}$	$49.11 \pm 4.72^{a,A}$	$49.61 \pm 3.82^{a,A}$
	Extensive	$48.54 \pm 2.86^{b,B}$	$51.32 \pm 6.30^{ab,\ A}$	$52.15 \pm 5.61^{a,\ A}$
a*	Intensive	1.99 ± 0.89^{ns}	2.17 ± 0.39^{ns}	2.03 ± 0.46^{ns}
	Extensive	2.01 ± 0.80^{ns}	2.24 ± 0.64^{ns}	2.15 ± 1.03^{ns}
b*	Intensive	$4.21 \pm 1.34^{a,\ B}$	$4.19 \pm 1.87^{a,B}$	$3.28 \pm 1.76^{a,\ B}$
	Extensive	$5.29 \pm 1.83^{b,A}$	$7.63 \pm 2.24^{a,A}$	$4.65 \pm 2.28^{b,\ A}$

Data are presented as mean ± SD; n = 20 (5 birds x 4 determinations).

$^{a\text{-}b}$ Means with differing superscripts in the same row under the same type of muscles are significant difference ($p<0.05$).

$^{A\text{-}B}$ Means with differing superscripts in the same column under the same type of muscles are significant difference ($p<0.05$).

^{ns} = non significant difference ($p\geq0.05$).

1.4 Shear force

The effect of age and rearing system on shear force values of the *pectoralis major* and *biceps femoris* muscles are shown in Table 6. The shear values of the indigenous chicken *pectoralis major* muscle, both raw and cooked, were significantly increased with increasing aged of chicken in both rearing systems (p<0.05). Thai indigenous chicken *pectoralis major* muscle aged 18 weeks had the highest shear force value. For *biceps femoris* muscle, the increase in shear force value with the increasing age (p<0.05) was found only in cooked muscle. However, there was non significant difference in shear force value of raw *biceps femoris* muscle among age (p≥0.05). The indigenous chicken of both muscles reared under the extensive farming system had higher shear force than the intensive farming system especially in cooked *pectoralis major* muscle aged 18 weeks. This was probably due to the difference in muscle protein composition and structure of intramuscular connective tissue of muscles between rearing system. Wattanachant and Wattanachant (2007) found that the content of myofibrillar protein was obtained higher in Thai indigenous chicken muscle reared by intensive system. The intensive system also contributed to less thickness of perimysium in Thai indigenous chicken muscle (Wattanachant and Wattanachant 2007). This may be result in more tenderness of muscle reared with intensive system which could be postulated by lower in shear value.

1.5 Cooking loss

Cooking losses of Thai indigenous chicken *pectolaris major* and *biceps femoris* muscles were not significantly influenced by age or rearing system are shown in Table 7. Honikel and Hamm (1994) have reported the cooking losses of chicken *pectolaris major* muscle were in the range 25-35%. The cooking losses obtained from this study were in range 23.86-26.28% and 27.99-30.77% for *pectoralis major* and *biceps femoris* muscles, respectively. Wattanachant *et al*. (2004) reported cooking loss of Thai indigenous chicken at 28.54% for *biceps femoris* muscle and 23.00% for *pectoralis major* muscle. The *biceps femoris* muscle was significantly higher cooking loss and shear value than *pectoralis major* muscle. Difference in the cooking losses values in Thai indigenous chicken muscles could be attributed to differences in the total collagen and soluble collagen contents as influenced by muscle types (Table 4). Wattanachant *et al*. (2004) reported muscles that is less soluble collagen after heat denaturation the more highly cross-linked collagen.

Table 6 Effect of age and rearing system on shear force values of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles

Muscle	Ages (weeks)	Raw		Cooked	
		Intensive	Extensive	Intensive	Extensive
Pectoralis m.	16	2.31 ± 0.49$^{c, A}$	2.48 ± 0.62^{c,A}	2.21 ± 0.57$^{b, B}$	2.27 ± 0.98$^{c, A}$
	18	4.01 ± 0.59$^{a, A}$	4.37 ± 0.44$^{a, A}$	3.63 ± 1.16$^{a, B}$	4.73 ± 0.38$^{a, A}$
	20	3.03 ± 0.81$^{b, A}$	2.97 ± 0.97$^{b, A}$	2.56 ± 0.56$^{b, B}$	3.09 ± 1.35$^{b, A}$
Biceps femoris m.	16	6.31 ± 1.55^{ns}	5.70 ± 1.27^{ns}	3.06 ± 0.61$^{b, A}$	4.13 ± 0.86$^{a, A}$
	18	7.19 ± 2.58^{ns}	5.45 ± 1.04^{ns}	4.25 ± 0.65$^{a, A}$	4.44 ± 1.19$^{a, A}$
	20	6.81 ± 1.24^{ns}	5.72 ± 1.25^{ns}	4.52 ± 0.42$^{a, A}$	4.80 ± 0.98$^{a, A}$

Data are presented as mean ± SD; n = 15 (5 birds x 3 determinations).

$^{a\text{-}b}$ Means with differing superscripts in the same row under the same type of muscles are significant difference (*p*<0.05).

$^{A\text{-}B}$ Means with differing superscripts in the same column under the same type of muscles are significant difference (*p*<0.05).

^{ns} = non significant difference (*p*≥0.05).

Table 7 Effect of age and rearing system on cooking loss of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles

Muscle	Ages (weeks)	Cooking loss (%)	
		Intensive	Extensive
Pectoralis m.	16	25.84 ± 2.78^{ns}	25.62 ± 3.37^{ns}
	18	23.86 ± 1.08^{ns}	26.28 ± 2.33^{ns}
	20	26.08 ± 0.75^{ns}	25.64 ± 1.36^{ns}
Biceps femoris m.	16	27.99 ± 1.62^{ns}	28.22 ± 2.82^{ns}
	18	29.18 ± 6.76^{ns}	30.77 ± 5.09^{ns}
	20	29.68 ± 1.75^{ns}	28.14 ± 1.77^{ns}

Data are presented as mean ± SD; n = 15 (5 birds x 3 determinations).

