Frying Quality and Oxidative Stability of High-Oleic Corn Oils

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ABSTRACT: To determine the frying stability of corn oils that are genetically modified to contain 65% oleic acid, high-oleic corn oil was evaluated in room odor tests and by total polar compound analysis. Flavor characteristics of french-fried potatoes, prepared in the oil, were also evaluated by trained analytical sensory panelists. In comparison to normal corn oil, hydrogenated corn oil and high-oleic (80 and 90%) sunflower oils, high-oleic corn oil had significantly ($P < 0.05$) lower total polar compound levels after 20 h of oil heating and frying at 190°C than the other oils. Fried-food flavor intensity was significantly higher in the normal corn oil during the early portion of the frying schedule than in any of the high-oleic or hydrogenated oils; however, after 17.5 h of frying, the potatoes fried in normal corn oil had the lowest intensity of fried-food flavor. Corn oil also had the highest intensities of off-odors, including acrid and burnt, in room odor tests. High-oleic corn oil also was evaluated as a salad oil for flavor characteristics and oxidative stability. Results showed that dry-milled high-oleic corn oil had good initial flavor quality and was significantly ($P < 0.05$) more stable than dry-milled normal corn oil after oven storage tests at 60°C, as evaluated by flavor scores and peroxide values. Although the high-oleic corn oil had significantly ($P < 0.05$) better flavor and oxidative stability than corn oil after aging at 60°C, even more pronounced effects were found in high-temperature frying tests, suggesting the advantages of high-oleic corn oil compared to normal or hydrogenated corn oils.
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KEY WORDS: Corn oil, flavor, frying, high-oleic corn oil, odor, oxidation, polar compounds, sensory, stability, volatile compounds.

Oils and fats intended for commercial frying applications must be stabilized to prevent deterioration caused by oxidation, polymerization, and hydrolysis during high-temperature use. Modifying the fatty acid composition of the oil—the most common method to stabilize frying oils—can be done by several methods. For example, blending polyunsaturated oils with more saturated or monounsaturated oils is an option to adjust fatty acid levels to optimal levels, such as combining high-oleic sunflower oil with corn oil or hydrogenated soybean oil with soybean oil (1–3). Chemically altering the existing fatty acid ratios by hydrogenation increases saturated fatty acids and decreases polyunsaturated fatty acids to produce a more stable oil (3–4). A recent approach has been to genetically modify fatty acid compositions of oilseeds to produce oils with greater frying stability, usually by decreasing linoleic acid and linolenic acid and increasing oleic acid (5). This approach began approximately 40 yr ago, when genetic variants of safflower were selected in which the ratio of linoleic acid and oleic acid was reversed to produce high-oleic safflower oil (6–8). During the past 10 yr, various oils were developed with fatty acid compositions modified by plant breeding, including low-linolenic soybean, high-oleic sunflower, low-linolenic canola, and high-oleic canola (9–15). All these modified oils have improved frying stability compared to unmodified oils.

Corn oil is widely used as an all-purpose cooking oil and for margarine because of its unique flavor attributes and because it is more stable to oxidation than linolenate-containing oils, such as soybean or canola (16–17). However, for continuous high-temperature uses, such as deep-fat frying, corn oil is usually stabilized by hydrogenation. As an alternative to hydrogenation, variants of corn were developed in which the fatty acid composition of the oil was altered to elevate oleic acid levels and to reduce linoleic acid (18). This study was initiated to characterize the oxidative and flavor stability of high-oleic corn oil and to compare its stability in frying applications to regular corn oil and other high-stability oils, including hydrogenated corn oil and high-oleic sunflower oils.

EXPERIMENTAL PROCEDURES

Materials. Dry-milled normal corn oil, wet-milled normal corn oil, dry-milled high-oleic corn oil, and wet-milled high-oleic corn oil were pilot-plant-processed and -deodorized. Hydrogenated corn oil and high-oleic sunflower oils with 80 and 90% oleic acid were obtained from commercial processors. No oils contained additives other than citric acid. No. 1 Russet potatoes were obtained from a local market.

