Review

Fats for lactating dairy cows

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Received 29 May 1990; accepted 2 October 1990

Fat provides essential fatty acids and a concentrated source of energy for dairy cows. The energetic efficiency of milk production is therefore also improved. Of the numerous fat sources that are available, oilseeds, especially cottonseed, probably offer the best opportunity of supplementing fat in dairy diets. It also seems improbable that the gossypol content of whole cottonseed can have detrimental effects if fed at moderate levels and in well-balanced diets. The heat treatment of oilseeds (cottonseed and soybeans) increased milk production in most studies and milk fat in several. The negative effects of fat on rumen microbes can be eliminated to a certain extent by supplementing with extra calcium and magnesium. Although the effect of niacin supplementation has not been consistent in alleviating the negative effect of fats on milk protein it is nevertheless recommended, especially for high-producing cows during early lactation. If fats are to be added above 5% of ration DM, which is the maximum for optimal rumen metabolism, they must be rumen-inert. High melting point fats or calcium salts of long chain fatty acids can be used for additional fat supplementation. However, more consistent results can probably be expected from the use of calcium salts.

Presented at the 29th Annual Congress of the South African Society of Animal Production at the University of Stellenbosch, Stellenbosch, on 27–29 March 1990.

The genetic potential of dairy cows has increased to such an extent that the higher energy requirements cannot be satisfied by increasing the cereal grain content of the diet.

According to Smith (1988a) incorporating additional fat in the diet offers several opportunities for altering the efficiency of energy utilization for milk production. Firstly, the high energy density of fat, (2,25 times the energy of carbohydrates) may allow increased energy consumption and milk yield where energy intake is limiting, and thus improve gross efficiency of net utilization. Secondly, increased fat availability from the diet may increase net efficiency of milk synthesis through achievement of an optimum ratio with other nutrients. Thirdly, direct transfer of dietary fat to milk fat would also result in an increase of partial efficiency of milk production. The fourth opportunity lies in the potential of substituting fat for rapidly fermentable carbohydrate in the diet fed to high-producing cows, thereby increasing forage fibre in relation to total dietary carbohydrate, improving rumen fermentation and fibre digestion, and consequently normal milk fat percentage.

The feeding of fat to dairy cows has received much interest in recent years and has been reviewed in detail by Palmquist & Jenkins (1980), Storry (1981), Moore & Christie (1984) and Palmquist (1984). This short review will concentrate on the practical aspects of feeding fat to dairy cows with the main emphasis on oilseeds, probably the most economical way for South African dairy farmers to benefit from the feeding of fat. Some attention will also be paid to rumen-inert fats.

Fat sources

The most commonly used fat sources are raw whole oilseeds (cottonseed, soybeans, rapeseed and sunflower seed) and processed (mechanically and/or heat-treated) oilseeds. Vegetable oils and acidulated vegetable soapstock, a byproduct from the plant–oil industry, can also be applied successfully when available. Although the availability of tallow and grease (animal fats with a titer of higher and lower than 40, respectively) is very limited in South Africa, it can be included beneficially in dairy diets. Poultry fats, from 100% poultry offal, and blended fats (blends of tallow, grease and/or poultry fat and vegetable fats) are also being applied successfully.

Physically protected fats, with a high proportion of saturated long chain fatty acids (palmitic and stearic acids) and thus a high melting point, chemically protected fats (rumen inertness is achieved by forming calcium salts of long chain fatty acids) or encapsulated fats (formaldehyde-treated protein or sodium alginate protection) are used when more than 5–6% fat has to be included in dairy diets.

Dietary fat and rumen fermentation

Rumen micro-organisms can only tolerate 3–5% unprotected dietary fat (Palmquist & Jenkins, 1980; Palmquist, 1984). Although the mechanism by which unprotected fat affects rumen fermentation is not clearly established, several studies have indicated certain modes of action which were summarized by Devendra & Lewis (1974). The effect is probably due to the coating of the fibrous portion of the diet with lipids, thus preventing microbial enzyme activity. Lipid supplementation also modifies the rumen population concerned with cellulose digestion. Fatty acids inhibit the growth of certain micro-organisms due to an effect on cell permeability brought about by adsorption of fatty acids to the cell wall. There is also a reduced retention of calcium and magnesium due to complex formation with fatty acids.

Numerous studies were conducted to investigate methods to alleviate or partially alleviate the negative effect of fats on rumen metabolism. Some of the most important studies are briefly summarized.

Calcium and magnesium

White, Grainger, Baker & Stroud (1958) showed that the positive effect of lucerne ash on the inhibition of fibre digestibility by corn oil (Brooks, Garner, Gehrke, Muhrer & Pfander, 1954) was due to the high Ca-content of lucerne ash.