^{ns} = non significant difference ($p \geq 0.05$).

1.6 Thermal denaturation

Effect of age and rearing system on transformation temperature and denaturation enthalpy of *pectoralis major* and *biceps femoris* muscles were investigated as shown in Table 8. The typical thermogram of protein denaturation of Thai indigenous chicken *pectoralis major* muscle from three ages had five endothermic peaks at peak temperature (Tp) of 55.4-56.5°C, 61.1-61.9°C, 65.6-66.7°C, 71.2-71.8°C and 77.6-77.9°C, respectively. While only three endothermic peaks were observed in *biceps femoris* muscle. The difference number of peaks could be attributed the denaturation of protein in difference temperature. The endothermic peak No.1 to 5 have been reported corresponding to the denaturation temperature and enthalpy of myosin (peak1), collagen (peak 2), sarcoplasmic protein (peak 3, 4) and actin (peak 5) (Kijowski and Mast, 1988; Murphy *et al*., 1998; Bircan and Baringer, 2002). However, the differences between the breast muscle thermoprofile with a higher proportion of white muscle fibers and the thigh muscle thermophile with more red fibers was not cleared. Kijowski and Mast (1988) studied chicken breast muscle of 7 weeks old chicken broilers have been reported to have 5 endothermic peaks at 57, 62, 67, 72 and 78°C while on thigh muscle had 3 transitions at 59.6, 65.6 and 75.8°C. These results were agreed with this study. Different results in Thai indigenous chicken were reported by Wattanachant *et al.*

(2005a) who found only endothermic peaks 1, 2 and 5. The difference in numbers of peaks could be due to the differences in source of raw material, age and storage of chicken meat (Murphy *et al*., 1998; Xiong and Brekke, 1989). Stabursvik and Martens (1980) concluded that greater differences were found between red and white muscle than between muscle from different animal species. The effect of rearing system and age had significant on transformation temperature and denaturation enthalpy only for peak No.1 of *pectoralis major* muscle and peak 2 and 5 of *biceps femoris* muscle were significant with increasing age (p<0.05). This result could elucidate that myosin of chicken *pectoralis major* muscle obtained from intensive rearing system had more heat resistance than that of extensive system. While protein collagen and actin of *biceps femoris* muscle increased their heat resistance according to the age of chicken muscle.

1.7 Microstructure of Thai indigenous chicken muscles

The result of quantitative structural measurements of raw Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles are shown in Table 9. The fiber diameter of Thai indigenous chicken muscles significantly increased with increasing age (p<0.01). The sarcomere length of muscle were significantly different among ages (p<0.01). There was no difference between the rearing system in the fiber diameter and sarcomere length of chicken muscles. Differences in muscles fiber diameter were possibly due to the difference in age, rate of rigor onset and degree of sarcomere shortening (Smith and Fletcher, 1988). Wattanachant *et al*. (2005a) reported the fiber diameter and sarcomere length of Thai indigenous chicken at age 16 weeks were 28.9±5.95 and 1.61±0.16 µm for *pectoralis major* muscle and 31.1±7.21 and 1.56±0.15 µm for *biceps femoris* muscle, respectively. The fiber diameter of *biceps femoris* muscle found in this study was smaller than previous research. The arrangement of fiber diameter from difference ages of Thai indigenous chicken is presented in Figure 1 and Figure 2. The fiber diameter of Thai indigenous chicken was greater with increasing age (Figure 1 and Figure2). The arrangement of muscle fiber raised in both rearing system had no significance. However, the effects of age were clearly observed in *biceps femoris* muscle. The fibers of chicken muscle aged 18 weeks were more compact than those of the other ages. This result related to the highest shear value at this age of chicken muscle.

The gab of muscle fiber were observed more in muscle at 20 weeks age. This might be due to the low in moisture content with increasing age and the loss of water holding capacity of muscle protein. More perimysium thickness of *biceps femoris* muscle compared to *pectoralis major* muscle was markedly noticed. This contributed to higher shear value in this muscle. On longitudinal sections (Figure3-4), no marked differences in microstructure were observed between rearing systems of *pectoralis major* and *biceps femoris* muscles.

Table 9 Effect of age and rearing system on microstructure of Thai indigenous chicken *pectoralis major* and *biceps femoris* muscles

Muscle	Age (weeks)	Fiber diameter (µm)		Sarcomere (µm)	
		Intensive	Extensive	Intensive	Extensive
Pectoralis m.	16	$28.97 \pm 3.27^{b,A}$	$28.77 \pm 2.04^{b,A}$	$1.58 \pm 0.04^{b,A}$	$1.57 \pm 0.04^{b,A}$
	18	$30.65 \pm 3.94^{a,A}$	$30.74 \pm 2.92^{a,A}$	$1.52 \pm 0.03^{c,A}$	$1.54 \pm 0.05^{c,A}$
	20	$31.04 \pm 3.27^{a,A}$	$31.22 \pm 2.93^{a,A}$	$1.60 \pm 0.07^{a,B}$	$1.71 \pm 0.08^{a,A}$
Biceps femoris m.	16	$21.29 \pm 2.87^{c,B}$	$23.02 \pm 3.15^{b,A}$	$1.53 \pm 0.16^{a,A}$	$1.60 \pm 0.15^{a,A}$
	18	$26.27 \pm 3.28^{a,A}$	$21.87 \pm 2.38^{c,B}$	$1.57 \pm 0.09^{a,A}$	$1.66 \pm 0.14^{a,A}$
	20	$24.22 \pm 2.94^{b,B}$	$25.45 \pm 2.67^{a,A}$	$1.56 \pm 0.05^{a,A}$	$1.50 \pm 0.07^{b,A}$

Data are presented as mean ± SD; n = 150 for measurement of sarcomere length and fiber diameter (5 birds x 3 video print x 10 areas).