Methods. Fatty acid compositions of the initial oils were determined by capillary gas chromatographic (GC) analysis with a Hewlett-Packard 5890 GC (Wilmington, DE), equipped with an SP2330 column (30 m, 0.20 mm i.d., 0.20

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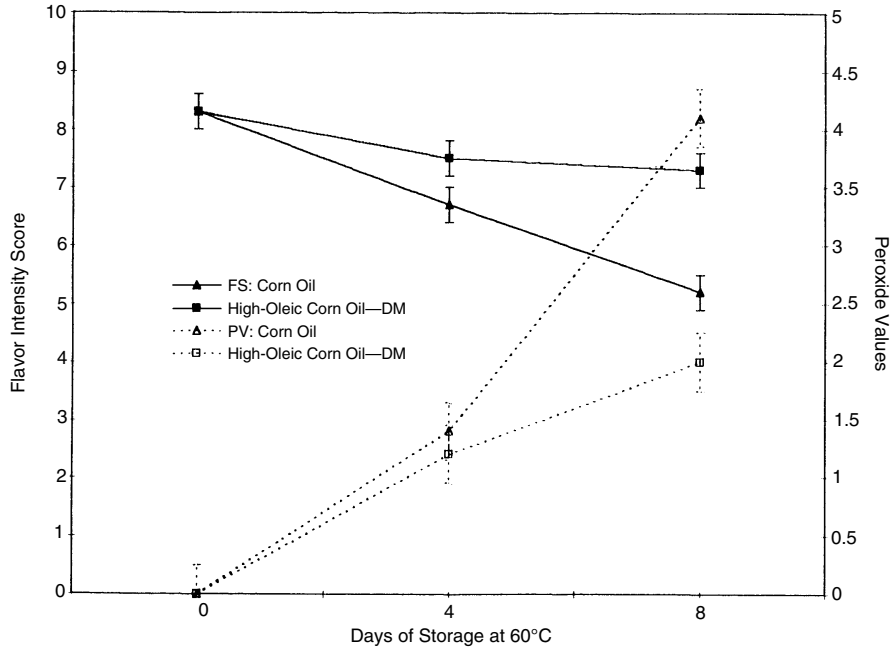

FIG. 1. Flavor scores (FS) (10 = bland and 1 = strong) and peroxide values (PV) of fresh and aged dry-milled (DM) high-oleic corn oil and DM corn oil.

micron film thickness) (Supelco, Bellefonte, PA). Column temperature was held at 190°C for 5 min, and temperature was programmed to 230°C at 20°C/min. Other GC conditions were: injector, 250°C; detector, 260°C. Iodine values were calculated from the fatty acid composition data by using AOCS method Cc 18-80 (19). Lovibond color was measured in a 5 1/4″ tube (19), and free fatty acid (FFA) values as percentage oleic acid were determined by AOCS method Ca 5a-40 (19). The drop point of the hydrogenated oil was determined with a Mettler FP83 HT (Mettler-Toledo AG, Greifensee, Switzerland) by following AOCS method Cd 1c-85 (19). Oxidative stability of the oils was measured by peroxide value (PV) (AOCS method Cd8-53) (19) after oven storage tests at 60°C at 0, 4, and 8 d and with the oxidative stability instrument (OSI) at 110°C with air flow at 20 L/h (19). A 14-member trained, experienced oil panel evaluated the oils for flavor intensity after 60°C oven storage at 0, 4, and 8 d (AOCS method Cg 2-83) (19,20).

Frying stability. The frying protocol included intermittent frying at 190°C with total heating/frying time of 20 h. Each oil (800 g) was heated in 1-L fryers (Model 2540; Presto Industries; Eau Claire, WI) for 6–7 h each day for 3 d. Fresh Idaho Russet potatoes were cut into 8-cm lengths of shoestring size (0.5 cm × 0.5 cm) and fried in 150-g batches. Potatoes used for sensory testing were parfried in 150-g batches for 2 min after 1 h of oil use, frozen, then finish-fried for 2 min before sensory panel sessions after 9.5 and 17.5 h of oil use. Each day 80 g of fresh oil was added as make-up oil to

TABLE 1
Fatty Acid Composition and Instrumental and Chemical Analyses of Oils[a]

