Low-Linolenic Acid Soybean Oils—Alternatives to Frying Oils

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Oil was hexane-extracted from soybeans that had been modified by hybridization breeding for low-linolenic acid (18:3) content. Extracted crude oils were processed to finished edible oils by laboratory simulations of commercial oil processing procedures. Oils from three germplasm lines N83-375 (5.5% 18:3), N89-2009 (2.9% 18:3) and N85-2176 (1.9% 18:3) were compared to commercial unhydrogenated soybean salad oil with 6.2% 18:3 and two hydrogenated soybean frying oils, HSBOI (4.1% 18:3) and HSBOII (<0.2% 18:3). Low-18:3 oils produced by hybridization showed significantly lower room odor intensity scores than the commercial soybean salad oil and the commercial frying oils. The N85-2176 oil with an 18:3 content below 2.0% showed no fishy odor after 10 h at 190°C and lower burnt and acrid odors after 20 h of use when compared to the commercial oils. Flavor quality of potatoes fried with the N85-2176 oil at 190°C after 10 and 20 h was good, and significantly better at both time periods than that of potatoes fried in the unhydrogenated oil or in the hydrogenated oils. Flavor quality scores of potatoes fried in the N89-2009 oil (2.9% 18:3) after 10 and 20 h was good and equal to that of potatoes fried in the HSBOI oil (4.1% 18:3). Fishy flavors, perceived with potatoes fried in the low-18:3 oils, were significantly lower than those reported for potatoes fried in the unhydrogenated control oil, and the potatoes lacked the hydrogenated flavors of potatoes fried in hydrogenated oils. These results indicate that oils with lowered linolenic acid content produced by hybridization breeding of soybeans are potential alternatives to hydrogenated frying oils.

KEY WORDS: Fatty acid composition, flavor quality, frying stability, hybridization breeding, laboratory simulation of commercial processing, linolenic acid, odor, room odor, sensory testing, soybean oils, soybeans.

Soybean strains that yield oils with low linolenic acid (18:3) content have been produced by hybridization (1). In earlier research, we evaluated the performance of oils with 18:3 contents ranging from 3.3–4.8%. Those oils were extracted by laboratory simulations of commercial processing procedures from soybeans produced by chemical mutagenesis and hybridization (2,3). At cooking and frying temperatures, those modified oils lacked the objectionable fishy odor generated by normal soybean oil and the hydrogenation odor of partially hydrogenated soybean cooking oil.

The development of genetically modified soybean varieties that have oil with even lower 18:3 content has generated much interest in the soybean food oil industry. Currently, soybean oil must be chemically altered by catalytic hydrogenation for improved stability and extended use at high cooking and frying temperatures in restaurants, institutions and elsewhere in the food industry (4). Theoretically, soybean oils that are naturally low in 18:3 should not require hydrogenation for most applications. In addition, foods produced from such oils would not contain the positional and geometrical isomers of poly- and monounsaturated fatty acids produced by catalytic hydrogenation (4). However, the proposed attributes of naturally low-18:3 soybean oils are virtually untested. Therefore, we report the results of studies to evaluate the oxidative stability and flavor quality of soybean oils with less than 3% 18:3 for use as cooking and frying oils.

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EXPERIMENTAL PROCEDURES

Materials. Three experimental soybean lines, N83-375, N85-2176 and N89-2009, were produced by hybridization at Raleigh, North Carolina. Duplicate one-bushel samples of each line were processed for these investigations. Crude oil extracted from samples of a commercial cultivar (HARDIN-90) served as a control in oxidative stability studies. For comparative purposes in sensory evaluations, a commercial unhydrogenated soybean salad oil with 6.2% 18:3 (Control) and two commercial hydrogenated soybean frying oils with 18:3 contents of 4.1% (HSBOI) and <0.2% (HSBOII) were purchased locally. Fresh Idaho russet potatoes were obtained locally and cut into 8-cm lengths of shoestring size (0.5 cm × 0.5 cm) for frying tests.

Oil extraction and processing. Soybeans were hexane-extracted in laboratory simulations of commercial extraction procedures (3), and recovered crude oils were processed to finished edible oils by laboratory simulations of commercial processing procedures (5). Methyl esters of the oils were prepared by alkaline transesterification procedures with sodium methoxide catalyst as described previously (6). Fatty acid composition was determined by capillary gas chromatography according to American Oil Chemists' Society (AOCS) Official Method Ce 1-62 (7).

