Soybean Oil: Update on Number One

D.R. ERICKSON, American Soybean Association, 777 Craig Road, St. Louis, MO 63141

ABSTRACT

The growth and present stature of soybeans and soybean oil production and utilization in the world and in the USA is presented. Compositions of soybeans and soybean oil are compared with other common vegetable oils. The current and optimal processing practices of extraction, degumming, neutralization (caustic and physical), hydrogenation, and deodorization are discussed. Where appropriate, new and innovative approaches are introduced. Utilization of soybean oil is covered, followed by a historical and present view on the subject of soybean oil flavor and present and future nutritional considerations of soybean oil.

INTRODUCTION

The use of soybean oil goes back many centuries, but its major growth to its current position as the world's number one edible oil is of fairly recent origin. In fact, the growth has been largely in the past 40 years as shown in Table I.

The approximate worldwide distribution of soybean production as of 1980-81 is shown in Table II. The most dramatic growth has been in North and South America.

The United States has led the world in soybean production and in soybean oil utilization. The growth of soy oil utilization in the USA is shown in Table III and in Table IV is shown the dominance of soybean oil in US edible oil products.

This growth has not been without problems. Soybean oil has probably been the subject of more research than any other oil. Recently the American Soybean Association, in conjunction with the USDA, published a soy oil bibliography covering mainly the period of 1966-79 with some selected and limited references going back to 1936 (8). This provided nearly 2,400 entries for the bibliography. In other words, this means that for this period there was, on the average, a publication approximately every other day about soy oil.

TABLE I

World Production of Soybean Oil (1940-80)

Year	Thousand metric tons
1935-39 (1)[a]	934
1945-49 (1)[a]	1,388
1950-54 (1)[a]	1,864
1960 (2)	3,295
1970 (2)	5,960
1979-80 (3)	14,340

[a]Averaged/year for time frame.

TABLE II

World Soybean Production (1980-81)—Leading Countries (4)

	Thousand metric tons
USA	48,772
Brazil	15,500
People's Republic of China	7,880
Argentina	3,500
Canada	713
Europe	656
Soviet Union	525

TABLE III

Growth of Soybean Oil Utilization in USA (SBO as % Total Domestic Disappearance Edible Fats/Oils)

Year	Percentages
1950 (1)	27
1960 (2)	36.7
1970 (5)	56.5
1980 (6)	66.5

TABLE IV

Dominance of Soybean Oil in 4 Classes of US Edible Oil Products 1980/81 (7)

	Percentages
Shortening	63.3
Margarine	82.3
Salad/cooking oils	80.8
Prepared dressings	95+

The soybean is different from most other oilseeds in that the oil content is ca. 35-40% of the value and the remaining value is in the high protein meal. The approximate composition of the soybean is 40% protein, 20% lipid, 17% cellulose and hemicellulose, 7% sugar, 5% crude fiber and 6% ash.

Soybean oil also has a unique composition in comparison with most other common vegetable oils, except for the oil from the newer varieties of rapeseed. This uniqueness is in its higher content of linolenic acid. A comparison of the fatty acid average composition and range of compositions of soybean oil are shown in Table V.

SOYBEAN OIL

Extraction of Soybean Oil

Most soybean oil is produced by solvent extraction. A schematic diagram of the unit processes used in modern solvent extraction plants is shown in Figure 1 (10). The basic technical principles in this processing are not new and have remained rather static as to changes going back to work started in Europe in the early 1900s. The changes that have come about within the past two decades have largely been increases in size of extractors and extraction plants and with relative reduction in numbers of plants. This is particularly true in the USA and this change is seen in Figure 2.

Other important changes relate to the growing worldwide concern about energy costs and more attention being given to control of solvent losses. This topic is being covered by other speakers at this conference.

The newer technical considerations since 1976 in soybean oil extraction are research and development directed toward effect of the extraction process on refinability of soybean oil and alternate processes for extraction.

