

UNDERSTANDING THE EFFECTIVENESS OF BLENDED FATS AND OILS IN POULTRY DIETS

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EXECUTIVE SUMMARY

Fats and oils are chemically diverse group of compounds, which have the highest energy density among all macro nutrients. Besides having high caloric values, they are major sources of essential fatty acids (Ω -3 and Ω -6), fat soluble vitamins (A, D, E and K) and lecithin. Moreover, supplementation of fats and oils to poultry rations increases the metabolizable energy of the total ration, the calculated energy of the diet. This “extra-caloric” effect of the fat comes from the increased utilization of other dietary components. The main factor affecting the metabolizable energy of fats is their digestibility, which is dependent on the length of carbon chain and the degree of saturation of the fatty acids. Fats of vegetable origin have high metabolizable energy as they contain high amounts of unsaturated fatty acids (U) unlike fats of animal origin, which contain high amounts of saturated fatty acids (S). Fats and oils from animal and vegetable sources are often blended to attain a specific U/S ratio, which increases the digestibility of animal fats, and thus produces a product with superior metabolizable energy. Also the quality of the fat is an important consideration as fats with high moisture, impurities and unsaponifiables (MIU) decrease digestibility, and thus metabolizable energy. Hence it is vital to account for the fatty acid profile, MIU and extra caloric effect, when calculating the metabolizable energy contribution of supplemental fats and oils in poultry diets.

INTRODUCTION

Historically, starch (specifically corn starch) has been the primary energy source for poultry diets in the United States. As corn is now being increasingly utilized in ethanol production, the cost and availability of starch as a low-cost energy source is being adversely affected. This makes dietary energy the costliest component in poultry diets with little moderation in sight since world consumption of energy will likely continue to increase rapidly. Energy costs will continue to drive grain prices, as more grain is diverted towards bio-fuel production, impelled by high crude oil prices. While continual usage of corn increases dietary costs and reduces margins, reduction of dietary energy might result in either slowed growth rates and/or reduced feed efficiency. Another option, however, is to use supplemental fats and oils to increase dietary energy content. This would allow for continued performance and give the most flexibility to poultry producers when pricing ingredients. Fats and oils have been used by the growing poultry industry around the globe as a supplemental dietary energy source in poultry diets to yield higher levels of metabolizable energy at an economically justifiable price. Hence, understanding fats and their metabolism is a critical factor when it comes to efficient utilization of the dietary energy contributed by fat supplementation.

FATS AND OILS - AN INTRODUCTION

In human, as well as in animal nutrition, the term “fat” is used as a synonym for lipid and refers to triglycerides or triacylglycerols of several profiles of fatty acids. Oils are esters of glycerol as with fats, however, oils are liquid unlike fats which are solid at room temperature (Lehninger, et al., 2008). Biological lipids are a chemically diverse group of compounds, the common and defining feature of which is their insolubility in water (Stevens, 2004). Triglycerides are primarily storage fats, and they contain three fatty acid molecules esterified to the three hydroxyl groups of glycerol. Simple triglycerides contain only one type of fatty acid, whereas mixed triglycerides have two or three types (Berg, et al., 2006). Free fatty acids are free floating acids not attached to any other organic component, like glycerol. The physical and chemical properties of fats are determined by their composition of fatty acids, degree of saturation and length of the carbonic chain. The term “saturated” indicates the absence of double bonds, whereas “unsaturated” is the presence of one or more double bonds (Murray, et al., 2009). An increase in length of the carbonic chain of a saturated fatty acid increases the melting point of the fat, while the presence of a double bond decreases the melting point. In addition, the longer the chain, the fewer the number of double bonds, and consequently the less soluble the fat will be in water (Lehninger, et al., 2008). Functions of lipids are as diverse as their chemistry and they constitute the main energy reserve of humans and animals, having the highest caloric value (energy density) among all macro nutrients.

FAT DIGESTION

The digestion and absorption of fat in the chicken occurs mainly in the small intestine (Scott, et al., 1982). The presence of digesta, with intact dietary fat in the duodenum, stimulates cholecystokinin secretion, which in turn induces the secretion of pancreatic enzymes and bile (Friedman and Nylund, 1980). While bile salts emulsify fat along with co-lipase providing more surface area for the enzymes to act upon, lipase hydrolyses the emulsified triglycerides on sn-1 and sn-3 positions to release monoglycerides and free fatty acids (Mu and Høy, 2004). Cholesterol esterase hydrolyses cholesterol-fatty acid esters into cholesterol and free fatty acids (Mu and Høy, 2004). Also large amounts of endogenous phospholipids enter through bile, predominantly phosphatidylcholine in addition to dietary phospholipids. Phospholipase A2 cleaves phospholipids at the sn-2 position to release lysolecithins and free fatty acids (Scott, et al., 1982).

