

Pork Fat Quality: A Processor's Perspective

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Jack Sprat could eat no fat, his wife could eat no lean, and so betwixt the 2 of them, they licked the platter clean (English rhyme, 1639).

Fat, or more specifically, the adipose tissue of pigs, is an important component of meat along with the other major components including protein, water, and ash. These exist in various proportions throughout the pig carcass. Much of the carcass fat exists in the subcutaneous depots that surround the major wholesale cuts, and other fat exists in the intermuscular fat depots lying between the muscles. A third depot is the fat located in the intramuscular (interfascicular) spaces, commonly called marbling. Much of the subcutaneous fat is trimmed from the wholesale and individual cuts and included in meat trims.

Pork Adipose Tissue: Background

Fat Quality

Definitions of quality for pork fat may differ among the users of the fat, but in general include such things as color, texture, composition, firmness, oxidative stability, flavor, continuity/fracturability, and nutritional considerations. A series of analytical measures have been used to describe the quality of animal fats; these include color, free fatty acid content (measure of degree of acylglyceride hydrolysis), iodine value or number (degree of unsaturation; grams of iodine absorbed/100 g of fat), moisture/unsaponifiable/impurities (measure of non-triacylglyceride materials), peroxide value (**PV**; abuse and degradation of the fatty acids), and saponification value (measure of fatty acid chain length; Haas, 2005). Some of these measures are more applicable in some situations than others. Iodine value (**IV**) has been used particularly for determination of the influences of dietary changes on the degree of satura-

tion of pork back fat (Wood, 1984; Gatlin et al., 2005; Latour et al., 2008; Wood et al., 2008) and is somewhat established as a standard objective measure. However, IV may not tell the whole story, as will be discussed below. Other methods of fat evaluation are available, but have not garnered the same acceptance as the IV value for various reasons, such as lack of standardization or their inherent empirical nature, but are used nonetheless in unofficial occasions. These include measures of fat firmness and can be made using subjective firmness scales and the Oscar Mayer belly "flop" test and its variations.

Pork Adipose Tissues

Adipose tissue is derived from mesenchyme cells that differentiate into loose connective tissue. These cells, called adipocytes, fill with lipid as the pig matures and fattens and exist in small groups. If the tissue consists almost entirely of these fat cells and is arranged in lobules, the tissue is called adipose tissue (Lawrence and Fowler, 2002). Lawrence and Fowler (2002) note further that 1) the lobules of fat cells are separated from each other by partitions of loose connective tissue (called septa), 2) the septa form the stroma of connective tissue and are responsible for carrying the nerves and blood vessels that are in intimate contact with the adipocytes, 3) adipose consists of 95% fat cells and 5% nonfat cells, 4) the lipid contained in adipose is primarily the depot fat (mainly triacylglycerides) and membrane lipids (phospholipids), 5) fat cells are supported by a network of reticular and collagenous fibers, and 6) fatty acids stored in the adipose are primarily synthesized in the adipose tissue in pigs, with the liver participating to a limited extent.

Types of Adipose Tissue

Two major types of adipose tissue exist (Table 1). They differ in several major ways, but primarily because brown adipose has metabolic activity responsible for heat generation and white adipose does not. The primary type of interest is the white adipose generally used for fat storage.

Fatty Acid Composition of Pork Adipose Tissue

Adipose tissue in mature animals is packed with different lipids in proportionately different concentrations. These lipids determine the physical characteristics of the fat we are interested in. For example, triacylglycerides

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Proceedings of the 61st American Meat Science Association
Reciprocal Meat Conference (pp. 1-7)
June 22-25, 2008, Gainesville, Florida
www.meatscience.org

