Providing Lubricity in Food Fat Systems

TERRY R. BESSLER and FRANK T. ORTHOEFER, A.E. Staley Manufacturing Company, Decatur, IL 62525

ABSTRACT

Lubricity, in particular mouthfeel, is an important factor in production of vegetable oil bases for food product formulations. Certain functional characteristics are necessary for good texture at various temperatures. These characteristics are dependent on degree of unsaturation, fatty acid distribution, and degree of geometrical isomerization during processing. Proper selectivity and activity of hydrogenation catalysts used in hardening of the oils are essential. Sufficient solid fat content must be balanced by necessary oxidative stability. Products discussed include salad oils and their formulations in pourable and spoonable salad dressings, mayonnaises, frying oils, imitation dairy products, margarines and bakery shortenings. Past, present and future industry technology will be evaluated for each type of food fat product. Customer needs have greatly affected the course of research in this area.

INTRODUCTION

Fats and oils are used widely both at home and institutionally. A summary, based partly on a 1977 ACS symposium (1) of where these oils go in the US diet is shown in Figure 1. The salad and cooking oils can be further subdivided into salad dressings and mayonnaises, household oils, and those used in institutional and commercial frying operations. This area will be discussed in the most depth because, unlike margarines and bakery shortenings, salad and cooking oils require no inherent structure, aeration or moisture barrier.

Oils make up a large portion of several food products as seen in Table I (2,3). Some of this oil is present as an intended formulation. However, when the oil is used as a heat exchange medium (mainly frying applications), the food products absorb some of that fat as the water leaves. Observing these amounts of lipid in some of the foods we eat, considerable importance must be given to the types and amounts of fats and oils used in food fat systems.

Mouthfeel is dependent on three factors, namely, temperature, tactiles (bitter, sour, sweet, etc.), and texture. The latter factor is the essence of where lubricity is involved. A dictionary definition of lubricity describes it as preventing cohesion between surfaces, reducing friction, and making something smooth and slippery. As it applies to oils, lubricity can refer to (a) ease of handling (how pourable the product is), (b) separation of gluten in dough (shortening effect), and (c) mouthfeel. Lubricity as it applies to mouthfeel imparts tenderness, richness and improved eating properties to the food (4). Mouthfeel can apply to both the ability of liquid oils to form an oily film, which is viscosity-related, and how well a solid fat melts in the mouth to give a pleasant cooling effect instead of a pasty, waxy feeling.

Lubricity can be measured at four temperature ranges. Based on the work of Cochran (W.M. Cochran, unpublished), the melting points of common triglyceride mixtures are broken down into the four groups shown in Table II. It should be remembered that oils do not consist wholly of any one of these and that the ratio of each particular triglyceride will determine the melting behavior. In most cases, there is still some liquid oil suspending solid fat in a seemingly solid sample and likewise an apparently liquid oil can contain dissolved solid fat. It is therefore, a predominance of triglycerides from one of these groups that determines its lubricity.

At refrigerator temperatures (41 F, 5 C), group I triglycerides will remain liquid. Group II triglycerides will remain liquid only if stored at room or ambient temperatures (77 F, 25 C). Group III triglycerides will melt near body temperature (98.6 F, 37 C) to give the cooling effect of melting butter. Group IV triglycerides are high melting triglycerides

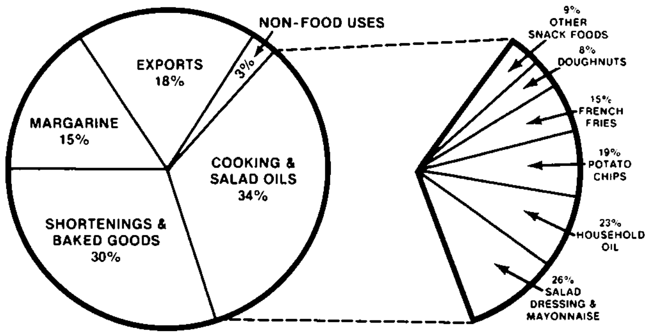

FIG. 1. US 1980 fats and oils disposition.

