Fatty Acid Composition of Oil from Exotic Corn Breeding Materials

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ABSTRACT: The fatty acid composition of corn oil can be altered to meet consumer demand for "healthful" fats. The first step in altering the oils is to survey existing corn breeding materials for fatty acid composition. The Latin American Maize Project (LAMP), an international program designed to evaluate the agronomic characteristics of maize accessions in Latin American and U.S. germplasm banks for future use, provides useful starting materials. LAMP was based on the cooperative efforts of 12 countries. In a two-stage evaluation, the project identified the highest-yielding open-pollinated top 20% of populations, then approximately the top 5% of those 20%. Twenty of the populations from four countries with temperate climates were randomly selected for fatty acid analysis. The populations were from United States, Chile, Argentina, and Uruguay. Fifty S_1 lines from each population were randomly chosen for analysis for a total of 1,000 genotypes sampled. Statistical differences in fatty acid composition were computed among the 20 populations and among the four countries. The findings showed a wide range of fatty acid profiles present in unadapted, elite corn breeding materials with ranges for each fatty acid as follows: palmitic acid, 6.3–18.2%; stearic acid, 0.9–4.5%; oleic acid, 18.5–46.1%; linoleic acid, 36.6–66.8%; linolenic acid, 0.0–2.0%; and arachidic acid, 0.0–1.4%. Several populations were significantly different from the others. Some lines had unusual fatty acid compositions, including one with 8.3% total saturates and another with 20.2% total saturates. This study shows that existing corn breeding materials could be used to produce high- and low-saturate oils, but other methods would probably be required to produce a high-oleic corn oil.
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KEY WORDS: Corn breeding materials, corn oil, fatty acid composition, genetic differences, Latin American Maize Project.

The Latin American Maize Project (LAMP) was an international program (now completed) designed to evaluate the agronomic characteristics of maize accessions in Latin American and U.S. germplasm banks for future use (1). LAMP was based on the cooperative efforts of 12 countries: Argentina, Bolivia, Brazil, Columbia, Chile, Guatamala, Mexico, Paraguay, Peru, United States, Uruguay, and Venezuela. In a two-stage evaluation, the project identified the highest-yielding open-pollinated top 20% from nearly 12,000 accessions, then approximately the top 5% resulting in 268 accessions. Adaptation of these populations ranges from temperate to highland tropical (1). The accessions were grouped by original habitat, growth characteristics (plant height), maturity, and race (1). These are elite, unadapted materials, which may vary widely in fatty acid composition and could be suitable materials for intermediate-term progress in developing new and unique corn oils.

The interest in developing new corn oils has been driven by consumer health concerns. Dietary guidelines from the United States Department of Agriculture (USDA) suggest that we should reduce fat consumption to 30% or less of our total caloric intake, and 10% or less should be saturated fat (2). Consumers are demanding highly unsaturated oils that contain less than 7% saturated fatty acids to balance the more saturated fats in the rest of their foods. These concerns, along with others, have led to efforts by plant breeders to alter the normal fatty acid composition of oil-producing crops. Soybean, canola, and sunflower oils, among others, have been targeted for research to alter their fatty acid composition to meet consumer demands as previously described (3).

In the past, corn oil has been regarded as exceptional in flavor and quality, and a premium price traditionally has been paid for it; however, if corn oil is to compete with new oils that are modified in their fatty acid composition, then corn oils with unconventional fatty acid compositions must be developed. New corn oils with different nutritional and functional qualities could open new markets for both food and industrial use.

A few studies have examined factors that affect the fatty acid composition of corn oil. Corn oil from warmer regions had a higher proportion of saturated fatty acids than did corn oil from cooler areas (4). Genetic factors, however, had a much greater influence than did environmental factors (5). It also has been determined that southern corn leaf blight (6) and nitrogen and boron (7) do not influence fatty acid composition.

