Effect of Altered Fatty Acid Composition on Soybean Oil Stability[1]

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During the last 15 years, hybridization and induced mutation breeding of soybeans have been successful in producing an altered fatty acid composition in the extracted oil. The objective of those investigations was to produce a low-linolenic acid soybean oil. Crude oils extracted from the seeds of three such genotypes were processed in laboratory simulations of commercial procedures to finished deodorized oils. Analysis of the fatty acid composition of the three oils showed the linolenic acid content to be 3.3%, 4.2% and 4.8%. The stability of these finished oils was compared to that of oil from a soybean variety having a linolenic acid content of 7.7% and of a commercial hydrogenated-winterized soybean oil (3.0% linolenic acid). Test and control oils were evaluated by a trained sensory panel initially, after accelerated storage at 60 C and during use at 190 C in room tests. Peroxide values were determined at the time of sensory evaluation. Results indicated there was no significant difference in flavor stability during storage between test and control oils. There was no significant difference, between the oils, in peroxide development during accelerated storage. Compared to control oils, the test oils had improved overall room odor intensity scores and lacked the fishy odors of non-hydrogenated soybean oil and the hydrogenated odors of commercial cooking oil.

Early research concerning flavor and stability problems of soybean oil implicated the linolenic acid constituent (1-4). Dutton et al. (1) reported flavor evaluations of stored soybean oil, cottonseed oil and a cottonseed oil interesterified with 7-9% methyl linolenate. The interesterified oil showed flavor deterioration characteristic of stored soybean oil. They concluded that linolenic acid was an unstable precursor of off-flavors in soybean oil. Evans et al. (2) extracted and processed oil from three varieties of soybeans with different levels of linolenic acid. Flavor evaluations of the oils initially and after accelerated storage indicated that the linolenic acid content would have to be less than 5% to achieve a significant quality improvement. The fishy odors generated by use of soybean oil at frying temperatures disappeared when the linolenic acid content was reduced to below 2.0% by blending with cottonseed oil (5). Subsequently, catalytic hydrogenation processes were developed to selectively reduce the linolenic acid content to below 4.0%. This produced a bland and stable product comparable to cottonseed oil. More recently, evaluations of refined, bleached, deodorized and citrated soybean oils, unhydrogenated and partially hydrogenated, showed that hydrogenation did not significantly improve the flavor stability during ambient temperature storage (6-7). However, hydrogenation did significantly lower the objectionable fishy odors generated during high temperature heating of soybean oil (8).

Breeding programs have been underway for many years to develop soybean varieties with low levels of linolenic acid (3). Until recently there has been little success in obtaining low-linolenic acid lines that maintained this characteristic in succeeding generations. Recently, mutation breeding programs at Iowa State University (9) and the cooperative USDA-Purdue University program (10,11) successfully developed such mutant lines low in linolenic acid. While catalytic hydrogenation produces a wide range of both positional and geometrical isomers of poly- and monounsaturated fatty acids (16), the low-linolenic acid oils produced by recurrent selection and mutation breeding are free of these isomerization products.

We now report the results of sensory evaluation studies of processed oils from soybean lines either developed by these breeding programs or selected from the U.S. Soybean Germplasm Collection.

EXPERIMENTAL

Materials. The low-linolenic acid soybean line developed at Iowa State University, designated A5, was planted and harvested at Ames, Iowa in 1983, and the oil was extracted at Texas A&M University. Four l of the crude oil were provided for further processing and stability evaluation.

Twenty lb of low-linolenic acid soybeans developed at Purdue University, designated C1640, were provided from the 1985 harvest at West Lafayette, Indiana.

More than 5,000 soybean samples from both the northern and southern soybean germplasm collections were analyzed for their fatty acid compositions by a rapid esterification procedure (11) in preparation for subsequent gas chromatography. Five plant introductions (PIs) with linolenic acid contents of less than 5.0% were planted at six sites in Georgia, Maryland, Iowa, Illinois and Indiana to evaluate the consistency of the linolenic acid content. The PI with the greatest consistency was planted (Jacksonville, IL, 1982) to provide quantities for evaluation.