TABLE I

Oil Content of Selected Food Products

Food product	% Oil content	Food product	% Oil content
Mayonnaise	60-80	Salad dressing	30-45
Doughnut	15-20	Potato chips	35-40
Pretzels	5-10	Soda crackers	8-12
Bread and rolls	3-6	Icings	20-25
Cakes	11-20	Cookies	10-15
Pie crust	20-60	Mellorines	6-10
Margarines	40-80		

TABLE II

Compositional/Functional Relationships

Group	MP (F)	Triglyceride	Function
I	8	LLL	Nutritional, lubricity at 41 F
	20	OLL	
	22	PLL	
	27	PLO	
	30	OOL	
	34	SLL	
II	42	OOO	Lubricity at 77 F
	43	SOL	
	60	OOP	
	73	SOO	
III	81	PPL	Aeration, lubricity at 98.6 F, moisture barrier
	86	SPL	
	91	SSL	
	95	PPO	
	100	SPO	
	107	SSO	
IV	133	PPP	Structure at 77 F, lubricity at cooking temperatures
	140	SPP	
	142	SSP	
	149	SSS	

P = Palmitic, S = stearic, O = oleic, L = linoleic.

usually present as stearines to maintain plasticity until baking temperatures are reached.

Each of these groups will be discussed as food product groups to try to link the older observations with this newer approach of considering why the physical characteristics of a particular food fat system are observed.

In Table III from Kartha (5) and List (6), the triglyceride compositions of some commonly used vegetable oils are shown. Perhaps the one most decisive physical value is the unsaturate to saturate (U/S) ratio. Using soybean oil as the guide, it can be seen why such oils as palm and cottonseed do not make good salad oils. The amount of group I triglycerides (UUU) is too low. In addition, olive and peanut oils have more diunsaturates (UUS) than triunsaturates (UUU), which makes them better suited for cooking oils having more group II character. Unsaturate to saturate ratios of other oils not in the work of Kartha and List include: cocoa butter, 0.6; coconut, 0.1; palm kernel, 0.2; canola, 14-15; and sunflower, 6.9. Safflower, sunflower and canola oils, therefore, can and do make good salad oils.

The final criterion to select the type of oil to use is price. A comparison of 1977 crude oil prices (7) shows why soybean oil has been the major oil used in food fat system formulations. However, as prices drop for sunflower and canola (currently 31¢ and 24¢ [Canada], respectively) they may be easily substituted in the salad oil category. Blending of a higher priced oil with soybean oil is a common practice now.

SALAD OILS

Pourable salad dressings are basically a two-phase system of oil and water, some of which are emulsified. Since many of these products are stored in the refrigerator after being opened, it is important to use an oil that is high in group I triglycerides. The main function of pourable salad dressing is to provide lubricity or palatability of the salad by forming a thin lubricant film on the greens.

Besides the unattractiveness of a cloudy product when refrigerated, it is necessary that no solid crystals be present which would give a waxy, tallowy tasting sensation in the mouth.

The other major use of salad oils is in mayonnaise and spoonable salad dressing. Oil constitutes 80% of the mayonnaise formulation and thus is responsible for the body and viscosity of the product. Spoonable salad dressing has only 35-50% oil whose function is to modify the mouthfeel of the starch paste which imparts the body. In both cases, a smooth, creamy, nonoily mouthfeel is desired. This will not occur if crystallization of solid fat occurs. These emulsions are very unstable and the presence of fat crystals will break the emulsion, rapidly causing oil pockets to form.

In general, oil products that are to be refrigerated should pass a cold test of 6-10 hr without clouding to be suitable. A cloud point of 10-15 F (well below refrigeration temperatures) can be achieved with an oil containing high amounts of group I triglycerides.

