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Original article

ANIMAL BIOTECHNOLOGY: PIG MUSCLE PART II, SIGNIFICANCE OF MUSCLE FIBER TYPES ON MUSCLE PERFORMANCE AND MEAT QUALITY IN PIGS

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Abstract Muscle fibers, represented by the content of four different myosin heavy chain isoforms, are responsible for the variation of growth performance and meat quality traits in farm animals. While total number of fibers is clearly evidenced to have a positive correlation with muscle mass, the functions of cross-sectional area and myofiber size to muscle growth are still controversial or poorly understood. For meat quality traits, although soft, pale and excudative pork contained the highest of type IIx/IIb fiber proportion, effects of pure type IIx and IIb fibers on water-holding capacity still deserve for further research. Results on the effect of fiber composition on ultimate pH, are inconsistent due to different pig breeds and kinds of muscle used in the study. Also, it is still unclear on the relationship between histological characteristics and sensory pork quality like intramuscular fat. All together, in spite of contradictory results found, muscle fiber traits have been used as additional selection criteria for muscle growth and meat quality in pigs. **Chiang Mai Veterinary Journal 2007;5(2):159-166**

Keyword: muscle fiber**,** meat quality, pig

Four out of eight muscle fiber-isoforms known in mammals have been identified in porcine muscle according to their specific expression of myosin heavy chain (MyHC)(1). Based on their metabolic and myosin adenosine triphosphatase(mAT Pase) activity, these fibers, each encoded by an individual gene, are categorized as slow-oxidative and fast-glycolytic (slow type I and IIb fiber, respectively),standing for extreme metabolic profiles. The type IIa and IIx fibers are defined as intermediates with the transition that type IIa fibers are more similar to type I and IIx fibers are more in relation to type IIb fibers(2,3). In the pig, type I fibers are found on chromosome 7 in one cluster, whereas type IIa, IIx and IIb fibers are located on chromosome 12(4). Different locations make them distinct function, different contribution to muscle mass and different effects on meat quality. Study on the relationship between muscle fiber types, muscle growth and meat quality traits are therefore needed in order to increase production efficiency as well as improve meat quality

Significance of muscle fiber types for growth performance

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There have been attempts to investigate the relationships between muscle fiber frequencies and muscle size or muscle performance in pigs [5,6]. It is well documented that total number of fibers (TNF), fiber cross-sectional area (CSA) and muscle length are important parameters to muscle characteristics as well as muscle weight[7].

Total number of fibers and muscle growth

In most cases, the TNF, a factor positively related to muscle growth poten-tial in pigs, remains unchanged after birth[8] and thus within a muscle, muscle fiber hypertrophy is dependent on the TNF. Klosowska and Fiedler (2003)[9] suggested an evidence that higher level of hypoplasia of individual fibers or higher number of TNF can be responsible for a higher meat content. This was in line with previously reported data by 2 research groups[10,11], who found a positive corre-lation between TNF and carcass lean meat content. Supportably, Fiedler et al. (2004)[12] investigated that live weight and loin muscle area are positively related to TNF and frequency of white fibers. In Meishan pigs, a lower TNF was shown to result in smaller semitendinosus muscle at birth and later affect on the proportion of white fibers[13]. All together, it is clear that TNF is significantly important to muscle size or muscle performance.

Fiber cross-sectional area and muscle performance

On the other hand, the correlation between CSA and muscle mass is controversial probably because of the fact that lean meat content is mainly influenced by TNF, a highly variable trait[14]. For example, Henckel et al. (1997)[6] reported a positive correlation between muscle gain and the oxidative enzyme citrate synthesis and the muscle capillarity of Large White and Landrace pigs. Additionally, daily gain was found to have a tightly link with CSA of type I fiber[15]. Conversely, Larzul et al. (1997)[16] were not able to point out any significant connection between CSA of individual fibers and average daily gain within the Large White breed. In most studies, glycolytic fibers are shown to exhibit the large CSA implying that, for a given TNF, an increase in muscle weight would be expected when the proportion of glycolytic fibers increases[7]. Moreover, the relationship between fiber diameters and perimeters were high and positively related to muscle fibers and hence it was concluded that fiber type proportion is more closely involved in their numerical abundance than their CSA[17]. Linear phenotypic correlation coefficients among those elements are presented in Fig 1.