FAT ABSORPTION

Bile salts are biological detergents, which are amphipathic i.e., they have both hydrophobic and hydrophilic ends (Mu and Høy, 2004). When the concentration of bile salts in the lumen is at or above “critical micellar concentration,” they arrange themselves on the surface of lipid digestion products, with their hydrophobic ends turned inward and hydrophilic ends turned outward (free fatty acids, monoglycerides, cholesterol and lysolecithin), forming “Mixed Micelles” (Garrett and Young, 1975). To get their lipid content absorbed actively by enterocytes, these mixed micelles can pass across the unstirred water layer, which bathes the enterocytes (Iqbal and Hussain, 2009). Inside the enterocytes, the MG, free fatty acids are re-esterified to form triglycerides and together with cholesterol, lipoproteins and lysolecithins, are assembled into portomicrons (Stevens, 2004). Around 15% of fatty acids present in the lumen are catabolized in the mucosal epithelium towards the maintenance energy requirement (Noy and Sklan, 1996). Short chain fatty acids and free glycerol are absorbed directly through passive uptake (Gropper, et al., 2008). The portomicrons, short chain fatty acids and free glycerol are transported through the portal venous system to the liver, since unlike mammals the lymphatic system of the birds is not well developed (Bensadoun and Rothfeld, 1972). Very low density lipoproteins carry triglycerides from the liver to the extra hepatic tissues like the ovary (for egg yolk synthesis) or muscle (for energy) (Phan and Tso, 2001).

IMPORTANCE OF DIETARY FAT TO POULTRY

Scott et al., have concluded that the net amount of energy obtained by chicks is 60% of the metabolizable energy of proteins, 75% of the metabolizable energy of carbohydrates, and 90% of the metabolizable energy of fats (Scott, et al., 1982), underscoring the high efficiency of metabolizable energy contributed by fat. Baião and Lara observed that the inclusion of oil in the starter diet increased the fat digestibility in broiler chicks during the first week of life and resulted in better performance through 21 days of age, compared to the chicks received rations without oil (Baião and Lara, 2005). Furthermore, chicks utilized metabolizable energy more efficiently for growth if part of the carbohydrate portion of the diet was replaced isocalorically with corn oil (Carew and Hill, 1964) or acidulated soybean soap stock (Lipstein and Bornstein, 1975). For growing chicks, the net availability of metabolizable energy from corn oil was about 10% higher than that of carbohydrate-rich feed ingredients; yellow corn and milo, (De Groôte, 1968). Also, chicks fed diets devoid of supplemental fat had higher levels of lipogenesis and increased adipose fat deposition (Dvorin, et al., 1998).

In laying hens, Whitehead et al. indicated that dietary fatty acids increase egg weight by stimulating the synthesis of oviductal proteins, a mechanism that is different from that causing the age-related increase in egg weight (Whitehead, et al., 1993; Whitehead, 1995). The increase in egg weight with age was associated with a greater increase in the proportion of yolk at the expense of albumen, whereas the increase in egg weight caused by supplemental fat was mostly due to an increase in egg albumen, although yolk weight was also increased (Whitehead, et al., 1991). These effects on egg production were found to be profound from 24 to 38 weeks of age (Grobias, et al., 1999). Thus, supplemental fat exerts favorable effects on lipogenesis, egg weight and egg production.