TABLE III

Triglyceride Composition of Selected Vegetable Oils

Soybean	UUU	58.4	U/S = 5.7
	UUS	35.7	
	USS	5.6	
	SSS	0.1	
Corn	UUU	57.5	U/S = 6.1
	UUS	40.3	
	USS	2.2	
	SSS	0	
Olive	UUU	38.6	U/S = 4.9
	UUS	61.4	
	USS	0	
	SSS	0	
Safflower	UUU	82	U/S = 10.1
	UUS	18	
	USS	0	
	SSS	0	
Cottonseed	UUU	28.3	U/S = 2.7
	UUS	58.4	
	USS	13.2	
	SSS	0.1	
Peanut	UUU	43	U/S = 3.9
	UUS	56	
	USS	1	
	SSS	0	
Palm	UUU	9	U/S = 1.0
	UUS	27	
	USS	54	
	SSS	9	

COOKING OILS

The role of fat in cooking or frying is essentially to provide an efficient heat transfer medium, transmitting heat rapidly and uniformly to the surface of the food being cooked. Additionally, the oil can contribute flavor and palatability to the food product depending on the type of oil used. Traditional geographic preferences exist as seen in the desire for high flavor contribution in foreign countries using olive, peanut and canola oils, whereas the USA has chosen blander oils like soybean, cottonseed, sunflower, safflower and corn.

Cooking and frying oils are used at high temperature often in the presence of hydrolyzing conditions, namely, water or steam. Unhydrogenated soybean oil would never be able to retain its flavor, color, viscosity, smoke point and other physical properties. Hydrogenating down to an iodine value of 90-100 gives the oil the necessary stability. This "brush" hydrogenation lowers the linolenic acid from 8% down to less than 3% without much increase in stearic acid. This prevents the overall triglyceride composition from shifting further than group II. This is accomplished through a catalyst with good selectivity. Although some institutional fryers prefer a winterized oil at these iodine values for handling convenience, it is not necessary since frying temperatures are often enough to keep those solids melted in an oil under daily use. This type of oil is suited for processed fried foods, pan griddle frying, sauces and household cooking oil. A typical analysis would be that in Table IV.

Lowering the iodine value a little farther gives increased stability for fried chicken, onion rings, doughnuts, breaded meats and most snack food (Table V). Doughnuts that are eaten quickly (short shelf-life needed) do not need as stable

TABLE IV

Cooking Oil or Pan Frying

Iodine value	104-112
AOM stability	20 hr
with TBHQ	35 hr
Palmitic	9-11.5
Stearic	4.1-4.7
Oleic	44.8-49.2
Linoleic	31.5-37.5
Linolenic	3% maximum
CMP (F)	72-75
SMI @ 50 F	2.5-5.5
70 F	1-3
80 F	0
92 F	0
104 F	0

TABLE V

Snack Food-Deep Fat Frying

Iodine value	90-98
AOM stability	35 hr
with TBHQ	70 hr
Palmitic	9-11.5
Stearic	4.9-5.4
Oleic	51.1-58.1
Linoleic	23.1-28.9
Linolenic	1.3-1.8
CMP (F)	80-83
SMI @ 50 F	9-11
70 F	2-4
80 F	0-0.5
92 F	0
104 F	0

a frying oil as snack foods that are packaged and may need to stay fresh up to several weeks. Here a lowered iodine value to ca. 90-98 (linolenic drops to less than 2%) affords the higher stability (AOM increased from 20 to 30 hr). Potato chip fryers may use this oil or cottonseed or corn oil. Again a question of higher price versus the "corny" flavor is dependent on consumer preference. This is a case where the blending of corn and soybean gives the desired stability along with a lower price.

Another consideration is surface appearance. If the frying fat is a liquid at room temperature, the chip will look soft, shiny and wet. If the frying fat is solid at room temperature, a dry, dull appearance is observed. Cottonseed oil with more diunsaturates and monosaturates will give a more non-oily look.

For very heavy duty frying, a plastic or even high stability frying shortening can be employed (Table VI). These products, however, are usually higher melting (high in group III triglycerides) and are often difficult to handle. Fractionating a liquid shortening from a highly hydrogenated fat will give fairly good stability and a product that is pourable at room temperature (8) (much more linoleic puts it back into group II), although usually at a premium price.