Table 1. Characteristics of white and brown adipose tissue.¹

Character	White adipose tissue	Brown adipose tissue
Cell shape and size	Spherical and large (up to 120 µm) with small rim of cytoplasm and flattened peripheral nucleus.	Polygonal and smaller (25 to 40 µm) in diameter and 8 to 32 pl in volume) with a greater cytoplasm to lipid ratio, with the cytoplasm not reduced to an outer rim and with the nucleus sometimes eccentric in position but not flattened at the cell periphery.
Type of lipid	Proportionately 0.98 to 0.99 of lipid occurs as triglyceride. With the exception of stearic acid, which is less in this tissue, fatty acid make-up of triglycerides is similar to that in brown adipose tissue in several species.	Proportionately 0.75 to 0.90 of lipid as triglyceride with phospholipids forming a high proportion of other lipid.
Gross appearance of lipid	Triglycerides form one large amorphous fat vacuole of lipid.	Triglycerides form many lipid droplets and cells contain many mitochondria.
Fatty acid oxidation	Fatty acids are mobilized and transported via the plasma to the liver and to peripheral tissues for oxidation.	Fatty acids are oxidized in situ without concomitant stoichiometric ATP synthesis resulting in the energy release appearing as heat.
Vascularity	Not prominent	Prominent vascular network with characteristic venous drainage, which is a factor in allowing the quick release of heat for oxidative processes.
Frequency of occurrence	High. Most abundant adipose tissue occurring at many sites within the body.	Low. Relatively small quantities occurring in more specific sites.
Responses to adipokinetics (e.g., catecholamines)	Positive response	No response

¹Lawrence and Fowler (2002).

make up 90 to 98%, with small amounts of diglycerides (1 to 2%), phospholipids (<1%), and cholesterol (<1%; Lawrence and Fowler, 2002). However, this not the case in younger, immature animals, where the adipose differs because it is not packed full of triacylglycerides. The adipose in younger animals contains a high proportion of water that decreases with age as the animal fattens (Figure

1). These changes in gross composition can have dramatic consequences for the commercially important characteristics of fat. In such immature animals fat is distributed in small adipocytes that feel soft and wet to the touch when compared with mature adipose tissue. Not only is the fat softer and wetter, but it also separates very easily from muscle tissue and also from other lobules of adipose

Table 2. Nomenclature of fatty acids in commodity oils and fats.¹

Fatty acid	Common name	Formula	Relative chain length
4:0	butyric	CH ₃ (CH ₂) ₂ CO ₂ H	short
6:0	caproic	CH ₃ (CH ₂) ₄ CO ₂ H	short
8:0	caprylic	CH ₃ (CH ₂) ₆ CO ₂ H	short/medium
10:0	capric	CH ₃ (CH ₂) ₈ CO ₂ H	medium
12:0	lauric	CH ₃ (CH ₂) ₁₀ CO ₂ H	medium
14:0	myristic	CH ₃ (CH ₂) ₁₂ CO ₂ H	
16:0	palmitic	CH ₃ (CH ₂) ₁₄ CO ₂ H	
18:0	stearic	CH ₃ (CH ₂) ₁₆ CO ₂ H	
18:1 9cis	oleic	CH ₃ (CH ₂) ₇ CH = CH(CH ₂) ₇ CO ₂ H	
18:2 9cis12cis	linoleic	CH ₃ (CH ₂) ₄ (CH = CHCH ₂) ₂ (CH ₂) ₆ CO ₂ H	
18:3 9cis12c15cis	α-linolenic	CH ₃ (CH ₂)(CH = CHCH ₂) ₃ (CH ₂) ₆ CO ₂ H	
22:1 13cis	erucic	CH ₃ (CH ₂) ₇ CH = CH(CH ₂) ₁₁ CO ₂ H	long
20:5 5cis,8cis,11cis,14cis,17cis	EPA ²	CH ₃ CH ₂ (CH = CHCH ₂) ₅ (CH ₂) ₂ CO ₂ H	long
22:6 4cis,7cis,10cis,13cis,16cis,19cis	DHA ³	CH ₃ CH ₂ (CH = CHCH ₂) ₆ CH ₂ CO ₂ H	long

¹Scrimgeour (2005).