Fatty acid	Corn		High-oleic corn		Hydro-	High-oleic sunflower	
Composition (%)	Dry-milled	Wet-milled	Dry-milled	Wet-milled	genated corn	80% Oleic	90% Oleic
$C_{16:0}$	10.9	11.2	9.0	9.1	12.2	3.6	2.9
$C_{18:0}$	1.7	1.7	2.3	2.2	10.1	4.3	3.9
$C_{18:1}$ *cis*	23.8	23.6	65.6	65.1	41.2	81.9	89.1
$C_{18:1}$ *trans*	0.0	0.0	0.0	0.0	33.0	0.0	0.0
$C_{18:2}$ *cis*	62.6	62.5	22.5	23.0	1.7	9.9	3.7
$C_{18:2}$ *trans*	0.0	0.0	0.0	0.0	1.5	0.0	0.0
$C_{18:3}$	1.0	0.9	0.6	0.6	0.0	0.0	0.0
Iodine value	131.6	131.0	97.0	97.4	69.6	87.8	83.4
Peroxide value (meq/kg)	0.0	0.0	0.0	0.06	0.05	0.14	0.03
Free fatty acid (% oleic)	0.01	0.02	0.01	0.01	0.03	0.02	0.01
Color (Lovibond 5 1/4″)	1.5Y 0.2R	7.1Y 1.6R	2.1Y 0.4R	3.0Y 1.0R	6Y 0.7R	6Y 0.4R	3Y 0.4R
OSI at 110°C (h)	9.0	9.0	18.0	14.0	131.5	18.9	33.3

[a]OSI, oxidation stability instrument.

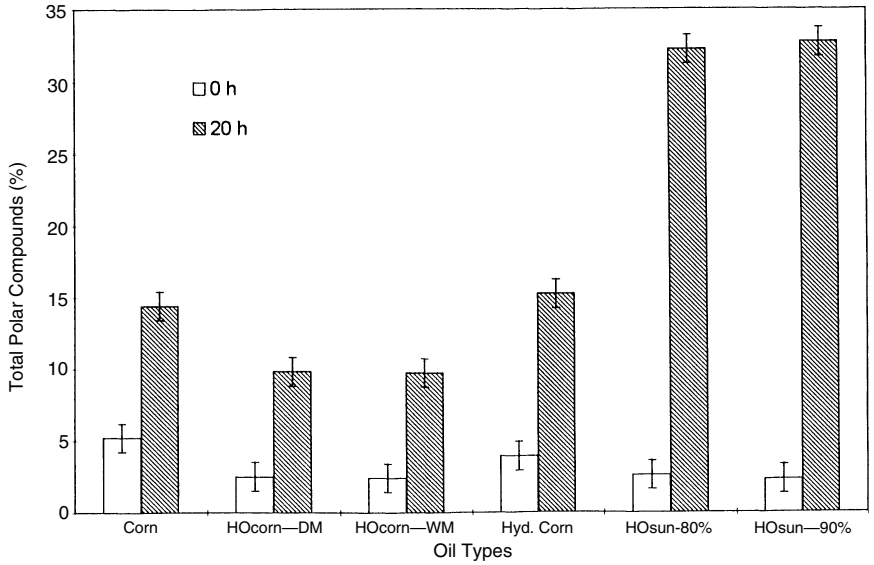

FIG. 2. Total polar compounds (%) in wet-milled corn oil, dry-milled (DM) and wet-milled (WM) high-oleic corn oils (HOcorn), hydrogenated corn oil (Hyd. corn), and high-oleic (80 and 90%) sunflower oils (HOsun) at 0-time and after 20 h of frying at 190°C.

each fryer. Total polar compound level was determined in duplicate by the AOAC column chromatography method (21). A 16-member analytical sensory panel, trained and experienced in evaluating fried foods, rated the french-fried potatoes for intensities of individual flavors, including fried potato, stale, waxy, fruity, woody, hydrogenated, and fishy, on a 10-point intensity scale with 0 = no intensity and 10 = strong flavor intensity. All evaluations were conducted in a panel room with individual booths, temperature control, and red lighting. Room odor was evaluated by a 13-member trained, experienced panel by following previously published procedures (22).