Triacylglycerol (TAG) oxidative stability. Crude oils were chromatographed by silica solid-phase extraction to yield the TAG fraction free of other oil components as previously described (8,9). Oxidative stabilities of the TAG, isolated from the oils of the three experimental lines and crude oil from the HARDIN-90 line, as measured by development of peroxide values in oxygen in the dark at 60°C and in the light at 25°C, were determined as previously reported (8,9).

Oil storage. Fully processed oils were exposed to accelerated deterioration conditions during storage in the dark and in the light. Oil samples (half volume) were placed in 240-mL clear glass bottles and loosely stoppered with a cellophane-covered cork. For accelerated storage in the dark, bottles were placed in a forced-draft oven at 60°C for 4 or 8 d. For accelerated storage in the light, bottles were exposed to fluorescent light at 7500 lux at 30°C for 4 or 8 h.

Frying protocol. Oils were used for intermittent frying of potatoes at 190°C for 3 d in a 1-L commercial fryer (Fry Daddy Fryer; National Presto Industries, Eau Claire, WI). Each oil (800 g) was held at 190°C for *ca.* 7 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. Two 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 10 and 20 h of oil usage. Each day, 80 g of fresh oil was added to each sample as make-up oil.

Sensory evaluation. The flavor stability of the samples during storage in the dark and in the light was evaluated for overall intensity and intensity of individual flavors by a trained, 15-member panel experienced in testing vegetable oils according to the AOCS Recommended Practice Cg 2-83 (7). The peroxide value (PV) of all oils was determined by AOCS Method Cd 8-53 (7) at the time of sensory analyses.

Room odor evaluation was conducted after 10 and 20 h of treatments by means of facilities and procedures described previously (10,11). No potato fryings were conducted during odor panel evaluations. A trained, experienced 16-member panel rated the odors for overall intensity and individual description intensity on a scale of 0 to 10, where 0 = none, and 10 = very strong (12).

Flavor quality of french-fried potatoes was rated by a trained, experienced 14-member panel on a 10-point quality scale (1 = bad, 10 = excellent) and an individual flavor description intensity scale where 0 = none, 10 = strong (12). French-fried potatoes prepared in cottonseed oil were rated by the panel as good-quality (with a score of 8) and were presented to the panel as a reference prior to each evaluation.

Heated oil characterization. Free fatty acid (FFA) content was determined by AOCS Method Ca 5a-40 (7). The percent polar compounds was determined by the AOAC column chromatography method (13). Total volatile content (TV) was determined by a static-headspace gas chromatographic (GC) procedure (14).

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

RESULTS AND DISCUSSION

The fatty acid compositions of the oils extracted from each experimental soybean genotype and the control cultivar are presented in Table 1. Oils from lines N85-2176 and N89-2009 were shown to have significantly lowered 18:3 content relative to line N83-375 and the commercial variety, HARDIN-90. In the subsequent discussion, low-18:3 will refer to the experimental lines N85-2176 and N89-2009. The oil samples are listed in increasing order of calculated oxidizability (OX) (16). Also presented in Table 1 is the experimentally determined oxidizability (ΔPV), the slope obtained by a linear regression plot of PV vs. time, for TAGs subjected to conditions of photooxidation and autoxidation (8,9). Among varieties, both photooxidation and calculated OX values increased with higher levels of 18:3. However, the oil from line N83-375 was less oxidatively stable in the dark than expected, based on the OX.

In studies reported separately (8,9), which included these low-18:3 oils, autoxidative and photooxidative stability was increased by TAGs containing oleic acid and decreased by TAGs containing linolenic acid and linoleic acid, and by linoleic acid located in the *sn*-2-position.

The results of fatty acid composition analysis of the commercial oils used in sensory evaluation studies are presented in Table 2. The Control is an unhydrogenated soybean salad oil, typical of commercial products now available to the consumer. Two types of frying oils were included in the studies, a lightly hydrogenated soybean oil, HSBOI, and a solid shortening, HSBOII. Hydrogenation lowers the 18:3 content of soybean oil, but produces geometrical and positional isomers of linoleic acid (18:2) and oleic acid (18:1) (4). All positional *trans* or *cis* isomers were summed for each unsaturated fatty acid and are reported in Table 2 as 18:1*t* or 18:1*c* and 18:2*tt,ct,tc* or 18:2*cc*. While the total of *trans* fatty acids for HSBOI is below 10%, the more heavily hydrogenated oil, HSBOII, shows a total *trans* content of about 48%. As noted in Table 1, low-18:3 oils from the experimental lines contained no *trans* fatty acids. As indicated by the results presented in Table 3, there was no significant difference in flavor stability between the test oils and the commercial control within a given storage treatment at 60°C in the dark. There was good correlation between the PVs determined at the time of sensory evaluation and flavor intensity scores after accelerated storage at 60°C in the dark. However, the results of the oxidative stability study in which TAGs were deteriorated at 60°C in the dark suggested that the low-18:3 oils should be significantly more stable than the Control oil. This observation suggests that factors other than development of TAG peroxides affected flavor. As shown in Figure 1, panelists did report slightly lower intensities of rancid flavors at four days for low-18:3 oils as compared with the Control oil. But after eight days, the panelists reported rancid and painty flavors for all oils.