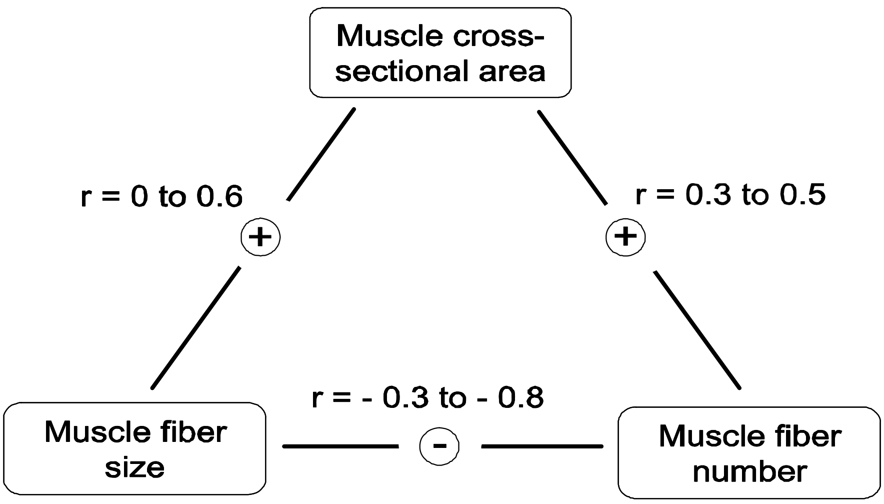

Fig 1. Relationships by linear phenotypic correlation coefficients between muscle cross-section area, muscle fiber size and muscle fiber number per cross-section (Adapted from Rehfeldt et al., 2000[19]).

In this figure, it is clearly shown that muscle cross-sectional area is positively correlated with both the size and the number of muscle fibers. However, these values are in a wide range, which means that there is a large variation in the number of total fibers as well as their growth rates even within the same litter[18]. Furthermore, the negative correlation between fiber number and fiber size can be explained by the equal distribution of energy in all fibers, but still there are animals highly exhibited not only fast-growing fibers but also fiber numbers as the value did not reach -1.0[19].

Myofiber length and muscle mass

Studies of myofiber length in different fibers have not been well documented, exclusive of a recent research done by Christensen et al. (2006)[20], who found shorter sarcomere in type IIb than type I fibers isolated from longissimus dorssi muscle. This might contribute to the defined as a combination of fresh meat or the degree of satisfaction of consumers to a given variation or differences in the mechanical properties of muscle fibers.

Significant of muscle fibers on meat quality

Muscle fiber composition is on one way affected by growth rate and, on the other, itself affects the muscle mass. Meat quality can be meat. Meat quality is accessed by measuring biophy-sical and chemical properties such as water holding capacity, color and light reflectance, pH, pigment content, shear force, intramuscular fat content and protein extractability[21] as well as eating quality and post-mortem maturation of the meat[7].The correlation coefficients between muscle fibers and these factors appear in the wide ranges, some of which are listed in Table 1.

Table 1. Correlation coefficients (r) between proportion of muscle fibers and meat quality traits[3,6,16,22,23]

Item	Muscle fiber types			
	MyHC I	MyHC IIa	MyHC IIx	MyHC IIb
pH24	-0.46 to 0.20	0.02 to 0.28	0.10 to 0.30	-0.23 to 0.11
Drip	-0.04 to -0.06	-0.28 to 0.00	-0.40	-0.04 to 0.36
Shear force	-0.34 to 0.23	-0.05 to 0.13	n.a	-0.04 to -0.13
IMF	0.00 to 0.04	-0.04 to -0.31	-0.03	0.03 to 0.21
Lightness (L*)	-0.12 to 0.02	-0.07 to 0.14	-0.09 to 0.10	-0.19 to 0.27
Redness (a*)	-0.08 to 0.44	-0.10 to 0.62	0.03	-0.14 to -0.48
Yellowness (b*)	-0.16 to 0.29	0.04 to 0.33	0.36	-0.35 to 0.07
Juiciness	-0.01 to 0.09	-0.20 to 0.09	na	0.05
Tenderness	-0.06 to 0.10	-0.22 to 0.05	na	0.01 to 0.06

