Performance Evaluation of Hexane-Extracted Oils from Genetically Modified Soybeans

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Soybeans produced by induced mutation breeding and hybridization were cracked, flaked and hexane-extracted, and the recovered crude oils were processed to finished edible oils by laboratory simulations of commercial oil-processing procedures. Three lines yielded oils containing 1.7, 1.9 and 2.5% linolenic acid. These low-linolenic acid oils were evaluated along with oil extracted from the cultivar Hardin, grown at the same time and location, and they were processed at the same time. The oil from Hardin contained 6.5% linolenic acid. Low-linolenic acid oils showed improved flavor stability in accelerated storage tests after 8 d in the dark at 60°C and after 8 h at 7500 lux at 30°C, conditions generally considered in stress testing. Room odor testing indicated that the low-linolenic oils showed significantly lower fishy odor after 1 h at 190°C and lower acrid/pungent odor after 5 h. Potatoes were fried in the oils at 190°C after 5, 10 and 15 h of use. Overall flavor quality of the potatoes fried in the low-linolenic oils was good and significantly better after all time periods than that of potatoes fried in the standard oil. No fishy flavors were perceived with potatoes fried in the low-linolenic oils. Total volatile and polar compound content of all heated oils increased with frying hours, with no significant differences observed. After 15 h of frying, the free fatty acid content in all oils remained below 0.3%. Lowering the linolenic acid content of soybean oil by breeding was particularly beneficial for improved oil quality during cooking and frying. Flavor quality of fried foods was enhanced with these low-linolenic acid oils.

KEY WORDS: Fatty acid composition, flavor quality, frying stability, genetic modification, linolenic acid, oils, soybean.

Chemical mutagenesis and hybridization have been used to produce soybean strains that yield oils with low-linolenic acid (Ln) contents (1). Such a modification has long been sought to respond to consumer preferences for sensory quality, product safety and nutrition (2). The introduction of soybeans with value-added traits into commercial production will be based on demonstrated performance attributes of the new low-linolenic acid oils for food product uses (3). In earlier research, we evaluated the performance of an oil from an experimental soybean line, A5, with an Ln content of 3.3% (4). The oil was hexane-extracted and processed by laboratory simulations of procedures in common use in the food oil processing industry. Results of room odor tests showed that, at cooking and frying temperatures, the modified oil lacked the objectionable fishy odor generated from soybean oil and the hydrogenated odor from partially hydrogenated soybean cooking oil.

Recently, new soybean genotypes have been produced by Hammond and Fehr (5) in extension of their previous research. Liu and White (6,7) reported evaluations of oils from these lines obtained by cold-press and deodorized according to a steam distillation procedure, with no citric acid addition. Such processing is not typical of the commercial soybean industry.

The objective of the current research was to evaluate in-use performance of salad and cooking oils prepared from the new low-linolenic soybean lines. To ensure the credibility of the results for use by formulators of food oil products, crude oils were obtained by hexane extraction and processed to finished products in laboratory simulations of commercial procedures (8).

EXPERIMENTAL PROCEDURES

Materials. Soybeans from three experimental lines [A16, A17 and A87-191039 (A87)] and a commercial cultivar (Hardin) were produced by W.R. Fehr, Iowa State University (Ames, IA) in 1989. Two bushels of each line were obtained for these studies. Fresh Idaho russet-type potatoes for frying tests were purchased locally.

Oil extraction and processing. Duplicate samples of soybeans (20 kg) were cleaned, cracked, dehulled and flaked in laboratory-scale equipment that simulated commercial practice. Steam-tempered flakes (103°C, 4 min) were hexane-extracted in a 40-L stainless-steel immersion extraction vessel. The crude oil was recovered by evaporative micella desolventization, and oil stripping was done on a rotovac (Brinkman Instruments, Westbury, NY) at 60°C. Crude oils were processed to finished edible oils by laboratory simulations of commercial processing procedures as described previously (8). Citric acid, *ca.* 100 ppm, was added to all oils during the cool-down stage of deodorization at about 100°C. Finished oils were characterized by AOCS Methods (9) for gas chromatography-fatty acid composition, Ce 1-62; iodine value (IV), Cd 1c-85; phosphorus, Ca 12-55; and iron, Ca 15-75.