The low-18:3 oils and the N83-375 oil showed higher PVs at time of evaluation and significantly lower flavor scores than the Control oil after storage in light for 4 and 8 h (Table 3). These modified oils were characterized as having more intense grassy/beany and rancid flavors than the Control oil (Fig. 2). This observation was unexpected and was not predicted by the development of peroxides during studies of the stability of TAGs in light-initiated oxidative

TABLE 1

Fatty Acid Composition of Extracted Oils and Oxidative Stability of Triacylglycerols

	Fatty acid composition (wt%)						ΔPV[a]	
Variety	16:0	18:0	18:1	18:2	18:3	OX[b]	Light	Dark
N85-2176	10.5	3.1	49.5	35.0	1.9	0.398	0.103	0.078
N89-2009	11.5	4.5	28.8	52.3	2.9	0.587	0.159	0.215
N83-375	12.8	4.1	26.0	51.6	5.5	0.631	0.213	0.432
HARDIN-90	10.9	3.8	23.9	55.0	6.5	0.685	0.349	0.383

[a]Slope obtained by linear regression plot of peroxide value (PV) vs. time (Refs. 8,9).
[b]Calculated oxidizability = (0.02 [18:1] + [18:2] + 2 [18:3])/100 (Ref. 16).

TABLE 2

Fatty Acid Composition (wt%) of Commercial Oils

	Control	HSBOI	HSBOII
16:0	11.4	10.0	11.5
18:0	3.9	4.0	8.6
18:1*t*	n.d.[a]	5.1	38.5
18:1*c*	24.2	32.5	30.7
18:2(*tt,ct,tc*)	n.d.	2.0	9.7
18:2*cc*	54.4	42.2	1.0
18:3	6.2	4.1	<0.2

[a]n.d., Not detected.

TABLE 3

Flavor Stability During Storage in the Dark and in the Light

	Flavor intensity scores[a,b]			
Storage	Control	N85-2176	N89-2009	N83-375
In dark at 60°C				
0 d	7.1 (0.0)[c]	7.5 (0.0)	7.6 (0.0)	7.0 (0.0)
4 d	6.6 (0.9)	6.5 (1.3)	6.8 (1.0)	6.6 (1.1)
8 d	5.5 (8.0)	6.0 (6.6)	5.7 (7.4)	5.9 (8.5)
At 7500 lux				
4 h	6.9[d] (0.8)	5.3[e] (1.3)	5.7[e] (1.2)	5.9[e](1.2)
8 h	6.6[d] (1.3)	5.0[e] (2.1)	5.3[e] (1.9)	5.7[de] (1.7)

[a]Overall intensity scale: 10 = bland; 1 = strong.
[b]Values in rows having different superscript letters (d,e) are significantly different (least significant difference, 1.0).
[c]Values in parentheses are peroxide values at time of tasting.

deterioration (Table 1) (9). The scope of our studies did not determine why the oils from the experimental lines had poorer flavor stability than the Control oil during light exposure tests. Analyses, to be reported later, of constituent oil components, such as tocopherols and sterols as affected by hybridization breeding of soybeans, may clarify the reason for this observation.

Low-18:3 oils showed improved room-odor intensity scores as compared to the Control, HSBOI and HSBOII (Table 4). Fishy odor, associated with the heated oils with higher 18:3 contents (Control, N83-375 and HSBOI), was reduced with low-18:3 oils and HSBOII (Fig. 3). The hydrogenation odor, associated with heated HSBOI and HSBOII, was the predominant odor for those oils reported by the panelists and was not present in the other heated oils (Fig. 3).

After 10 h of oil use, flavor quality scores of potatoes fried in low-18:3 oils were significantly better than that of potatoes fried in the Control, N83-375 and HSBOII oils (Table 5). Only the potatoes fried in N85-2176 oil showed a significantly better flavor quality score than those fried in HSBOI. After 20 h, potatoes fried in the low-18:3 oils had significantly better flavor scores than those fried in the Control and HSBOII oils only.

