

Factors Affecting the Quality of Feed Grade Fats and Oils

Diversified Laboratories, Inc.

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SUMMARY

Feed grade fats and oils rank among the most important ingredients used in poultry and livestock feed both in volume consumed and in nutritional importance. The value of fats and oils is based on both their safety and their efficacy. There are numerous factors in each of these areas that affect the quality of these products. This paper has attempted to identify those factors and address them as important chemical parameters that provide the quantitative basis for the evaluation of quality. To insure the highest quality feed grade fats and oils, these parameters should be known, understood and routinely monitored. This approach will help to insure the use of the highest quality energy supplements available and the optimum production of poultry and livestock.

FACTORS AFFECTING THE QUALITY OF FEED GRADE FATS AND OILS

The practice of supplementing poultry and livestock rations with fats and oils has prevailed, and indeed flourished, for more than four decades. The beneficial effects of their high caloric value and their effect on the efficiency of feed conversion are well known. Consequently, fats and oils represent one of the principal dietary ingredients and it is estimated that five billion pounds are utilized annually in the United States for poultry and livestock rations. However, despite its broad acceptance, feed grade fat remains the least understood of all major feed ingredients with respect to measures of its quality and value.

The lack of understanding is rooted in the wide range of animal, vegetable and marine sources used, the lack of uniformity or standardization of the feed grade products and the complexity of the information that correlates chemical composition with biological value parameters such as metabolizable energy. Based on the degree of variability among fat products and studies reported in the scientific literature, it is clear that all fats and oils are not chemically the same or biologically equivalent. The logical approach to evaluating the differences in quality involves the understanding of the important factors, parameters or criteria by which their quality can be measured.

The factors affecting the quality of fats and oils can be divided into two principle categories: safety and efficacy. The safety criteria relate to the presence of substances that may have deleterious effects on the health and performance of the animal or the presence of substances that may result in the accumulation of toxic residues related to human health concerns. The efficacy criteria relate primarily to the energy value of the fat product and secondarily to such factors as essential fatty acid content, oxidative stability and palatability. Additionally, such factors as color, melting point, and handling characteristics may be of importance under certain circumstances.

SAFETY CONSIDERATIONS

Health and Performance of Poultry and Livestock

Substances present in fats and oils that are deleterious to animals may be naturally occurring or man-made. These substances cause poor performance and in certain instances may be lethal to exposed poultry or livestock. Historically, free gossypol and cyclopropenoid fatty acids present in cottonseed oils and the erucic acid present in rapeseed oils were responsible for performance problems in poultry and livestock. However, the problems due to these naturally occurring substances are well-known and have not been reported for some time.

The most significant man-made compounds found in fats and oils are chlorinated substances. Polychlorinated dibenzo-p-dioxins, often referred to as the "chick edema factor" caused large scale mortality in broiler chickens in 1957. The ingestion of these compounds caused the accumulation of serous fluids in the pericardial sac and subsequently induced heart failure. The source of contamination was identified as a byproduct from fatty acid processing. Since that time only trace levels of these dioxin isomers and the related chlorinated dibenzo furans have been detected in feed grade fats and oils and, hence, pose more of a potential tissue residue problem than a deleterious effect to animals.

Other halogenated hydrocarbons such as polychlorinated biphenyls (PCBs) and polybrominated biphenyls (PBBs) can cause similar effects in animals but are less potent than the chlorinated dioxins. The contamination of fishmeal with PCBs in the Southeastern part of the U.S. in the early 1970's had a major impact on the health of large numbers of broiler chicks and resulted in a high rate of mortality. The contamination of dairy feed with PBBs due to a feed manufacturing error is well-known and resulted in performance problems among dairy herds as well as a threat to human health. However, these notable incidents were not the result of the presence of these substances in dietary fat supplements.

Further, as a result of the banning of PCBs and tighter controls on brominated compounds, the principle concern of such substances in feed grade fats is related to their potential as tissue residues in meat destined for human consumption and not toxicological considerations in the health and well being of poultry and livestock.

Heavy metals have been observed in fats and oils from time to time and are generally associated with recovered oils. Although monitoring is generally infrequent no excessive levels have been reported or observed recently.