Statistical analysis. Data were evaluated by analysis of variance (23). Statistical significance is expressed at the $P < 0.05$ level unless otherwise indicated.

RESULTS AND DISCUSSION

Fatty acid composition. Composition of the six oils ranged in iodine values (IV) from 131.6 for unmodified dry-milled corn oil to 69.6 for hydrogenated corn oil (Table 1). Increasing oleic acid content in high-oleic corn oils decreased IV to approximately 97. Levels of oleic and linoleic acids were reversed between corn oil samples and high-oleic corn oils, with approximately 23% oleic and 64% linoleic acid in corn oils and approximately 64% oleic and 22% linoleic acid in high-oleic corn oils. Saturated fat levels were similar in all corn oils. Initially, all PV were zero or at low levels of 0.14 or less. FFA in the fresh oils were also at low levels of 0.06 or less. The drop point of the hydrogenated corn oil was 45°C.

Oxidative and flavor stability. Oxidative stability of dry-milled corn oil and dry-milled high-oleic corn oil after oven storage at 60°C showed no significant difference in PV between the two oils after 4 d; however, the PV for corn oil (4.1) was significantly higher than that of high-oleic corn oil (1.8) after 8 d (Fig. 1). These values are similar to those reported by Frankel and Huang (24) for corn oil and high-oleic sunflower oil aged 8 d at 60°C. The PV in this study were much lower than values reported in an AOCS collaborative study of oxidative stability of polyunsaturated oils, which showed that PV of 10–12 were indicative of moderate oxidation as related to flavor (16). Good oxidative stability of normal corn oil was also reported by Huang *et al.* (25) who found that, even after storage for 28 d at 35°C in the dark, corn oil had a PV of only 3.8. Scores for overall flavor intensity for dry-milled corn oil and dry-milled high-oleic corn oil were both 8.3 initially (Fig. 1). Based on the AOCS flavor intensity scale (19–20), in which a score of 10 indicates no flavor (bland) and 1 indicates strong overall flavor intensity, both oils had

TABLE 2
Flavor Intensity Scores[a] for Fresh and Aged Dry-Milled Corn Oil and Dry-Milled High-Oleic Corn Oil

Storage days at 60°C	Corn oil		High-oleic corn oil
0	Nutty	0.5 a	0.3a
	Buttery	0.6 a	0.6a
4	Nutty	0.3 a	0.3 a
	Buttery	0.8 a	0.8 a
	Grassy	0.3 a	0.0 a
	Rancid	0.2 a	0.0 a
	Other	0.4 a (stale)	0.2 a (bacon, metallic)
8	Nutty	0.2 a	0.5 a
	Buttery	0.6 a	0.7 a
	Rancid	0.9 a	0.0 b
	Burnt	0.7 a	0.2 b
	Other	1.1 a (cereal, sweet, woody)	0.4 b (woody)

[a]Intensity scale of 0 = none, 3 = strong; scores with letters in common in each row are not significantly different ($P > 0.05$).