TABLE V

Fatty Acid Composition of Soybean Oil (9)

Component acid		Fatty acid composition (wt %) Range	Average
Saturated			
Lauric		–	0.1
Myristic		<0.5	0.2
Palmitic		7-12	10.7
Stearic		2-5.5	3.9
Arachidic		<1.0	0.2
Behenic		<0.5	–
	Total	10-19	15.0
Unsaturated			
Palmitoleic		<0.5	0.3
Oleic		20-50	22.8
Linoleic		35-60	50.8
Linolenic		2-13	6.8
Eicosenoic		<1.0	–
	Total	–	80.7

In the area of the effects of the extraction process on refinability, this has been largely driven by the current interest in physical or steam refining. Briefly, the proposed changes are to destroy the possibility of enzymatic action prior to and during extraction. This leads to more efficient degumming of the oil in preparation for steam refining. The theoretical basis and research results of this have been published (11,12).

The current published processes that could be considered for such enzyme inactivation are:

- "Alcon process"–cooking of flakes prior to extraction (12).
- Continuous steam pressure cooking of whole soybeans prior to extraction (13).
- Microwave vacuum heating (H.F. McKinney, private communication).

This is not intended as a complete listing of possible alternatives, as there are probably other conceivable routes to accomplish enzyme deactivation.

The alternative extraction processes now under study and worthy of mention are:

- Aqueous extraction (14,15).
- Alternative common solvents (16).
- Supercritical carbon dioxide extraction (17).
- Flake expander prior to extraction (W.B. Hendrick, private communication).

The use of an aqueous extraction process for soybeans is attractive because it eliminates the problem of solvent

