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APPLICATIONS OF PALM OIL IN ANIMAL NUTRITION

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ABSTRACT

Palm oil and its derivatives play a significant role in animal nutrition, and the opportunity to increase usage in this sector is large. Fats and oils are used as energy sources, to supply dietary essential fatty acids (linoleic and linolenic acids) that cannot be synthesized by the animal, to aid in the absorption of fat-soluble vitamins, and to provide specific bio-active fatty acids. The amount of fat or oil that can be used in animal diets varies depending on the species and its digestive physiology. The digestive systems of cattle, pigs and poultry differ with respect to the way in which fats/oils are broken down, absorbed and utilized. Cattle are ruminants in which the fermentation of carbohydrates in the rumen provides energy for the animal. Dietary triglycerides are largely hydrolyzed in the rumen by the resident microbial population, while the unsaturated fatty acids are hydrogenated to saturated fatty acids. Feeding large amounts of triglycerides (>3% of the diet), particularly those which are unsaturated, inhibits rumen microorganisms and makes biohydrogenation incomplete. If biohydrogenation does not occur fully, a flow of unsaturated or partially unsaturated fats/oils with trans*-double bonds into the small intestine can decrease feed intake and depress milk fat production, as well as alter milk fat profiles. To overcome this problem, fats/oils for ruminant feeding need to be in a form that makes them inert in the rumen, such as in the form of a calcium salt or soap of palm fatty acid distillates (CaPFAD), or after crystallizing the saturated fatty acids by beading or flaking. Pigs and poultry are non-ruminants (monogastrics) and rely on their own enzymes for the breakdown of dietary triglycerides. Fatty acids are then absorbed in the small intestine along with mono- or diglycerides. Pigs and poultry can utilize relatively saturated as well as unsaturated fats in their diet, but the inclusion of unsaturated fats/oils results in more unsaturated fatty acids in their body fat, which makes the carcass fat softer and this can reduce carcass quality. Increased energy levels in the diet of dairy cows can benefit the production of milk and milk components, improve reproductive efficiency, reduce heat stress, and improve general health and well-being. Increasing fat/oil levels in pig diets improve growth rates, reproduction and lactation. Hard (more saturated) dietary lipids help produce firmer carcass fat. Increasing fat/oil levels in poultry diets improves feed efficiency and growth rates. Medium-chain triglycerides (MCTs) are also of interest, particularly in young animals where their rapid absorption can help provide a readily available energy supply. Palm oil and palm kernel oil can be used to replace butterfat in milk replacers for feeding young animals to substitute their mother's milk. Fats are also used in the diets of companion animals (dogs and cats) and horses. Worldwide animal production is increasing rapidly. As standards of living increase, more animal products are being consumed in the diet, including meat, milk and eggs. Livestock consume approximately 33% of global cereal grain production, and the animal nutrition industry consumes between 8 and 10 million tonnes of fats and oils per annum. This use will increase significantly in the next 15 years as more animal products are consumed. In addition, there is greater focus on finding ways to replace cereal energy in animal nutrition as cereals are increasingly being*

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diverted to human foods or biofuel production. Fat/oil levels in feed are generally lower than the levels that can be utilized by the animal based on its digestive and metabolic processes. More calories could be supplied by fats/oils but there are limitations based on the physical characteristics of the fats and oils and their interactions with the target animal's physiology.

Keywords: animal nutrition, palm oil, livestock production, digestive processes, ruminants.

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INTRODUCTION

A significant amount of palm oil and its derivatives is used in animal nutrition, and the opportunity to increase usage in this sector is large. Fats and oils serve a variety of applications in animal diets. Fats and oils are used as energy sources that supply approximately 2.25 to 2.5 times the equivalent energy of carbohydrates. Fats and oils supply the 'dietary essential' fatty acids (linoleic and linolenic acids) that cannot be synthesized by the animal, but which are necessary for the formation of cell membranes and various signaling molecules such as prostaglandins and leukotrienes. Dietary fats and oils aid in the absorption of the fat-soluble vitamins A, D, E and K. In recent years, focus has been on the individual fatty acids provided by dietary fats, including various specific bioactive fatty acids such as eicosapentaenoic acid and conjugated linoleic acid (CLA) that exert effects on metabolism and health.

Fats and oils are digested, absorbed and utilized differently, depending on the target animal species and its own unique physiology. This article examines the application and opportunities for lipid components derived from palm oil processing in the major production animal species, what the benefits are for the animals, and what will be the economic benefits derived from these applications.

GLOBAL LIVESTOCK PRODUCTION

Livestock continue to play a vital role in the nutrition of humans worldwide. The major species furnishing food for humans are cattle (both dairy and beef), pigs, poultry, sheep and goats. Worldwide distribution of these animals by region is shown in *Table 1*. Animal products contribute about 16% of human food energy and 33% of human food protein (FAO, 2009). Ruminant species such as cattle, sheep, goats and water buffalo provide this human food value while consuming in a large portion of their diet those materials that are unusable directly by humans, such as forages, roughages, cellulosic food-processing by-products, and browse plants. Non-ruminant livestock such as pigs and poultry consume mostly cereals and oilseed products that potentially are usable by humans, although they too can consume some by-product feedstuffs that are not directly utilized by humans. Worldwide it is estimated that animals consume about 33% of the global cereal grain production (FAO, 2009).