Often the fryer conditions can be altered to caused a bigger change in fryer life than any reformulation in the fat used. Temperature is very critical in frying (9), especially at fast-food restaurants. Too low a temperature does not keep out the oil through the release of water (or steam) from the food and oil absorption increases giving a greasy product. Too high a temperature will cause the smoke point to fall below the fryer temperature causing problems. Often proper turnover of make-up with fresh oil can keep the smoke point just above frying temperatures.

Polymerization, either thermal or oxidative, can affect the lubricity or greasiness of the fried food. As the viscosity goes up from polymerization, oil absorption increases giving a greasier product (Table VII) (10). With doughnuts, this increase is desirable to give a better formed product. The oil is often "broken in" for up to 48 hr to give better frying quality. However, a 30-40% increase in fat absorption in other fried foods would be undesirable.

MARGARINES AND IMITATION DAIRY PRODUCTS

Products in this category often have very narrow plastic ranges. Often structure is important up to room temperature and then sharp melting is desired to give lubricity at body temperature. When the product "melts in the mouth", a pleasant cooling sensation occurs. Therefore, it is advantageous to have as large a fraction melt near body temperature as possible. It is here that the selectivity of hydrogenation is most critical. The selectivity of hydrogenation can be measured not only as the polyunsaturate to monounsaturate to saturate ratios, but also the geometric *cis* to *trans* ratio. A simple change from oleic (*cis* C18:1) to elaidic (*trans* C18:1) acid will change the melting points from 61 F to 111 F, respectively (stearic melts at 156 F). The corresponding triglycerides OOS, OES and OSS vary accordingly.

Most margarines are formulated as a blend of a hard stock and a soft stock or a hard stock and a liquid stock. The lower priced lines of margarines usually use the latter blend, but often sacrificing stability for price. Mixing of 200 hr AOM with a 15 hr AOM will not average to a 100 hr AOM. Often a blend of a partially hydrogenated soybean oil base (IV=85 max, mp=85 F) is blended with a harder stock (IV=55-65, mp=110 F) to give a product of better stability. Generally, the hard stock will have a "hump" in the SFI profile at 70 F and a sharp drop between 70 and 92 F. Typical profiles are shown below (Table VIII).

Generally, a rule of thumb is an SFI value of less than 4 at 92 F is needed for good melt-in-the-mouth feeling. Values above this give a waxy, pasty taste due to coating of the palate by the solids. A sandy taste or texture has been blamed on too much stearine in the hardstock which can result from improper blending or poor hydrogenation selectivities.

Products in this class usually have a Wiley melting point just below body temperature (95-98 F). In this respect, they resemble butterfat. This characteristic makes this product also valuable in the confectionary and coatings market as well as puddings and pie fillings. Imitation dairy products such as mellorines, filled milk, simulated cheese, coffee whiteners, whipped toppings, milk shakes and egg nog, are all attempts to replace butterfat. All of these food materials, in order to resemble butterfat, must have high solids at room temperature (structure) and sharp melting at body temperature (lubricity).

BAKERY SHORTENINGS

Bakery shortenings are used to produce tender texture in crusts, crackers, cakes and pastries. Whereas margarines and

TABLE VI

Heavy-Duty Frying Oils

	Plastic	High-stability	Liquid
Iodine value	75-83	71-74	88-92
AOM stability (hr)	50-75 min	200 min	50-75 min
Palmitic	9-11.5	9-11.5	9-11.5
Stearic	7-10	8-12	7-11
Oleic	67-73	72-76	42-46
Linoleic	9-13	4 max	24-31
Linolenic	1 max	0.5 max	1-2
Capillary mp (F)	90-92	102-108	74-78
SFI @ 50 F	26-30	49-52	6-11
70 F	11-13	35-38	4-9
80 F	5-6	26-29	2-5
92 F	0.5	11-13	1 max
104 F	0	4 max	0

TABLE VII

Effects of Thermal Oxidation on Frying Oil

	Fresh	96 hr in air
Viscosity (centistokes @ 212 F)	8.25	14.95
FFA (as oleic)	0.04	2.09
% Fat absorption (doughnuts)	18.0	25.1