As shown in Figure 4, fishy flavors, detected in potatoes fried in the Control, were significantly reduced with low-18:3, N83-375 and HSBOI oils and eliminated with HSBOII. Even at low levels of 18:3, fishy flavors can be detected, although they have a less negative impact on flavor quality scores. The hydrogenated-flavor response, indicated for potatoes fried in HSBOI and HSBOII oils, was not present with potatoes fried in the low-18:3, N83-375 and Control oils. Potato and fried-food flavors were retained during use of all the oils, even after 20 h of frying.

No significant difference was determined in physical characteristics of heated fats, such as polar content, TVs or FFAs among oils in all experiments; therefore, these data are not presented.

Low-18:3 oils produced by hybridization showed significantly lower room-odor intensity scores than the commercial soybean salad oil, frying oil and shortening. The N85-2176 oil, with an 18:3 content below 2.0%, showed no fishy odor after 10 h at 190°C and lower burnt and acrid odors after 20 h of use when compared to the commercial oils. Flavor quality of potatoes fried with the N85-2176 oil (1.9% 18:3) at 190°C after 10 and 20 h was good and significantly better at both time periods than that of potatoes fried in the unhydrogenated oil and in

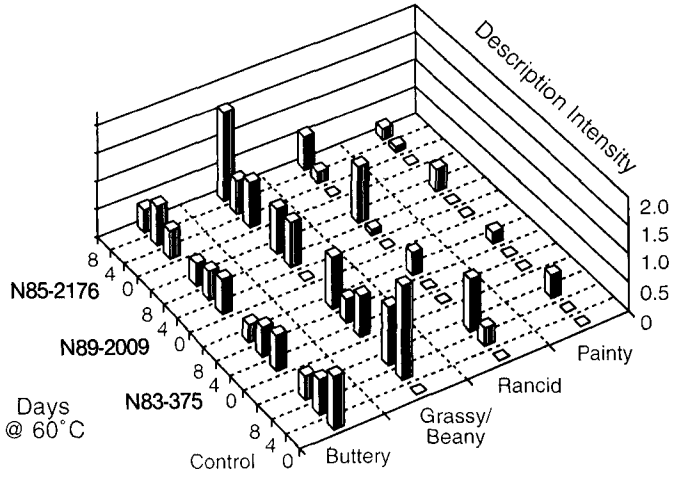

FIG. 1. Flavor description intensity scores—accelerated storage in the dark at 60°C. Description intensity score: [1 × (number of weak responses) + 2 × (number of moderate responses) + 3 × (number of strong responses)]/number of panelists.

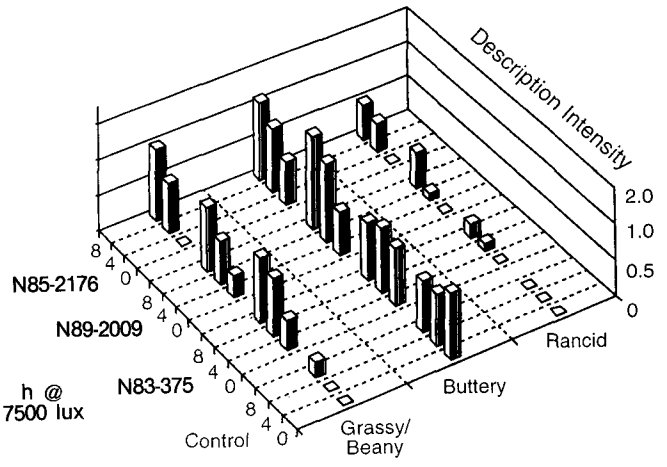

FIG. 2. Flavor description intensity scores—fluorescent light exposure at 30°C. Description intensity score: [1 × (number of weak responses) + 2 × (number of moderate responses) + 3 × (number of strong responses)]/number of panelists.

TABLE 4

Room Odor Evaluation of Heated Oils

Heat/Fry (h at 190°C)	Room odor intensity score[a,b]					
	Control	N85-2176	N89-2009	N83-375	HSBOI	HSBOII
10	5.8[d]	4.3[e]	4.2[e]	4.2[e]	6.1[d]	7.1[c]
20	5.8[d]	4.3[e]	4.1[e]	4.2[e]	6.3[d]	7.3[c]

[a]Intensity scale: 0 = none; 10 = strong.
[b]Values in rows with different superscript letters are significantly different (least significant difference, 1.0).