$^{a-b}$ Means with differing superscripts in the same column under the same type of muscles under the same type of muscles are significant difference (p<0.05).

$^{A-B}$ Means with differing superscripts in the same row under the same type of muscles are significant difference (p<0.05).

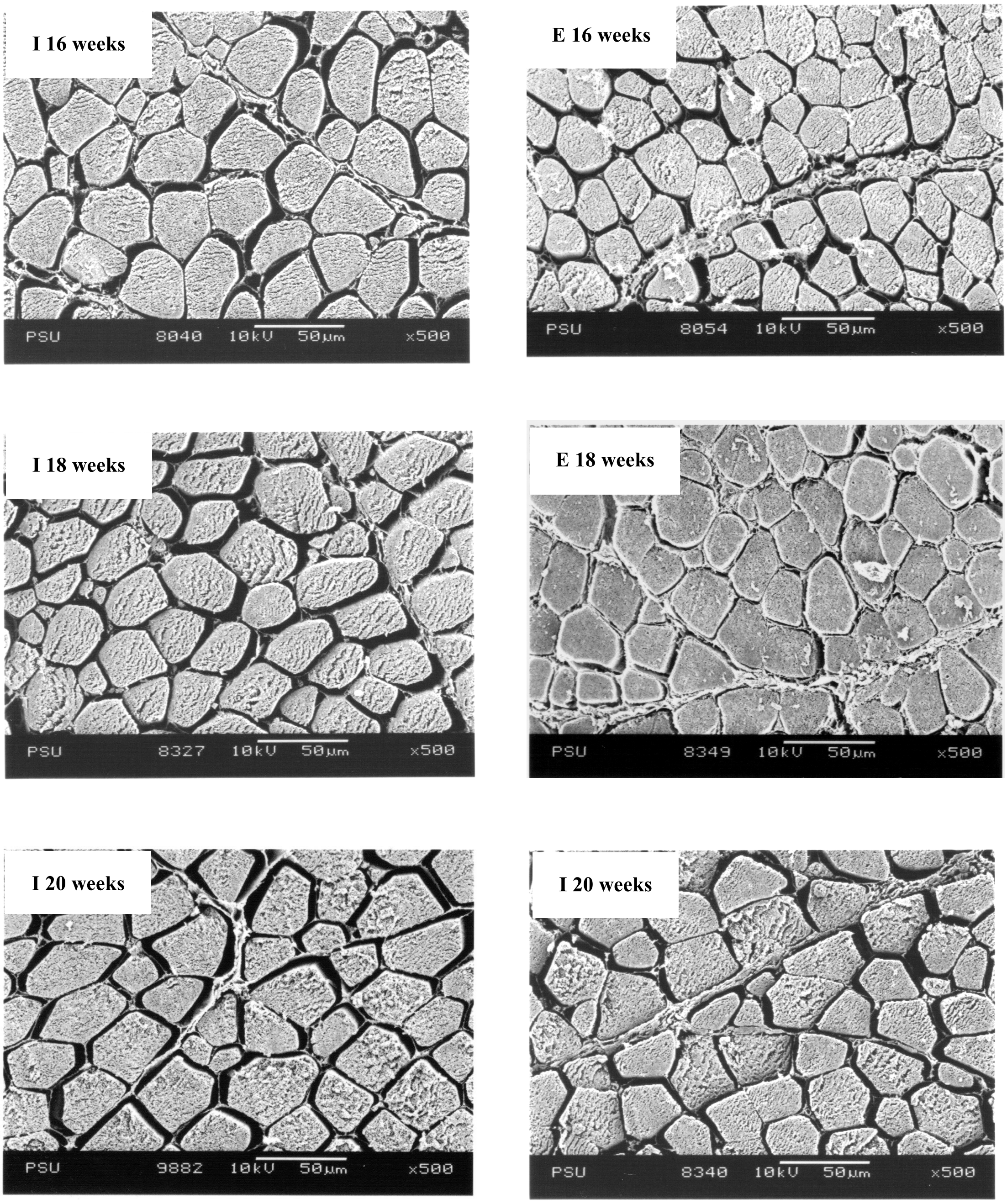

Figure 1 SEM micrographs of transverse sections at different age (16, 18 and 20 weeks) of indigenous chicken *pectoralis major* muscle reared under intensive (I) and extensive (E) systems.