Although the rate of growth in the world population has slowed somewhat in recent years, current estimates put the world population at more than 7.7 billion people by 2020. Economic advancement in the developing countries has lifted millions of people out of poverty; yet predictions are that over 1 billion people will remain

TABLE 1. ESTIMATED WORLD ANIMAL PRODUCTION BY REGION, 2007

Region	Dairy cattle (m)	Beef cattle (m)	Sheep and goats (m)	Pigs (m)	Poultry (m)
Africa	55	30	160	17	3 000
Americas	51	113	36	210	20 000
Asia	90	96	609	859	22 000
Europe	41	48	99	295	8 000
Oceania	6	13	64	8	1 000
Total	243	300	968	1 389	54 000

Source: FAO (2009).

TABLE 2. CHANGE IN WORLD DAIRY COW POPULATION, 1991-2006

Number of milk cows (1 000)	1991	2006
North America	17 676	17 006
South America	17 500	17 440
Europe	31 699	24 944
Asia	62 175	60 191
Oceania	4 352	5 970
Total	133 402	125 551

Source: USDA-NAHMS (2007).

TABLE 3. MAJOR FEEDSTUFFS USED AS SOURCES OF PROTEIN, LIPIDS AND CARBOHYDRATES IN LIVESTOCK DIETS

Protein	Fats/oils	Carbohydrates
Soyabean	Palm	Corn/maize
Cottonseed	Soyabean	Barley
Canola	Cottonseed	Wheat
Flax/linseed	Tallow	Rice
Fish	Lard	Millet
Animal by-products	Fish	Cassava

undernourished by 2020 (FAO, 2009). As disposable incomes increase in most developing countries, the demand for animal products in the diet also increases. Taking into account these dynamics, it is estimated that animal product consumption will double by 2020, just over 10 years from now.

This unprecedented growth in demand for high-quality animal products will place incredible demands on feedstock supplies and availability. Gains in efficiency of nutrient use will likely continue, as observed over the last half-century. For example, the number of milk cows in the world has actually decreased over the last two decades (*Table 2*), yet milk production has continued to grow as individual animals and herds become more productive.

Total feed utilization will have to grow substantially to provide the increased demand for animal products by 2020, which means new sources of feeds and new feedstocks must be identified, and innovative ways must be pursued to increase the nutritive use of more widely available materials by the animals. The major feedstuffs used in animal nutrition (other than the forages and roughages used in ruminant feeding) are shown in *Table 3*.

Replacing some of the dietary energy in livestock diets now provided by cereals with fats and oils represents one strategy to meet the growing demand for feed energy. Currently, global use of fats and oils in animal nutrition is estimated to be 8 to 10 million tonnes annually. Feed use represents the second largest category of utilization of inedible fats, coming behind their conversion to methyl esters, at approximately 1.4 million tonnes annually, or more than 28% of the total. Of this amount, about 90% originates from animal fats (tallow and grease) with only 10% from edible fats and vegetable oils.

While fats and oils currently are widely used in animal nutrition programmes, the opportunity exists for even greater utilization, perhaps within new paradigms in animal nutrition. As shown in *Table 4*, even a modest market penetration with additional fats has the potential to account for 5.7 million tonnes of fats annually. Clearly, there is a substantial upside for the palm oil industry when animal nutrition applications are contemplated.

Considerations of the potential increased role for palm products in animal nutrition must be in the context of the challenges facing the livestock industries globally. Growing populations and increasing use (at least in the short-term) of cereals for the production of biofuels place livestock feeding in direct competition with humans for their use. The intensity of livestock production continues to increase, with specialized operations that are in many cases uncoupled from the local production of feeds. Nutrient management and environmental degradation are key concerns in many countries, with the need to improve the efficiency of nutrient capture into the final animal products and to limit the excretion of wastes. Carbon balance, methane reduction and climate change will alter the way in which feeds are grown and fed, and the location where they are grown. Food safety

TABLE 4. POTENTIAL MARKET FOR FATS AND OILS IN ANIMAL NUTRITION WORLDWIDE

	Dairy cattle	Beef cattle	Sheep and goats	Pigs	Poultry	Total
Concentrate feed per head/year (kg)	2 000	100	30	200	4	-
Added fat in diet (%)	2.0	0.2	1.0	3.0	2.0	-
Total fat (t) (× ’000) (25% market)	2 430	5	72.6	2 083	1 086	5 677

issues worldwide will likely bring about increasing scrutiny of feedstock production and utilization in animal nutrition. Consumers in developed countries are becoming ever more focused on the role of diet in health and in prevention of chronic diseases. Animal products have many positive roles to play here, in terms of protein quality, bioactive fatty acids such as CLA, calcium, vitamins such as B_{12}, and many minerals. Finally, continued genetic progress for highly productive and efficient animals places concurrent demands on nutritionists to meet the nutrient requirements of these animals for production and health, while minimizing the environmental impact from animal production.