It is generally accepted that increasing the calcium content of fat supplemented diets minimizes the negative effect of fat on fibre digestibility (Ikwuegbu & Sutton, 1982; Chalupa, Rickabaugh, Kronfeld & Sklan, 1984). This is probably due to the formation of insoluble soaps, which are presumed not to be detrimental to the rumen micro-organisms, by the saponification of long chain fatty acids by calcium. The calcium soaps dissociate in the abomasum at a lower pH and become available for absorption. Soaps are again formed at the higher pH level in the large intestine and are excreted.

It has, however, been demonstrated that no appreciable saponification took place within the rumen when calcium was provided in the form of calcium hydroxide (Spearow & Clark, 1984), or limestone (Palmquist, Jenkins & Joyner, 1986). Palmquist *et al.* (1986) demonstrated that the beneficial effects of added calcium in high-fat diets were not caused by increased calcium soap formation in the rumen, while Grainger, Bell, Stroud & Baker (1961) found that the addition of calcium or iron alleviated or partially alleviated the negative effect of corn oil on cellulose digestibility by sheep. They concluded that the balance of the rumen cations, which determines the solubility of the saturated long chain fatty acids, affected rumen microbial activity and should be examined more closely. Palmquist (1987a) speculated that improved animal response due to calcium supplementation of high-fat dairy diets could probably be due to the calcium affecting the animal post-ruminally.

Although it is not clear why added calcium reduces the negative effect of fat on fibre digestibility, it is generally accepted and recommended that the Ca-content of fat-supplemented diets for dairy cows should be 0,8 to 1,0% of diet DM and that the Ca should originate from more rumen-soluble calcium sources like calcium chloride (Palmquist, 1987a; Harris, 1987; Chandler, 1988b). If calcium chloride is used, not more than 0,5% of diet DM should be included because the bitterness of this salt may lower feed intake (Palmquist *et al.*, 1986). It is also generally recommended that the magnesium content of fat supplemented diets for dairy cows should be increased to 0,3% of diet DM (Chandler, 1988b).

Surface active agents

The digestibility of tallow by chicks was increased by including ox bile (Fedde, Waibel & Burger, 1960) or a non-ionic surface active agent in the diet (Bolton, 1961). Although saturated and unsaturated lipids are equally well digested by ruminants (Bayley, 1963), it is possible that, at high levels of lipid supplementation, surface active agents may be beneficial in increasing digestibility. Devendra & Lewis (1974) concluded that the failure of non-ionic detergents to correct rumen crude fibre digestibility in their studies could be attributed to possible breakdown of the agents in the rumen, their effect on microbial activity, or their inhibition of pancreatic lipase secretion. Smith (1988b) found that the inclusion of 2% lanolin did not significantly increase the digestibility of complete diets by sheep.

Although there may be some merit in the theory of Devendra & Lewis (1974) that surface active agents may render the fibre surface hydrophilic, an action which will benefit the cellulolytic micro-organisms, very little success has been achieved in this field.

Niacin

The mechanism whereby the feeding of whole cottonseed (WCS) and other forms of supplementary fat (Emery, 1978; De Peters, Taylor, Franke & Aguirre, 1985), especially protected fat (Palmquist & Jenkins, 1980), depresses the protein percentage of milk has yet to be defined. Because of the toxic effect that certain fats appear to exert on rumen micro-organisms (Devendra & Lewis, 1974) the addition of niacin, which increases protozoal numbers (Dennis, Arambel, Bartley, Riddell & Dayton, 1982; Horner, Coppock, Moya, Labore & Lanham, 1987), microbial protein synthesis (Dennis *et al.*, 1982; Shields, Schaefer & Perry, 1983) and thus ruminal ammonia and propionic acid production (Abou Akkada & el-Shazly, 1964; Dennis *et al.*, 1982), seems to alleviate the depressing effects of fats on the percentage protein in milk (Horner *et al.*, 1987). This

Table 1 The effect of niacin and whole cottonseed on the performance of lactating dairy cows