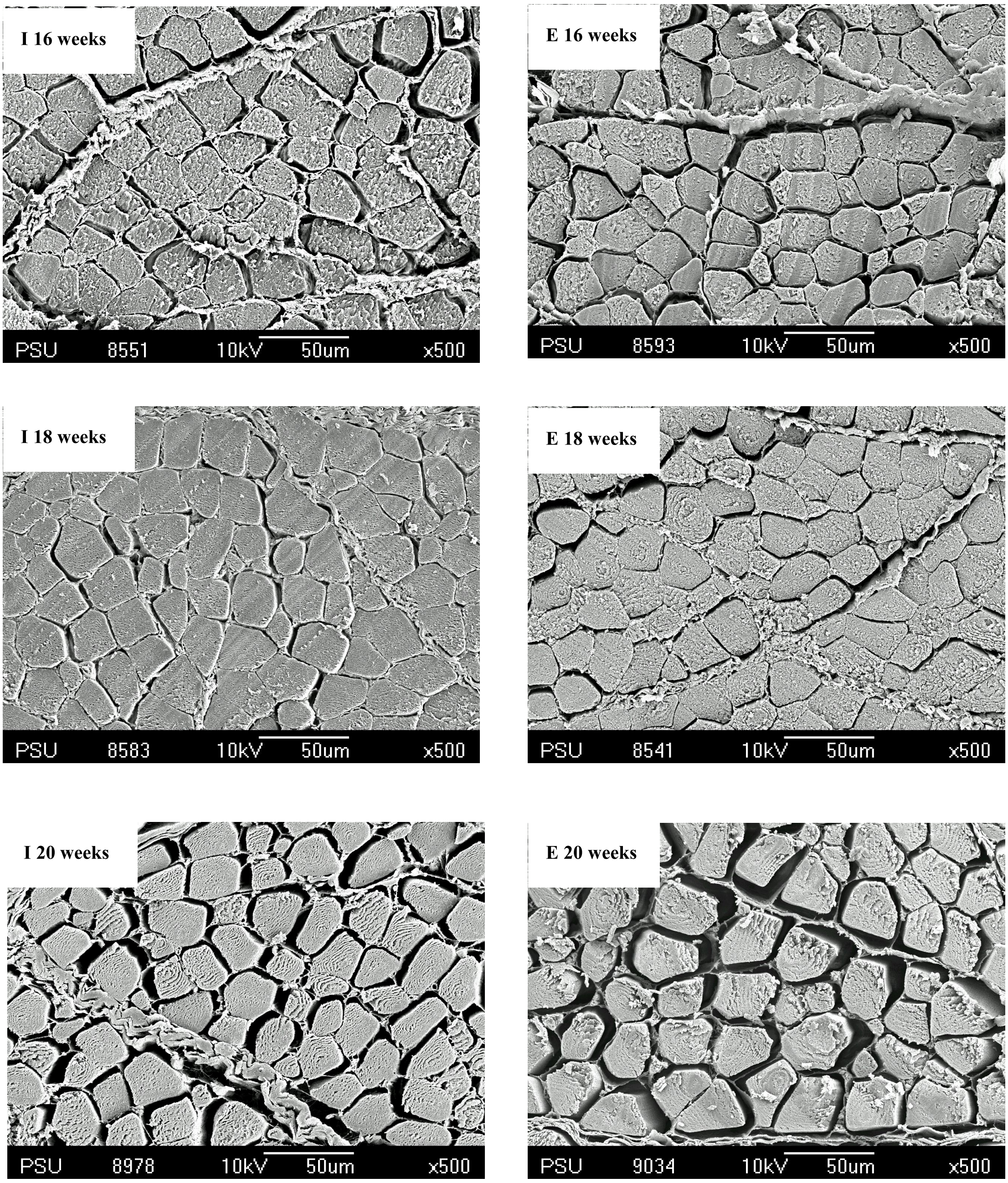

Figure 2 SEM micrographs of transverse sections at different age (16, 18 and 20 weeks) of indigenous chicken *biceps femoris* muscle reared under intensive (I) and extensive (E) systems.

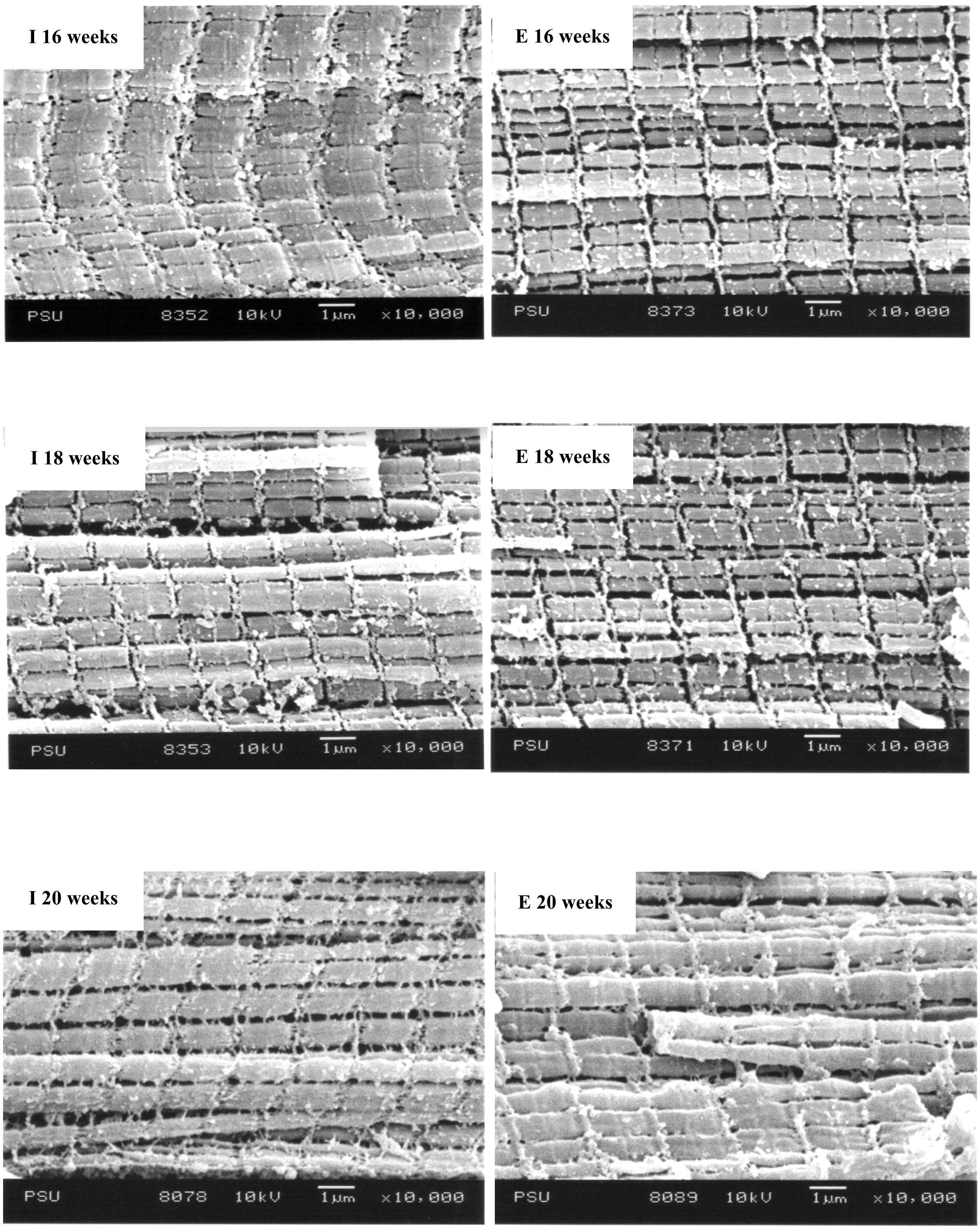

Figure 3 SEM micrographs of longitudinal sections at differing ages (16, 18 and 20 weeks) of indigenous chicken *pectoralis major* muscle reared under intensive (I) and extensive (E) systems.