The development of corn oils with unique fatty acid compositions might be approached in several different ways, one of which is breeding (8). Because high crop yield is the main

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objective of corn breeders, it is useful to know the fatty acid compositions of high-yielding unadapted materials for intermediate-term breeding uses, which may have unusual profiles not found in adapted Corn Belt materials.

EXPERIMENTAL PROCEDURES

Samples. The protocol of LAMP, a germplasm evaluation project, has been described previously (1). Accessions from participating countries with regions below 1,100 m above sea level and latitudes greater than 25°N or S (Argentina, Chile, Uruguay, and the United States) were evaluated in two stages as populations per se within the country of origin. Grain yield was the primary criterion for selecting the top 20% in the first stage, then the top 5% of the 20% in the second stage. All were open-pollinated. The top 5% of the populations were interchanged among all four countries for further evaluation as described (1).

Twenty of these top 5% temperate populations, five from each of the four countries involved in the temperate evaluations, were randomly selected for fatty acid analysis (Table 1). All populations were grown in a nursery at the Agronomy and Agricultural Engineering Research Center near Ames, Iowa, in 1992. Individual plants of each population were self-pollinated to produce S_1 lines. Fifty lines from each population were randomly chosen for analysis, for a total of 1,000 genotypes sampled.

Oil extraction and sample preparation. Two kernels per line were randomly selected and homogenized in a Tekmar A-10 analytical mill (Cincinnati, OH). These samples then were defatted overnight in hexane at room temperature. After centrifugation at 13,600 × *g* for 5 min, the hexane/oil layer was decanted, and the hexane was allowed to evaporate from the oil. The oil droplets were stored in vials at −18°C until they were analyzed for fatty acid content. The oil was dissolved in hexane. Transesterification of the fatty acids to their methyl esters and preparation for gas-chromatographic analysis were performed as described previously (3,9).

Gas–liquid chromatography. The samples were analyzed for their fatty acid methyl esters on a Hewlett-Packard model 5890 Series II gas chromatograph (Avondale, PA) equipped with a split/splitless injector, a flame-ionization detector, an automatic sampling device, and a 15-M Durabond-23 capillary column (J&W Scientific, Deerfield, IL), which was 0.25 mm i.d. with a film thickness of 0.25 μ. The column temperature was programmed from 140 to 200°C, at 12°C/min, and the injector and detector ports were set at 250°C. The carrier gas was helium, with a flow rate of 100 mL/min. Peak areas of duplicate injections were measured with a Hewlett-Packard 3390A reporting integrator. The standards used were methyl esters of dodecanoate (12:0, lauric acid), tetradecanoate (14:0, myristic acid), hexadecanoate (16:0, palmitic acid), 9-*cis*-hexadecenoate (16:1, palmitoleic acid), heptadecanoate (17:0, margaric acid), octadecanoate (18:0, stearic acid), 9-*cis*-octadecenoate (18:1, oleic acid), 9,12-*cis*-*cis*-octadecadienoate (18:2, linoleic acid), 9,12,15-all *cis*-octadecatrienoate (18:3, linolenic acid), eicosanoate (20:0, arachidic acid), 9-*cis*-eicosenoate (20:1, gadoleic acid), and 13-*cis*-docosenoate (22:1, erucic acid) (Alltech Associates, Deerfield, IL). Theoretical response factors for each fatty acid were applied as calculated by Craske and Bannon (10).

Statistical analysis. The 20 populations were compared by using the General Linear Models Procedure on the Statistical Analysis System (SAS) Release 6.06 (11). Statistical significance was accepted at a level of $P \leq 0.05$.