ADVANTAGES OF DIETARY FAT SUPPLEMENTATION

1. Essential Fatty Acids

Birds are not able to synthesize all fatty acids and thus, some are considered metabolically essential viz. linoleic (18:2, n-6) and linolenic (18:3, n-3) fatty acids. However, to date the NRC has only defined the dietary requirements for linoleic acid (NRC, 1994). These essential fatty acids are absorbed from the feed, in which dietary fat is the major source (Dvorin, et al., 1998). Fatty acids obtained from crude soybean oil and corn oil are very high in unsaturated fatty acids, with high levels of linoleic acid (Scragg, et al., 1987). Any deficiency of linoleic acid adversely affects egg production, and it has been proven that supplementation of linoleic acid, present in vegetable oils, increases egg weight (Shutze and Jensen, 1963; Balnave, 1971). Depressed growth (especially in male chickens) may be the first sign of an inadequate supply of essential fatty acids (Wiseman, 1984). Zero hatchability represents the most acute deficiency of linoleic acid that has been reported to date. It was manifested by increased susceptibility to respiratory infections, poor egg production, small egg size, and low fertility (Miller, et al., 1963; Menge, et al., 1965). Furthermore, the conjugated isomers of linoleic acid have been reported to be effective in minimizing reduced growth rates by preventing the catabolic effects of immune stimulation (Cook, et al., 1993).

2. Micronutrients

Dietary fats play a significant role in the absorption of fat-soluble vitamins (A, D, E and K) by acting as their "carriers" - apart from serving as major sources of these vitamins (Iqbal and Hussain, 2009). The fat-soluble vitamins are incorporated into portomicrons for transportation after absorption, and are also deposited in body lipid stores (Drevon, 1991). Hence impairment of the absorption of fat-soluble vitamins is the most serious consequence of a dietary deficiency of fat (Jacob, et al., 2011).

Vitamin A: Acid oil and corn oil are rich vegetable sources of carotenoids which are precursors for the synthesis of vitamin A. Vitamin A plays a significant role in regulating cell growth, specifically epithelial cells. It is also necessary for bone metabolism through involvement with osteoblasts (bone forming cells) and osteoclasts (cells involved in bone resorption) (Surai, et al., 2001). Vitamin A influences both antibody production and T-lymphocyte proliferation responses, thus a deficiency can result in decreased immune responses (Friedman and Sklan, 1989a, b). Moreover it has been observed that for maximal immune response in growing chickens, it may be beneficial to include dietary vitamin A at higher levels than NRC (NRC, 1994) recommendations (Sklan, et al., 1994) and dietary fats would be an ideal option in doing so.

Vitamin D: Vitamin D is required for normal calcium absorption and utilization, hence inadequate levels of vitamin D induces calcium deficiency resulting in decreased egg production (Fritts and Waldroup, 2003; Jacob, et al., 2011). Vitamin D also plays a vital role in the immune responses of chickens, particularly cellular immune responses (Aslam, et al., 1998). Moreover vitamin D prevents tibial dyschondroplasia by increasing bone health substantially (Edwards Jr, 1990). Recently, it has also been reported that vitamins A and D regulate bile acid synthesis, thus controlling fat absorption as well as their own absorption (Schmidt, et al., 2010).

Vitamin E: Lipid and myoglobin oxidation are major causes of meat quality deterioration during storage (Jensen, et al., 1998) and poultry meat has higher sensitivity to oxidation damages among all meats, which may be ranked according to oxidation susceptibility in the following order: turkey > chicken > pork > beef > lamb (Tichivangana and Morrissey, 1985). It has also been successfully demonstrated that dietary vitamin E supplementation significantly increased the α -tocopherol content of muscle membranes in many animals (Lauridsen, et al., 1997). α -tocopherol functions as a lipid antioxidant and free radical scavenger (Hsu and Guo, 2002). Moreover vitamin A and E also have a profound effect on alleviating heat stress in chickens (Sahin, et al., 2001). The cost factor of dietary vitamin E supplementation demands efficient utilization of dietary vitamin E as well as lipid metabolism (Zouari, et al., 2010).

3. Lecithin

Lecithin (phosphatidylcholine) is a phospholipid that is extracted commercially from soybeans. It promotes the incorporation of fatty acids into micelles by acting as an emulsifier, facilitating fat absorption (Cho, et al., 2008). Dietary lecithin plays an important role in the transport of triglycerides out of intestinal mucosa by providing surfactant lecithin for the PM envelope and supporting mucosal protein biosynthesis (O'Doherty, et al., 1973). Lecithin also alters the serum hormone levels, affects hepatic gene expression, and thereby regulates fat metabolism of broilers (Huang, et al., 2008). Dietary supplementation of lecithin increased the metabolizable energy of added fat, but parallel to lipid availability (Sibbald and Kramer, 1980). Lecithin has also been observed to improve the tenderness of meat (Collins, et al., 2011). When supplemented at 6%, lecithin significantly increased yolk percentage, improved haugh unit score (albumen density) and yolk color, while increasing fat digestibility and plasma total lipids (Attia, et al., 2009).