Human Health - Residue Contamination in Poultry and Livestock Tissue

As a food safety measure, the U.S. Department of Agriculture (USDA), the Food and Drug Administration (FDA) and the U.S. Environmental Protection Agency (EPA) regulate the use and the levels of man-made chemicals in food products destined for human consumption. One of the most important groups of chemicals associated with these regulations in the feed industry are the chlorinated pesticides. The common concerns for these chlorinated substances include their persistence in the environment, their bioconcentration in the tissues of animals and humans and their chronic toxicity, particularly those believed to function as carcinogenic agents.

The potential for the presence of chlorinated pesticides is of particular concern in fats and oils since they are fat soluble compounds that may be dissolved in the fat portion of rendered products, feed grade vegetable oils and marine oils. The contamination may result from industrial accidents including direct contact with pesticide residues during processing, storage and shipping of fat products. In the case of feed grade vegetable oils it has resulted from uptake of chlorinated pesticides contaminated in soil and their concentration in feed grade byproducts during the refining of crude vegetable oils. Contamination of marine oils may arise from the bioconcentration of chlorinated pesticides in fish from more dilute concentrations in water, aquatic biota and other small aquatic organisms.

Tissue residues of chlorinated hydrocarbons other than pesticides also are of concern to regulatory agencies for the same reasons previously mentioned. The most notable of these substances include, polychlorinated biphenyls (PCBs), chlorinated dibenzo-p-dioxins and chlorinated phenols. However, many other classes of chlorinated compounds continue to be manufactured and commercialized. Generally, these substances appear as tissue residues as a result of inadvertent commercial or industrial contamination of the environment or the food chain.

Regulatory agencies also have concerns for tissue residues of certain nonchlorinated compounds. These include the organophosphate pesticides, the phenoxy acid herbicides and the triazine herbicides. Based on our experience, the organophosphate pesticides are the most likely to be present. Although this group of pesticides does not exhibit the same persistence, bioconcentration and chronic toxicological properties as the chlorinated compounds, they are known neurotoxic agents and are regulated accordingly.

Each year the USDA publishes a National Residue Program Plan that lists both the compounds of interest to the agency and the published residue limits (1). The residue limits are described as "tolerances" or "action levels" and have been published in the Code of Federal Regulations for various tissues and organs of poultry, swine, cattle, horses, sheep and goats including fat (adipose tissue), kidney, liver, muscle, edible tissue, skin, skin with fat and skeletal muscle. These compounds represent those which are most closely monitored by USDA during that particular year. However, the regulatory agencies have the authority to take action on any residue found in agriculture products at any time. A summary of the residue that may be found in feed grade fats and oils is presented in Table I.

EFFICACY OF FEED GRADE FATS AND OILS

Fats and oils possess the highest caloric density of all known nutrients. Although other factors such as the essential fatty acid content, oxidative stability, palatability, and handling characteristics are considered to be important, the efficacy of fats and oils in poultry and livestock rations is judged primarily on its digestible or metabolizable energy value. Generally the useful calories in fat are measured as the true metabolizable energy (TME) value, the apparent metabolizable energy (AME) value adjusted or unadjusted for nitrogen, or the digestible energy (DE). These energy levels are expressed as kilocalories per pound or as kilocalories per kilogram.

Based on studies reported during the past thirty-five years in chickens, turkeys and pigs, it is clear that all fats and oils do not exhibit the same DE, AME or TME (2,3,4,5,6,7,8,9,10,11). Many of these same studies, as well as others, have attempted to demonstrate relationships between the biological energy value and the chemical composition of the fats or oils tested. The factors which affect the energy value of a fat or

oil fall into two general categories: those components of feed grade fats and oils that dilute the caloric value of the material as a result of their presence and those chemical factors that effect the formation of lipid-bile salt micelles. With the possible exception of the oligomers, the components that dilute the energy value of the fat or oil are well known and the methods to identify and quantify their presence are relatively simple. The chemical considerations related to the formation of lipid-bile salt micelles are more complex and less well understood by most nutritionists.