na: not available

Water-holding capacity

A possible definition of water-holding capacity (WHC) is the ability of meat or meat systems to retain all water or part of its own and/or added water[24]. This ability relies on the handling method and the state of the system, and is important because muscle contains approxi-ately 75% water and other components such as protein (20%), lipids (5%), carbohydrate (1%) and vitamins and minerals (1%)[25]. In highly processed pork products, the higher the WHC, the more valuable will the pork be. However, the levels of WHC vary among muscles likely because of the differences in postmortem degradation of intermediate filament proteins, and thus it was hypothesized that greater WHC would be achieved when rapid degra-dation of intermyofibril linkages (des-min)occurred[26]. The understanding about the relationship between muscle fiber type distribution and WHC is still poor, although WHC is one of major factors directly related to fresh pork, with pale soft and exudative (PSE) and dark, firm and dry (DFD) being the extreme types of meat. Accor-ing to metabolic rate, Ryu and Kim (2006)[27] deter-mined a difference in type I fiber composition with an increased percentage from fast to slow metabolic group. A lower percent-tage of type IIa fibers in PSE than in DFD pork were also mentioned. Particularly, fast-glycolyzing PSE pork contained the highest proportion of type IIx/IIb fiber, which may be more prone to undesirable pork because of its anaerobic nature, greater glycogen content and lower pH at 24 h post-mortem (ultimate pH; pHu) [27,28]. However, as suggested by Ryu and Kim (2006) [27], further research is needed to clarify the functions of pure type IIx and IIb fibers on meat quality traits.

Acid-base (pH)

Measurements of pH at 45 min post-mortem (pH1) and pHu can indicate the rate and extent of post-mortem glycolysis and are good indicators of meat quality. After slaughter, glycogen is metaboliszed into lactic acid, which is accumulated in the muscle. As a result of increasing lactic acid concentration in a still-warm muscle, the biophysical properties of meat are altered leading to PSE. A series of studies have demonstrated the relation of fiber type compositions and the rate and extent of post-mortem pH decline. In 1999, Karlsson et al.[21] stated that high frequency of glycogen depleted in fibers at slaughter, in particular, type IIb fibers will have an influence on meat quality. Unexpectedly, Larzul et al. (1997)[16] found no significant correlation between fiber traits and pHu although IIb fibers were investi-ated to contain more glycogen than other types of fibers[29,30]. In contrast, Ryu and Kim (2005)[22] and Matin et al. (1997)[31] men-ioned a significant inverse relation between pHu, type IIb fibers as well as a positive link between pHu and the oxidative capacity and the area of slow fibers. In the context of pHu values, the view that oxidative fibers are esirable in meat quality was supported by Chang et al. (2003)[3], who demonstrated greater abundance of type IIa and IIx fibers with higher pHu in psoar muscle. Given these points, the inconsistency on the effects of fiber composition on pH changes may originally come from different pig breeds and kinds of muscle used in those studies. Indeed, in an attempt to compare the changes of pH among pig muscles, Lefaucheur (2006)[14] concluded that fiber type composition is far related to the rate of post-mortem pH decline, but closely associated with the extent of post-mortem pH decline with the evidence of decreasing pHu when the proportion of fast glycolytic fibers increases.