Control oils were (a) extracted from 1985 Williams variety soybeans (SBO), and (b) commercial hydrogenated-winterized soybean oil (HWSBO).

Methods. Soybeans were cleaned, cracked, dehulled and flaked in laboratory scale equipment that simulated commercial practice. Steam-tempered flakes (103 C, 4 min) were extracted in an all-glass soxhlet extractor, and the crude oil was recovered by micella desolventization on a Rotovac at 60 C. Crude oils were processed to finished edible oils by laboratory simulations of commercial processing procedures (12). One-gallon quantities of each oil were degummed by stirring (5,000 rpm) for 15 min at 60 C with water (2% by weight); gums were separated by centrifugation and decantation of the oil phase. Degummed oils were caustic-refined by stirring for 15 min at 60 C with the required amount of 14°Be'

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lye that included 0.5% excess; soap stock was separated by centrifugation, and the refined oil was decanted. The oil was washed twice with water (20% by weight). Bleaching was accomplished by stirring the degummed, refined and washed oils for 15 min at 105 C under vacuum with Super Filtrol bleaching earth (0.5% by weight). The oil was cooled to 60 C and filtered under vacuum through a bed of Celite filter aid. Recovered filtered oils were steam deodorized for one hr at 260 C at 1 mm Hg vacuum. All oils were treated with 0.01% citric acid on the cooling side of deodorization (at ca. 100 C). Flavor evaluations were conducted according to methods described by Moser et al. (13), modified as reported earlier (6). Facilities and procedures for room odor evaluation have been described previously (8, 14). AOCS Official Methods were used for oil analyses (15).

RESULTS AND DISCUSSION

Evaluation of the fatty acid composition of the more than 5,000 soybean samples analyzed in the USDA germplasm study yielded 12 PI with linolenic acid content less than 5.0%. Five of these low-linolenic acid PI were selected for further study (Table 1). One of the PIs selected, PI 361088B, had normal oleic acid content and a slightly higher than usual linoleic acid content. Analyses of the linolenic acid content of the samples harvested from plantings of the five selected PIs and two standard varieties at six test sites are presented in Table 2. Only PI 361088B maintained a low-linolenic acid content consistently regardless of test site. During the subsequent growing season (1982) this PI was planted and harvested for oil evaluation.

TABLE 1

Composition of Oil from Low-Linolenic Acid Plant Introductions (wt %) (1980)

Variety	Fatty acids				
	C16:0	C18:0	C18:1	C18:2	C18:3
PI 361088B	13.2	3.2	21.7	57.6	4.2
PI 378677C	13.0	3.9	29.0	49.2	4.9
PI 404156	10.6	3.2	41.2	40.1	4.9
PI 417455	10.7	3.2	39.2	41.7	5.0
PI 423865	10.2	4.0	42.4	38.3	4.5

The fatty acid compositions of processed test and control oils are shown in Table 3. The A5 oil closely approximated the fatty acid composition of the HWSBO. The other two test oils, C1640 and PI 361088B, were low in linolenic acid, but their linoleic acid content was greater than that found in the control SBO, thus the calculated iodine values were quite similar.

The results of paired-sample flavor evaluations of each test oil versus the control SBO, initially and after accelerated storage, are shown in Table 4. The PI 361088B oil had a significantly higher flavor score initially and after accelerated storage. Generally, an observed difference in flavor scores between freshly deodorized oils is an artifact of processing and not attributable to a difference in flavor stability. Low-linolenic acid oils did not show improved flavor stability after the four-day accelerated storage, which is approximately equivalent to three month's storage

TABLE 2

Consistency of Linolenic Acid (C18:3) Content (wt %) (1981)