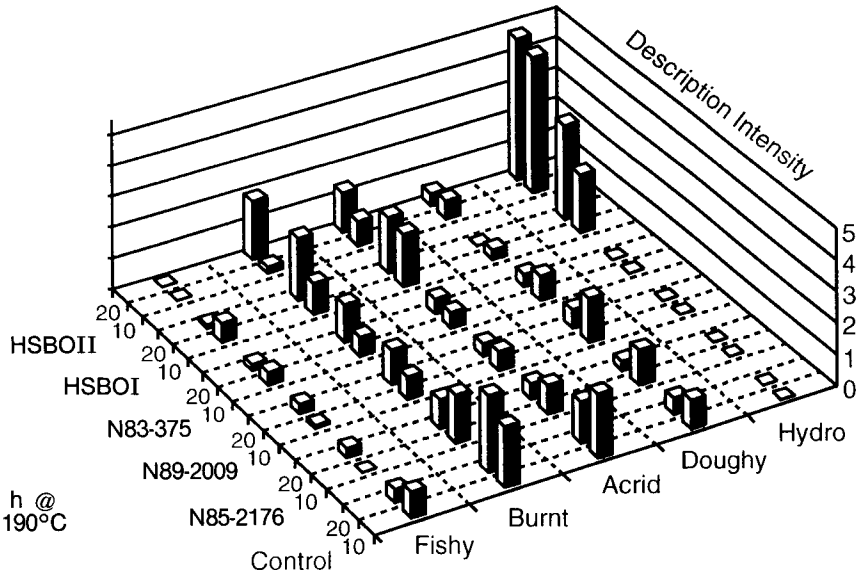

FIG. 3. Room odor description intensity scores of oils from experimental lines vs unhydrogenated and hydrogenated soybean oils. Description intensity scale: 0 = none; 10 = strong. Hydro = hydrogenated.

TABLE 5

Flavor Quality of Potatoes Fried in Oils

Heat/Fry (h at 190°C)	Flavor quality scores of french-fried potatoes[a,b]					
	Control	N85-2176	N89-2009	N83-375	HSBOI	HSBOII
10	5.5[e]	7.0[c]	6.6[cd]	5.6[e]	6.0[de]	5.6[e]
20	5.6[d]	6.6[c]	6.5[cd]	6.4[cd]	6.3[cd]	5.6[d]

[a]Flavor scores: 10 = excellent; 1 = bad.
[b]Values in rows with different superscript letters are significantly different (least significant difference, 1.0).

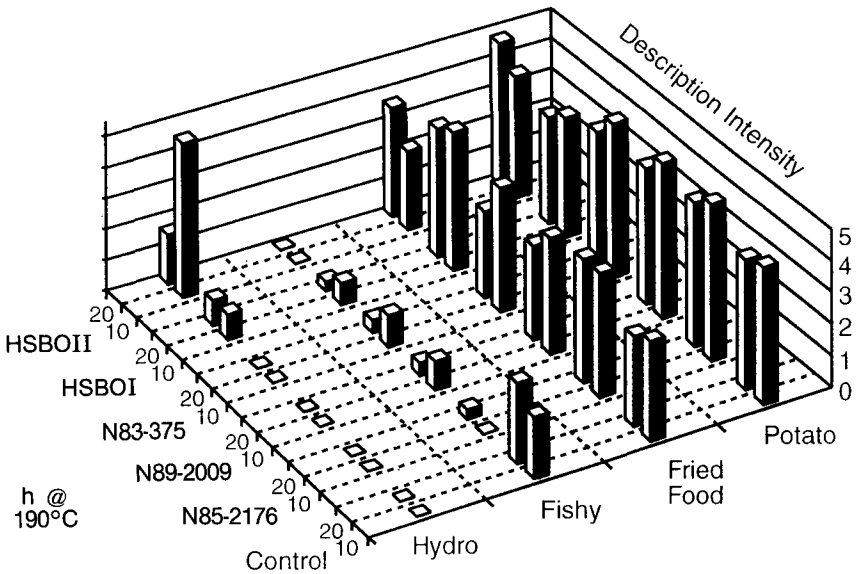

FIG. 4. Flavor description intensity scores of fried potatoes. Oils from experimental lines vs. unhydrogenated and hydrogenated soybean oils. Description intensity scale: 0 = none, 10 = strong. Hydro, hydrogenated.

both hydrogenated oils. Flavor quality scores of potatoes fried in the N89-2009 oil (2.9% 18:3) after 10 and 20 h was good, and equal to that of potatoes fried in the HSBOI oil (4.1% 18:3). Fishy flavors, perceived with potatoes fried in the low-18:3 oils, were significantly lower than those reported for potatoes fried in the unhydrogenated control oil, and the potatoes lacked the hydrogenated flavors of potatoes fried in hydrogenated oils. These results indicate that oils with lowered linolenic acid content produced by hybridization breeding of soybeans are potential alternatives to hydrogenated frying oils.

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