4. Milling Benefits

Added fat in the diet acts as a binder, improving pellet quality and providing optimal durability (Winowiski, 2008). It has also been observed for many years that dietary fat reduces dusting and wastage of feed during the milling process (Winowiski, 2008).

5. Diet-Induced Thermogenesis

The reduced heat increment of fat-containing diets, which appears to be one of the primary causes of the extra-caloric effect, has been explained (Lipstein and Bornstein, 1975) as follows: the conversion of carbohydrates and protein to fatty acids is a heat-producing process, while the presence of an adequate level of dietary fat prevents this process. A high proportion of the dietary fatty acids can be used directly in the synthesis of tissue triglycerides, while fatty acids formed from carbohydrates must pass through a series of heat-producing metabolic transformations. The heat increment lost to the environment constitutes a loss of expensive energy utilized to produce fatty acids. Moreover, this additional heat produced during the fatty acid synthesis from dietary carbohydrate may also accentuate the effects of heat stress, under hot weather conditions. In high-temperature environments adequate amounts of dietary fat should be present in order to inhibit the conversion of dietary carbohydrates to fatty acids, a heat-producing process (Edwards, 1969). The beneficial effects of vegetable oil on the efficiency of energy utilization was due to a reduced heat increment rather than to a reduction in the basal component of the heat production (Shannon and Brown, 1969).

FAT DIGESTIBILITY IN YOUNG CHICKS

It has been proven that fat digestibility is not a limiting factor in the growth of young broilers (Noy and Sklan, 1996). These authors reported that the true digestibility of the unsaturated fatty acids in four-day old birds was over 85%, which demonstrates that the activity of lipases and bile salts by the fourth day of age were sufficient for near complete fat digestion. It has also been shown that fats of vegetable origin are more digestible in young birds. For example, the capability of broiler chicks to absorb vegetable oil increased from 84% during the first week of age to 95% during the second, while the absorption of tallow increased from 40 to 79% over the same time period (Carew Jr, et al., 1972). The metabolizable energy of a corn-soy diet supplemented with soybean oil was maximized as early as two weeks of age in broilers (Batal and Parsons, 2002). Day-old broiler chicks had increased apparent fat digestibility when fed with soy oil at a dietary inclusion level of 3.5% (Zollitsch, et al., 1997).

FREE FATTY ACID CONTENT ON ENERGY DIGESTIBILITY

Although the energy utilization from diets high in free fatty acids was once considered to be lower compared to diets with triglycerides (Huyghebaert, et al., 1988), it has been researched and long proven that free fatty acids were not responsible for the inefficiency. Feeding free fatty acids, properly stabilized by antioxidants, were utilized equally well and showed no negative effect on chick performance, regardless of the free fatty acids content (Siedler, et al., 1955; De Groôte, 1968). Similarly, there was no difference in the performance of broilers fed diets supplemented with animal-vegetable (AV) fat blends, either with low or high free fatty acids content (Lewis and Payne, 1963; Waldroup, et al., 1995). In a study with laying hens, it has also been reported that high amounts of dietary free fatty acids had no adverse effects on egg production (Treat, et al., 1960).

But more recently, additional research points toward the fatty acid composition of the dietary fat source, which sheds more light on the real reason behind reduced energy utilization. The perceived negative effects of dietary free fatty acids on energy utilization are directly related to the degree of saturation of the free fatty acids (Wiseman and Salvador, 1991). Vila and Esteve Garcia have reported that in three week old broilers dietary saturated fatty acids (i.e., palmitic acid [C16:0] and stearic acid [C18:0]) decreased the digestibility and metabolizable energy of added dietary fat, whereas dietary unsaturated fatty acids (i.e., oleic acid [C18:1] and linoleic acid [C18:2]) did not (Vila and Esteve Garcia, 1996a). In two week old broilers, they have also observed very limited effects of dietary free fatty acid content on energy availability. Therefore, the fatty acid composition of the dietary fat content by itself was a poor predictor of its metabolizable energy (Vila and Esteve Garcia, 1996b). Thus, as long as there is a substantial proportion of unsaturated fatty acid in the dietary fat, the free fatty acid concentration does not negatively affect the energy value of the dietary fat, mineral retention, eggshell quality, or egg production in mature birds.