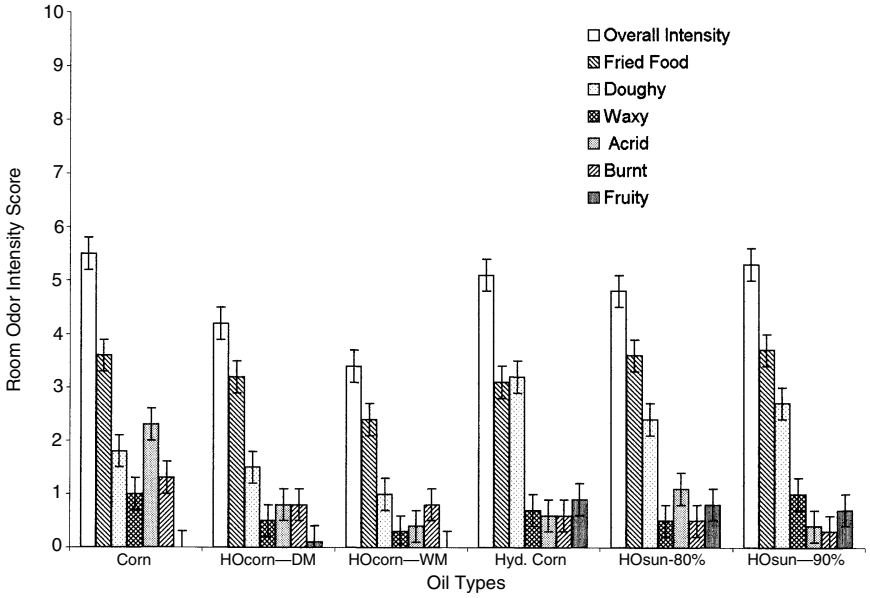

FIG. 3. Room odor intensity scores (0 = none; 10 = strong) for wet-milled corn oil, dry-milled and wet-milled high-oleic corn oils, hydrogenated corn oil, and high-oleic (80 and 90%) sunflower oils after 1 h heating at 190°C. See Figure 2 for abbreviations.

weak overall flavor intensities. As storage time increased from 0 to 8 d, flavor scores decreased for both oils; however, corn oil was rated as significantly stronger in overall flavor intensity than high-oleic corn oil at both 4 and 8 d of aging at 60°C. Scores for high-oleic corn oil decreased only slightly from 0 to 8 d at 60°C, indicating good flavor stability. Initially, both dry-milled corn oil and dry-milled high-oleic corn oil had only weak intensity levels of nutty and buttery flavors (Table 2). After 4 d of storage, both oils showed increases in buttery flavor intensity, and corn oil was also described as having weak grassy and weak rancid flavor intensities. By 8 d of storage, the only off-flavors detected in high-oleic corn oil were weak burnt and woody; however, the corn oil was rated as having weak rancid, burnt, cereal, and woody flavors.

Oxidative stability of all oils, measured by the OSI at 110°C, demonstrated that the corn oils were significantly less stable than any of the other oils (Table 1). Hydrogenated corn oil had the longest induction period of 131.5 h. The OSI induction period for dry-milled high-oleic corn oil was not significantly different from the induction period for 80%-oleic acid sunflower oil.

*Frying stability***.** Although corn oil showed good stability as a salad oil, researchers have found that corn oil is not stable in frying applications. Abdel-Aal and Karara (26) reported pronounced deterioration in corn oil after intermittent heating and frying for 50 h, as measured by physical and chemical indices. In addition, corn oil did not produce fried foods that were as oxidatively stable as food fried in hydrogenated oil or low-linolenic acid canola oil (27). Oils such as sunflower, safflower, and canola have shown improved frying stability when their levels of oleic acid were increased by plant breeding (7,13,28). Therefore, increasing the oleic acid content of corn oil also may contribute to increased frying stability. In this study, total polar compounds were used as a measure of high-temperature stability and polymerization of the frying oils. Polar compound levels ranged from 3 to 5% in the fresh oils and from 10 to 33% in oils used for 20 h (Fig. 2). After 20 h of frying, both dry-milled and wet-milled high-oleic corn oils had significantly lower amounts of polar compounds than any of the other oils. Wet-milled corn oil and hydrogenated corn oil had approximately 15% total polar compounds each. High-oleic sunflower oils had the highest total polar compound levels in this study at approximately 33%. Based on a German standard of 27% total polar compound as an indicator of poor frying oil stability (29), the high-oleic corn oils, wet-milled corn oil, and the hydrogenated corn oil had acceptable polar compound levels after 20 h of heating and frying. Based on these results and on previous work (28,30), total polar compound levels were higher than might be expected in high-oleic sunflower oils. It appears that total polar compound levels cannot be predicted from only fatty acid composition data. In addition, the fact that corn oil and hydrogenated corn oil had OSI values of 9.0 and 131.5, respectively, indicates that OSI is not a good predictor of frying stability because both samples had total polar compound levels of approximately 15%. Further research is needed to determine additional factors that contribute to frying stability.