Components Which Dilute the Energy Value of Fats and Oils

Table 2 presents a summary of the important parameters which measure the dilution of energy in fats and oils. The components measured by the methods listed here contribute little or no energy and reduce the metabolizable energy (ME) level in direct relationship to their presence. Those that contribute no energy or virtually no energy include moisture, insoluble matter and unsaponifiable matter. Those substances present which contribute significantly less energy than the glyceryl esters and free fatty acids include free glycerol, phospholipids, oxidation products of fatty acids, and polymerization products of fatty acids and glycerides measured as oligomer/polymer content. As the level of these substances increases, the percentage of total available fat present as glyceryl esters and free fatty acids decreases and the potential metabolizable energy is reduced correspondingly.

A relatively simple chemical parameter that is often used to estimate the portion of a fat product that is potentially available as an energy source to poultry and livestock is the total fatty acid or TFA fraction as defined by the method of the Association of Official Analytical Chemists (AOAC) (12). However, in addition to the free fatty acids originally present in the sample or that have been formed by the saponification step in the actual test procedure, the TFA fraction contains both the unsaponifiable fraction and the fatty acid oligomers. Since these components do not represent portions of a fat product that are available for lipid metabolism, the unadjusted AOAC value is of limited utility in evaluating the quality of a fat or oil. To effectively evaluate the potential energy value of a fat product, adjustments should be made for the unsaponifiable matter and the fatty acid/glyceryl ester oligomers to determine the "true" TFA value (Figure 1). To indicate the adjustments that have been made, the subscripts "u" and "p" have been added for the unsaponifiable and polymerized (oligomer) fractions, respectively. Hence, the nomenclature for the "true" TFA used in our laboratory and for the purpose of this paper is "TFA_{up}".

With the exception of the polymerized fat portion, the analytical methods required to obtain valid data for the energy diluting substances are relatively simple. However, we have observed significant variations in the results reported by different laboratories that have analyzed portions of the same sample for these parameters. Therefore, irrespective of the simplicity of the analytical test it is important that scientifically valid methods be employed and sound quality assurance/quality control procedures be included with each analysis to insure accuracy and precision.

The polymerized fraction or oligomer content of fats and oils represents the most recent and the most complex chemical parameter to be added to the factors that dilute the potential energy level. When fats and oils are subjected to elevated temperatures in the presence of air (oxygen), both oxidation and another series of reactions known as polymerization can take place (13,14,15). Like oxidative degradation, this process involves free radical formation and targets the polyunsaturated fatty acids present. However, this pathway actually joins fatty acids and/or glyceryl esters together to form higher molecular weight species as contrasted to oxidative degradation where fatty acids are broken down to lower molecular weight components such as aldehydes and ketones. The phenomenon of polymerization of fats and oils has been known for some time

although the previous methods used to identify and characterize "polymeric" substances in feed grade fats and oils have been relatively crude. Methods such as those measuring non-eluting substances observed during gas chromatographic analysis of fatty acids are nonspecific and, hence, do not provide useful qualitative or quantitative information. Recently, studies in our laboratories have indicated that the principle polymerized products in feed grade fats and oils are relatively low molecular weight species called "oligomers" (15,16). These substances are characterized by the covalent bonding of fatty acids and/or glyceryl esters to each other to form dimers, trimers, tetramers, and only trace quantities of higher molecular weight oligomers and polymers. It is well established that the covalent bonding that takes place among the unsaturated fatty acids during polymerization in air result in carbon-carbon (c-c) bonds, carbon-oxygen-carbon (-c-o-c-) bonds (ether linkages), and carbon-oxygen-oxygen-carbon (-c-o-o-c-) bonds (peroxy bridges). Preliminary studies in our laboratory indicate that these linkages are not severed by gastric acidity or pancreatic lipase and that the fatty acid oligomers are not well utilized by broiler chickens (15,16).