PALM OIL PRODUCTS FOR ANIMAL NUTRITION

The manufacturing processes that result in products available to the feed industry are shown in *Figure 1.*

Palm oil products used in animal nutrition derive from either the refining process of crude palm oil (CPO), or the crushing of palm kernels to produce palm kernel oil (PKO). Palm fatty acid distillate (PFAD) is the distillate left after refining of palm oil. This product is used extensively in animal feed, frequently reacted with calcium to produce the calcium salt or soap (CaPFAD) which is a hard granular product. This process enables PFAD to be handled easily and also renders the fatty acids semi-inert in the rumen of the cow, which thus helps to prevent inhibition of the fermentation process occurring in the rumen.

Palm oil after refining can be fractionated to produce different melting point fractions. These specific fractions can be tailored to different applications in animal nutrition. Higher melting point fractions (>55°C) can be beaded or flaked, which enables them to be packed into bags and handled easily in animal rations. Softer fractions can be hardened or hydrogenated by the addition of hydrogen in the presence of a catalyst. Liquid fats can also be used directly in animal rations. These products are fed to dairy cattle, beef cattle and to poultry.

Fatty acids split from triglycerides by hydrolysis leaves glycerol as a by-product. Saturated fatty acids (particularly C16 and C18) are used in ruminant rations. Fatty acids are blended in different ratios depending on the desired melting point and iodine value for the specific application. Blends with melting points above 55°C are frequently flaked or beaded for ease of handling and addition to rations.

PKO can be subjected to similar fractionation processes to produce different chain-length triglycerides, including medium-chain triglycerides (MCT) which are sometimes used in the diets for young animals due to their rapid absorption and utilization as an energy source.

Residue streams from the industrial oleochemical industry can also be used in animal nutrition. Generally, the criteria that must be applied to test suitability for use in animal nutrition include fatty acid profile, melting point, ratio of saturated to unsaturated fatty acids, and levels of nickel if the streams come from a hydrogenation process. These criteria then must be matched to the particular nutrition application. Residue streams must also be relentlessly checked to ensure that they are free of adulterants, pesticides and other toxic materials.

Nutrition applications are discussed in detail below. Saturated long-chain fatty acids such as palmitic and stearic are generally considered better for ruminant animals, whereas unsaturated fatty acids and triglycerides are generally considered preferable for monogastric animals.

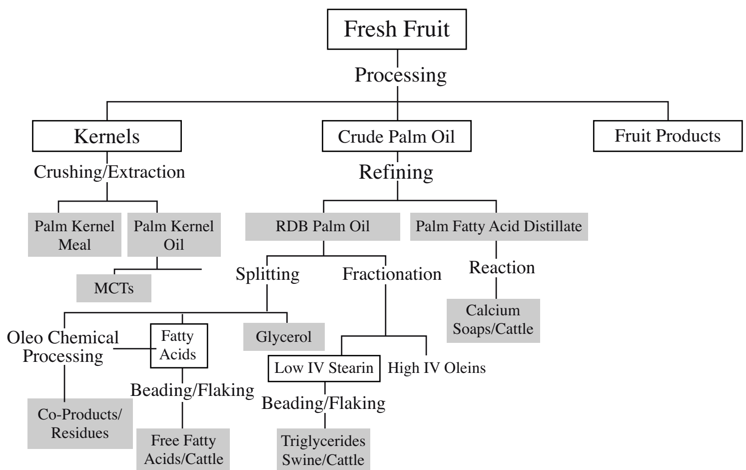

Figure 1. Scheme for palm oil processing and products for animal nutrition.

TABLE 5. COMPOSITION AND PROVISION OF ENERGY AS FAT IN THE FIRST FEEDS OF NEONATAL ANIMALS

	Cow (milk)	Pig (milk)	Chicken (egg)	Sheep (milk)	Goat (milk)
Fat (%)	3.6	5.7	10	6.8	4.2
Protein (%)	3.1	5.2	11	5.6	3.5
Carbohydrate (%)	4.8	5.4	0	4.6	4.6
% energy from fat	50.6	53.4	67	60	53.8

UTILIZATION OF FATS AND OILS BY KEY PRODUCTION SPECIES

Energy Levels from Fat in First Feeds

With the exception of poultry, the first feeds of young production livestock are milk or milk substitutes (milk replacers). For poultry, the first feed is the egg yolk. The composition of mother's milk and egg from these species is shown in *Table 5*. Of note here is that fat makes up a larger portion of the total dietary solids than in most growing or production diets. Indeed, fat constitutes more than 50% of the feed energy in the first feeds, and typically more than 15% in growing and production diets.

The reasons for the much larger use of fats in the first feeds compared with that in diets for older animals are not well understood. A large portion is likely due to the emulsified nature of the first feeds compared with dry diets for older animals. The fat in milk or egg yolk is highly emulsified, with extremely fine droplet size and optimal biological emulsifying agents. In ruminant diets, higher fat levels interfere with microbial fermentation in the rumen. Finally, the fatty acid profile of the feed fats is typically quite different from that of milk fat or egg yolk lipids.