TABLE VIII

Typical Margarine Profiles

	SFI @50	70	92	IV	C16	C18	C18:1	C18:2	C18:3
		Soybean							
Regular stick margarine	25-28	13-18	1.5-4	83	11	7	59	17	1
Soft tub margarine	11-14	7-9	2 max	101	12	7	38	34	4
Liquid margarine	9-11	5-7	1-2	109	11	6	35	41	3
		Corn							
	SFI @50	70	92		*cis,cis* C18:2 + C18:3				
	19-24	12-14	1.5-3		32.5-35%				

other group III products have very narrow plastic ranges, it is desirable for bakery shortenings to have as wide a plastic range as possible. This is achieved by blending of partially hydrogenated basestock with a fully hydrogenated stearine (SSS, SSP, SPP). The stearines used can be either soybean (β crystal) or cottonseed and palm (β' crystal). Generally, the β' crystal is preferred because it affords a much smoother, creamier appearance.

Shortenings are often formulated with emulsifiers which are added to increase the shortening's ability to incorporate air or to aid the lubricity of the dough. The mouthfeel of the crust is often measured by the flakiness, where it is not necessary for the shortening to melt in the mouth. The lubricity of the shortening here arises in how well it tenderizes the dough. The plasticity of the shortening makes it capable of being extended to form streaks or films to lubricate larger surfaces of the dough. By preventing the gluten of the starch from agglomerating, a lighter, more tender texture is obtained. The bakery product then breaks or separates along the planes where the fat was present.

The proper melting point can be produced by the addition of the stearine. This changes the total plasticity by raising the SFI profile at all temperatures. The functional range is often referred to as 65-80 F where structure is important for leavening. However, the melting point is raised from ca. 90 F up to 115 F or greater, which allows proper extrusion of the dough (normally ca. 106 F).

The amount of fat is also important in formulation of the dough. Less than 10% shortening will give a low tenderness product. Using more than 30% fat will usually cause some of the fat to melt out, giving a greasy product. Roll-in fat is usually firm and waxy with puff pastry usually possessing the highest melting point of all vegetable-based oil products (118-124 F). For less waxy mouthfeel, a softer fat can be used with refrigerated equipment employed in processing.

Solid shortenings are often classified according to plastic range. High stability shortenings are those with ca. 5% stearine added to a selectively hydrogenated oil (IV = 70). They have a narrow range of plasticity but longer shelf-life. All-purpose shortenings generally have a moderate plastic range and lower stability. Usually, these products have 10-15% stearine added to an oil of iodine value 80-90. Typical SFI profiles are shown in Table IX.

TABLE IX

Bakery Shortening Profiles

	High stability	All purpose
SFI @ 50 F	38-42	28-32
70 F	24-28	20-23
80 F	20-24	18-22
92 F	8-12	14-17
104 F	4-7	10-14
Melting point (F)	109	119

REFERENCES

1. Supran, M.K. (ed.), Lipids as a Source of Flavor ACS Symposium, August 1977.
2. Mattil, K.F., in Bailey's Industrial Oil and Fat Products, edited by D.Swern, 3rd edn., Wiley Interscience, New York, 1964, pp. 249-388.
3. Fats in the Diet, A Scientific Status Summary by the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition, December 1981.
4. Wiedermann, L.H., JAOCS 55:823 (1978).
5. Kartha, A.R.S., JAOCS 31:85 (1954).
6. List, G.R., JAOCS 54:408 (1977).
7. Brignoli, C.A., J. Am. Diet Assoc. 68:224 (1976).
8. Latondress, E.G., in Handbook of Soy Oil Processing and Utilization, edited by D.R. Erickson, E.H Pryde, O.L. Brekke T.L. Mounts and R.A. Falb, ASA, AOCS Monograph no. 8 AOCS, Champaign, IL, 1980.
9. BFMIRA, Survey of the Literature on the Changes in Frying Oils with Special Reference to Foaming, Science and Technology Survey no. 114, Leatherhead, Surrey, England, 1979.
10. Rock, S.P., JAOCS 41:228 (1964).

[Received December 15, 1982]