Oil storage. Flavor and oxidative stability of oils during warehouse storage was evaluated by aging in accelerated storage in the dark. Oils aged at 60°C in the dark were in 8-oz clear glass bottles, filled one-half with oil, one-half with air in the headspace and loosely stoppered with a cellophane-covered cork. Bottles were placed in a forced-draft oven for 4 and 8 d. On-the-shelf storage in the light was simulated by accelerated storage of oils packaged as described above and then exposed to fluorescent light at 7500 lux at 30°C for 4 and 8 h. The peroxide value (PV) of all oils was determined by AOCS Method Cd 8-53 (9) at time of sensory analyses. Total volatile content (TV) was determined by static headspace procedures (10).

Frying protocol. Oils were used for intermittent frying of potatoes at 190°C for 4 d in 4-cup commercial fryers (Multi-Fry-Cook; Nordic Ware, Northland, MN). Each oil (800 g) was held at 190°C for 5 h, then cooled to room temperature for the remainder of each 24-h period. Total heating/frying time was 20 h for each oil. Fresh russet-type Idaho potatoes were cut into 8-cm lengths of shoestring size (0.5 cm × 0.5 cm) and fried in 100-g batches for 4 min. Three 100-g batches of potatoes were par-fried for 90 s after the oil had been heated for 3 h. Each batch was frozen and later finish-fried for 2 min prior to panel evaluations at 5, 10 and 15 h of oil usage. Each day,

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20 g of fresh oil was added as makeup oil to each sample.

Sensory evaluation. Oils were evaluated for quality characteristics as salad oils and as frying oils. The flavor quality and stability of the samples as salad oils were evaluated by a 15-member trained panel experienced in testing vegetable oils. They rated the intensity of overall flavor by using the AOCS 10-point intensity scale and individual flavors on a 3-point scale, with 1 = weak, 2 = moderate and 3 = strong intensity (Cg 2-83) (9).

Room odor evaluation of frying oils was conducted in facilities previously described (11,12), after 1, 5, 10 and 20 h of oil usage. No frying was conducted during odor panel evaluations. A 16-member trained, experienced panel rated the odors in each of the two chambers for overall intensity and individual description intensity on a scale with 0 = none, 10 = very strong (12).

Flavor quality of french-fried potatoes was rated by a 14-member trained, experienced panel by using a 10-point quality scale (1 = bad, 10 = excellent) and an individual flavor description intensity scale with 0 = none, 10 = strong (13). A french-fried potato control prepared in cottonseed oil was identified as good quality with a score of 8 and presented to the panel prior to each evaluation.

Heated-oil characterization. Free fatty acid (FFA) content was determined by the AOCS method Ca 5a-40 (9). The polar content was determined by the AOAC column-chromatography method (14). TV content was determined by static headspace procedures (10).

Statistical analysis. Data were interpreted by analysis of variance (15). Statistical significance was expressed at the $P < 0.05$ level unless otherwise indicated.

RESULTS AND DISCUSSION

The results of fatty acid composition analyses of the extracted, fully processed soybean oils are presented in Table 1. Ln content of the oils from the experimental varieties was reduced by 74% (A16), 71% (A17) and 62% (A87), relative to the oil from the commercial Hardin variety. In addition, the total saturated fatty acid content of A16 was increased by 17% and of A17 by 54%. Based on previous research, oils with reduced Ln content and increased saturated acid content can be expected to have improved oxidative and flavor stability relative to commercial soybean oils (4).