Differences in Digestive Processes in Ruminants, Pigs and Poultry

Fats and oils are digested very differently between ruminant animals (cattle, sheep, goats) and non-ruminants (pigs, poultry). The primary differences are a consequence of the activities of anaerobic bacteria in the rumen on dietary lipids in ruminants which are lacking in non-ruminants. Several bacterial species in the rumen possess lipase activity that can hydrolyze dietary lipids in ruminants, whereas the animal's lipase enzymes carry out this function in non-ruminants. Another difference is the nature of the products of lipid digestion that are available for absorption: primarily saturated free fatty acids in ruminants and primarily 2-monoglycerides and fatty acids in non-ruminants.

Ruminants

Ruminants consume diets containing the vegetative portions of plants (forages) as well as various cereals or oilseed products. The carbohydrate portion of these materials is extensively fermented by the incredibly robust and diverse microbial population that lives within the rumen, the first compartment of the four-chambered ruminant stomach. The end-products of this fermentation are the volatile fatty acids (VFA) or short-chain fatty acids, principally acetate, propionate and butyrate, which serve as the major energy fuels for ruminant tissues. The microbial cells produced in the rumen serve as the major protein source for the animal after they are washed out of the rumen and flow into the small intestine.

The main types of lipid in ruminant diets are the glycolipids found in forage stems and leaves, as well as triglycerides found in cereals and oilseeds. Glycolipids are similar to triglycerides except that they have two or more sugars linked to one position of the glycerol backbone instead of the third fatty acid. The most common are galactolipids, which have galactose (a component sugar of milk lactose) linked to the glycerol. The two fatty acids that make up the glycolipids are generally unsaturated, with a high proportion of linolenic acid. Glycolipids are structural components of plant tissues. In most forages, whether fresh, dry or ensiled, glycolipids are extensively hydrolyzed in the rumen.

The microbial population within the rumen contains a number of bacterial species that actively hydrolyze the glycolipids and triglycerides found in feeds. The glycerol released is largely fermented to propionate and butyrate. The unsaturated fatty acids that are released by bacterial hydrolysis are extensively biohydrogenated to saturated fatty acids of the same chain-length by other species of rumen bacteria. This process accounts for the fact that ruminant fats (in milk or beef) are generally more saturated than the feeds the animals consume and are more saturated than the body or milk fats of non-ruminants. Bacterial biohydrogenation appears to be a defense mechanism for the microbes because the polyunsaturated fatty acids are toxic to the fibre-digesting microbial population within the rumen.

Under normal basal feeding conditions, the unsaturated fatty acids are extensively biohydrogenated by the microbial population without detriment to the rumen, but when the supply of unsaturated fatty acids in the rumen is increased by supplementation, the amount of unsaturated fatty acids may overwhelm the hydrogenating capacity of the microbial population. The resultant accumulation of unsaturated fatty acids and intermediates with *trans*-double bonds (particularly *trans*-10 in 18-carbon fatty acids) can decrease digestion of fibre (cellulose and hemicellulose) within the rumen, decrease feed intake by the animal, and decrease overall conversion of the feed to milk or meat. To prevent the negative effects of fat on the microbial population, and to prevent formation of these detrimental *trans*-isomers, a number of commercial fat supplements have been developed. Most important among these are calcium soaps of fatty acids and mixtures of mostly saturated fatty acids crystallized by beading or flaking. Palm oil is a major starting material for these products worldwide.

Fatty acids are not absorbed in the rumen, but rather pass into the lower digestive tract where they are absorbed from the small intestine. In contrast to non-ruminants, most of the lipid reaches the small intestine as highly saturated free fatty acids rather than the mostly unsaturated dietary triglycerides that reach the intestine in non-ruminants. Ruminants have evolved highly efficient systems of emulsification and micelle formation in the intestine to efficiently absorb the large quantities of saturated free fatty acids that reach the intestine daily. This occurs predominantly via the lysolecithin-bile salt system, in which lysolecithin is produced as a result of the action of pancreatic phospholipase enzyme acting on lecithin (phosphatidylcholine) coming into the intestine either as a component of microbial cell membranes or as a component of pancreatic juice and bile. Within the intestinal cells, fatty acids are esterified to α-glycerol-phosphate, produced from glucose metabolism, to form triglycerides. In turn, triglycerides are packaged with specific apolipoproteins, phospholipids and cholesterol to form a lipoprotein particle called a very-low-density lipoprotein (VLDL). VLDL carries triglycerides in blood to such tissues as the muscle, heart, adipose and mammary, where the enzyme lipoprotein lipase hydrolyzes the triglycerides to free fatty acids that can be taken up by the tissues. Fatty acids delivered from the diet in this way are major sources of milk fat and body fat, as well as an immediate energy source for muscle and heart.

Non-ruminants

Non-ruminants such as pigs and poultry consume mostly triglycerides in the cereals and oilseeds that make up most of their diet. Additional fats and oils often supplement the diet, mainly as triglycerides because free fatty acids (particularly saturated free fatty acids) are not well absorbed in non-ruminants.