SIGNIFICANCE OF UNSATURATED: SATURATED FATTY ACID RATIO (U/S) IN DIETARY FAT

Increased absorption of dietary carbohydrates leads to increased de-novo lipogenesis in the liver, the process of synthesizing fatty acids from non-fat dietary sources (Hillard, et al., 1980). These fatty acids are stored in adipose tissue which is positively correlated with total body fat (Becker, et al., 1979). Fatty acid synthase is a multi-enzyme complex responsible for de-novo lipogenesis (Yeh and Leveille, 1973; Saadoun and Leclercq, 1983). It has been observed that while the fatty acid synthase activity was significantly lower, the rate of β -oxidation was higher in birds fed diets high in unsaturated fatty acids and low in saturated fatty acids (Yeh, et al., 1970; Leyton, et al., 1987). A higher rate of dietary poly-unsaturated fatty acid absorption resulted in greater substrate availability, leading to faster β -oxidation of poly-unsaturated fatty acids, eventually lowering the postprandial plasma triglyceride concentration (Leyton, et al., 1987; Shimomura, et al., 1990). Thus lipogenesis was negatively affected, indicating reducing fat storage, by favoring unsaturated over saturated fatty acids in the diet (Leveille, et al., 1975; Donaldson, 1985). This has been confirmed by further individual studies in which broiler chickens fed diets enriched with poly-unsaturated fatty acids compared to diets high in saturated fatty acids had low abdominal fat (Sanz, 1999) or total body fat (Sanz, et al., 2000). Furthermore in laying hens, the catabolism of adipose fat through β -oxidation is essential for ovulation and yolk formation in minimum concentration (Bornstein, et al., 1984).

Fatty acids with high polarity have higher solubility, hence they increase the formation of mixed micelles (Garrett and Young, 1975; Baião and Lara, 2005). Increased mixed-micelle formation effectively increases the absorption of both unsaturated fatty acids and saturated fatty acids. Unsaturated fatty acids readily form micelles along with monoglycerides, when linked to the conjugated bile salts, increasing their absorption (Baião and Lara, 2005). But in contrast, polarity decreases with saturation and carbon chain length, thus saturated fatty acids with their characteristic low polarity impede absorption (Garrett and Young, 1975; Baião and Lara, 2005). In young broilers and post-peak laying hens, most of the dietary unsaturated fatty acids (oleic acid, C18:1) were absorbed by the birds as opposed to saturated fatty acids (palmitic acid, C16:0) (Ketels, et al., 1987; Ketels and De Groote, 1989). The digestibility of fat is optimized when there is at least 80% unsaturated fatty acids, since long-chain unsaturated fatty acids have a greater ability to form micelles. In addition, they may act synergistically in the absorption of saturated fatty acids when mixed with them (Baião and Lara, 2005). Moreover, fat digestibility increases above 90% when the U/S ratio is higher than 4.0, in a typical corn-soy diet (Stahly, 1984). The metabolizable energy content is around 7,100 kcal/kg for saturated fats such as tallow, compared to 9,500 kcal/kg for vegetable oils, which are high in unsaturated fatty acids (Wiseman, 1984). Diets deficient in unsaturated fatty acids will cause metabolic disorders (Wiseman, 1984). Abnormalities in the structure of membranes, capillaries and skin, as well as a general depression of immunity are among the most severe consequences of major deficiencies (Wiseman, 1984). Thus, it has been advocated for decades that the U/S ratio is the vital regulating factor in the efficient utilization of dietary fat (Bensadoun and Rothfeld, 1972).