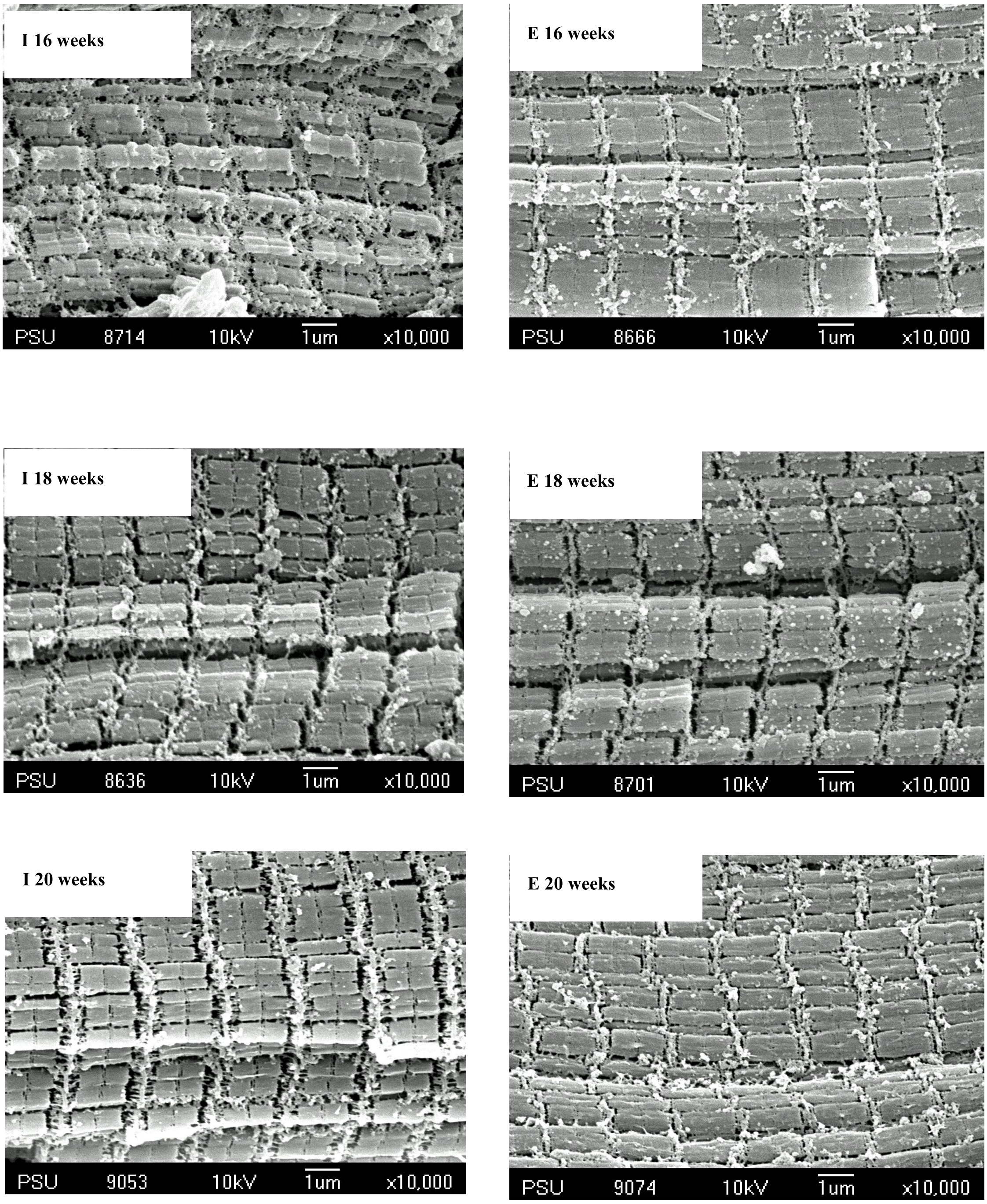

Figure 4 SEM micrographs of longitudinal sections at differing ages (16, 18 and 20 weeks) of indigenous chicken *biceps femoris* muscle reared under intensive (I) and extensive (E) systems.

The results of all treated Thai indigenous muscles showed that chicken meat quality within age ranges 16-20 weeks obtain from the intensive rearing system was less difference as compared to the meat obtain from extensive rearing system. The effect of age was more significance on chicken meat texture than the rearing system. Chicken muscles aged 18 weeks had the highest shear value and concomitant with more compact arrangement of muscle fiber among age ranges 16-20 weeks. Currently, rearing chicken with intensive system is really needed due to it is a close system that has more potential in protection H5N1 virus contamination. Therefore, chicken muscles reared under intensive system at age 18 weeks were selected for further study.

2. Chemical and physical properties of chicken meat from different breeds and muscle types

In Thailand broiler and Thai indigenous chicken produced commercially for meat consumption. However, the production of Thai indigenous chicken was uncertain and did not meet the demand of consumer in some situations. This may be caused by the lack of knowledge in farm management of the farmers which were mostly from small enterprises or individual homesteads. Chicken meat from spent hen, therefore, may be accepted from consumers to be substituted for indigenous chicken meat. This was probably due to both breeds chicken meat had similar firm texture. In this part of study was to determine comparatively the chemical and physical properties of chicken meat from those three breeds before and after heating in Tom Yum soup condition.