Dietary fats are released from the feed matrix as the feed is chewed and then further mixed in the stomach. The mechanical action of contractions in the stomach and the shear forces of expulsion of the digesta into the intestine result in the formation of a coarse emulsion of fat in the intestinal contents. Bile, which is produced in the liver, stored in the gall bladder, and secreted into the upper small intestine, contributes bile salts and phospholipids that are important emulsifying agents for fat digestion. Emulsification of dietary fats increases greatly as the digesta mixes with these substances. Pancreatic juice secreted into the upper small intestine contributes the fat-digesting enzyme lipase, which acts on the surface of lipid droplets in the intestinal lumen to hydrolyze fatty acids from the 1 and 3 positions of the glycerol backbone. Pancreatic lipase is inhibited by bile salts, and the pancreas also secretes a protein called colipase, which acts to disperse bile salts from the surface of the lipid droplet and anchors lipase to the droplet.

The products of lipase activity on triglycerides, 2-monoglycerides and free fatty acids, spontaneously form mixed micelles in the presence of the bile salts. Micelle formation is necessary to allow for the absorption of fatty acids and monoglycerides into the intestinal epithelial cells. Within the intestinal cells, the monoglycerides are re-acylated to form triglycerides, which are packaged along with specific apoproteins, cholesterol and phospholipids to form a lipoprotein called a chylomicron, which is analogous to the intestinal VLDL formed in ruminants. The chylomicra are secreted from the cells, enter the lymphatic system, and then enter the venous blood. Like VLDL in ruminants, the triglycerides are hydrolyzed by lipoprotein lipase in peripheral tissues.

In poultry, lipid digestion follows a similar process to that in non-ruminant mammals, with the exception of the route of absorption of the chylomicron particles into the blood. In contrast to non-ruminant mammals, chylomicra in poultry are able to be absorbed directly into the portal blood system rather than the lymph. Owing to this process, these chylomicra are often called portomicrons in birds. Absorption into the portal blood means that the dietary lipoprotein particles reach the liver before the rest of the animal.

USE OF PALM PRODUCTS AND OTHER FATS OR OILS BY PRODUCTION ANIMALS

Neonatal Ruminants

The neonatal ruminant is born with a digestive tract similar to that of a monogastric animal, and relies on a milk diet during its early stages of development. A major industry has grown worldwide to produce milk replacers for the young bovine to replace the dam's milk so that the high-value milk can go to market rather than be fed to the calves. Calf milk replacers typically contain levels of fats/oils ranging between 15% and 20% of the dry matter (DM), with the remaining dry matter being protein and lactose.

Commercial calf milk replacers are manufactured using oils and fats of animal or vegetable origin to replace butterfat. Palm oil and PKO are frequently used in these applications. The digestibility of the fat and DM is improved in the very young calf when a blend of PKO is added to the palm oil (typically up to 20% of the total fat level).

Dairy Cattle

Comparison of supplemental fat sources. There are three main forms of supplemental fat sources from palm oil which are fed to dairy cattle: triglycerides, free fatty acids and calcium salts of palm fatty acids (made by the saponification of PFAD). The latter are commonly referred to as calcium soaps.

1. Triglycerides
   Triglycerides of palm oil origin fed to dairy cattle are generally produced by the fractionation of refined, bleached and deodorized (RBD) palm oil, and have generally a melting point above 125°F (>51.5°C). These fats are then flaked or beaded to produce a product which is easy to handle by the dairy producer, and can be mixed into a feed ration.
2. Ca soaps (CaPFAD)
   CaPFAD are a popular form of supplemental fat. They consist of approximately 82% fat, which is approximately 50% saturated and 50% unsaturated, while the remainder is ionic calcium. The fatty acids are dissociated from the calcium in the abomasum, releasing the fatty acids for absorption. The unsaturated fatty acids are extensively dissociated from calcium in the rumen and are biohydrogenated in the rumen to saturated fatty acids.
3. Free fatty acids
   Free fatty acids are the most energy-dense form of dry fat. They can either be in the form of saturated or unsaturated fatty acids. Saturated fatty acids are preferred over unsaturated fatty acids. Cows are especially well-equipped to digest and absorb saturated free fatty acids, so this type of fat requires no modification before digestion. In addition, unsaturated fatty acids have been shown to depress dry matter intake, while saturated fatty acids do not affect dry matter intake.

Data from experiments relating to the performance of cows fed with supplemental fat.

1. Dry matter intake
   The addition of certain supplemental fats to the diet causes changes in dry matter intake. Dr Mike Allen of Michigan State University examined this issue extensively in a review (Allen, 2000). There is no significant effect of feeding saturated free fatty acids on dry matter intake. However, there are significant decreases in dry matter intake when feeding with CaPFAD (-5.0% and -3.3% relative to non-fat controls). These decreases in dry matter intake can have a substantial effect on cows in early lactation when dry matter intake is already lagging behind milk production. CaPFAD are slightly more digestible than hydrogenated PFAD (Elliott *et al.*, 1996) or hydrogenated palm oil (Weiss and Wyatt, 2004) in dairy cattle.
2. Milk production
   The addition of supplemental fat results in increased milk production because more energy is being supplied to the dairy cow. In a recent review, milk production increased by 0.9 kg per day for cows fed CaPFAD and by 1.8 kg per day for cows fed saturated free fatty acids relative to controls fed no supplemental fat (Loften and Cornelius, 2004). These data show that feeding saturated free fatty acids leads to an increase in milk production.
3. Milk composition
   In a recent experiment, supplementation with saturated free fatty acids increased the amount of milk fat by 0.19 kg per day relative to cows fed no supplemental fat, and by 0.26 kg per day relative to cows fed CaPFAD (Relling and Reynolds, 2007). Milk protein was increased slightly for cows fed no supplemental fat and saturated free fatty acids, producing 0.05 and 0.06 kg per day more milk protein, respectively, than those fed Ca-soaps (Relling and Reynolds, 2007). Similar results have been documented on US commercial dairy farms that switched from feeding with CaPFAD to feeding with saturated free fatty acids. Over a two-month period, milk fat increased from 3.87% to 4.25% (+0.38%),