Trial No.	No. cows	Intake Diet DM kg/day	WCS % diet	Niacin g/day	Responses: Milk kg/day	Fat %	Protein %	Reference
1	7	23,16	0	0	$31,2^{a}$	$2,97^{a}$	$3,13^{ab}$	Horner *et al.* (1986)
	7	23,37	15	0	$31,6^{a}$	$3,38^{b}$	$3,02^{a}$	
	7	23,72	0	6	$32,2^{a}$	$3,41^{b}$	$3,33^{c}$	
	7	23,18	15	6	$30,1^{a}$	$3,21^{b}$	$3,20^{bc}$	
2	7	22,02	15	0	$29,9^{ab}$	$4,03^{a}$	$3,10^{a}$	Horner *et al.* (1988)
	7	20,96	15	3	$28,8^{a}$	$3,78^{a}$	$3,01^{b}$	
	7	21,37	15	6	$30,3^{ab}$	$3,91^{a}$	$2,99^{b}$	
	7	22,35	15	12	$30,8^{b}$	$3,97^{a}$	$3,05^{ab}$	

$^{a, b, c}$ Means in the same column with different superscripts differ ($P < 0,05$)

effect is, however, not always consistent (Horner *et al.*, 1987). The results of two of the most recent studies on the effect of niacin on the protein production of dairy cows consuming fat supplemented diets are summarized in Table 1. Although more work in this field is required before specific recommendations can be made, the effectiveness of niacin in diets for high-producing cows during early lactation is well documented (Chandler, 1988b; Erasmus, 1988). Results from these studies suggest that niacin should be included at 6 g/cow/day.

How much fat can be fed to dairy cows?

Except for the known restriction due to the rumen, the maximum amount of lipids that can be absorbed or oxidized, or directly taken up by the mammary gland, is not clear.

Although fasting ruminants can derive up to 80% of their metabolic energy from the oxidation of long-chain fatty acids (Lindsay, 1975), most estimates in lactating cows indicate that only 5–10% of the expired CO_2 is derived from the oxidation of fatty acids while a much larger proportion originates from acetate oxidation (Palmquist, 1989). ATP production from oxidative pathways is about 10% more efficient for long chain fatty acids (LCFA) than for acetate (Baldwin, Smith, Taylor & Sharp, 1980). Baldwin *et al.* (1980) also indicated that the theoretical and real partial efficiencies for the conversion of acetate to LCFA were 68 to 72% and 30 to 60%, respectively, whereas the theoretical and real efficiencies for the conversion of dietary fat to body fat or milk fat were 94–96% and more than 90%, respectively. Therefore, increasing dietary fat should increase energy efficiency in ruminants.

Energy efficiency (mCal milk per mCal NE_L intake), was increased by 10% over controls by feeding 15 to 30% protected tallow supplements to Holstein cows during the first 15 weeks of lactation (Smith, Dunkley & Franke, 1978). Brumby, Storry, Bines & Fulford (1978) estimated that the optimum percentage of fatty acid energy digested during lactation weeks 2–6 and 7–13 was 14% and 18%, respectively. According to Palmquist (1987a), most studies suggest maximal energetic efficiency of ruminant animals, with 15 to 20% (5 to 8% fat in diet DM) of metabolizable or net energy being derived from dietary fat. Reasons for the inability to increase energy efficiency with higher intakes of LCFA are not clear and need further investigation.

About 3% of the average dairy ration consists of fatty acids. Conventional commercial fats (tallow or animal-vegetable blends) or whole oilseeds (whole cottonseed, soybeans, sunflower seed) can be used to provide an additional 3% fatty acid (about 0,5 kg of fat) in the ration (Palmquist, 1988). If the total fat is to be raised above 6%, inert fats should be used to provide the additional 2 to 3% fat in the ration dry matter (Palmquist, 1988).

Oilseeds

Whole cottonseed

Whole cottonseed (WCS) is a source of dietary fat used widely in the United States, and to a certain extent, in South Africa for feeding dairy cows. Whole cotton seed is an ingredient that contains (DM basis) a high level of energy (96% total digestible nutrients or 16,0 MJ ME/kg or 9,3 MJ NE_L/kg), protein (25%), fibre (17,2%), ADF (26%) and fat (23,8%) (NRC, 1989). Because of its unique nutritive composition, it offers great opportunity as an ingredient in diets for high-producing dairy cows which are invariably in a negative energy balance (De Peters *et al.*, 1985; Coppock, Lanham & Horner, 1987). In least-cost linear programmed formulations of diets for high-producing cows with the constraints for energy and fibre in opposition, WCS has been shown to be worth twice its cost (White, 1983).

In an examination of 18 recent trials, Coppock *et al.* (1987) found no significant differences in dry matter (DM) intake when whole cottonseed was included at levels of up to 25% of the diet and concluded that, in most trials, an increase in consumption of NE_L occurred. The studies summarized by Coppock *et al.* (1987) did not suggest any depression in fibre digestibility when WCS was included at levels of up to 30% of the diet. This implies that total fat intake with 30% WCS in the diet was not a restricting factor on rumen metabolism.