Storage stability in the dark. Flavor stability of the oils aged in the dark at 60°C, to simulate commercial warehouse storage, showed that lowering the Ln content of the oils produced samples with significantly ($P < 0.05$) better flavor scores than Hardin after the greatest stress condition, 8 d (Table 2). No significant differences were noted among the scores of the three low-linolenic oils aged under these conditions. Higher intensity levels of off-flavors reported for the Hardin, such as rancid and painty, contributed to the lower flavor scores (Fig. 1). Oxidative stability measured by PV and TV decreased with increasing IV (Fig. 2). Sample A17 (22.6% saturates; 113.8 IV), had significantly ($P < 0.05$) lower PV and TV after 8 d at 60°C than the other samples. A16 (17.2% saturates; 119.2 IV) also had significantly ($P < 0.05$) lower PV and TV than Hardin (14.7% saturates; 132.7 IV) and A87 (14.9% saturates; 126.3 IV). Hardin, with an IV of 132.7, was the least stable, although the difference in stability between it and A87 was not significant. Variation between the results of flavor and oxidative-stability measurements may result because flavor evaluations detect more than changes in oxidation and in the development of volatiles. Nonvolatile and nonoxidative changes can occur that may not be detected by instrumental or chemical analyses (13,16).

Storage stability in the light. In the photooxidative stability tests, all low-linolenic oils were rated better than Hardin; however, only the A17 oil was rated significantly ($P < 0.05$) better at both 4 and 8 h of light exposure (Table 2). After 8 h of light exposure, the A87 oil was also rated significantly ($P < 0.05$) better than the control. Interestingly, the A16 oil, which had the lowest level of Ln acid, did not show significant improvement in photooxidative stability. Perhaps, the greater amount of saturated fatty acids in the A17 oil, 31.8% greater than in the A16 oil, contributed to improved photooxidative stability. Lower intensity scores for rancid flavor characterized the improved stability of the A17 oil (Fig. 3). All low-linolenic oils had significantly ($P < 0.01$) less volatiles formation after 4 and 8 h at 7500 lux at 30°C than Hardin (Fig. 4). The oils with lowered Ln showed little increase in TV from the initial levels in the unaged oil. PVs of the light-exposed oils did not differ significantly ($P < 0.05$) among oil types at either 4 or 8 h. The PVs ranged from 2.0 to 2.3 for all samples at both times, in concurrence with previous results, which showed that PVs are not good indicators of photooxidation (17).

High-temperature uses. Results of room odor evaluations of the oils are presented in Table 3 and Figure 5. Odor description intensities must be considered simultaneously with overall room odor intensity when interpreting the effect of oil modification. While there were few significant differences in the overall scores, the panelists perceived significantly ($P < 0.05$) lower fishy odor intensities with the low-linolenic oils compared to the Hardin oil. Because soybean oil can produce fishy odors at high temperature, these results suggest that the oils with lowered Ln content have better high-temperature stability than Hardin.

TABLE 1

Composition (wt%) of Oils from Low-Linolenic and Normal Soybean Strains

	Fatty acids					
Strain	C16:0	C18:0	C18:1	C18:2	C18:3	Calc. IV[a]
A16	12.3	4.9	29.6	51.6	1.7	119.2
A17	17.3	5.3	25.2	50.3	1.9	113.8
A87-191039	10.6	4.3	26.7	55.9	2.5	126.3
Hardin	10.9	3.8	23.9	55.0	6.5	132.7

[a] Iodine value (IV) calculated from gas chromatography fatty acid composition (Ref. 7).

TABLE 2

Flavor Scores of Fresh and Aged Oils

Storage	Flavor intensity scores[a,b]			
	A16	A17	A87	Hardin
(days @ 60°C)				
0	7.2c	7.6c	8.0c	7.4c
4	6.2c	6.4c	6.7c	6.4c
8	5.6c	6.1c	6.0c	4.7d
(h @ 30°C 7500 lux)				
4	5.6c,d	6.3c	5.7c,d	5.0d
8	5.5c,d	5.9c	6.0c	5.0d

[a] Flavor intensity scale: 10 = bland; 1 = strong (Ref. 7).
[b] Values in rows having different letters are significantly different ($P < 0.05$) (Ref. 15).