	Original	Georgia	Illinois	Iowa	Indiana	Maryland	Illinois
PI 361088B	4.2	4.1	4.6	4.7	5.1	4.5	4.4
		4.2	4.8	5.4	5.9	4.3	4.4
PI 378677C	4.9	5.4	6.2	6.5	6.8	6.9	6.7
		4.7	6.2	6.9	6.9	7.0	6.1
PI 404156	4.9	5.1	7.4	7.5	7.7	7.8	6.4
		5.4	7.5	7.5	8.3	8.1	6.7
PI 417455	5.0	5.5	8.7	8.4	8.6	6.1	7.5
		4.9	8.6	7.9	8.3	8.2	7.7
PI 423865	4.5	4.5	7.8	7.0	7.2	6.4	6.5
		4.4	7.2	7.1	7.3	7.4	6.1
Weber[a]	8.4	8.3	9.2	10.5	10.4	9.9	-
		8.7	9.8	10.4	9.6	10.2	-
Corsoy[a]	6.5	6.5	7.4	8.2	8.5	7.0	-
		6.6	8.0	8.2	8.0	7.2	-

[a]Standard commercial varieties.

TABLE 3

Composition of Oils (wt %)

Oil	Fatty acid					
	C16:0	C18:0	C18:1	C18:2	C18:3	Calc. IV[a]
SBO[b]	10.5	3.6	23.8	54.4	7.7	134.8
HWSBO[c]	9.2	3.9	47.8	36.1	3.0	111.5
A5 (1983)	10.8	4.5	45.0	36.4	3.3	110.4
C1640 (1985)	10.6	3.6	24.6	56.4	4.2	130.6
PI 361088B (1982)	13.1	3.6	16.6	61.9	4.8	134.1

[a]Calculated Iodine Value.
[b]Unhydrogenated soybean oil (1985 Williams).
[c]Hydrogenated-winterized soybean oil.

TABLE 4

Flavor Scores[a] of Low-Linolenic Acid Oils

Storage (days @ 60 C)	SBO	A5	C1640	PI 361088B	Difference
0	7.3 (0)[b]	7.4 (0)			NS[c]
	7.6		8.0 (0)		NS
	7.2			8.1 (0)	*[d]
4	6.8 (0.8)	6.7 (1.0)			NS
	6.8		7.1 (0.6)		NS
	6.8			7.5 (1.1)	*
8	5.5 (5.8)	6.6 (3.0)			**[e]
	5.9		6.6 (4.9)		*
	6.2			7.0 (5.4)	*

[a]Scores based on 1-10 scale with 10 as bland and 1 as strong.
[b]Figures in parentheses are peroxide values determined at the time of tasting.
[c]NS, not significant.
[d]*, significance at the 5% level.
[e]**, significance at the 1% level.

in the dark at ambient temperature. A significant difference in flavor scores was observed after the eight-day accelerated storage. Under these extreme conditions all of the low-linolenic acid oils showed improved flavor stability compared to the control SBO. Accelerated storage for eight days is a stress test, which has not been correlated with a particular storage period at ambient temperature.

Interpretations of the results of room odor evaluations of the processed oils must consider both the overall odor intensity score and the odor description intensity. Results of paired sample evaluations of the test oils versus control oils are presented in Table 5. Room odor description intensity levels for all oils are given in Figure 1. Fishy and hydrogenated odors are considered to be objectionable room odors generated during frying and cooking. The fried food odor is characteristic of good-quality cooking oils. In comparison with the control SBO (Table 5), at one hr heating (190 C) both the A5 and PI 361088B oils had significantly improved (lower) overall odor intensity scores. After five hr of heating only the A5 oil was significantly improved. While the SBO had an objectionable fishy odor, none of the low-linolenic acid oils were described as fishy even after five hr of heating.

The low-linolenic acid oils scored significantly better than the control HWSBO in all room odor evaluations (Table 5). This can be attributed to the strong hydrogenated odor that was perceived for HWSBO by the panelists. As might be expected, there was no hydrogenated odor generated during use of the low-linolenic acid oils at high temperature. While acrid and burnt odors were reported for C1640 and burnt odor for A5 after one hr heating, the odor of PI 361088B was described as fried food only. Even after five hr, the slight acrid odor reported for PI 361088B was the lowest intensity level.