The inclusion of WCS in diets for high-producing dairy cows often increases milk production (Anderson, Adams, Lamb & Walters, 1979; Smith 1988b), with the most consistent effect being an increase in milk fat percentage in the order of 0,2 to 0,3 absolute percent units or more (Linn, 1983; Coppock *et al.*, 1987). Some of the most recent production trials in this field are summarized in Table 2.

Ruminants are considered to be relatively tolerant to gossypol, a polyphenolic toxin found in the pigment glands of cottonseed. This is ascribed to the binding of gossypol in the rumen to the ϵ-amino group of lysine (Reiser & Fu, 1962), iron (Jonassen & Demint, 1955), calcium, sodium, potassium (Berardi & Goldblatt, 1969) and certain amines, especially octylamine (Singleton & Kratzer, 1973). However, Lindsey, Hawkins & Guthrie (1980) showed that diets supplying 24 g free gossypol per lactating Holstein cow per day caused depressions in haemoglobin and total blood protein. Increased erythrocyte fragility and increased respiration rates in hot weather were also reported which questioned the ability of the rumen to detoxify large amounts of free gossypol. In contrast to this finding, Coppock, West, Moya, Thompson, Rowe, Nave, La Bore & Gates (1985) did not find any gossypol toxicity using 13 blood metabolites as indicators in lactating Holstein cows that were fed diets containing up to 30% whole cottonseed or in dry Holstein cows that were fed diets containing up to 55% whole cottonseed.

Because gossypol inhibits spermatogenesis in experimental animals and humans with minimal or no side effects, the antispermatogenic effect is regarded as its first probable physiological detriment (National Coordinating Group on Male Antifertility agents, 1978; Tso & Lee, 1981; Smalley & Bicknell, 1982). Jimenez, Chandler, Adkinson, Nipper, Baham & Saxton (1988) fed 30 mg total gossypol per kg live body weight (BW) to yearling Holstein bulls while Smith, Vosloo, van Niekerk & Theron (1988) fed 75 mg free gossypol per kg BW to two-year-old Holstein bulls. Neither spermatogenesis nor sperm quality were affected and it was concluded that the free gossypol was probably efficiently detoxified in the rumen. Until further proof can be obtained, it seems improbable that the gossypol content of whole cottonseed can cause toxic effects in dairy cows,

Table 2 The effect of whole cottonseed on DM intake, milk yield and milk composition

Trial No.	No. cows	Intake Diet DM kg/day	WCS % diet	Responses Milk kg/day	Fat %	Protein %	Reference
1	24	22,0 [a]	0	23,5[a]	3,62[a]	3,26[a]	Dale, Roffler &
	24	21,9 [a]	10	23,8[a]	3,49[a]	3,20[a]	Thomas (1984)
	24	21,5 [a]	20	23,8[a]	3,72[a]	3,12[a]	
2	3	19,0 [a]	0	24,4[a]	3,19[a]	3,24[a]	De Peters *et al.*
	3	19,3 [a]	10	25,0[b]	3,45[b]	3,15[b]	(1985)
	3	19,1 [a]	15	25,5[b]	3,51[b]	3,15[b]	
	3	19,0 [a]	20	25,4[b]	3,61[b]	3,16[b]	
3	8	17,4 [d]	0	21,8[d]	3,66[d]	3,47[d]	Palmquist (1987b)
	8	18,0	9,4	22,6	3,97	3,40	
	8	16,8	20,2	21,5	4,02	3,42	
	8	15,9	32,1	20,9	4,32	3,34	
4	8	17,59[a]	0	21,9[a]	3,20[a]	2,95[a]	Smith (1988b)
	8	18,32[a]	25	23,0[b]	3,86[b]	2,95[a]	

[a, b, c] Means within the same column within a category with different superscripts differ ($P <$ 0,05)

[d] Response trends were highly significant ($P <$ 0,01) for fat and protein percentages and significant ($P <$ 0,05) for milk production and DM intake

provided that it is fed at moderate levels and is included in well-balanced diets with adequate protein, iron and calcium.

Soybeans

Because of the exceptionally high prices that are being paid for protein sources in South Africa, agronomists have again become interested in the production of soybeans. The annual crop of 30 000 tons for 1987 trebled to 89 000 tons for 1989 (Erasmus, 1989).

Raw or heat-treated whole soybeans are an excellent source of protein and energy for high-producing dairy cows. Raw soybeans have (DM basis) a high energy (91% total digestible nutrients or 15,1 MJ ME/kg or 8,8 MJ NE_L/kg) high protein (42,8%), low fibre (5,8%), ADF (10%) and a high-fat content (18,8%) (NRC, 1989).