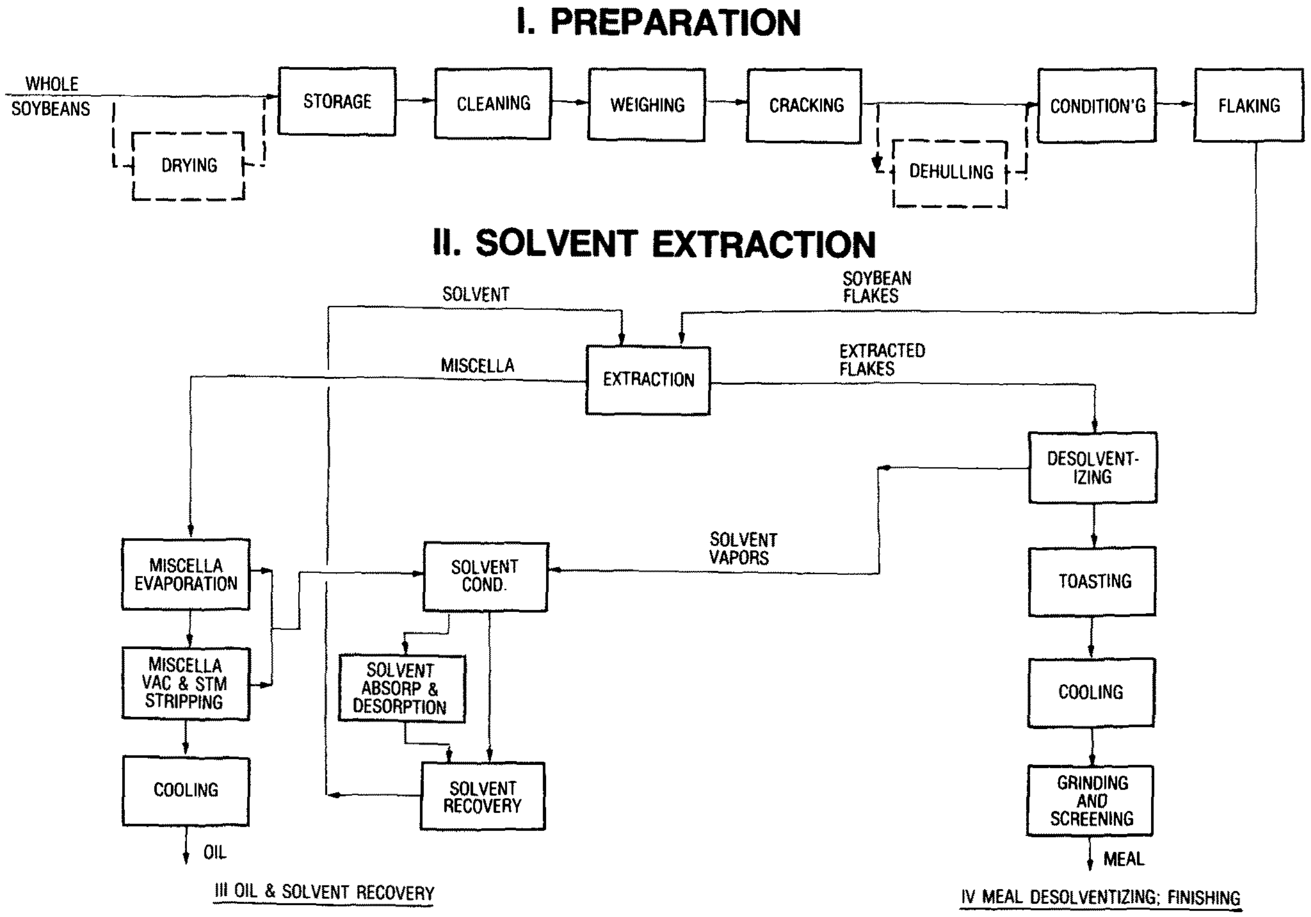

FIG. 1. Typical soybean solvent extraction process.

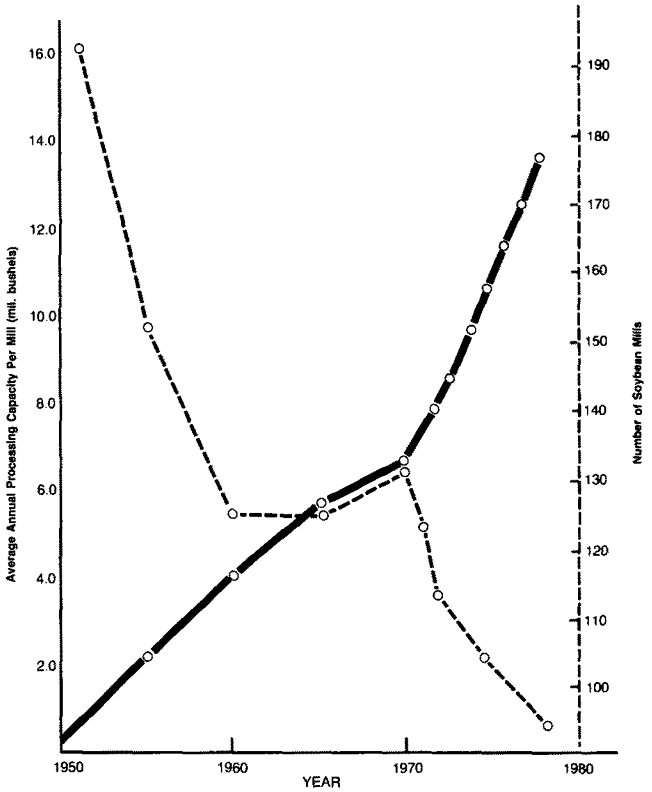

FIG. 2. Average annual capacity and number of US soybean mills.

safety and thus could require much less capital investment. It also might be more suitable for small plants. The major drawbacks currently are inefficient extraction, deemulsification problems, cleanliness requirements (dairy-type process), and higher operating costs for water removal. Appropriate combinations of new and innovative techniques quite possibly may make this a viable process in the future.

The use of alcohols or aqueous alcohols has been demonstrated. The advantages are said to be safer operation due to higher flash points and miscibility of the solvents with water, lower gum content in the extracted oil, and reduction of enzyme activity and protein solubility during extraction requiring less toasting of the meal. In the latter case, the advantage is for production of meal for animal feed but a disadvantage in production of meals with a high protein solubility for use in soy protein production.

It is claimed these solvents can be used in existing hexane plants with some modification; however, there may be a problem with increased corrosion.