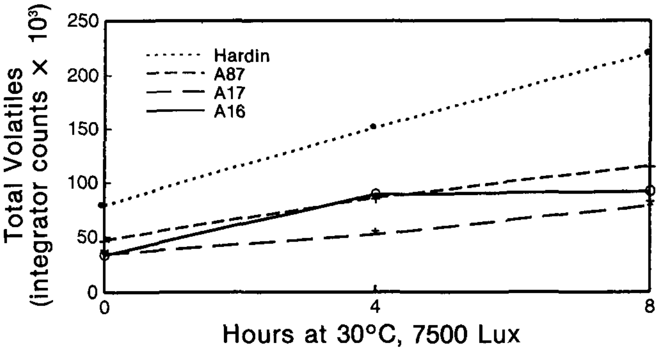

FIG. 3. Photooxidative stability indicator for fresh and aged oils.

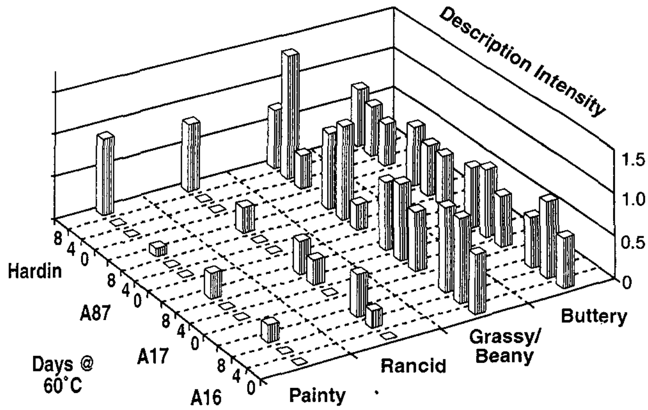

FIG. 1. Flavor description intensity scores: accelerated storage. Intensity scale: 1 = weak; 2 = moderate; 3 = strong (Ref. 7).

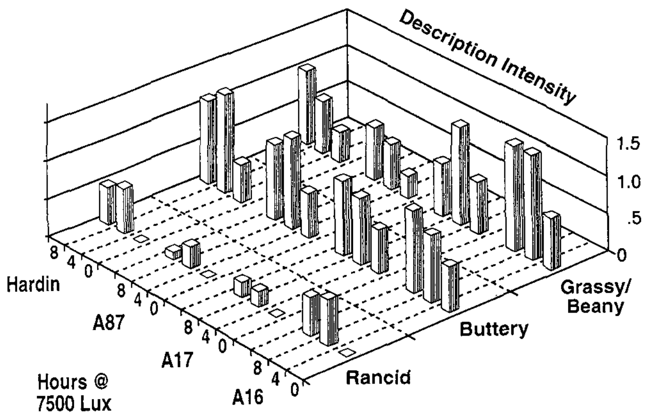

FIG. 4. Flavor description intensity scores: fluorescent light exposure. Intensity scale: 1 = weak; 2 = moderate; 3 = strong (Ref. 7).