TABLE 1
Germplasm Description for the Twenty LAMP Accessions Analyzed for Fatty Acid Composition[a]

PI number	Name or Latin American bank number	Race	Country or state (U.S.) of origin
PI 222493	Golden Glow	Corn Belt Dent	Michigan
PI 278710	Cash	Corn Belt Dent	Ohio
PI 452040	Golden Queen	Corn Belt Dent	Ohio
PI 452046	Jellicorse	Southern Dent	Tennessee
Ames 13236	Gold King	Corn Belt Dent	Iowa
PI 467137	CHZM 04 027	Camelia	Chile
PI 467151	CHZM 05 001	Cristalino Chileno	Chile
PI 467168	CHZM 05 018	Camelia	Chile
PI 467208	CHZM 06 011	Camelia	Chile
PI 485610	CHZM 04 028	Camelia	Chile
PI 491741	ARZM 01 150	Dente Blanco Rugoso	Argentina
PI 491797	ARZM 03 054	Cristalino Colorado	Argentina
PI 492746	ARZM 13 026	Dentado Amarillo	Argentina
PI 493091	ARZM 18 057	Cristalino Colorado	Argentina
PI 516043	ARZM 16 042	Cristalino Colorado	Argentina
Ames 14311	URZM 13 050	Semidentado Riograndense	Uruguay
Ames 14314	URZM 01 114	Cateto Sulino	Uruguay
Ames 14316	URZM 13 052	Semidentado Riograndense	Uruguay
Ames 14319	URZM 16 001	Dente Branco	Uruguay
PI 479163	URZM 02 005	Cateto Sulino	Uruguay

[a]LAMP, Latin American Maize Project; PI, plant introduction.

To determine the standard error of the mean and the standard deviation for each fatty acid within a sample, ten samples of Wesson corn oil were analyzed every day for three days. The standard error of the mean for each fatty acid was 0.11% or less, and the standard deviation was 0.54% or less. To determine the differences between kernels on an ear, five kernels from two inbred lines of corn (B73 and Ohio 43) from the middle of the ear were analyzed. The standard error of the mean was 0.44% or less, and the standard deviation was 1.08% for 16:0, 0.74% for 18:2, and 0.49% or less for the remaining fatty acids.

RESULTS AND DISCUSSION

Fatty acid composition of elite, unadapted materials. A wide range of fatty acid profiles was present in elite, unadapted corn breeding materials. Table 2 shows the average fatty acid values for each of the 20 LAMP populations, plus the average values and ranges in fatty acid composition of the populations within a country. The percentages of 16:0, 18:1, 18:2, and the total saturates from corn oils of U.S. populations were significantly different from the percentages in oils from populations of foreign origin. The oil from corn of foreign origin was slightly more saturated than that of U.S. origin. The average percent for each fatty acid in corn oils from Chile and Argentina was not significantly different between countries except for the 18:3 content (a difference of only 0.06%). The percentages of 16:0, 18:1, 18:2, and total saturates in corn oil from Uruguay were significantly different from these fatty acid percentages in corn oil from the other countries.

Comparisons of corn oil fatty acid composition with data from previous researchers. Table 3 shows various corn oil compositions reported by previous researchers. The fatty acid profiles of the corn oils originating from the U.S. were quite similar to each other. Each of the five U.S. populations evaluated in the current study had a fatty acid composition comparable to the fatty acid profiles for corn originating and grown in the U.S. as shown in Table 3. Data reported in Table 2 for U.S. corn oil showed an average 18:1 content of 30.5% and an average 18:2 content of 53.7%. The profile for the U.S. corn in the current study most closely matched that of Tan and Morrison (13) for U.S. oil. Dunlap *et al.* (3) reported fatty acid averages of 25.2% 18:1 and 59.7% 18:2, somewhat comparable to the fatty acid profiles of the refined oils (4,15).