Since the formation of oligomers requires prolonged heating at elevated temperatures in the presence of air, restaurant cooking oils represent a likely source of oligomers. Preliminary work suggests that many fats and oils and virtually all used restaurant greases contain oligomers. However, the data indicates that the oligomer content varies considerably among restaurant greases and in many cases is below a level where the impact on ME value could be measured in an energy balance study (15). A single energy balance study with young broiler chicks reported that no statistically significant differences in metabolizable energy value or feed efficiency could be detected within the level of sensitivity of the assay with restaurant greases containing up to 2.78 percent total oligomers (16). However, in the same study a significant difference in metabolizable energy value and feed efficiency was observed in a restaurant grease containing 17.2 percent oligomers that were prepared under laboratory conditions. Further, analysis of the feed and feces of chickens fed the fat containing high levels of oligomers indicates that the fatty acid oligomers were not utilized and the glycerol ester oligomers showed a progressive decrease in utilization from the dimers to the tetramers (15).

Studies in our laboratory have demonstrated that fats or oils containing high levels of unsaturated fatty acids will form measurable quantities of oligomers during prolonged periods of heating in the presence of air (15). Further, our studies indicate that the amount of oligomer formation appears to be a function of not only the fatty acid composition of the fat or oil, but also the availability of oxygen, the time and temperature to which the material is subjected and the level of antioxidant present. Methodology for qualitative and quantitative analysis of fatty acid and glyceryl ester oligomers is relatively new and not widely available. The results reported here are based on methods developed in our laboratory.

Factors Related to Lipid-Bile Salt Micelle Formation

Numerous workers, including those previously cited, have reported significant differences in the utilization and/or metabolizable energy values of various fats and oils in chickens, turkeys and pigs. In general, the data indicate that oils containing high levels of unsaturated fatty acids such as corn or soybean oil possess the highest metabolizable energy values while the ME values for beef tallow and other highly saturated fats are significantly lower (17,18,19). The ME values for greases and poultry oils which contain intermediate levels of both saturated and unsaturated fatty acids lie between these high and low limits. Studies clearly indicate that the long-chain saturated fatty acids are poorly utilized by poultry. Further, extensive work has demonstrated the effects of the

unsaturated fatty acids on increasing the utilization of the saturated fatty acids (20,21,22,23).

Because of these observations and the interest among nutritionists to quantify the caloric value of commercial fat supplements, attempts have been made to develop predictive methodologies that relate chemical composition data of fats and oils to their metabolizable energy value. Approaches for predicting the ME value of fats and oils include the use of parameters such as the iodine value and the level of the triglyceride fraction (24), the unsaturated:saturated fatty acid (U:S) ratio (25), the U:S ratio and the level of free fatty acids (26), the iodine value and the fatty acid composition (27) and the content of palmitic and stearic acids (28).

The predictive models listed here are quite limited in their application. These methodologies suffer from an incomplete number of the important parameters required for a wide variation in fat composition and employ overly simplistic or nonspecific parameters. For example, although the iodine value determines the degree of total unsaturation of a fat or oil, it does not discriminate among the various monoene, diene, triene and possibly more highly unsaturated fatty acids present. Its usefulness is restricted to the evaluation of a specific fat of consistent fatty acid composition and known raw material source where the caloric value has been established and previously correlated with the iodine value, an unlikely circumstance in commercial situations.

The use of the unsaturated:saturated (U:S) fatty acid ratio as the principal or sole parameter for determining caloric value is limited and understates the complexity of the physico-chemical phenomena in the intestinal tract during fat absorption. The U:S ratio per se is an over simplified parameter and does not consider differences in properties among saturated fatty acids and among unsaturated fatty acids and their respective contribution to lipid-bile salt micelle formation. One predictive methodology considers moisture, insoluble matter, unsaponifiable matter, free fatty acids, fatty acid composition, iodine value and the non-polar fraction eluted from open column chromatography (24). Although this method expands on the number of chemical parameters employed, it does not adequately address important factors related to the ME value such as the specific properties and affects of the various saturated and unsaturated fatty acids, the composition of the free fatty acid fraction and the presence and impact of fatty acid and oligomer glyceryl ester oligomers.

As previously stated, the potential energy of a fat or oil is based primarily on the free fatty acids and the glyceryl esters present with fat or oil. The "true" TFA_{up} represents the best available measure of this potential energy. However, the utilizable energy or the ME of a fat or oil is ultimately based on the amount of the TFA_{up} that is absorbed by the animal. The absorption in turn is based primarily on the degree of solubilization of the TFA_{up} components in mixed lipid-bile salt micelles in the intestinal tract of birds and animals.