The basic principle of supercritical carbon dioxide extraction has been demonstrated. It remains to be seen whether one can scale up from current, relatively small batch processes to the continuous multithousand ton per day requirements of the modern soybean industry.

The flake expander is a treatment of soybean flakes, which can be thicker than normal, through an extrusion process making a "full fat pellet" which is said to be quite porous. The "pellets" are said to be easier to extract than normal flakes, allowing an increase of 30% in extractor throughput, a richer miscella, and better drainage, thus reducing the load on the desolventizer/toaster. The latter two advantages should reduce energy costs. The effect of the expander on enzyme destruction or protein solubility has not been published.

Processing of Soybean Oil

Like soybean oil extraction, the processing of soybean oil is done largely with processes that are not particularly new. They are only improvements in application of well known and long practiced basic techniques.

The unit processes used in soybean oil processing are shown in outline form in Figure 3. The principal steps in the refining of soybean oil are degumming, neutralization, bleaching, hydrogenation and deodorization (steam refining).

Refining of Soybean Oil

A comparison of the average composition of crude soybean oil and fully refined oil are shown in Table VI and depict what needs to be removed in the refining process (18). Generally speaking, soybean oil is a "low-loss" oil in terms of refining and presents no particular problem in refining, but does require judicious use of adjusted treatment practices to maximize final refined soybean oil quality.

The initial steps of the degumming, neutralization and bleaching have been covered in an excellent paper by Wiedermann (19). Of interest at this point is Table VII which shows the effects of soybean quality and the extraction process on food oil quality, alluded to in the section

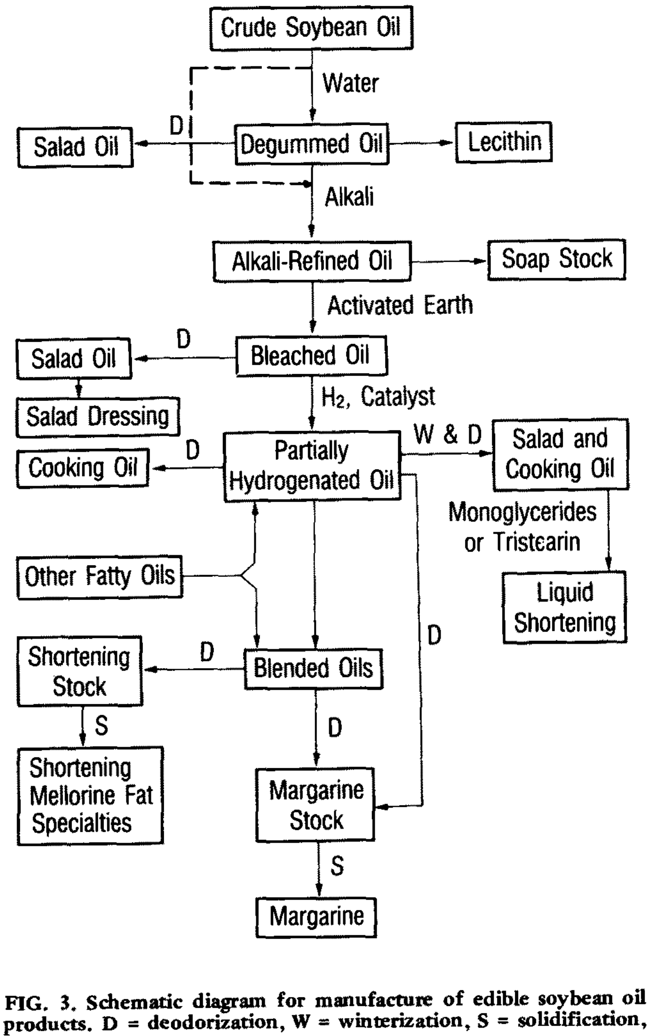

FIG. 3. Schematic diagram for manufacture of edible soybean oil products. D = deodorization, W = winterization, S = solidification, and H_2 = hydrogen gas.

on soybean oil extraction.