TABLE 2
Fatty Acid Compositions of LAMP Populations of U.S. and Foreign Origin

Country of origin	PI number	Population mean % fatty acid				
		16:0[a]	18:0	18:1	18:2	Total saturates
United States	222493	9.7^{n}	$2.11^{a,b,c}$	$31.9^{f,g,h}$	54.4^{c}	12.0^{l}
	278710	$10.9^{k,l}$	2.22^{a}	$31.7^{e,f,g,h}$	$52.5^{d,e}$	$13.5^{h,i}$
	452040	10.4^{m}	$1.90^{d,e,f,g}$	30.4^{h}	$54.1^{c,d}$	$12.6^{j,k}$
	452046	14.1^{a}	$1.89^{d,e,f,g}$	$33.9^{b,c,d}$	$47.5^{k,l}$	16.4^{a}
	Ames 13236	10.3^{m}	$1.75^{g,h}$	25.6^{i}	59.2^{a}	$12.4^{k,l}$
	U.S. average[b]	11.0^{z}	$2.0^{x,y}$	30.5^{z}	53.7^{x}	13.4^{z}
	range	6.3–16.0	1.0–4.5	18.5–41.6	41.2–66.8	8.3–18.2
Chile	467137	$12.6^{c,d,e,f}$	$1.91^{d,e,f,g}$	$32.3^{d,e,f,g}$	$50.4^{f,g,h}$	$14.9^{d,e}$
	467151	$11.4^{j,k}$	$1.86^{e,f,g}$	$33.7^{b,c,d}$	$49.9^{g,h,i,j}$	$13.6^{g,h}$
	467168	$13.1^{b,c}$	$1.99^{b,c,d,e}$	$32.2^{d,e,f,g,h}$	$49.9^{g,h,i,j}$	$15.5^{b,c}$
	467208	$12.0^{g,h,i}$	$1.88^{d,e,f,g}$	26.3^{i}	56.6^{b}	14.2^{f}
	485610	$11.8^{i,j}$	$1.94^{d,e,f}$	$34.2^{b,c}$	$49.3^{h,i,j}$	$14.1^{f,g}$
	Chile average	12.2^{y}	1.9^{y}	31.7^{y}	51.3^{y}	14.5^{y}
	range	8.9–18.2	1.2–3.4	20.8–45.2	37.7–64.1	11.0–19.8
Argentina	491741	$10.6^{l,m}$	$2.03^{b,c,d}$	$32.2^{d,e,f,g}$	$52.3^{d,e}$	$13.0^{i,j}$
	491797	$12.0^{h,i}$	$1.96^{c,d,e,f}$	$32.8^{c,d,e}$	$50.4^{f,g,h}$	14.3^{f}
	492746	$12.7^{b,c,d,e}$	$1.81^{f,g,h}$	$30.6^{g,h}$	$51.7^{e,f,g}$	$15.0^{c,d}$
	493091	$12.7^{c,d,e}$	$2.04^{b,c,d}$	$33.2^{b,c,d,e}$	$49.4^{h,i,j}$	$15.1^{c,d}$
	516043	$12.4^{e,f,g,h}$	1.69^{h}	$31.1^{f,g,h}$	$51.9^{e,f}$	$14.4^{e,f}$
	Argentina average	12.1^{y}	1.9^{y}	32.1^{y}	51.1^{y}	14.4^{y}
	range	8.9–17.2	0.9–3.1	21.5–44.5	37.8–62.5	10.9–20.0
Uruguay	Ames 14311	$12.5^{d,e,f,g}$	$2.04^{b,c,d}$	$33.7^{b,c,d}$	$48.6^{j,k}$	$14.9^{d,e}$
	Ames 14314	$12.2^{f,g,h,i}$	1.70^{h}	$32.5^{c,d,e,f}$	$50.4^{f,g,h,i}$	14.3^{f}
	Ames 14316	$12.7^{c,d,e,f}$	$2.14^{a,b}$	$33.8^{b,c,d}$	$48.6^{i,j,k}$	$15.2^{b,c,d}$
	Ames 14319	13.3^{b}	$2.12^{a,b,c}$	36.0^{a}	45.8^{l}	15.7^{b}
	479163	$12.9^{b,c,d}$	$1.98^{c,d,e}$	$34.8^{a,b}$	$47.4^{k,l}$	$15.3^{b,c,d}$
	Uruguay average	12.7^{x}	2.0^{x}	34.1^{x}	48.1^{z}	15.1^{x}
	range	9.9–16.7	1.3–4.5	21.4–46.1	36.6–61.5	11.4–19.4

[a]Methyl esters of fatty acids: 16:0 = palmitic, 18:0 = stearic, 18:1 = oleic, 18:2 = linoleic; total saturates = 16:0 + 18:0 + 20:0. See Table 1 for abbreviations.