²Eicosapentaenoic acid.

³Docosahexaenoic acid.

Table 3. Melting points of some fatty acids.¹

Fatty acid	Melting point (°C)
8:0	16.5
10:0	31.4
12:0	44
14:0	58
16:0	62.9
17:0	61.3
18:0	70.1
18:1 <i>9cis</i>	16.3
18:1 <i>9trans</i>	45
18:2 <i>9cis,12cis</i>	-5
18:2 <i>9trans,12trans</i>	29
19:0	69.4
20:0	76.1

¹Scrimgeour (2005).

(Wood, 1984; Lawrence and Fowler, 2002). This younger fat also is grayer in color due to the higher proportion of connective tissue present (Wood, 1984).

Triacylglycerides are the body's primary method of storing excess energy and consist of 3 fatty acids attached to a glycerol backbone (Lehninger et al., 1993). These fatty acids vary by carbon chain length, by the number of double bonds present, their isomers (*cis* or *trans*), by arrangement of fatty acids on the glycerol backbone, and by location of the double bonds in the chain (ω -3, ω -6; Table 2). The physical properties of fatty acids (e.g., melting point), also differ by some of these factors as shown in Table 3, where

it can be seen that the melting point (**m.p.**) of pure fatty acids varies by chain length (m.p. increases with chain length), degree of unsaturation (m.p. increases with increasing unsaturation), and unsaturated fatty acid isomers (m.p. lower for *cis* than for *trans*). Even though triacylglycerides are not composed entirely of one fatty acid, but of mixtures of them, many of these characteristics are carried over to the fat in pork adipose because the proportion of fatty acids in the adipose can be manipulated through several measures, including diet (Table 4).

The following are a series of short bullet points that illustrate important facts concerning fat development in pigs.

Notes on Fat Deposition

- de novo synthesis (formation from the metabolism of glucose) accounts for approximately 74% of the triacylglycerides found in pork fat (Dunshea and D'Souza, 2003). The remainder are preformed and come primarily from the pig's diet.
- Adipose tissue (fat) consists of loose connective tissue and adipocytes, along with blood vessels, capillaries, and nerves. The mass of adipose increases because of an increase in cell number (hyperplasia) and size (hypertrophy). Cell numbers increase up to at least 6 mo of age. In general, the largest increase in adipose is due to hypertrophy, but this may not take place uniformly in a pork carcass.
- Adipose tissue exists in subcutaneous fat tissues (outside of muscles), intermuscular tissues