Soybeans are heated to destroy the trypsin inhibitor, inactivate urease activity, destroy enzymes (chiefly lipase) which cause fat deterioration and especially to increase the amount of bypass protein and to improve palatability (Barmore, 1988). Trypsin inhibitors are destroyed in the rumen, although the maximum ability of the rumen to detoxify is unknown (Chubb, 1982). On the other hand, it is not known whether the feeding of moderate levels of urea, especially with whole, raw soybeans, will cause insufficient utilization of urea or urea poisoning. It is, however, recommended that urea should not be fed with raw soybeans (Schingoethe, 1984). By not cracking or grinding the raw soybeans, the fat is not exposed to oxidation, thereby allowing long-term storage (Barmore, 1988). Owen, Larson & Lowry (1985) found that grinding soybeans (10,7% of ration dry matter) resulted in a higher fat yield (3,40 *vs* 3,28%) which, although highly significant ($P <$ 0,01), did not produce any other significant benefits. Suggested recommendations and limits for the feeding of raw soybeans are normally conservative. Howard (1988) suggests 10 to 15% of dry matter while Barmore (1988) suggests 2 to 2,5 kg (+ 10% of dry matter) per cow per day. Intakes of up to 25% of dry matter have been reported which have not caused any digestive or other problems (Steele, Noble & Moore, 1970). If raw whole soybeans without urea are included in formulations for dairy cows by linear programming, the most important constraint would probably be to add not more than 4 to 5% unprotected fat to the ration.

Sunflower seeds

Whole sunflower seed has (DM basis) a high energy (83% total digestible nutrients or 8,0 MJ NE_L/kg), high protein (17,9%) fibre (31,0%), ADF (39,0%) and a high fat content (27,7%) (Bath, Dunbar, King & Berry, 1989). Whole, unprocessed sunflower seeds were included at 0, 10, 20, and 30% of concentrates and fed to 16 Holstein cows during early lactation. Cows fed 10% sunflower seed (4,5% of ration DM) produced more milk ($P <$ 0,05) than the control group and were more energetically efficient (Rafalowski & Park, 1981). According to McGuffey & Schingoethe (1981), production indices suggest that whole sunflower seeds may constitute as much as 10% of the total ration dry matter without adversely affecting production. On the other hand, Anderson, Obadiah, Boman & Walters (1984) found that 12% whole sunflower seeds in the ration DM depressed DM intake, milk yield, fat and protein content. Finn, Clark, Drackley, Schingoethe & Sahlu (1984) found that the addition of 1,54% limestone to a ration containing 9,7% sunflower seed per DM increased 4% fat corrected milk production ($P < 0,01$) from 28,1 to 30,3 kg per cow per day. White, Ingalls & Sharma (1987) found that the addition of 9% whole sunflower seed per diet DM increased milk fat percentage and yield ($P < 0,05$) but that the additional inclusion of 1% sodium bicarbonate did not increase fat percentage significantly.

The inclusion of whole or processed sunflower seeds in diets for dairy cows would seem to be more limiting than that of soya beans or whole cottonseed. Even with the addition of extra lime, which is recommended at all levels, sunflower seeds added at 10% of DM would seem to be an absolute maximum, with the understanding that not more than 4–5% are included in total ration DM as unprotected fats.

Heat-treated oilseeds

Heat-treatment of soybeans for dairy cows has become common practice in the U.S.A. According to Barmore (1988), the three most common methods of heat-treating soybeans are extrusion, flame roasting and popping. Extrusion involves forcing the soybeans through a die under pressure. The friction that is generated during extrusion heats the soybeans uniformly. Fat cells are ruptured, partially releasing the fat from the soybean plant cells. Flame roasting is a continuous flow process where soybeans come into direct contact with a flame. The bean is heated quickly to temperatures in excess of 120°C. Both flame roasting and popping use mechanical cooling to bring the soybean temperature down gradually. Popping soybeans is similar to the process of flame roasting, except that the soybeans are heated by hot air and do not come into direct contact with the flame. Popped soybeans are rapidly heated to 160–195°C and then cooled gradually. Kenelly & de Boer (1986) also described jet-sploding, a process which utilizes high temperatures for a relatively short period of time. The feedstuff is fed by gravity into a heat exchanger. Air, heated to 316°C, is pumped through jets into the exchanger, where it rapidly heats the seed and transports it through the unit. As the seed containing very hot moisture at high pressure leaves the unit, it passes through a roller which 'explodes' the seed.