Nominal working conditions for degumming of soybean oil are shown in Table VIII, for caustic refining in Table IX, and waterwashing in Table X (19).

Bleaching of Soybean Oil

Proper bleaching is a critical step in soybean oil processing. Bleaching of vegetable oils is normally done for color reduction, and such reduction is the usual method for determining dosage of bleaching earth. The final color of fully refined soybean oil normally presents no problem since adequate reduction is accomplished due to the combined effects of bleaching, deodorizing and hydrogenation when applied.

The modern US practice of bleaching soybean oil is adjustment of bleaching earth dosage so as to achieve a zero peroxide value in the bleached oil using an acid-activated earth. Table XI shows a comparison of such activated earth and their effects on peroxide value in a laboratory situation and Table XII shows a comparison of a neutral and acid activated earth on a plant scale (19). Exhaustive removal of bleaching clay from the oil is very important since any residual earth could act as a very active prooxidant.

The theoretical basis of this bleaching practice is to eliminate all oxygen-containing compounds.

A key consideration after this type of bleaching is prevention of any new build-up of peroxides through either immediate deodorization or by protecting the bleached oil against further thermal or oxidative abuse.

TABLE VI

Average Compositions for Crude and Refined Soybean Oil (18)

	Crude oil	Refined oil
Triglycerides (%)	95-97	>99
Phosphatides (%)	1.5-2.5	0.003-0.045
Unsaponifiable matter (%)	1.6	0.3
Plant sterols (%)	0.33	0.13
Tocopherols (%)	0.15-0.21	0.11-0.18
Hydrocarbons (squalene) (%)	0.014	0.01
Free fatty acids (%)	0.3-0.7	<0.05
Trace metals		
Iron (ppm)	1-3	0.1-0.3
Copper (ppm)	0.03-0.05	0.02-0.06

TABLE VII

Crude Oil Quality, Effect of Abuse Characteristics (19)

Abuse characteristics	Increase in
Weed seed	d,f
Immature beans	f
Field-damaged beans	a,b,c,e
Splits (loading/transport/unloading)	a,b,c
Bean storage (time/temp/humidity)	a,b,c
Conditioning beans for extraction	a,b,d,e
Solvent stripping oil (overheating)	b,d
Oil from stripper (overheating)	b
Crude oil storage (time/temp)	c,d

[a] Total gums/phosphatides.

[b] Nonhydratable phosphatides.

[c] Free fatty acids.

[d] Oxidation products.

[e] Iron/metal content.

[f] Pigments.

TABLE VIII

Working Conditions for Batch-Continuous and Continuous Degumming (19)

Batch-continuous
- 2% water in mix tank
- 30 min-1 hr @ 60-70 C (140-160 F)
- Centrifuge

Continuous
- Preheat oil 60-70 C (140-160 F)
- Add 2% water
- 10-15 min mix-residence time
- Centrifuge

Acid pretreatment
- 0.05-0.2%, 75% phosphoric acid
- Mix 4 hr in day tank @ 33 C (90 F)
- 1 min @ 70-90 C (160-195 F)/supermix

TABLE IX

Working Conditions for Continuous Alkali, Wet Refining (19)

Proportion 16-18 Baume caustic plus
0.12-0.15 for crude oil
0.10-0.12 for degummed oil

To cold, 33 C (90 F) oil

5-10 min contact time

Heat to 75 C (165 F)

Centrifuge

TABLE X

Water Washing Conditions (19)

Single
- 15% Hot (93 C/200 F), soft water
- Mix
- Centrifuge

Double
- Twice with 10% hot/softened water

TABLE XI

Comparison of Some Activated Bleaching Clays Available in the World Market (19)

	Total acidity			Bleach[b]	
	%	KOH[a]	pH	PV	Color
Filtrol 105	0.42	4.8	3.0	0	1.3 R
Vega Plus	0.39	4.5	3.0	0.2	1.3 R
Optimum X-FF	0.32	3.7	3.5	1.2	1.4 R
Filtrol 54	0.15	1.7	3.5	1.2	1.4 R
Optimum FF	0.04	0.4	3.0	1.0	2.0 R
Refined oil	–	–	–	4.0	5.2 R

[a] mgKOH/g.