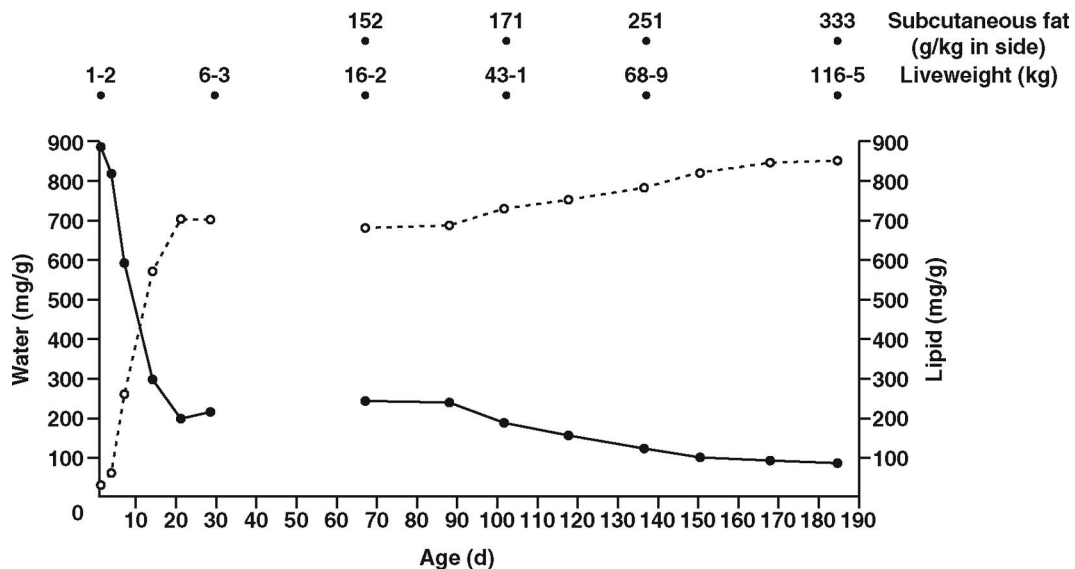


Figure 1. Water and total lipid concentrations of outer layer of subcutaneous fat in castrated male and female Large White pigs. Samples from shoulder (d 1 to 28) and last-rib region (d 66 to 184). Values are means of 2 pigs (d 0 to 28) or 4 pigs (d 66 to 184). From d 66 a pelleted diet containing 190 g of crude protein, 35 g of fat, and 13.0 MJ of ME/kg was fed.

Table 4. Influence of diet on the fatty acid compositions (% of total) of pork fat and beef adipose tissue.¹

Fatty acid	Pork fat ²		Pork fat ³		Beef fat ⁴	
	Tallow diet	Soy oil	Corn and soy meal	Canola oil	Corn and cottonseed meal	Rapeseed and cottonseed oil
14:0	1	0.8	1.3	0.5	3.9	3.6
16:0	26.6	22.1	25.6	10.8	26.7	24.3
16:1	4.1	2.5	0.9	0.4	2	2
18:0	12.1	11.3	12.9	4.3	20.2	20.5
18:1	40.5	33.2	46.9	56.1	41.2	43
18:2	11.2	24.4	11.5	21.5	4.8	5.5
18:3	4	4.9	0.9	6.5	—	—
20:4	0.3	0.5	—	—	—	—
22:6	0.2	0.2	—	—	—	—
Total saturates	39.6	34.2	39.8	15.6	50.8	48.4

¹Haas (2005).²Monahan et al. (1992).³St. John et al. (1987).⁴Diets contained 3% tallow or soy oil

(between muscles), and intramuscular tissues (marbling). Subcutaneous fat exists in layers, with a distinct layer of connective tissue dividing them; at least 2 layers in backfat exist, and some workers have observed 3. These layers grow at different rates and have different metabolic enzyme rates during growth. They also contain different fatty acid profiles, with the outermost layer being lower in saturated fatty acids than the innermost. Rates of lipogenesis appear to be greater for the second (inner) layer than for the first (outer) layer. A separation between these fat layers has been observed in thin/leaner bellies (Anderson and Kauffman, 1973; Hausman and Kauffman, 1986; Lawrence and Fowler, 2002).

- The intense pressure to reduce fat in pork carcasses has usually resulted in a uniform reduction of fat throughout the carcass, but some data suggest that may not be the case any longer. Some workers have shown a redistribution of the fat in pork carcasses and an increase in the fatness of pork bellies (D'Souza et al., 2004).
- When breeding for high-lean carcasses, the relative amount of unsaturated fatty acids in the adipose has increased (Wood et al., 2008).
- Adipose from lean pigs usually contains more moisture than that from fatter pigs because the high proportion of fat decreases the moisture and protein content on a weight basis. This may account for the observation that pork bellies now contain 10% less fat and 10% more water

than at previous times. This most likely will result in softer pork belly fat.