2.1 Chemical compositions

The proximate composition of Thai indigenous chicken, spent hen and broiler *pectoralis major* and *biceps femoris* muscles are presented in Table 10. Thai indigenous chicken muscles contained the highest protein and fat but the lowest in ash content, compared to spent hen and broiler (p<0.05). *Pectoralis major* muscle showed higher protein content than *biceps femoris* muscle in all breeds. Protein and fat content of Thai indigenous chicken muscles found in this study were higher compared to previous study by Wattanachant *et al*. (2004). This is probably due to the difference in raising system. Difference proximate compositions in chicken muscles were governed by many factors including age, species, breeds, growth stage and rearing system (Smith *et al*., 1993; Noppawan *et al*., 1998; Ding *et al*., 1999; Van Marle-Koster and Webb, 2000; Wattanachant *et al*., 2004).

Thai indigenous chicken and spent hen muscles contained higher total collagen but low soluble collagen than those of broiler muscles ($p<0.05$). Differences in the collagen contents among three breeds could be attributed to differences in the age of the bird at slaughter as well as their intrinsic property. It has also been shown that the heat solubility of collagen decreases with increase collagen cross-linking and cross-linking increases as animal ages (Dawson *et al.,* 1991).

Table 10 Chemical properties of raw chicken muscles from Thai indigenous chicken, spent hen and broiler

Properties	Breed		
	Indigenous	**Spent hen**	**Broiler**
Pectoralis m.			
Protein (%)	23.85 ± 0.41^{a}	20.34 ± 0.72^{b}	21.02 ± 0.31^{b}
Fat (%)	3.09 ± 0.26^{a}	1.64 ± 0.18^{b}	1.33 ± 0.21^{b}
Ash (%)	4.86 ± 0.32^{a}	0.19 ± 0.84^{c}	1.44 ± 0.30^{b}
Moisture (%)	73.46 ± 1.15^{b}	74.83 ± 0.15^{b}	76.62 ± 0.37^{a}
Total collagen (mg/g muscle)	8.75 ± 2.82^{a}	7.47 ± 2.79^{a}	3.93 ± 1.69^{b}
Soluble collagen (% of total collagen)	24.50 ± 3.02^{ab}	19.14 ± 0.48^{b}	29.36 ± 0.87^{a}
Biceps femoris m.			
Protein (%)	17.81 ± 1.13^{a}	16.44 ± 0.65^{b}	16.98 ± 0.32^{b}
Fat (%)	1.55 ± 0.78^{b}	1.28 ± 0.35^{a}	0.51 ± 0.14^{b}
Ash (%)	0.95 ± 0.06^{a}	1.29 ± 1.60^{a}	1.43 ± 1.34^{a}
Moisture (%)	79.27 ± 0.33^{a}	79.42 ± 0.81^{a}	77.30 ± 0.66^{b}
Total collagen (mg/g muscle)	11.02 ± 0.50^{b}	13.11 ± 1.77^{a}	9.59 ± 1.87^{b}
Soluble collagen (% of total collagen)	23.09 ± 5.43^{b}	16.02 ± 2.45^{b}	31.61 ± 1.98^{a}

$^{a-c}$ Means with differing superscripts in the same row are significantly different ($p<0.05$); n = 10 (5 birds x 2 determinations).

2.2 Physical properties

Physical properties of all chicken breeds are shown in Table 11. The shear force values of the indigenous chicken and spent hen muscles were significantly higher than broiler muscles. The *biceps femoris* muscle has been reported to be tougher than *pectoralis major* muscle, which is concomitant with shear value found in this study (Liu *et al*., 1996; Wattanachant *et al*., 2004). The highest cooking loss was found in spent hen *biceps femoris* muscle. This is probably related to the difference in content of collagen between chicken breed and age slaughter. In addition, the muscle proteins of spent hen might be less heat resistance than those of other chickens. This hypothesis could be elucidated by the result of thermal denaturation of three breeds chicken muscles from DSC (Table 12). The spent hen *pectoralis major* and *biceps femoris* muscles had the lowest endothermic peak temperature for peak 1 and 3 as compared to indigenous chicken and broiler muscles (p<0.05). This result corresponding to myosin and sarcoplasmic protein of spent hen muscles were denatured at lower temperature than those of broiler and indigenous chicken. The *pectoralis major* muscle of spent hen and indigenous chicken had significantly lower denaturation temperature of protein collagen (peak 2) than the broiler muscle (p< 0.05). Therefore, during cooking spent hen muscles, the denatured collagen with less soluble would shrink and squeeze the denatured myosin with loss of water holding capacity leading to higher cooking loss in this breed of chicken muscle. Thai indigenous chicken and spent hen *pectoralis major* muscle had higher L* and b* value than broiler *pectoralis major* muscle (p<0.05). However, the *biceps femoris* muscle of spent hen had less a* value than the others. This result was probably related to significant difference in muscle pH among the breeds. Muscle pH and meat colour are highly correlated. Higher muscle pH is associated with darker meat than that of lower pH (Allen *et al*., 1998; Fletcher, 1999a, b). The high ultimate pH in broiler muscles especially in *biceps femoris* muscle has been reported by Wattanachant *et al*. (2004).