[b] Laboratory bleach, 1% earth; Lovibond index.

Hydrogenation

Soybean oil is an easy oil to hydrogenate when properly refined and bleached. The two principal catalyst poisons found in improperly refined and bleached soybean oil are soaps and phosphatides. The theory and practice of hydrogenation is well known (20) and the process for hydrogenation of soybean oil has been thoroughly covered by Hastert (21). Hydrogenation conditions for soybean oil to produce a series of base stocks for subsequent production of a wide variety of products has been well covered by Latondress (22).

Deodorization

Deodorization is again not a new process, but effective deodorization is critical to obtaining the best quality of soybean oil. The optimum conditions for deodorization of soybean oil have been well described by Gavin (23).

Normal commercial deodorization conditions are shown in Table XIII (24). Most specifications for deodorized soybean oil show a 0.05% free fatty acid (FFA) maximum. Better quality is achieved at maximum levels of 0.03% and such soybean oil normally has a maximum color value of ca. 10 yellow and less than 1 red. It is a normal practice that citric acid be added to the cooling section of the deodorizer at a level of not less than 50 ppm.

Physical Refining

There is currently a great interest in physical or steam refining of soybean oil mostly to avoid potential pollution problems inherent in the more conventional wet alkali refining. The key to production of high quality soybean oil by physical refining is thorough degumming before deodorizing.

TABLE XII

Plant Bleaching Test: Comparison of Activated Bleaching Earths[a] (19)

	Batch no.	pV	Color[b]
Refined oil to bleacher		2.2	7.9 R
Filtrol 54	1	1.7	3.5 R
(0.15% acidity)	2	1.3	3.2 R
(3.5 pH)	4	1.5	3.3 R
	6	0.5	3.1 R
Filtrol 105	1	0.4	2.0 R
(0.42% acidity)	2	0.0	2.0 R
(3.0 pH)	4	0.0	1.8 R

[a] 0.5% earth added @ 180 F; temperature raised to 220 F; hold 20 min and pressed out; atmospheric conditions; 6-batch capacity press.

[b] Lovibond red index.

TABLE XIII

Commercial Deodorization Conditions (24)

Absolute pressure	1-6 mm Hg
Deodorization temperature	210-274 C
Holding time at elevated temperature:	
Batch type	3-8 hr
Continuous and semicontinuous types	15-120 min
Stripping steam: wt % of oil	
Batch type	5-15%
Continuous and semicontinuous types	1-5%
Product free fatty acid:	
Feed, including steam refining	0.05-6%
Deodorized oil	0.02-0.05%

This topic was covered very well in a recent conference (25). From this conference there seemed to be different opinions about whether the most desirable refining process for soybean oil was caustic or physical. At this point the best advice is to analyze carefully both processes in terms of initial investment, quality of available crude soybean oil, byproduct disposal, flexibility, energy efficiency, local pollution control situation, etc.

Only by putting alternatives on a side-by-side comparison can a reasonable decision be made for any individual plant as to which is the better process.

Utilization of Soybean Oil

Properly refined, bleached and deodorized (RBD) soybean oil is an excellent salad oil, requiring no winterization or dewaxing. As an RBD oil it can be, and is, used in salad dressings and mayonnaise, and as a liquid oil in margarine or shortening formulations.

Utilization of hydrogenated soybean oil in shortenings and margarines has steadily increased in the USA, despite the fact that hydrogenated soybean oil crystallizes in the β form. It has been found that this β tendency can be somewhat overcome by the use in formulation of two and three component base stocks made of hydrogenated soybean oils. Such formulation information and guidelines for the different base stocks have been published by Latondress (22).

Soybean Oil Flavor

No discussion about soybean oil would be complete without discussing flavor. As we pointed out earlier in our discussion, soybean oil is nearly unique in its content of linolenic acid. The only other common edible oil with a comparable or higher linolenic content are the newer varieties of rapeseed oil.