[b]Each country average represents 50 lines from each of five accessions for a total of 250 different lines.[a–n]Means for populations in the same column with the same superscript are not significantly different ($P \leq 0.05$); [x–z]Means for countries in the same column with the same superscript are not significantly different ($P \leq 0.05$).

TABLE 3
Fatty Acid Composition (%) of Corn Oil as Reported by Previous Researchers

% Fatty acid								
16:0[a]	18:0	18:1	18:2	18:3	Origin of seed	Place grown	Number of lines analyzed	Reference
11.1–15.0	1.9–3.2	28.9–45.5	38.3–55.2		Argentina	United States	1 (7 S_1 ears)	12
12.8–16.4	1.7–2.4	45.5–64.3	19.8–35.4		Chile	United States	1 (1 S_1 ear)	12
10.3–11.6	1.4–1.6	24.4–29.6	56.1–61.3		France	United States	1 (6 S_1 ears)	12
11.0	1.4	24.1	62.8	0.7	France	France	1	13
13.4–18.2	1.5–5.2	25.9–43.3	38.4–49.3		Italy	United States	1 (5 S_1 ears)	12
10.6	1.5	20.3	66.3	1.3	Italy	Italy	1	13
13.1	2.0	27.8	55.2	1.0	Italy	Italy	Refined oil	14
8.4–12.2	1.6–2.3	21.4–37.2	50.5–62.9		Iowa	United States	1 (5 S_1 ears)	12
12.0	2.0	29.3	55.0	1.7	Illinois	Illinois	1	13
11.5	2.2	26.6	58.7	0.8	United States	United States	Refinedoil	15
11.0	2.0	24.1	61.9	0.7	United States	United States	Refined oil	4
6.4–16.5	0.7–4.7	16.2–43.8	39.5–69.5	0.0–3.1	United States	United States	418	3

[a]See footnote in Table 2 for definition of fatty acids.

Similarities in fatty acid composition of oils from these three studies (3,4,15) might be expected because the source of corn was mainly Corn Belt populations.

The oil from the S_1 ear originating from Chile and analyzed by Jellum (12) was more monounsaturated and less polyunsaturated than the average fatty acid composition of the five Chilean populations analyzed in this study. The five populations analyzed in our study from Argentina fell within Jellum's (12) ranges for 7 S_1 ears from Argentina.

The differences among results for Italian corn, as reported by Jellum (12), Tan and Morrison (13), and Strocchi (14), are apparent, probably because only one line of refined oil per study was analyzed, thus limiting the pool. The commercial Italian corn oil was more saturated than the U.S. refined oils. The fatty acid values for French corn analyzed by Jellum (12) and Tan and Morrison (13) were similar to each other.

Nearly all of the averages and ranges for each fatty acid reported by previous researchers, regardless of seed origin or place grown (Table 3), fell within the ranges reported by Dunlap *et al.* (3) for U.S. corn. The 16:0, 18:0, and 18:2 ranges reported by Jellum (12) for Italian corn overlapped ranges reported by Dunlap *et al.* (3). The ranges in Table 2 for corn of foreign origin, as with the U.S. corn, were slightly lower in 18:2 content and slightly greater in 18:1 content than the ranges for U.S. corn reported by Dunlap *et al.* (3). Other researchers have reported wider ranges for 18:1 and 18:2 than those reported by Dunlap *et al. (3)*. Weber and Alexander (16–18) found ranges of 20–60% and 25–71% for 18:1 and 18:2, respectively.