while milk protein increased from 3.09% to 3.34% (+0.23%). These data confirm that feeding with saturated free fatty acids has a positive effect on milk composition.

4. Reproduction
   Two studies have looked at the effect of supplementation with saturated free fatty acids on subsequent reproductive performance. Transition cows were fed saturated free fatty acids for the last 21 days of gestation. In the subsequent lactation, more of these cows were confirmed pregnant (86% *vs*. 58% for non-fat controls) (Frajblat and Butler, 2003). In addition, cows supplemented with saturated free fatty acids had fewer days open (*i.e.*, being non-pregnant) compared with non-fat controls (110 *vs*. 148 days) (Frajblat and Butler, 2003). Supplementation of lactating cows with saturated free fatty acids resulted in improved first service conception rate as well as overall conception rate relative to a non-fat control (59.1% *vs*. 42.6% and 59.3% *vs*. 40.7%) (Ferguson *et al*., 1990). Cows supplemented with saturated free fatty acids also had fewer services per conception relative to a non-fat control (1.57 *vs*. 1.96) (Ferguson *et al*., 1990). While supplementation with a saturated free fatty acid source in both of these studies resulted in improved reproductive efficiency, it remains unclear if this was the result of an improvement in energy status, or an effect of a specific fat or type of fat. However, regardless of the mechanism, supplementation with saturated free fatty acids appears to result in improved reproductive efficiency.
5. Heat stress
   Studies conducted in Shanghai during the height of summer have shown that feeding saturated free fatty acids to dairy cows had a significant impact on mitigating the impact of heat stress. This resulted in increased milk production, milk fat production and milk protein production. The cows with added fat in their diet had significantly lower body temperatures during the heat stress periods.

Beef Cattle

Much research has focused on the use of fats in diets for growing and fattening beef cattle, as well as for cows and heifers to aid in re-breeding. As an energy source, gains in performance for cattle fed fat have not been large enough to be justified economically in most cases. Feedlot diets may contain small additions of liquid fat to control dust and to hold the ration together, particularly in drier climates where large amounts of wet or ensiled feeds are not fed. Fats typically increase dressing percentage and kidney, pelvic and heart fat percentages (Zinn and Jorquera, 2007). There is considerable potential to increase the use of fats in high-concentrate beef rations (Hess *et al*., 2008). Owing to the negative effects on the fibre-digesting and methane-producing microorganisms in the rumen, supplemental fats such as yellow grease or vegetable oils can improve feed efficiency in cattle (Zinn, 1989). Addition of palm oil at 10.7% of dietary DM increased carcass fat content without affecting carcass quality grade in fattening lambs (Lough *et al*., 1993).

Research has demonstrated that vegetable oils and oilseeds that furnish linoleic acid may improve reproductive success in beef cows and heifers as they often do in dairy cattle (Santos *et al*., 2008). However, in beef cows, these responses have been inconsistent (Funston, 2004). There is considerable opportunity for understanding the influences of fat supplementation on reproduction in beef cattle.

Swine

There is a growing opportunity for feeding milk replacer to baby pigs to supplement sow's milk. Piglets with free access to milk replacer have greater gains in body weight and lean mass than their suckled littermates (Zijlstra *et al*., 1996). This represents a new opportunity for increased use of palm oils. In addition, MCT show benefits in improving piglet survival, weight gain and body fat (Wieland *et al*., 1993).

The use of fats and oils in the diets for growing pigs is common because of the high-energy value of fats and oils. Animal fats have been the most common fat sources used, primarily because of their lower cost. Typical inclusion rates are about 5% added fat. Lauridsen *et al.* (2007) showed that several vegetable fat sources (palm oil mix, palm oil, coconut oil, rapeseed oil) could be used as alternatives to animal fat in diets for weaning and growing pigs.

Supplemental fat also may be useful during pregnancy and lactation in sows. Supplemental fat during gestation and lactation improved sow body condition and improved suckling pig performance without affecting energy intake during lactation, which implies that the efficiency of energy utilization by sows was improved (Gatlin *et al*., 2002).

A consequence of feeding more unsaturated fat sources, such as vegetable oils or yellow grease, is that carcass fat becomes softer due to the lower melting point of these dietary fats. A solution is to feed more saturated fatty acid supplements, such as hydrogenated palm oil. More higher-melting point fat sources make the body fat firmer, without sacrificing animal growth performance (Gatlin *et al*., 2003).