It has been shown that heat treatment of oilseeds effectively decreases the rumen degradability of crude protein. Kenelly & de Boer (1986) found that the 'effective' dry matter and 'effective' crude protein disappearance of canola seed decreased from 66,1 and 75,0 to 24,6 and 34,7, respectively, with jet-sploding at 177°C. Although disappearance of rumen undegradable protein in the lower intestine tended to be lower for jet-sploded seeds, increasing jet-sploding temperature from 116 to 177°C did not reduce the disappearance.

Fox, Sniffen & Van Soest (1981) found that the application of dry heat reduced the solubility of protein in whole soybeans from 44,2 to 8,9%, whilst Coomer & Stiles (1989) found that the dry matter and nitrogen disappearance of heat-treated whole soybeans *in situ* for 24 h were reduced from 94 to 38,9% and from 97,1 to 32,6%, respectively.

The dry heating of whole cottonseed for 20 min decreased crude protein disappearance from dacron bags which were kept in the rumen for 12 h from 87 to 48% as the temperature increased from 140 to 180°C (Tagari, Pena & Satter, 1985). Smith (1988b) found that heat treatment of whole cottonseed with microwaves at 155°C for 20 min reduced organic matter, fat and protein disappearance *in situ* with a rumen outflow rate of 0,05/h from 53,9 to 33,2%, 60,7 to 35,1% and from 64,6 to 39,3%, respectively. The heat-protected protein in the seed seems to protect the fat to the same extent against rumen metabolism as all fat globules are surrounded by a protein matrix.

Some of the most recent studies on the effect of heat-treated oil seeds on the performance of lactating dairy cows are summarized in Table 3. In most studies where heat-treated soybeans were compared with raw soybeans, milk production was increased significantly ($P < 0,05$) by the soybeans (Owen *et al.*, 1985; Faldet & Satter, 1989). Milk fat percentage was also increased ($P < 0,05$) in some of the studies. The higher milk fat percentage that was found could probably be ascribed to a larger portion of inert fat in the heat-treated beans (Smith, 1988b), which would not depress rumen function and the formation of acetic acid. Comparing a concentrate containing 20% soybean meal to one containing 25% heat treated soybeans, Ruegsegger & Schultz (1985) found that the cows on the treated soybeans peaked later in milk production (5 *vs* 3 weeks) but at a higher level (39,8 *vs* 39,4 kg/day) and produced 0,8 kg/cow/day more milk (37 *vs* 36,2 kg/cow/day) than the controls for a 15-week experimental period. Smith (1988b) also found a trend towards higher milk and milk fat production (Table 3), when raw whole cottonseed was fed.

Rumen-inert fats

Rumen-inert refers only to the lack of inhibitory effects of certain fats on the metabolism of sensitive protozoa and gram-positive bacteria. A rumen-inert fat should be nonreactive to the rumen micro-organisms, be readily absorbed, have optimum fatty acid structure for metabolism and be readily incorporated into the ration (Palmquist & Cummings,1989).

The CSIRO in Australia developed formaldehyde-protein-protected-fat in *ca.* 1970 (McDonald & Scott, 1977). In the USA, formaldehyde has not been approved for use in dairy feeds, therefore the product has not become available commercially (Palmquist, 1988). Although the intention of using formaldehyde-protein-protected-fat to increase polyunsaturated fats in ruminant products (McDonald & Scott, 1977) did not become a reality, increased productive performance of cows fed high fat in a rumen-inert form was readily demonstrated (Palmquist, 1988).

According to Chandler (1988b), recent developments in the dairy industry have resulted in the availability of two types of fat materials with rumen-inert potential. Firstly, calcium soaps of long-chain fatty acids, which were developed by Jenkins & Palmquist (1982), are being produced commercially as a dairy feed supplement. The calcium soap product is rumen-inert, as long as the fatty acids are maintained in a calcium soap form. Being pH sensitive, any tendency towards acidosis will result in some breakdown of the soaps and the liberation of long-chain

Table 3 The effect of heat treated oilseeds on DM intake, milk yield and milk composition