It is interesting to review the history of the development of soybean oil as an edible product. This has been done previously by Dutton (26), but a somewhat different perspective is deemed also to be of interest. As with Dutton, we would like to confine the discussion to US history. However, this could be applicable in context to experiences in other countries.

Soybean oil was first being used extensively in the USA in the late 1940s and early 1950s. It was introduced essentially into a market based on cottonseed oil. Early attempts to process soybean oil were with techniques then being applied to cottonseed oil. This gave a soybean oil of poor quality, which was not acceptable to the US consumer used to cottonseed oil. There seemed to be no problem with hydrogenated soybean oil in products at that time.

There was originally thought to be something strange about fully refined soybean oil because it apparently developed an off-flavor that was not recognized as oxidative in nature. This flavor was said to be like the flavor or odor of the original crude soybean oil and was thus called "reversion" flavor because the flavor of the refined reverted back to that of the crude oil.

This nomenclature persists to the present time, despite later evidence showing that the flavor was indeed due to oxidation.

This evidence was found through use of better and improved analytical techniques. With this knowledge in hand, ordinary techniques for preventing oxidation could then be applied. One of the earlier techniques applied was the use of citric acid, which overcame the effects of copper and iron as oxidation catalysts.

Earlier research on the flavor of soybean oil led to the theory that the linolenate component might be responsible. This was deemed by some to be proved by the USDA experiment (27), where an interesterification of linolenic acid into cottonseed oil at a level equivalent to that of soybean, gave an oil which was identified by taste panels as a soybean oil.

Armed with this information, a liquid soybean oil with a reduced level of linolenate (3-4%) was reintroduced to the US market in the early 1960s in the form of a lightly hydrogenated and winterized (LHW) soybean oil, which quickly became accepted. In addition, it was used as the liquid oil component of salad dressings, mayonnaises, margarines and shortenings.

Starting in the 1970s, improvements achieved in processing of soybean oil produced an RBD oil that was acceptable for uses other than retail salad/cooking oils. As of this date, even this latter use is being served in some instances in the USA by RBD oil. I hasten to add, however, that while pan frying is quite prevalent in the US home, there is very little deep fat frying involving multiple repeated use.

Another issue needing discussion is the so-called "room-odor" problem with LHW soybean oil. This may have been a problem several years ago and may even then have been of interest or concern only to expert tasters. In 1978, the American Soybean Association compared LHW soybean oil, sunflower, and corn oil in an in-home use test where the oils were presented as unidentified oils to a national sampling representing the US consumer. All of the oils were deemed highly acceptable and the only statistically significant difference was the preference for soy over corn, because soy was said to be "lighter". There were no differences among the oils as to comments about off-odors upon heating. In other words, while some experts may consider LHW soybean oil to have a "room-odor" problem, it was not detected by the US housewife (28).

The "linolenate theory" has not been universally accepted as being the principal cause of off-flavor in soybean oil but it was certainly instrumental in the introduction of LHW soybean oil and the consequent improvement in the acceptance of soybean oil.

Other theories, such as residual phosphatides and lipoxygenase activity have also been put forth and may indeed be important in the development of off-flavors. Certainly, one would expect that modern processing techniques, such as the bleaching mentioned before, would eliminate phosphatides and also the oxygenated products which could result from lipoxygenase activity.

In our opinion, the application of the refining practices mentioned above have gone a long way toward overcoming development of objectionable off-flavors in RBD soybean oil. This viewpoint is reinforced by actual utilization data, at least in the USA.

Even under the best conditions of optimal processing, an expert experienced in oil tasting could probably identify each individual refined common vegetable oil as presented. This may be of consequence, however, only to the expert tasters since the consuming public has no such expertise and may only object if the oil is less than reasonably bland. The fact that soybean oil may have a different or possibly objectionable low-level flavor to an expert taster thus may have no meaning unless the consumers also object. This latter can only be found out by actual consumer testing using unbiased methodology.