Table 11 Physical properties of raw chicken muscles from Thai indigenous chicken, spent hen and broiler

Properties	Breed		
	Indigenous	Spent hen	Broiler
Pectoralis m.			
Cooking loss (%)	23.86 ± 1.08[a]	24.07 ± 2.59[a]	20.39 ± 1.42[b]
Shear force (kg)	4.01 ± 0.59[b]	3.14 ± 1.19[a]	1.59 ± 0.17[c]
pH	5.93 ± 0.01[c]	6.05 ± 0.02[b]	6.23 ± 0.01[a]
Color			
L*	59.47 ± 2.62[a]	47.79 ± 3.41[b]	42.48 ± 3.49[c]
a*	-1.20 ± 0.41[b]	-0.73 ± 1.68[b]	1.44 ± 1.45[a]
b*	9.10 ± 1.48[a]	7.74 ± 2.73[a]	9.43 ± 1.75[a]
Sarcomere length (µm)	1.52 ± 0.03[b]	1.62 ± 0.14[a]	1.55 ± 0.88[b]
Fiber diameter (µm)	30.65 ± 3.94[b]	33.01 ± 3.87[a]	29.22 ± 3.20[b]
Biceps femoris m.			
Cooking loss (%)	27.99 ± 1.62[b]	34.91 ± 1.50[a]	18.59 ± 2.84[b]
Shear force (kg)	7.19 ± 2.58[a]	7.24 ± 1.50[a]	3.99 ± 1.03[b]
pH	6.06 ± 0.06[b]	6.22 ± 0.07[a]	6.25 ± 0.02[a]
Color			
L*	48.54 ± 2.86[a]	48.13 ± 4.01[a]	43.84 ± 2.93[b]
a*	0.16 ± 1.20[a]	-0.77 ± 1.11[a]	0.09 ± 0.63[a]
b*	5.29 ± 1.83[a]	5.70 ± 2.44[a]	6.35 ± 1.64[a]
Sarcomere length (µm)	1.57 ± 0.09[b]	1.64 ± 0.93[a]	1.61 ± 0.13[a]
Fiber diameter (µm)	26.27 ± 3.28[c]	34.36 ± 2.92[a]	26.45 ± 2.78[b]

[a-c] Means with differing superscripts in the same row are significantly different (p<0.05); n = 10 (5 birds x 2 determinations) for cooking loss, shear force and pH; n = 20 (5 birds x 4 determinations) for color; n = 150 (5 birds x 30 determinations) for sarcomere length and fiber diameter.

2.3 Microstructure of muscles

The results of quantitative structural measurements of raw Thai indigenous, spent hen and broiler chicken *pectoralis major* and *biceps femoris* muscles are presented in Table 11. The means of sarcomere lengths of the raw muscles from three breeds were significant difference (p<0.05) in ranges of 1.55-1.62 µm for *pectoralis major* muscle and 1.53-1.64 µm for *biceps femoris* muscle. *Biceps femoris* muscle of indigenous chicken had the shortest sarcomere length compared to those of the others (p<0.05). The sarcomere length of both muscle types was in range 1.56-1.64 µm for Thai indigenous chicken and broiler muscles have been reported by Wattanachant *et al*. (2005a).

The fiber diameter of spent hen muscles was larger than Thai indigenous and broiler chicken muscles, respectively (p<0.05). Fiber diameter of *pectoralis major* muscle from Thai indigenous chicken and spent hen was larger than the fiber diameter of *biceps femoris* muscles while opposite result were obtained from the broiler. The average diameter of chicken muscle white fiber has been reported to be 38-46 µm (Smith and Fletcher, 1988) and 26-28 µm (Wattanachant *et al*., 2005a). These differences in muscle fiber diameter were possibly due to the differences in age, rate of rigor on set and degree of sarcomere shortening (Smith and Fletcher, 1988).

The SEM micrographs of transverse sections of three breeds chicken muscles are performed in Figure 5. Bigger, more compact and dry coarseness muscle fibers were clearly seen in spent hen muscles. More thickness with many sheets of perimysium connective tissue was observed in this breed of chicken muscle. This might contributed to the higher shear value in muscle than those of other breeds. For longitudinal section (Figure 6), myofilaments of spent hen muscle showed more tight arrangement and had thicker Z-disk as compared to broiler and indigenous chicken muscles. This result could be attributed the stronger texture of muscle from the spent hen.