Intramuscular fat

The intramuscular fat is an important charac-teristic in evaluation of sensory quality. Intra-muscular fat is composed of two major cons-tituents triglycerides and phospholipids repre-senting more than 50% of fresh pig longissimus muscle[32,33]. Despite intensive research, it is still unclear on the relationship between histological characteristics and sensory pork quality. It was observed that intramuscular fat values are closely related to triglyceride content in the muscle, which in turn negatively associated with mean fiber area[21] and that neutral lipids are contained in all type I fibers but only in about

26% of type IIa and 1% of type IIb fibers. In a comparison on muscle fiber characteristics of eight different breeding populations, Maltin et al. (1997)[31] indicated a significant contribution of fast twitch oxidative glycolytic fibers to the variation of meat tenderness. More specifically, Essen-Gustavsson et al. (1994)[34] found lipids present mainly in type I and some type IIa fibers, whereas Henckel et al. (1997)[6] reported the frequency of type IIb fiber and intramuscular fat content are positively corre-lated and thus flavor and tenderness, seemed to have a negative relationship with type IIa, but positive correlation with type IIb fibers. Interestingly, in a sensory test by taste panels, the meat from half-Chinese crossbred pigs offered more tender, juicy and tasty than that from European pigs. However, in a consumer's survey Touraille et al. (1989)[35] found no difference in the overall acceptability between two pork sources. In contrast to data regarding total intramuscular fat content, muscle fiber proportion is also related to the nature of phospholipids, which is shown to present more in oxidative than glycol-lytic muscles[32]. Because phosphor-lipids are determinants of cooked meat flavor, muscle fiber is likely to have an effect on flavor but further studies are encouraged to unravel this correlation.

Meat tenderness

Meat tenderness is influenced by many factors including the physical size of muscle bundle and the amount of connective tissue and fat. Historically, researches on pork tenderness have received little attention since it was considered to be relatively tender, but in practice this trait varied among muscle and animals[36]. The extent to which meat tenderizes can be accessed by shear force measurement because of their rather high correlation[37,38]. In pigs, shear force has been detected to have low correlation with muscle fiber percent-tage[6,23]. However, when taking only type I fibers into consideration, both a nega-tive[3] and a positive[22] correlation between this fiber type and shear force of cooked pork LD muscle have been reported. Previous findings also demonstrated that fast glycolytic fibers (type IIb) are negatively related with toughness in pigs[39] and cattle[40]. In fact, increasing the proportion of type I fibers were considered to improve tenderness and juiciness in cattle [41]. Nevertheless, in normal cattle breeds, no correlations found between fiber characteristics and meat quality traits[42], including tender-ness[43]. Despite variable and sometimes controversial results, there is evidence suggesting the relationship between muscle fiber characteristics and meat tenderness, especially in pork[30].

Meat color

Another important quality para-meter, lightness, was discovered to be negatively related to type I and IIa fiber percentages implying that a decrease in these two types would lead to increasing lightness[22]. Similarly, in a F2 population Duroc x Berlin Miniature Pig, it was found that type IIb fibers are accom-panied with a light color and high conductivity [44]. These two findings are also in agreement with results from a study by Larzul et al. 1997 [45], who demonstrated that lightness (L*) is positively related to the percentage of white fibers and negatively to the percentage of red fibers which are in line with the their color cha-racteristics. Not surprisingly, this may reflect the amount of myoglobin found in the tissues as similar results were additionally reported by Depreux et al. 2002[46]. However, there was no evidence on the relationship between muscle fiber and fiber charac-teristics with both L* and a* (redness) values[31]. The discrepancy on the effect of muscle fiber on L* data between two studies might come from the selection of pigs with the presence of absence of halothane positive (nn) as this genotype offered a signify-cantly higher L* value[46]. In short, these findings have evidenced and clarified the effects of muscle fibers on meat color accordingly with the metabolic charac-teristics of individual fiber.

Conclusion

In most studies, muscle fiber size shows a positive relation with muscle weight and loin eye muscle area but is conversely related to properties of meat post-mortem. The complex correlation among muscle fiber size, cross-sectional area and fiber number make animal breeders difficult in selection. However, it is possible to include muscle fiber characteristics in breeding programs to improve meat quality but preserve optimal production traits[21]. Results from a simulated selection on the use of muscle fiber traits as additional selection criteria for muscle growth and meat quality[12] strongly support this view and thereby stimulate more detailed studies on muscle fiber type especially on physiological mechanisms so that these characteristics can be effectively exploited in animal breeding programs.

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