Trial No.	No. cows	Intake Diet DM kg/day	Oilseed % diet		Responses Milk kg/day	Fat %	Protein %
1[1]	12	21,4[a]	10,7	Raw whole soya	29,5[a]	3,28[a]	2,87[a]
	12	22,8[b]	10,7	Roasted soya	31,4[b]	3,46[b]	3,04[a]
2[1]	12	20,5[a]	10,7	Raw ground soya	29,8[a]	3,40[a]	2,99[a]
	12	22,3[a]	10,7	Roasted ground soya	30,7[b]	3,57[b]	2,93[a]
3[2]	15	21,0[a]	6,5	Raw whole soya	34,2[a]	3,50[a]	2,89[a]
	15	22,8[a]	6,5	Roasted soya	38,9[b]	3,41[a]	2,85[a]
4[3]	8	18,3[a]	25,0	Raw whole cottonseed	23,0[a]	3,86[a]	2,95[a]
	8	18,7[a]	25,0	Heat treated cottonseed	23,9[a]	4,02[a]	2,99[a]

a, b Means in the same column within a specific trial with different superscripts differ ($P < 0,05$)
1 Owen *et al.*, 1985
2 Faldet & Satter, 1989
3 Smith, 1988b

fatty acids, which will be detrimental to rumen function (Chandler, 1988b). The second group of products consists of saturated fatty acids which have a high melting point with low microbial inhibition in the rumen. However, the same physical characteristics which contribute inertness to this type of fat may also lower absorption from the small intestine (Palmquist, 1988). The fat, calcium and energy content of the two most available rumen-inert fats in the USA are presented in Table 4 (Chandler, 1988b).

Sodium alginate encapsulated dry tallow (Booster Fat®) and tallow (Max-Fat®) were also reported by Grummer, Hatfield & Dentine (1989).

Summaries of US university and field trials for dairy cows that received 0,5 kg Megalac® per cow per day are presented in Tables 5 and 6 (Palmquist & Cummings, 1989).

According to Palmquist & Cummings (1989), an average increase of approximately 2,5 kg/day (Tables 5 and 6) should be expected from the additional feed energy provided. Although heifers tended to give a lower milk response, persistency of lactation and growth were improved. Milk fat percentage tended to increase while protein decreased, which is consistent with known effects of fat in dairy diets.

Table 4 Comparison of Megalac® and Energy Booster® (Chandler, 1988b)

Material	Fat (%)	Ca (%)	TDN[a] (%)	NE(lac)[b] (mCal/100 kg)
Megalac® (Ca-soap)	80,0	8,0–9,6	162	175
Energy Booster® (Saturated fatty acids)	99,0	–	200	217

a Calculation based on ninety percent digestion of fat.
b Calculated from TDN as: NE(lac) mCal/kg = 0,0245 TDN – 0,12
Note Industry publications quote net energy of these fat sources based on the assumption that absorbed fatty acids from these products are used at the same efficiency as those mobilized from adipose tissue which is 82,4 (*J. Dairy Sci.*, 54: 548. 1971).

Clapperton & Steele (1982) reported an increased milk yield from 15,4–17,2 kg/day with no change in milk fat percentage feeding 500 g/cow/day 'dairy fat prills' (45% palmitic, 45% stearic and 10% oleic-acid).

Chalupa, Vecchiarelli, Ferguson, Shotzberger, Sklan & Kronfeld (1986) fed prilled fatty acids (Dairy Fat Prills, B.P. Nutrition, U.K.) at levels of 0; 3; 6; or 9% of diet DM to four cows (4×4 Latin Square). Milk fat increased (2,57; 2,78; 2,84; and 3,27%; $P < 0,01$) but intake decreased (15,2; 14,4; 13,9; and 14,0 kg/d; $P < 0,06$) as did milk production (19,1; 19,8; 17,7, and 16,3 kg/d; $P < 0,01$).

Grummer & Maurer (1987) compared a zero supplement (C) to 0,68 kg prilled fat (PF1), 0,91 kg prilled fat (PF2) or 0,68 kg calcium salt of palm oil (CaS) per cow per day added to a diet consisting of 50% concentrate and 50% corn silage–alfalfa silage (1:1). Production responses are summarized in Table 7. Milk fat increased on the 0,68 kg prilled fat supplemented diet while milk yield increased on the 0,68 kg calcium salt supplemented diet.

Highly saturated triglycerides result in fats with physical characteristics which resist dispersion and hydrolysis in the

Table 5 A summary of US university trials which have reported milk production with feeding of 0,5 kg/ Megalac®/cow/day (Palmquist & Cummings, 1989)

8 Locations – 249 cows Response	Range	Average
Milk (kg/day)	0,9 — 3,1	2,0
Energy-corrected milk (kg/day)	1,2 — 3,5	2,3
Milk fat (%)	–0,1 — +0,2	+0,05
Milk protein (%)	0	–0,08

Table 6 A summary of US field trials which have reported milk production with feeding of 0,5 kg Megalac®/cow/day(Palmquist & Cummings, 1989)

7 Locations – 239 cows Response	Range	Average
Milk[1] (kg/d)	0 — 1,2	—
Milk[2] (kg/d)	1,7 — 3,0	2,5
Fat (%)	0 — 0,13	0,066
Protein (%)	–0,07 — 0,1	–0,085

[1] First lactation heifers
[2] Mature cows

rumen and which are also less soluble in the small intestine (Macleod & Buchanan-Smith, 1972) and have a lower utilization than similarly saturated fatty acids in free form. The level of saturation and the fatty acid composition of fats would probably influence production responses.