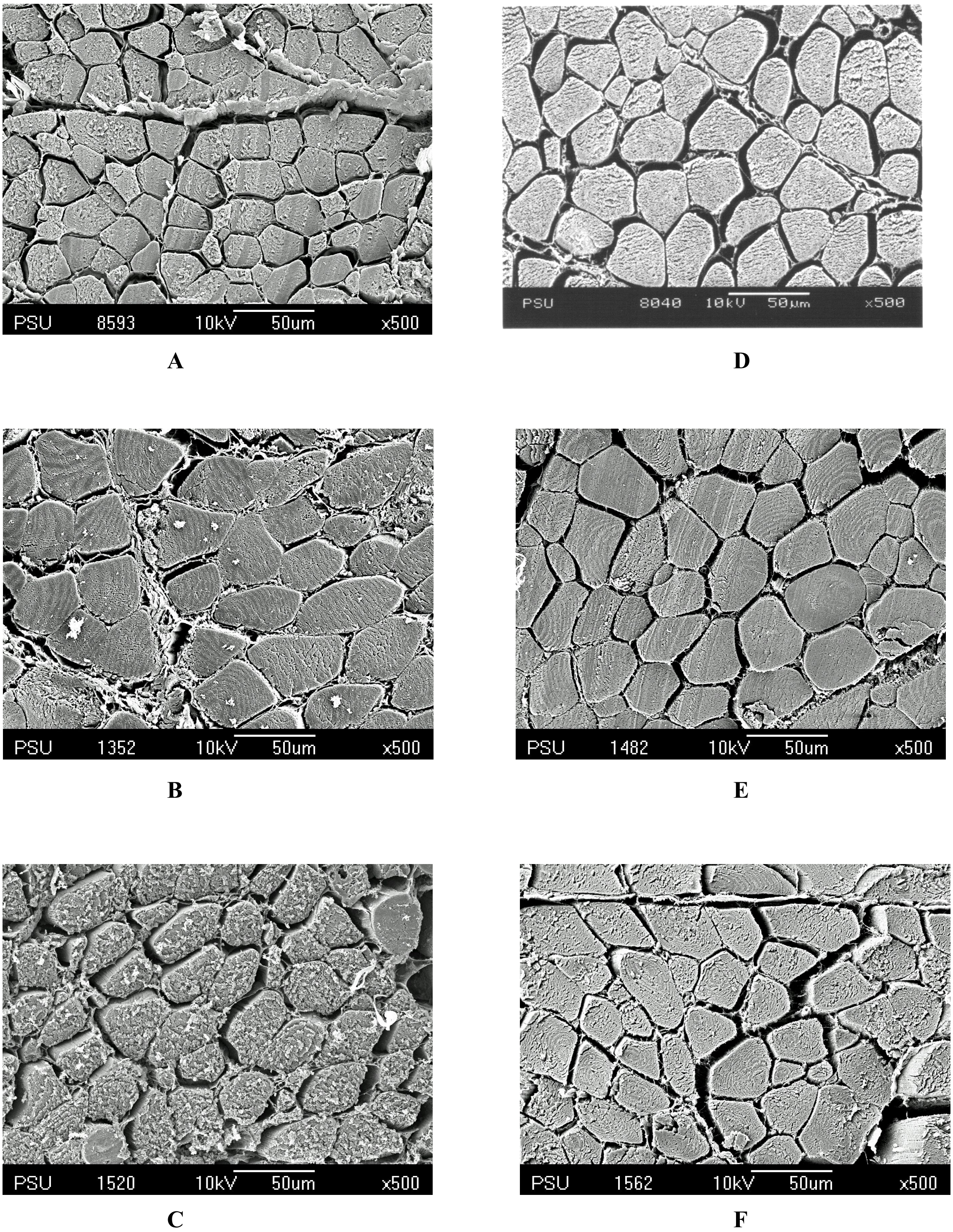

Figure 5 SEM micrographs of transverse sections of chicken muscles; *pectoralis major* muscle of Thai indigenous chicken (A), spent hen (B) and broiler (C); *biceps femoris* muscle of Thai indigenous chicken (D), spent hen (E) and broiler (F).

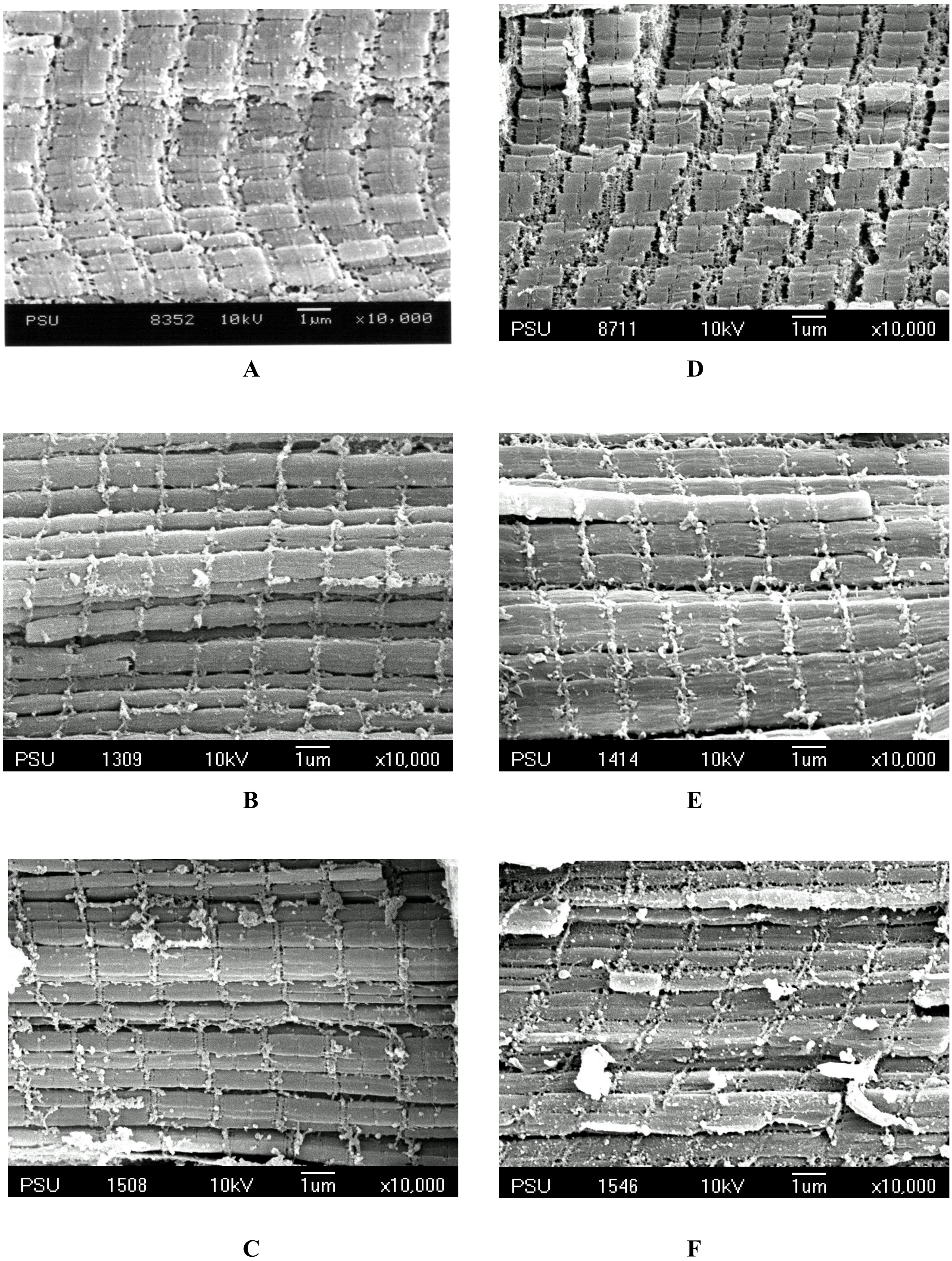

Figure 6 SEM micrographs of longitudinal sections of chicken muscles; *pectoralis major* muscle of Thai indigenous chicken (A), spent hen (B) and broiler (C); *biceps femoris* muscle of Thai indigenous chicken (D), spent hen (E) and broiler (F).