Corn lines with the most unusual fatty acid compositions. Table 4 shows the corn lines with the most unusual fatty acid profiles. The lines with the lowest total saturates came from the two populations with the lowest average total saturates: PI 222493 (12.0%) and Ames 13236 (12.4%), as shown in Table 2. A line from the Golden Glow accession (PI 222493) from the United States had a total saturate level of 8.3%, and two other lines listed had saturate levels of 9.1%. These levels are not low enough to compete with low saturate oils such as canola (6% saturates); however, this germplasm could be used in a breeding program to develop such an oil.

The accession with the highest monounsaturates had only 46.1% 18:1. To compete with the high-oleic varieties of canola, soybean, safflower, and sunflower, an oil with 64–80% 18:1 would be needed (19). This type of oil might be produced through a traditional breeding program, or one involving a high-oleic variety of exotic corn or a wild-type relative. Otherwise, mutagenesis or genetic transformation could be used.

Although a U.S. southern dent population (PI 452046) had the highest average total saturates (16.4%), a value significantly different from all other populations' means, this population did not contain the individual lines with the highest total saturates (Tables 2 and 4). Except for PI 452046, which had the highest total saturates (16.4%), most corn populations with high total saturates came from corn of foreign origin. An oil high in saturates could be developed from the Argentinean line PI 493092-22, which had 20.2% saturates (Table 4). As noted earlier (5), genetic factors have a greater influence on fatty acid composition than does climate; therefore, high saturation should persist in other climates. Other high-saturate oils are listed in Table 4, and there were other lines not shown that had 17–18% total saturates. These oils, if interesterified, may be saturated enough for use without hydrogenation in all-vegetable margarines and spreads. The fatty acid composition of fats and oils in typical margarines ranges from 33–52% monounsaturates and 17–19% saturates (20), which is quite similar to the fatty acid composition of the oils, found here.

It also may be possible to produce an oil high in 18:2 to compete with highly polyunsaturated oils such as sunflower oil (70% 18:2). As shown in Table 2, the population Ames 13236 had a significantly higher percentage of 18:2 (59.2%) than did all the other populations, and the lowest average percentage of 18:1 (25.6%), which was not significantly different from the 18:1 value for PI 467208 (26.3%), a population from Chile. The highest 18:2 content found in this survey was 66.8%, in line 14 from the Golden Glow population (PI 222493) (specific data not shown).

The oil compositions of rapeseed (21) and soybean (22,23) have been changed through breeding systems. Because oil

TABLE 4
Corn Lines with Unusual Fatty Acid Compositions

	PI and S_1 number	% Fatty acid						
		16:0[a]	18:0	18:1	18:2	18:3	20:0	Total saturates
Low saturates	PI 222493 –40	6.3	1.4	25.3	64.1	0.93	0.61	8.3
	PI 222493 –9	7.6	1.1	30.6	57.7	0.93	0.43	9.1
	Ames 13236 –28	7.2	1.4	26.9	61.8	0.80	0.45	9.1
High 18:1	Ames 14311 –2	10.2	3.4	46.1	37.5	0.82	0.56	14.2
	Ames 14316 –32	12.3	2.1	44.9	38.4	1.01	0.48	14.9
	Ames 14316	13.9	2.4	43.9	36.6	0.93	0.95	17.3
High saturates	PI 493091 –22	17.2	2.1	32.0	45.7	0.90	0.89	20.2
	PI 467168 –9	18.2	1.4	28.0	50.3	0.90	0.39	20.0
	Ames 14319 –6	16.7	2.1	31.1	47.7	0.98	0.82	19.6

[a]See footnote in Table 2 for definition of fatty acids. See Table 1 for abbreviation.

composition is a highly heritable trait in corn (24–27), it is probable that the fatty acid composition of corn oil also could be changed.

These results give a starting point for future work of breeding corn designed to produce oils of specific fatty acid composition. There is much variability in corn oil composition, and these unadapted materials could possibly be used with adapted corn breeding materials to develop new oils and expand the corn market.

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