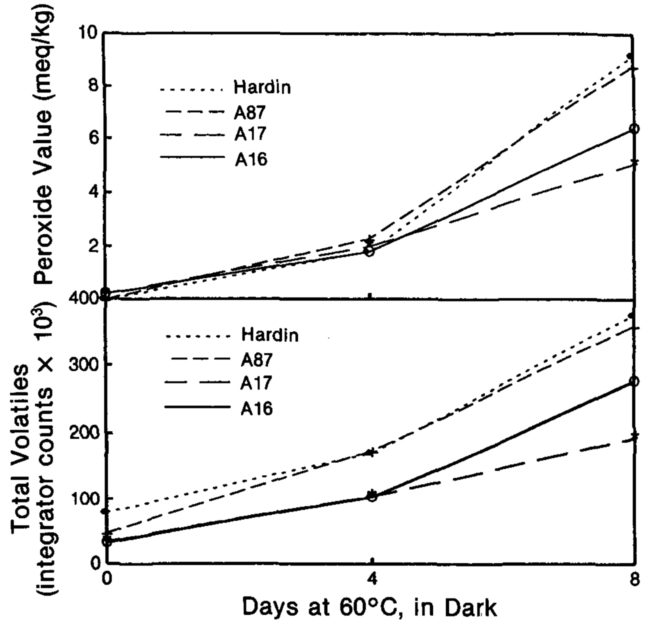

FIG. 2. Oxidative stability indicators for fresh and aged oils.

TABLE 3

Room Odor Intensity Scores of Heated Oils

Heat/Fry	Room odor intensity score[a,b]			
	A16	A17	A87	Hardin
(h @ 190°C)				
1	4.1c,d	4.4c	3.3d	4.4c
5	3.4c	4.6d	3.9c,d	4.0c,d
10	4.6c	4.8c	4.1c	4.4c
15	4.3c	4.1c	4.3c	4.2c

[a] Room odor intensity scale: 0 = none; 10 = strong (Ref. 10).
[b] Values in rows having different letters are significantly different ($P < 0.05$) (Ref. 15).

Our previous studies (4) indicated that such low-linolenic oils performed better in room odor tests than did partially hydrogenated low-linolenic (3.3% Ln) cooking oil because they have no hydrogenation odor. Panelists reported waxy odors with A16 and A17 that are indicative of oils with higher levels of saturates. As presented in Table 4 and Figure 6, the flavor quality of fried potatoes was significantly ($P < 0.05$) improved by use of the low-linolenic oils. Panelists rated the flavor quality of potatoes fried in all low-linolenic oils as good, whereas the quality of potatoes fried in the Hardin oil was rated poor. Fishy flavors were eliminated with the potatoes fried in low-linolenic oils, while potato and fried-food flavors were retained even after 15 h of frying. Fishy flavors are characteristic of foods fried in soybean oil, and the elimination of these flavors is an important improvement obtained by lowering the Ln content.

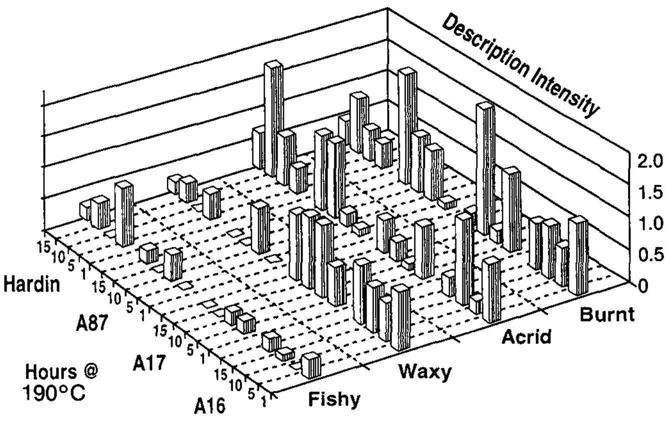

FIG. 5. Odor description intensity scores: room odor. Intensity scale: 0 = none; 10 = strong (Ref. 12).

TABLE 4

Flavor Quality Scores of Potatoes Fried in Modified Soybean Oils[a]

	Flavor quality scores[b,c]			
Heat/Fry	A16	A17	A87	Hardin
(h @ 190°C)				
5	6.9c	7.0c	7.6c	5.2d
10	7.4c	6.8c	7.2c	4.5d
15	6.6c	7.4c	7.1c	4.4d

[a] Flavor quality score of potatoes fried in cottonseed oil = 8.0.

[b] Flavor quality scale: 10 = excellent; 1 = bad (Ref. 11).

[c] Values in rows having different letters are significantly different ($P < 0.05$) (Ref. 15).