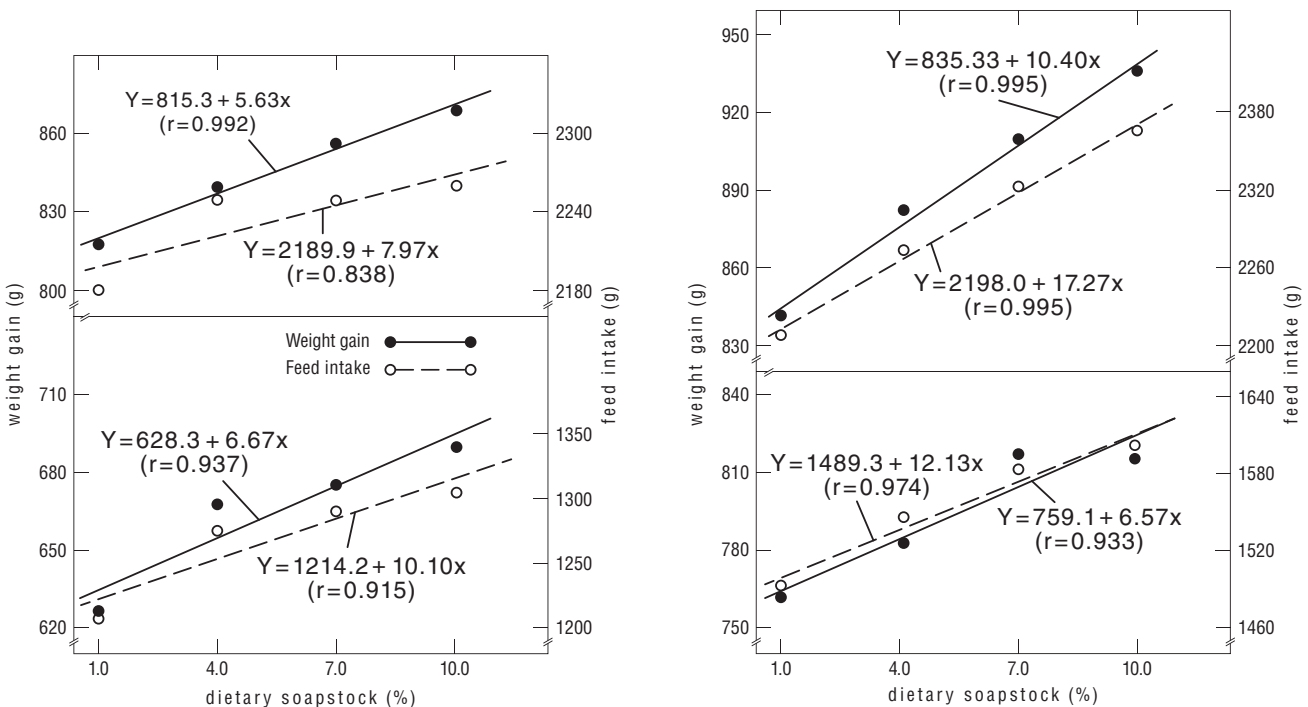
EFFICIENT UTILIZATION OF DIETARY FAT

The main factor affecting the metabolizable energy value of fats is their digestibility, which is dependent on the length of carbon chain and the degree of saturation of the constituent fatty acids (Renner and Hill, 1961a; Leeson and Summers, 1976; Waldroup, et al., 1995; Leeson and Summers, 1997). Interactions between the degree of saturation, relative to fat absorption have been suggested by several authors (Young and Garrett, 1963; Leeson and Summers, 1976). The poultry grease and palm oil samples consistently had the lowest metabolizable energy values, while blends apparently based on soybean oil consistently had the highest metabolizable energy values (Pesti, et al., 2002). Renner and Hill (1961) asserted that fats which had previously been used for deep frying such as restaurant grease have substantially lower and more variable metabolizable energy values. This decrease depends to a great extent on the duration of heating, temperature used, and fatty acid profile. Heating increases the loss of poly-unsaturated fatty acids, as they are much more sensitive to oxidative degradation than saturated fatty acids, and it changes the fatty acid profile (Renner and Hill, 1961a). Metabolizable energy values may also be reduced by the presence of damaged fats including, for example, dimeric or polymerized fatty acids. This same pattern is applicable to animal fats such as tallow, choice white grease and poultry fat, which typically have very low poly-unsaturated fatty acid levels with high saturated fatty acid content. These "animal" renderers' fats have wide variation not only in metabolizable energy value, but also in chemical characteristics. Consequently, the metabolizable energy of these saturated fats may be increased if the basal diet contains fats high in poly-unsaturated fatty acids (Lewis and Payne, 1966; Ketels, et al., 1987; Wiseman and Salvador, 1991). It has been proven that the best way to use fats with more saturated fatty acids, viz. stearic and palmitic acids, such as animal and palm fats, is by blending them with unsaturated fatty acids (Renner and Hill, 1961a, b). Oleic acid (C18:1) plays a more direct role in the absorption process, either in the lumen or in the mucosa cells, to facilitate the increased absorption of saturated fatty acids (Young and Garrett, 1963). These researchers have usually found a synergism between fatty acids that improve fat digestibility, and the resulting impact on its metabolizable energy content, particularly at high levels of dietary inclusion.