Poultry

Digestibility of fats in poultry is lower in the young animal than in mature birds. There is evidence in poultry that the bile salt system is undeveloped in the young, and that emulsifiers improve the digestion of dietary lipids in poultry (Krogdahl, 1985). Digestibility of more highly unsaturated oils such as soyabean oil is higher than that of more saturated fats such as tallow or lard. Saturated fatty acids such as palmitic are absorbed very poorly in poultry unless they are in the form of 2-monoglycerides. However, animal fats are well-utilized and usually cheaper on an absorbed energy basis than vegetable oils.

Dietary fats are used in poultry to increase the energy density of the diet and to lower heat production by the birds in hot climates. Dietary fats produce an 'extra caloric effect' in poultry, in which the net energy value for maintenance and production is greater than would be predicted by apparent metabolizable energy (ME) measurements. Fats also improve the ME value of other dietary ingredients by slowing down the rate of passage of the feed through the digestive tract.

Palm oil was shown to increase egg size and improve the performance of pullets when fed up to 5% of the diet (Isika *et al.*, 2006). Addition of vegetable oils to the diets of layer hens increases egg size. To provide adequate energy for high egg production, most layer diets contain 1%-3% supplemental fat. For broilers, diets typically contain 2%-4% added fat, resulting in as much as an 8% increase in feed conversion efficiency. Increased use of palm oil by poultry seems to hold a great deal of promise (Preston, 1992).

USE OF PALM PRODUCTS AND OTHER FATS OR OILS BY HORSES AND COMPANION ANIMALS

Horses

Within the last 10 years, there has been considerable interest in the addition of fats into the feeds of horses, including those used for racing, draft and pleasure. Horses during periods of 'work' require high energy levels, but attempts to increase dietary energy by the addition of higher starch levels through cereal inclusion in the ration have sometimes been counterproductive. It is now understood that the digestion of starch leading to high blood glucose levels can create adverse responses, and sometimes makes the animals excitable and unworkable. Higher blood glucose levels also cause insulin responses, and in some cases leads to insulin resistance. The addition of fat in the form of beaded palm triglycerides (iodine value 12-15) to high forage diets has been a very successful process for increasing energy levels without the detrimental effects caused by extra starch addition (Tomkins, 2009).

Dogs and Cats

Fats and oils are important components in the diets for dogs and cats. Fats and oils provide a concentrated source of energy for growth and energy storage, as well as providing a source of essential fatty acids (linoleic and linolenic acids) that cannot be made within the animal body. Fats also contribute to palatability and an acceptable texture of the foods. As in other species, fats are important as carriers for absorption of the fat-soluble vitamins. Young dogs are typically fed diets that contain about 8%-10% fat, but can tolerate a wide range of fat contents (up to 40% of diet) and sources as long as the essential fatty acid requirements are met. Recommendations for older dogs are somewhat lower (5%-6% fat; NRC, 2006). The current recommendation for the fat content of cat diets is 9% of DM (19% of energy) but cats can effectively utilize diets that contain fat as high as 67% of energy (NRC, 2006). Diets with 20%-25% fat (on a DM basis) are usually more palatable than lower-fat diets for cats (NRC, 2006).

Apparent digestibility of fats in dogs fed mixed triglycerides ranges from 85% to 95% of intake, with the digestibility of dry extruded fats reported to be somewhat lower (70%-90%; NRC, 2006). Digestibilities are lower for fats that contain less than 40% unsaturated fatty acids compared with fats providing more than 50% unsaturated fatty acids (NRC, 2006). In cats, digestibilities of fat are more than 90%, and are higher in young cats than in aged cats (NRC, 2006). Digestibility is generally greater for more unsaturated fats than for saturated fats.

While palm oil has been used in formulating experimental diets, the authors are not aware of any large-scale studies comparing the use of palm oil in the diets of dogs and cats. Given the increasing numbers of pets worldwide, this may be a fruitful market to pursue.

FUTURE OPPORTUNITIES

The animal nutrition industry represents considerable current markets for palm oil products, but the potential for future growth is even more substantial. Nearly all sectors could use more palm oil or palm products as fat supplements. Growth in this demand would be hastened by careful research in several areas.

First, the factors that limit the use of fat in mature animals to a greater extent than when the same species is young need to be determined. With the identification of the changes that occur, perhaps due to suboptimal emulsification or to changes in metabolism, the amount of fat that can be fed efficiently could be increased. This could become even more important and beneficial as the demand for cereal grains continue to increase in food and non-food industrial uses.

The roles of fats and oils in reproduction, gestation, body condition maintenance and lactation need to be more clearly defined and better understood. If the use of specific fatty acids can improve reproductive success, prospects for increased dietary use of those fats will be improved tremendously.

The potential opportunities afforded by the ability to produce MCT for animal nutrition applications are large. There is a growing body of evidence that MCT will play an increasingly important role in animal nutrition, particularly in the nutrition of the neonatal animal where rapidly available energy can make the difference between high and low mortality.

Finally, systems research to document the benefits of integrated fats/oils production and livestock enterprises needs to be conducted. Outcomes of interest here include both the economic benefits as well as the implications on carbon balance and nutrient management in the environment.