As discussed earlier, Evans et al. (5) had speculated that a linolenic acid content below 2.0% was required to eliminate the fishy odor generated from soybean oil at high temperature. All of the low-linolenic acid lines developed by recurrent selection or mutation breeding

TABLE 5

Overall Room Odor Intensity Scores[a]

Heating at 190 C (hr)	Oil					Difference
	SBO	HWSBO	A5	C1640	PI 361088B	
1	4.1		3.1			*[b]
		5.9	3.1			**[c]
	4.6			4.3		NS[d]
		6.1		4.1		**
	4.4				3.3	**
		6.1			3.5	**
5	4.8		3.3			**
		6.5	3.3			**
	4.4			4.3		NS
		6.4		4.1		**
	4.1				4.0	NS
		6.8			3.7	**

[a]Based on 0-10 scale with 0 = none; 10 = strong intensity.
[b]*, significant at 95% confidence level.
[c]**, significant at 99% confidence level.
[d]NS, not significant.

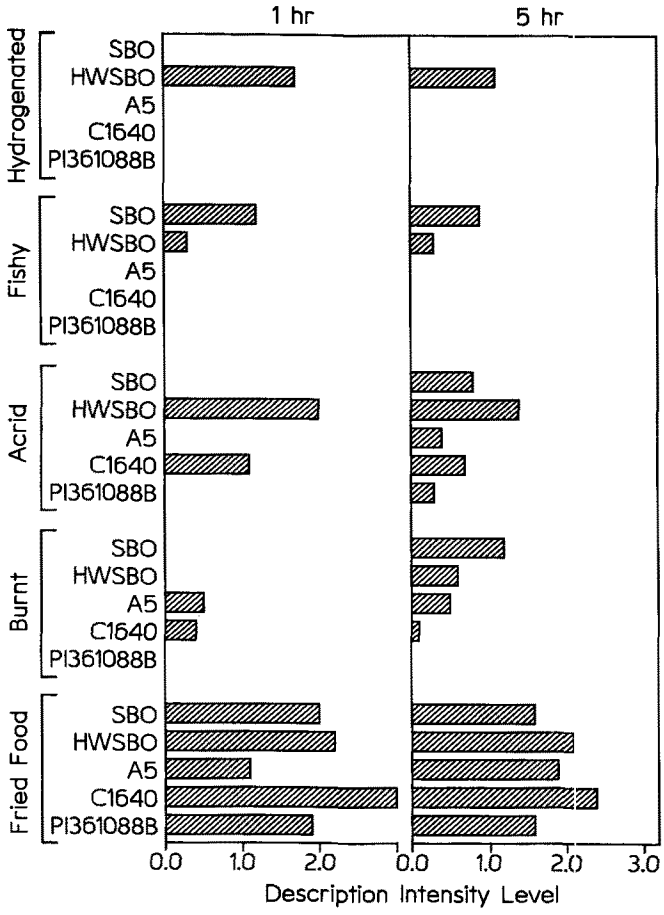

FIG. 1. Room odor descriptions for oils heated at 190 C (1.0 = weak; 2.0 = moderate; 3.0 = strong intensity) (fried food - acceptable; hydrogenated and fishy - objectionable).

gave oils with improved room odor stability for use at high temperatures. This was somewhat unexpected because the linolenic acid content ranged from 3.3-4.8%. While small differences in relative quality between the test oils have been observed, there does not appear to be a basis for recommending one in preference to the other.

The results reported here indicate that a satisfactory lowering of the linolenic acid content has been achieved. Emphasis should be placed on assuring the consistency of the low-linolenic acid content during subsequent growing seasons, regardless of environmental factors. Improvement in the harvest yield of these lines (ca. 75% of commercial varieties) is also required to assure that they will be economically viable (9-11). Nevertheless, these lines offer the opportunity for producing stable liquid soybean cooking oils without the 3-5 cents/lb cost of commercial catalytic hydrogenation.

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