Vegetable soap stocks such as acidulated soybean soap stock, corn oil, and soybean distilled fatty acids, which are all typically high in free fatty acids, have been shown to support excellent performance in poultry feeds (Menge and Beal, 1973; Lipstein and Bornstein, 1975; Bornstein, et al., 1984). These fats of vegetable origin have high unsaturated fatty acid content with high degrees of metabolizable energy, which are well absorbed and utilized as a source of energy by the bird (Young and Artman, 1961). A synergistic effect occurs when these vegetable fats are mixed with fats high in saturated fatty acids (animal fats, palm fats or restaurant greases), providing a higher metabolizable energy level to the blend. By increasing the level of unsaturation, digestibility and ME of fats from different sources were improved up to an optimum value when the U/S ratio was 2.5 (Ketels and De Groote, 1989). These authors demonstrated that the addition of unsaturated fat (vegetable oil) or linoleic acid to saturated fat (animal fat), improved the metabolizable energy value of the blend (Ketels and De Groote, 1989). Also it has been reported that an increase in dietary unsaturated fatty acids improves metabolizable energy by lowering the amount of heat produced during metabolism (Dvorin, et al., 1998). Sophisticated fat suppliers often blend various sources of fats and oils to attain a specific U/S ratio and thus produce a product with superior metabolizable energy, as demonstrated by several studies (Sibbald, et al., 1960; Sibbald, et al., 1962; Young, et al., 1963; Lewis and Payne, 1966; Leeson and Summers, 1976). Surprisingly, the metabolizable energy of the blends is higher than expected from the arithmetic mean of the metabolizable energy of constituent parts (Lewis and Payne, 1966; Leeson and Summers, 1976).

EXTRA CALORIC EFFECT

Several fats and oils have stimulating effects which cannot be explained in terms of variations in dietary energy values or calorie:protein (C/P) ratios. These "extra-caloric" effects increase with the level of dietary fat inclusion (Sibbald, et al., 1962). When fats or oils are added to poultry rations, the resultant increase in metabolizable energy of the total ration is greater than the gross energy supplied by the fat. This extra energy comes from increased utilization of other components of the diet and not from the fat itself (Sibbald, et al., 1962; Carew Jr, et al., 1963).



The effect of isocaloric replacement of carbohydrates by soap stock on broiler performance (Lipstein and Bornstein, 1975).
 Left lower part: 13-34 day period; upper part: 35-55 day period; Right lower part: 7-32 day period; upper part: 33-55 day period

Over the past five decades, the reasons behind the extra-caloric effect have been researched and explained, and they are:

1. Decreased rate of passage and therefore, improved digestion and intestinal absorption (Mateos and Sell, 1980, 1981a, b; Mateos, et al., 1982).
2. Synergistic enhancement of saturated fatty acid absorption in the presence of unsaturated fatty acids of the basal diet (Renner and Hill, 1961a, b; Sibbald, et al., 1962).
3. Lowered heat increment of the supplemented diet resulting in improved utilization of metabolizable energy (Shannon and Brown, 1969; Lipstein and Bornstein, 1975).
4. Fat may improve the physical characteristics and palatability of the diet to an extent which promotes increased feed consumption (Dale and Fuller, 1979; Cherry, 1982).

The above reasons also summarize the major advantages of feeding fats. In spite of the recognition of this phenomenon by researchers, rations are almost always formulated using a single metabolizable energy value for fats, and these metabolizable energy values are usually less than their gross energy values (Scott, et al., 1982). While satisfying technical feeding requirements, rations thus formulated may be economically inefficient by undervaluing the true relative contribution of fat to the metabolizable energy of the diet.