The *in vivo* formation of lipid-bile salt micelles is based on a complex series of chemical parameters including those shown in Table 3. Our laboratories have developed and routinely use a predictive methodology to estimate the caloric value of fats and oils (15,29,30). The predictive methodology includes a consideration of both the energy dilution factors and the chemical and physical properties of fats and oils and their relationship to mixed lipid-bile salt micelle formation during the absorption of dietary fats. These data have contributed much to our understanding of the various reports on the poor utilization of glyceryl esters saturated fatty acids, the difference in utilization among saturated fatty acid homologs, the effect of unsaturated fatty acids on the utilization of saturated fatty acids, the differences in utilization of triglyceride fats and their respective free fatty acids and the importance of saturated fatty acid position on the triglyceride molecule. A summary of the relationship of the key chemical parameters to the ME value

is shown in Figure 2. The important chemical parameters include the individual and collective properties of the saturated and unsaturated fatty acids, the interactions between the unsaturated and saturated fatty acids, the differences in properties of free fatty acids and glycerides, a consideration of the levels of fatty acid and glyceryl ester oligomers/polymers present, as well as a consideration of the components that dilute the caloric value of the free fatty acids and glyceryl esters previously discussed in this paper.

It is possible that additional chemical parameters related to the metabolizable energy values of fats and oils remain to be elucidated and that certain of the known chemical parameters will require further research and adjustment. However, the current predictive methodology appears to be applicable to fats and oils from a broad range of raw material sources and chemical composition.

A general summary of the energy dilution factors and the micellar solubility factors are shown in Table 2. As can be seen, there is considerable variability in the values for each of the chemical parameters both across product lines and within the various product classes of feed grade fats and oils.

Oxidative Stability

Another chemical parameter not directly related to caloric value should be considered when evaluating the quality of feed grade fats and oils. These are the parameters that address oxidative stability.

There are two primary considerations on the subject of oxidative stability of fats and oils. First is the history of the fat with respect to oxidation and, secondly, its resistance to further oxidation. The "oxidative history" is generally evaluated using either the initial or secondary products of oxidation. The initial products of oxidation include the peroxides and the hydroperoxides and are measured by the initial peroxide value. The secondary or final products of oxidation including aldehydes, ketones and other substances generated during oxidative degradation are measured using methods such as the thiobarbaturic acid (TBA) test. There are pros and cons regarding the usefulness of these tests. The initial peroxide test measured the levels of intermediates in the oxidative pathway and have been criticized because it only measures a transient pool of substances. The TBA test and similar tests measure final products such as the aldehydes and ketones and have been thought to provide a more quantitative picture of the oxidative history. However, in the case of feed grade fats, the constant elevated temperature result in the loss of these low molecular weight, volatile substances resulting in a poor quantitative picture of the "oxidative history". Our experience has indicated that the initial peroxide value is a satisfactory parameter in most instances.

The second important consideration, the "oxidative future", is determining the resistance of a fat to further oxidation. The most widely used method for determining oxidative stability is the active oxygen or AOM method. This procedure entails the acceleration of oxidation under controlled conditions using both heat and aeration (oxygen) with the determination of peroxide/hydroperoxide levels generated during specific time intervals. Generally a 20 hour test period is used. Although the method has been criticized as being unreliable, we have not found this to be the case in our laboratory. We believe that any unreliable or erroneous data generated is a result of questionable laboratory procedures, poor quality assurance/quality control procedures and inadequate interpretation of the results.