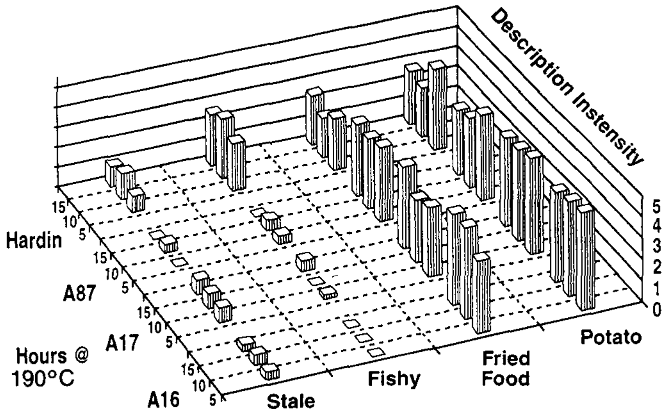

FIG. 6. Flavor description intensity scores: fried potatoes. Intensity scale: 0 = none; 10 = strong (Ref. 13).

Analysis of the polar content of the heated fats indicated that the Ln level had no significant effect on the accumulation of polar materials (Fig. 7). At 15 h of frying, all of the oils had polar contents between 25 and 34%, near the level recommended for discarding frying oils (18,19). While not significant, the polar content of the Hardin tended to be lower than that of the low-Ln oils at all test periods. Likewise, there was no significant difference in TV or FFA content determined for the heated oils (Fig. 7). At 15 h of frying, the FFA content in all oils remained below 0.3%.

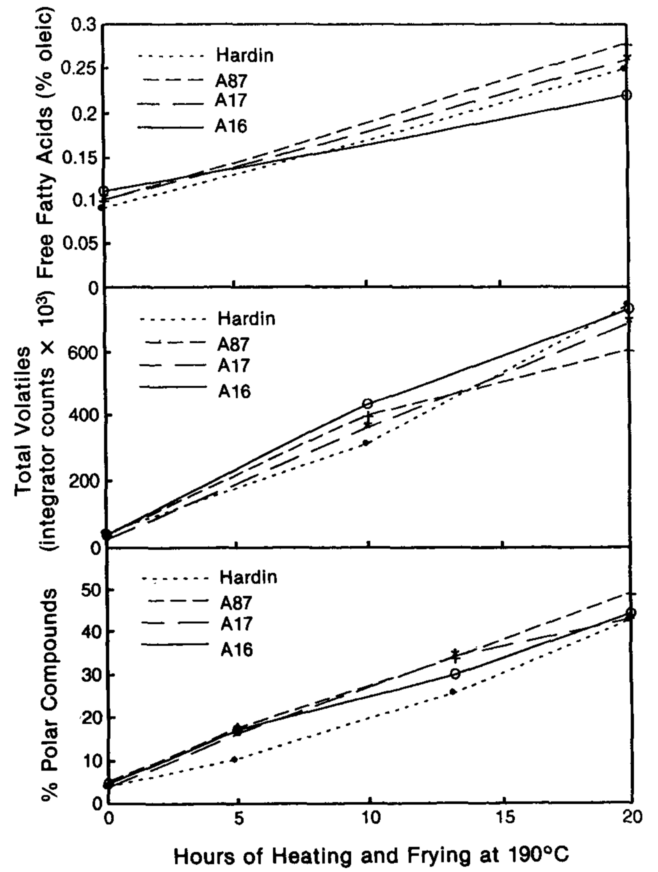

FIG. 7. Heated oil characterization. Content of free fatty acids, total volatiles and polar compounds determined by methods cited in the Experimental Procedures section.

Evans *et al.* (20) evaluated soybean oils with Ln contents of 10.4, 9.4 and 5.2% and suggested that the Ln content of the oil must be less than 5.0% to achieve significant improvement of room odor scores with commercially processed oils. Data reported here support this conclusion. The results indicate that oil from low-linolenic acid soybean lines was more stable during end-use at high temperature than oil from a commercial cultivar. The flavor quality of the fried potatoes was a sensitive indicator of reduced Ln acid content.

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