Notes on Effects of Nutrition

- As pigs ingest feed, increasing energy intake increases protein deposition to a maximum rate, beyond which increasing energy does not increase deposition. Fat accumulation is also linear with energy intake but increases drastically once the protein deposition rate is exceeded. Knowing this inflection point is crucial in knowing how much energy to feed the pigs. In general, young pigs of less than 120 lbs. cannot consume enough to maximize protein deposition, whereas older pigs (gilts and barrows) can consume excess energy and add more fat. Barrows have a similar maximal rate of protein disposition but a higher ad libitum feed intake and can be fatter than gilts (Dunshea and D'Souza, 2003).
- Linoleic acid (18:2n-6) is not synthesized in the adipose cell and comes from the diet. The concentration of linoleic acid increases in pigs fed typical diets containing grains and oil seeds because this is a common fatty acid in these feed materials (Wood, 1984). Generally, the proportion of it increases linearly with dietary intake. The melting point of linoleic acid (−5°C) is significantly lower than that of stearic acid (70.1°C) and oleic acid (16.3°C). Therefore, the pork fat will become softer (at refrigerator temperatures) as the content of linoleic acid increases.

Table 5. Some pros and cons of using iodine value (IV) to quantify fat firmness.¹

Pros	Cons
Objective measurement	Labor and time intensive (high cost) Issues of variability in measurements ▪ high standard deviations
Can identify firm vs. soft bellies/fat with a relatively high degree of reliability	▪ analysis conducted using very small sample sizes Inability to determine economics of lower IV ▪ inconclusive data indicating lower IV bellies have higher slicing yields ▪ difficulty in finding economic advantage for the appearance of firmer fat on cuts
Can maintain trends in fat firmness over time	
Can determine variability in fat firmness among raw material suppliers	

¹N. Matthews (personal communication, March 6, 2008).

- The fatty acid composition can be further manipulated by the addition of different feeds. For example, the polyunsaturated:saturated (P:S) ratio can be manipulated by feeding more unsaturated fatty acids, and the concentration of n-3 fatty acids can be increased by feeding flaxseed/linseed. The incorporation of linoleic acid is more efficient than that of linolenic acid. This may be important if it is thought the fatty acid profile should conform more to recent dietary recommendations (Anonymous, 2005).
- The use of IVP (iodine value product) when formulating feeds can be used to predict the iodine value of carcass fat. Iodine values will vary in carcass fat depending upon the fatty acids fed (Boyd et al., 1997). It will also depend upon which fat depot is tested and can vary within a fat depot. For example, the fatty acid composition in the different layers of backfat can vary depending upon the age and feed regime at any particular stage.

Fat Firmness Issues

- The composite adipose tissue from pigs melts between 25 and 50°C. Adipose composed of more unsaturated fat melts at lower temperatures and that containing more saturated melts at higher temperatures (Wood et al., 2008).
- Fat thickness can affect fat firmness and cohesiveness between fat and lean. The concentration of stearic acid increased and linoleic acid decreased as P_2 fat thickness increased. Pigs with 16 mm of backfat had firmer fat and less fat/muscle separation than pigs with 8 mm of fat. The proportion of linoleic acid was the best predictor of fat firmness (Schinckel et al., 2002).
- Based on the proportion of unsaturated fatty acids, the external layer of fat should be the softest, although it has the highest amount of connective tissue and has more physical

resilience (from mechanical stretching; Schinckel et al., 2002).

- Differences in fat cohesion may be related to the degree of cross-linking (maturity) of adipose collagen.

Measuring Fat Quality (Primarily Firmness)

Iodine value is a gross measure of the amount of unsaturated fatty acids and has been generally accepted as an industry standard to the point where some use it as a research tool and as a method to value pigs (Scheeder and Wenk, 1998; Schinckel et al., 2002). It has been used because it is objective, able to accurately classify soft from firm bellies, and can be used to monitor the fat in bellies from pigs fed different diets (Table 5). However, it does have some drawbacks, including cost, variability, low correlations between lower IV values and product sliceability, and an inability to value meat with low IV values. Perhaps a more direct physical measure would be more appropriate. There are no official belly firmness measures at present, although the Oscar Mayer belly “flop” test has been used by many researchers and has been adapted in many ways. This is because of its empirical nature and lack of a standardized protocol. Variations include calculating the angle between the drooping ends, measuring the distance between the 2 drooping ends, cutting a standardized portion from the belly and drooping that over the bar, adjusting values for belly thickness (Streff et al., 2002). Even with these shortcomings, the flop test has found general acceptance to classify bellies as soft or firm. A physical measure like the flop test does get at a characteristic that has commercial value (firmness) but it has the limitation that it cannot be used to diagnose variations in firmness.