Although various instrumental and chemical tests are conducted on frying oils, the true measure of food oil quality is in the odor and flavor analysis. The room odor test is a sensory analysis of the intensity of the odors produced as oils are heated at frying temperature. A good-quality oil has weak-to-moderate intensity levels of overall room odor (score of 5 or less on a 10-point intensity scale, with 0 = none and 10 =

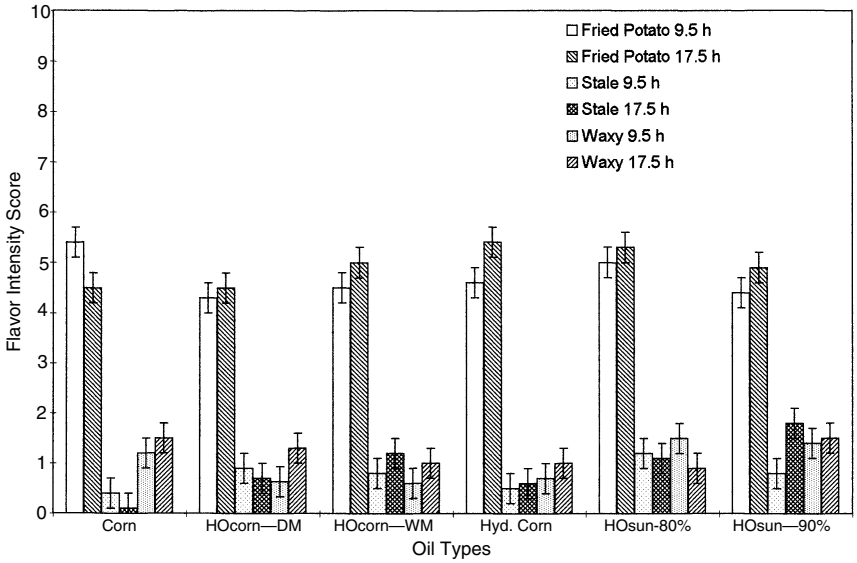

FIG. 4. Flavor intensity scores for french-fried potatoes fried in wet-milled corn oil, dry-milled and wet-milled high-oleic corn oils, hydrogenated corn oil, high-oleic (80 and 90%) sunflower oils after 9.5 and 17.5 h of frying at 190°C. See Figure 2 for abbreviations and flavor intensity scores.

strong) and none-to-low levels of negative odors, such as acrid, fishy, and burnt (20). In this study, both high-oleic corn oils had significantly lower overall room odor intensities than wet-milled corn oil or hydrogenated corn oil or high-oleic sunflower oils (Fig. 3). As a frame of reference, an unmodified canola oil heated under the same conditions would have a strong odor intensity with an overall intensity score of 7–8 (20). Wet-milled high-oleic corn oil had the lowest overall odor intensity and the lowest intensities of all positive and negative odors except burnt odor. Negative odors typical of polyunsaturated oils—acrid and burnt—were higher in the corn oil than in any of the other oils that contained more stable fatty acids. Negative off-odors of waxy, acrid, burnt, and fruity were low in all samples. Hydrogenated corn oil had no characteristic odors, such as sweet, waxy, paraffin, candle wax or hydrogenated, that are typical of hydrogenated soybean or canola oils (20), possibly because corn oil contained lower amounts of linolenic acid than did soybean or canola oils before hydrogenation.

Because of limited quantities of oil, sensory analysis of french-fried potatoes prepared in these oils was only conducted at two frying times of 9.5 and 17.5 h. Potatoes fried in corn oil at 9.5 h had significantly higher fried-food flavor intensity than any of the other samples except the high-oleic (80%) sunflower oil sample (Fig. 4). However, as frying time increased, potatoes fried in any of the high-oleic oils or in hydrogenated corn oil increased in fried food flavor intensity. On the other hand, intensity of fried-food flavor decreased in potatoes fried in corn oil from the 9.5 h sample to the 17.5 h sample. In other studies with high-oleic oils, fried-food flavor intensity of potato products was low at early stages of frying but also increased with increased heating time (11,13). Negative flavors, waxy and stale, were present at only low—less than 2.0—intensity levels in all samples (Fig. 4). As found in room odor analysis of the heated oils, french-fried potatoes prepared in hydrogenated corn oil had no characteristic flavor typical of hydrogenated soybean or canola oils (20).

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