Dairy cows have a requirement for fatty acids and significant increases in the milk yield and all milk constituents can be expected when fatty acids are supplemented to diets that are deficient in lipids (Banks, Clapperton, Ferrie & Wilson, 1976; Papas, Ames, Cook, Sniffen, Polan & Chase, 1984). In general, however, fat supplementation results in variable effects regarding milk yield and fat and protein contents of milk (Thomas & Chamberlain, 1984). Although the net results of protected tallow feeding are an increase in milk energy output and an increase in estimated partial efficiency of milk synthesis (Smith, 1988b) mentioned results of Clapperton & Steele (1982), Chalupa *et al.* (1986), Grummer & Maurer (1987) and Jenkins & Jenny (1989) tend to be variable, with probably less positive production responses than with calcium soaps.

Summarizing conclusions

Commercial fats or whole oilseeds can be used to supplement the fatty acid content of 3% in an average dairy ration, to a maximum of 6%. If more than 6% fat is to be included, inert fats should be used to provide an additional maximum of 3% in the ration dry matter (Palmquist, 1988).

The total of whole cottonseed, soybeans or animal fat should not add more than 4% fat to the diet (Howard, 1988).

Although other oilseeds may be fed successfully, the results are far more variable than with whole cottonseed (Smith, 1988a). Whole cottonseed is more a roughage or forage type replacement while soybeans is more a protein type replacement (Chandler, 1988a).

Table 7 Production responses of dairy cows on diets supplemented with no supplemental fat (C); 0,68 kg prilled fat (PFl); 0,91 kg prilled fat (PF2) or 0,68 kg calcium salt of palm oil (CaS) (Grummer & Maurer, 1987)

	Diets			
Factor	C	PF1	PF2	CaS
Dry matter intake (kg/day)	18,20	17,70	16,40	17,00
Milk (kg/day)	20,00	20,20	20,70	23,00
Milk fat (%)	3,58	3,72	3,50	3,48

Both products were inert in the rumen as measured by rumen volatile fatty acid ratios and NDF digestibility *in sacco.*

The suggested limit for feeding whole cottonseed is 2,5–3 kg/cow/day or 15% of diet DM (Howard, 1988), although up to 30% of dietary DM has been fed to dairy cows without any detrimental effect (Coppock *et al.*, 1985). The suggested limit for soybeans, raw or heated, is 15% of diet DM (Howard, 1988), although intakes of up to 25% of diet DM have been reported without any negative results. To eliminate the possibility of fat deterioration or undesired urease activity, heated and especially raw soybeans should be fed whole.

Adequate roughage should be fed in fat-supplemented diets. Type of roughage may be important, as most studies show a greater response in performance when lucerne hay is a part of the diet. Always replace concentrate with supplemented fat (Harris, 1987). Animals on diets with added fat tend to eat smaller, shorter meals more frequently (Heinrichs, Palmquist & Conrad, 1982). It is therefore advised that fats should be fed with the roughage part of the diet, in complete diets or with electronic concentrate feeders and not with concentrates once or twice daily with time being a limiting factor.

Increase the protein content of dairy diets by 1% for each 3% increase in fat (% of DM). The extra protein must be rumen undegradable to provide maximum benefit to the cow (Palmquist, 1987a).

Increase the calcium content of dairy diets to at least 0,75% of diet DM (Harris, 1987) or 0,81% of diet DM (Palmquist *et al.*, 1986). Palmquist *et al.* (1986) recommends supplementary calcium chloride, but warns that not more than 0,5% of diet DM should be included because of the bitterness of the salt. Increase the magnesium content of dairy diets to at least 0,30% of diet DM (Chandler, 1988b).

Because the pK_a (where K_a is the dissociation constant) of calcium salts of long-chain fatty acids is 4 to 5, dietary buffers may be needed along with certain feeding strategies to maintain pH above 6, thereby preventing dissociation of the calcium salts (Chalupa & Ferguson, 1987).

At this stage it is also recommended that 6 g/cow/day of niacin (vit B_3) be included in the ration especially for all high-producing cows and for all cows in early lactation that are metabolizing body reserves (Chandler, 1988b; Erasmus, 1988).

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