Controlling Fat Firmness in Pork Bellies

It is important for growers and processors to know that pork bellies can be too soft to make good bacon. The defects from such soft bellies exhibit themselves in poor brine retention, reduced slicing yields, and poor consumer acceptance. The incidence of the softness defect is

likely to increase for many reasons: leaner pigs being fed for shorter times, increased usage of distillers dried grains and solubles, increased use of ractopamine, decreased usage of beef tallow, quality differences in distillers dried grains and solubles, and many more, including the usage of restaurant grease (Latour et al., 2008). It is understandable that growers want to maximize their profits by utilizing the feed ingredients that will provide the greatest economic gains, but they need to understand that decisions they make can and do affect the quality of bacon produced. It is possible to manipulate the ingredients and time of use during the growing/finishing period so that the gains and feeding efficiencies are economical, but do not compromise pork fat quality. Gatlin et al. (2003) demonstrated that feeding pig diets with 5% choice white grease with increasing degrees of hydrogenation (resulting in increasing iodine values ranging from 80 to 20) resulted in thicker bellies, a linear decrease in belly length, and decreasing iodine values of the fat (from 73.9 to 67.4). Because the majority of the fat in pork bellies is accumulated and deposited in the belly adipose toward the end of the finishing period (D'Souza et al., 2004), one way to ensure adequate belly fat quality could be to feed cheaper feed greases/oils earlier and finish the pigs with ration higher in saturated (A. P. Schinckel, personal communication, March, 2008; Leszczynski et al., 1992).

The fatty acid composition of pigs can also be manipulated with the feeding of conjugated linoleic acid (CLA) and with the incorporation of ractopamine (Paylean) to increase the lean content and decrease carcass fat. The general conclusions from Schinckel et al. (2002) were that feeding supplemental CLA reduced midline last-rib fat thickness and 10th-rib backfat depth, improved subjective color values, substantially increased belly firmness, marbling score, and predicted fat-free carcass lean. In addition, a 4-week feeding of ractopamine increased the IV values in carcass fat tissues by 2 to 2.5 IV units with no impact on intramuscular fat. The increased belly fat firmness due to the feeding of CLA is most likely due to inhibition of the Δ^9 -desaturase in adipose tissue (Dunshea and D'Souza, 2003).

Other husbandry practices have also been shown to increase fat softness. For example, White et al. (2008) observed that housing pigs at higher than thermoneutral temperatures (32.2°C) with a decreased special allocation resulted in an increased IV (66.8 to 70.4) and a decreased saturated:unsaturated fatty acid ratio when fed the same diets. Apparently, the complexity of feed sources, feeding practices, and weather all influence the fatty acid synthesis of pigs and can influence belly IV and presumably fat softness.

Some may be tempted to manipulate the fatty acid composition of pork fat to obtain a product that conforms more to USDA dietary guidelines (Anonymous, 2005) by increasing monounsaturated fatty acids, decreasing saturated fatty acids, and perhaps even increasing n-3 fatty acids. Although this can no doubt be accomplished (Pas-

cual et al., 2007), growers need to be cognizant that pork bellies from pigs manipulated in these manners may result in inferior fat softness and off-flavors due to "fishy" long chain fatty acids from fish meal (Milkowski, personal communication). The oxidative stability of fats containing elevated concentrations of unsaturated fatty acids may also decrease.

Acknowledgments

Special thanks to Rodrigo Tarté and Tim Knight for their review and comments of the manuscript.

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