Coupled with research on animal utilization, there is the need for continual improvement in the way fats are incorporated into animal diets. Methods for making fats easier to handle by the end-user are of great importance. Very few production systems, other than those with very large numbers of animals in close proximity, have the ability to handle large quantities of liquid fats at the farm level. Much of production animal agriculture is dependant on compounded feed or feeds in a dry form that can be easily added to rations. It is frequently difficult to do this when fats are in a liquid form. Technologies such as saponification of fatty acids and beading of high-melting point fats will certainly improve the production opportunities.

REFERENCES

ALLEN, M S (2000). Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *J. Dairy Science, 83*: 1598-1624.

ELLIOTT, J P; DRACKLEY, J K and WEIGEL, D J (1996). Digestibility and effects of hydrogenated palm fatty acid distillate in lactating dairy cows. *J. Dairy Science, 79*: 1031-1039.

FAO (2009). *FAO Statistical Yearbook 2009*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FERGUSON, J D; SKLAN, D; CHALUPA, W V and KRONFELD, D S (1990). Effects of hard fats on *in vitro* and *in vivo* rumen fermentation, milk production and reproduction in dairy cows. *J. Dairy Science, 73*: 2864-2879.

FRAJBLAT, M and BUTLER, W R (2003). Effect of dietary fat prepartum on first ovulation and reproductive performance in lactating dairy cows. *J. Dairy Science, 86 (Suppl. 1)*: 110 (Abstract).

FUNSTON, R N (2004). Fat supplementation and reproduction in beef females. *J. Animal Science, 82 (E-Suppl)*: E154-E161.

GATLIN, L A; ODLE, J; SOEDE, J and HANSEN, J A (2002). Dietary medium- or long-chain triglycerides improve body condition of lean-genotype sows and increase suckling pig growth. *J. Animal Science, 80*: 38-44.

GATLIN, L A; SEE, M T; HANSEN, J A and ODLE, J (2003). Hydrogenated dietary fat improves pork quality of pigs from two lean genotypes. *J. Animal Science, 81*: 1989-1997.

HESS, B W; MOSS, G E and RULE, D C (2008). A decade of developments in the area of fat supplementation research with beef cattle and sheep. *J. Animal Science, 86(14 Suppl)*: E188-E204.

ISIKA, M A; AGIANG, E A and OKON, B I (2006). Palm oil and animal fats for increasing dietary energy in rearing pullets. *International Journal of Poultry Science, 5*: 43-46.

KROGDAHL, A (1985). Digestion and absorption of lipids in poultry. *J. Nutrition, 115*: 675-685.

LAURIDSEN, C; CHRISTENSEN, T C; HALEKOH, U and JENSEN, S K (2007). Alternative fat sources to animal fat for pigs. *Lipid Technology, 19*: 156-159.

LOFTEN, J R and CORNELIUS, S G (2004). Review: responses of supplementary dry, rumen-inert fat sources in lactating dairy cow diets. *The Professional Animal Scientist, 20*: 461-469.

LOUGH, D S; SOLOMON, M B; RUMSEY, T S; KAHL, S and SLYTER, L L (1993). Effects of high-forage diets with added palm oil on performance, plasma lipids, and carcass characteristics of ram and ewe lambs. *J. Animal Science, 71*: 1171-1178.

NRC (NATIONAL RESEARCH COUNCIL) (2006). *Nutrient Requirements of Dogs and Cats.* National Academies Press, Washington, DC.

PRESTON, T R (1992). Alternative non-cereal diets for poultry. *Livestock Research for Rural Development, 4*: 31-35.

RELLING, A E and REYNOLDS, C K (2007). Feeding rumen-inert fats differing in their degree of saturation decreases intake and increases plasma concentrations of gut peptides in lactating dairy cows. *J. Dairy Science, 90*: 1506-1515.

SANTOS, J E; BILBY, T R; THATCHER, W W; STAPLES, C R and SILVESTRE, F T (2008). Long chain fatty acids of diet as factors influencing reproduction in cattle. *Reproduction in Domestic Animals, 43 (Suppl 2)*: 23-30.

USDA-NAHMS (2007). *Dairy 2007, Part I: Reference of Dairy Cattle Health and Management Practices in the United States, 2007*. USDA-APHIS-VS, CEAH, Fort Collins, Colorado, USA.

WIELAND, T M; LIN, X and ODLE, J (1993). Utilization of medium-chain triglycerides by neonatal pigs: effects of emulsification and dose delivered. *J. Animal Science, 71*: 1863-1968.

WEISS, W P and WYATT, D J (2004). Digestible energy values of diets with different fat supplements when fed to lactating dairy cows. *J. Dairy Science, 87*: 1446-1454.

ZIJLSTRA, R T; WHANG, K Y; EASTER, R A and ODLE, J (1996). Effect of feeding a milk replacer to early-weaned pigs on growth, body composition, and small intestinal morphology, compared with suckled littermates. *J. Animal Science, 74*: 2948-2959.

ZINN, R A (1989). Influence of level and source of dietary fat on its comparative feeding value in finishing diets for feedlot steers: metabolism. *J. Animal Science, 67*: 1038-1049.

ZINN, R A and JORQUERA, A P (2007). Feed value of supplemental fats used in feedlot cattle diets. *Veterinary Clinics of North America Food Animal Practice, 23*: 247-268.