Pragmatically speaking, there now exist processing techniques which largely overcome the problem of "reversion flavor". We must also say that this does not overcome the inherent potential development of oxidation off-flavors due to the high level of polyunsaturation in RBD soybean oil or the exclusion of any concern about "reversion flavor" where less than optimum refining methods are used.

All the highly polyunsaturated oils, such as safflower, sunflower, corn oil, rapeseed oil and soybean oil would not be recommended for heavy-duty deep fat frying or for other applications demanding high stability toward oxidation. One should always consider hydrogenated counterparts of these oils for such use.

The American Soybean Association is currently sponsoring research by soybean plant breeders directed toward reduction of the linolenic acid content in the soybean itself. Progress has been slow because it has been nearly impossible to find a natural variety with a low linolenic content which greatly slows selective breeding. Varieties with linolenate contents of ca. 4% have been developed and grown for further testing.

We have discussed linolenic acid in a negative sense until now, but there is growing evidence that it probably has a unique essentiality in human nutrition and may be a required constituent in the human diet (29). Evidence is also growing that the class of ω-3 polyunsaturated fatty acids, which includes linolenic acid, may be of nutritional importance and desirable in the diet (30). These latter two things may be interrelated. They certainly bear watching in the future.

REFERENCES

1. US Fats and Oils Statistics (1909-1965), Statistical Bulletin 376, USDA ERS, Washington, DC, 1966, p. 176.
2. US Fats and Oils Statistics (1950-1971), Statistical Bulletin 489, USDA ERS, Washington, DC, 1972, p. 168.
3. Soya Blue Book, American Soybean Association, St. Louis, MO, 1981, p. 141.
4. Ibid., 1982, p. 168.
5. Ibid., 1980, p. 156.
6. Ibid., 1981, p. 166.
7. Current Industrial Reports, (M 20-K 81-13) US Bureau of Census, 1982, Table 3B.
8. Cowan, J.C., Soy Oil Bibliography: Processing, Composition, Reactions and Edible and Related Uses, ASA, St. Louis, MO, 1981.
9. 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, AOCS Monograph 8, AOCS, Champaign, IL, 1980, p. 17.
10. Becker, K.W., JAOCS 55:755 (1978).
11. Ong, J.T.L., Proceedings of the 2nd ASA Symposium on Soybean Processing, Brussels, Belgium, 1981.
12. Kock, M., Ibid., 1981.
13. Swift & Company, Br. Patent 1385303 (1973).
14. Lawhon, J.F., et al., J. Food Sci. 46:391 (1981).
15. Lusas, E.W., et al., Oil Mill Gaz. April:28 (1982).
16. Sullivan, D.A., Ibid. April:24 (1982).
17. Friedrich, J.P., and G.R. List, J. Agric. Food Chem. 30:192 (1982).
18. 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, AOCS Monograph 8, AOCS, Champaign, IL, 1980, p. 14.
19. Wiedermann, L.H., JAOCS 58:159 (1981).
20. Allen, R.R., in Bailey's Industrial Oil and Fat Products, 4th edn., vol. 2, Wiley-Interscience, New York, NY, 1982, pp. 1-95.
21. Hastert, R.C., JAOCS 58:167 (1981).
22. Latondress, E.G., Ibid. 58:185 (1981).
23. Gavin, A.M., *Ibid. 58:175 (1981).*
24. Zehnder, C.T., Ibid. 53:364 (1976).
25. Proceedings of the 2nd ASA Symposium on Soybean Processing, American Soybean Association, Brussels, Belgium, 1981.
26. Dutton, H.J., JAOCS 58:234 (1981).
27. Dutton, H.J., A.W. Schwab, H.A. Moser and J.C. Cowan, Ibid. 25:385 (1948).
28. Erickson, D.R., and R.A. Falb, World Soybean Research Conference II: Proceedings, edited by F.T. Corbin, Westview Press, Boulder, CO, 1980, pp. 851-858.
29. Holman, R.T., Am. J. Clin. Nutr. 35:617 (1982).
30. Brongeest-Schoute, H.C., et al., Ibid. 34:1752 (1981).