CALCULATION OF THE METABOLIZABLE ENERGY OF DIETARY FAT

For more than half-century, it has been proven that all fats and oils do not exhibit the same metabolizable energy values. It is also well understood that these values differ for each livestock species, too (Sibbald, et al., 1960; Renner and Hill, 1961a, b; Young and Artman, 1961; Sibbald, et al., 1962). The metabolizable energy value of a fat or oil is not related to one chemical or physical variable, but rather to a set of combined or derived variables, such as the following:

- Factors improving metabolizable energy value
 - Total fatty acid content
 - Unsaturated fatty acid (Linoleic Acid, Linolenic Acid, Oleic Acid) content
 - U/S ratio
- Factors decreasing metabolizable energy value
 - Moisture, Insolubles and Unsaponifiables (MIU)
 - Saturated fatty acid (Stearic Acid, Palmitic Acid) content
 - Phospholipids (Ethanol amine, Inositol, Choline)
 - Oxidation status and by-products
 - Polymerization oligomers (Dimers, Trimers)

The wide variation in chemical composition of fat may be affected by processing, mixing ratio, fat sources and supplementation or dilution with "less valuable" fatty materials, or fat substitutes like glycerin. Of all the metabolizable energy calculation methods reported thus far, the one proposed by Garrett et al. (unpublished) considers multiple factors discussed above (fatty acids, free fatty acids, MIU, oxidation and polymerized oligomers) compared to other methods which didn't comprehensively take account of all the essential factors, but considering only U/S ratio and free fatty acid content (Wiseman and Salvador, 1991). Thus, Garrett's method does more justification in calculating the predictive metabolizable energy of fats and oils.

Given the "extra-caloric effect" as noted in some of the studies discussed earlier, it is essential to consider the following facts before assigning metabolizable energy values to fats:

- (i) the concentration of unsaturated and saturated fatty acids, which help to shape the fat's metabolic performance,
- (ii) the inclusion level of the fat, particularly when there is an isocaloric replacement of dietary carbohydrates,
- (iii) the quality of the fat, viz. the type of free fatty acids, the fatty acid profile, oxidation status and MIU.

IMPORTANCE OF THE DIETARY FAT QUALITY

Due to dissimilarities in feed stocks, processing techniques, and additives, among other factors, fat and oil products obtained in different regions of the United States may not be of the same chemical composition as those reported in the literature. This means the energy levels of fat products for poultry, even within the same class or type, can vary significantly in a given area. Thus, using a metabolizable energy value reported in the literature may or may not be appropriate (Huyghebaert, et al., 1988; Zumbado, et al., 1999). When blending oil or fat products in any region, the product's feed stocks should be analyzed by chemical and biological means to optimize their use and produce the right blends for specific animal feeding purposes (Zumbado, et al., 1999). It is also important to consider that in the U.S., feed fats are marketed with specific names such as "hydrolyzed vegetable and animal fat" or "white or yellow greases", which are the result of different combinations of animal fats (tallow and lard), restaurant greases, acidulated soap stocks, and other residues of the oil refining industry. Some of these products have specifications for feed purposes as determined by their MIU content, as well as free fatty acid levels. Baião and Lara (2005) have outlined the specifications of various parameters for poultry fats and oils in their meta-analysis review. Since moisture interferes directly with the energy content of fat and can accelerate rancidity, the maximum accepted moisture values are between 1.0 and 1.5%. Similarly, impurities should be lower than 1% since they displace caloric content. Finally, unsaponifiables, which comprise steroids, pigments and hydrocarbons, are indigestible. Hence, the higher their percentage, the lower the energetic value of the oil or fat - the saponification value increases when triglyceride chains are shorter. Since peroxides indicate the presence of secondary products produced through decomposition, peroxide values are used to evaluate the quality of oils, fat and sub-products with high percentages of fat. Oxidative Stability Index also indicates the stability rate of the fat or feed by measuring the time needed to degrade organic acids derived from aldehyde and ketones, as well as to concentrate peroxide products in solution.

SUMMARY

- Besides directly supplying high caloric energy, the supplementation of fat to poultry diets:
 - (i) provides an "extra caloric effect" by improving the absorption of other dietary nutrients in the ration;
 - (ii) delivers essential fat-soluble vitamins and increases their uptake; and
 - (iii) decreases diet induced thermogenesis which is the loss of energy as heat.
- To increase its efficiency, dietary fat should contain at least 80% unsaturated fatty acids, and specifically a minimum of 50% Linoleic acid.
- When assigning metabolizable energy values to fats, all the quality parameters, including the extra caloric effect, should be accounted for as per the Garrett model. It is not scientifically appropriate to just consider the U/S ratio and free fatty acid content of fat as this may deliver an incomplete or misleading energy value of the fat.
- Accounting for these "energy additive" effects while developing a better understanding of key fat quality indicators, will improve the overall cost-benefit ratio of supplementing fat in the diet while optimizing the efficiency of the feed ration.

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