Table 1

POTENTIAL RESIDUES IN FEED GRADE FATS AND OILS

SUBSTANCES	COMMENTS	CONCERN LEVELS
Organochlorine pesticides, metabolites and isomers	Highly persistent. Bioconcentrate in animals.	Tolerance levels set by FDA/EPA and monitored by USDA. Vary from chemical to chemical.
(PCBs) Polychlorinated biphenyls	Highly persistent. Bioconcentrate in animals.	Tolerance level of 3.0 ppm for total congeners in fats and oils.
Organophosphate pesticides, metabolites and isomers	Less persistent and more readily metabolized than the organochlorine pesticides.	Tolerance levels set by FDA/EPA and by USDA vary from chemical to chemical
Polychlorinated dibenzo-p-dioxins ("chick edema factor) and polychlorinated dibenzo furans	Broad distribution at very low levels. Persistent in the environment with bioconcentration in animals.	Below limits of detection using FDA analytical methods.
Other chlorinated hydrocarbons	Inadvertent contamination from commercial or industrial applications	Generally no level established or zero level (i.e., below limits of detectability).
Heavy metals (i.e. lead, mercury, arsenic chromium, nickel, and cadmium).	Very limited distribution. May be associated with recovered greases in isolated cases.	Generally no levels established. Typically levels <1 ppm.

Table 2.
SUMMARY OF THE IMPORTANT ENERGY DILUTION FACTORS (EDFs)

Moisture
Phospholipids
Insoluble matter
Products of oxidation
Unsaponifiable matter
Products of polymerization
Free glycerol

TABLE 3

BILE SALT MICELLAR SOLUBILITY FACTORS (MSFs)

Glyceryl ester profile
Total free fatty acids
Fatty acid profile of free fatty acid fraction
Fatty acid profile of glyceryl ester fraction
Position of long chain saturated fatty acids in glyceryl esters
Levels of individual saturated fatty acid homologs
Levels of individual unsaturated fatty acid isomers
Profile of glyceryl ester oligomers/polymers
Profile of fatty acid oligomers/polymers

(Key chemical parameters related to in vivo formation of mixed lipid-bile salt micelles)

Table 4

Summary of Important Parameters and Range of Values for General Classes of Feed Grade Fats and Oils

	Beef Tallow %	Yellow Greases %	Poultry Fats %	Restaurant Greases %	Animal/Vegetable Blends %
Total Fatty Acids (TFA)*	90-92	90-92	90-92	90-92	90-94
Tru Fattay Acids (TFA_{up})*	88-90	88-90	88-90	84-90	82-92
Moisture*	0.5-1.0	0.5-1.0	0.5-1.0	0.6-1.3	0.7-2.2
Insoluble Matter*	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5
Unsaponifiable Matter*	0.5-1.5	0.7-2.0	0.7-1.5	0.7-1.8	1.5-5.0
Acetone Insolubles*	< 0.5	< 0.5	< 0.5	<0.5	0.5-1.75
Oxidized Fatty Acids*	0.2-1.0	0.3-1.0	0.2-0.7	1.0-3.0	0.7-3.0
Initial Peroxide Value (meq/Kg)*	1.0-2.0	1.0-5.0	1.0-2.0	2.0-8.0	1.0-6.0
Oligomer/Polymer Content**/	<1	<1	<1	2.5-9	<1-8
Stearic Acid**	18-26	12-16	4-6	6-18	8-20
Linoleic Acid**	2.0-4.0	9-15	15-22	8-34	15-35
Free Fatty Acids**	3.0-15.0	3.0-15.0	2.0-8.0	5.0-15.0	20.0-60.0
Total Saturated Fatty Acids**	48-52	34-43	27-32	17-40	25-45
AOM Stability(20 Hrs), meq	1-10	1-20	1-20	5-20	2-20
Metabolizable Energy (Kcal/lb)	2950-3300	3350-3650	3675-3740	3300-3760	3200-3900

*Parameters measuring energy diluion

**Parameters measuring micellar solubility

(Other important parameters not shown include fatty acid profiles of glyceryl ester and free fatty acid fractions, oligomer/polymer profiles).

FIGURE 1

DETERMINATION OF "TRUE" TOTAL FATTY ACIDS (TFA_{up})

<p>"True" total fatty acids = Total fatty acids - [unsaponifiable matter + adjustment for polymerized products]</p> <p>(TFA_{up}) (TFA via AOAC method)</p>
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FIGURE 2

RELATIONSHIP OF KEY CHEMICAL PARAMETERS TO METABOLIZABLE ENERGY VALUE OF FATS AND OILS

Key Chemical Parameters in Fats and oils EDFs ; MSFs	>	Mixed lipid bile salt formations	>	Fat Absorption	>	Metabolizable Energy Value
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