Variability in Seed Oil Composition of 43 *Linum* Species

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Astract

Analyses of the seed oil of 43 *Linum* species showed great variability in fatty acid composition. The species can be grouped in two broad categories on the basis of seed oil composition: 1) Those with high linolenic, low linoleic and low oleic acid content, and 2) Those with high linoleic, low linolenic and low oleic acid content. A positive correlation was observed between iodine value and linolenic acid content, and a negative correlation between linolenic and linoleic acid content. There was no correlation between fatty acid composition and chromosome number.

THE CHEMICAL COMPOSITION of the oil of many oilseeds, from a variety of plant genera, has been determined as a result of an extensive investigation initiated by the US Department of Agriculure to discover new industrial raw materials. Many of the species investigated are wild and belong to genera which do not include any related cultivated species. In these cases it is presumed that a species having a valuable oil would be used as foundation material for the development, through plant breeding, of an agronomic crop which could be grown profitably and on a large scale by farmers.

It would be of great value to extend the overall investigation to as many species as possible within each of the plant families already analyzed, especially those which include established agronomic crops. In such cases an additional plant breeding technique would be available, i.e., the transfer of genes controlling valuable traits through interspecific hybridization from the wild to cultivated varieties already having a commercial status. This latter approach, in some instances, might be a quicker and cheaper method of reaching the same objectives.

The value of linseed oil as an industrial raw material is delimited by its high linolenic acid content. Its present potential, however, might be increased substantially if different types of linseeed oil were available (in terms of chemical composition) which could make possible a wider spectrum of industrial application. Of particular interest would be a linseed oil with low linolenic acid content produced as an edible oil, especially in countries with cold climate where few or no other oil crops are adapted. Screening the world collection of cultivated flaxseed has not yet led to the discovery of any lines producing oil radically different from that now available (1–3). One way of attempting to enlarge the gene pool available to flax breeders is to utilize, if possible, the germplasm found in wild species. The present paper reports data on the fatty acid composition of 43 species of flax collected from 28 botanical gardens in 20 countries on all 5 continents under project 2118 of the University of California in Riverside.

Materials and Methods

Fatty acid analyses of seed samples from a collection of wild species of flax existing at the US Department of Agriculture, Southwestern Irrigation Field Station, Brawley, California, revealed that considerable variability was present among those species (4). Of particular interest was the fact that the collection included two species producing oil with extremely low linolenic acid content. These findings underlined the importance of a thorough investigation of the genus *Linum* which includes more than 100 species. Seeds were collected in the botanical gardens listed in Table I. Efforts to include more species than those shown in Table II were impaired, primarily by the fact that most wild species of flax are dehiscent and this restricts the time span during which seed can be collected.

At least 50 seeds per sample were ground in a tissue grinder with petroleum ether. Methyl esters of the fatty acids were analyzed with a HY-FI Aerograph Model 600-D. A 6-ft, ¼ in. column was used, packed with 19% DEGS on Chromosorb W Column and injector temperatures were 185C and 210C, respectively, Nitrogen flow was maintained at 30 ml per minute. All data obtained on these collections are shown in Table II.

Discussion

The data in Table II indicate that a great deal of variability in fatty acid composition is available among the species of the genus *Linum*. Most of these seed collections are genetically heterogeneous and single plant selections could probably be made from them with widely varying oil compositions. Striking examples of this possibility are apparent in other

TABLE I
Source of Seed of the Linum Species Analyzed

1.	Herbiers de la Faculté des Sciences de Lyon 86 Rue Pasteur Lyon (7eme), Rhone, France
2.	Botanical Museum, The University, Lund, Sweden
3.	Biology Department, Gordon College, Rawalpindi, West Pakistan
4.	Dr. C. M. Rogers, Department of Biology, Wayne State University, Detroit, Michigan, USA
5.	Jardin Botanico de Universidade de Lisbon, Lisbon, Portugal
6.	Botany Division, Experimental Station, Abu Ghraib Farm, Baghdad, Iraq
7.	East African Herbarium, Ainsworth Hill, Box 5166, Nairobi, Kenya
8.	Division of Plant Science, University of British Columbia, Vancouver, British Columbia, Canada
9.	Plant Pest and Disease Research Institute, Tehran, Iran
10.	Department of Scientific and Industrial Research, Botany Division Private Bag, Christchurch, New Zealand
11.	Faculté des Sciences de Toulouse, 39 Allées Jules-Guesde, Toulouse, France
12.	Hortus Botanicus Universitatis, Fen Fabültesi Botanik Enstitüsü Ankara, Turkey
13.	Royal Botanic Gardens, Kew, England
14.	Universitetes Botanicks Hage, Frondheimsvegen 23, Oslo 5, Norway
15.	School of Botany, Trinity College, Dublin, Irish Republic
16.	W. Atlee Burpee Company, Riverside, California, USA
17.	Lycée d'Etat Paul Sabatier, Carcassone, France.
18.	British Museum of Natural History, Cromwell Road, London, S.W. 7, England
19.	Jardin Botanico de Madrid, Plaza de Murillo 2, Madrid 14, Spain
20.	Botanical Museum and Herbarium, Gothersgade 130, Copenhagen K., Denmark
21.	Institut de Botanique, Université de Montpellier (MPU) 5, Rue Auguste Broussonet, Montpellier (Herault), France
22.	Ontario Agriculture College, Department of Botany, Guelph, Canada
23.	Royal Botanic Garden, Edinburgs 3, Scotland
24.	Geobotanisches Institut, Stiftung Rubel, Zurichbergstrasse 38, Zurich 44, Switzerland
25.	Royal Botanic Gardens and National Herbarium, Sydney, Australia
26.	Instituto de Botanica, Campo Alegre, Portugal
27.	Agronomy Department, University of California, Riverside, California
28.	Botanischer Garten, 2 Hamburg 36, Belden Kirchhöfen 18, Germany

No. 1722, University of California Citrus Research Center and Agriculture Experiment Station, Riverside, California.

TABLE II

Chromosome Number, Seed Weight, Iodine Value, Origin and Fatty Acid Composition of 43 *Linum* Species

Species	Chrom No. (2n)	Accession No.	Weight (g) 100 seeds	% Fatty acids					Iodine value [f]	Origin [g]
				Palmitic	Stearic	Oleic	Linoleic	Linolenic		
L. africanum	30	QC0103	0.37	6.6	4.9	26.0	14.6	47.8	172	19
L. album	18	QC5201	0.33	6.5	2.2	21.5	64.1	5.7	144	9
L. alpinum	18	QC0206	0.34	3.5	1.4	19.8	24.1	51.2	192	13
L. anglicum	[e]	QC6601	0.14	5.2	1.4	19.7	23.4	50.3		
		6602	0.14	4.6	2.4	14.4	24.9	53.7	195	13
		Mean	0.14	4.9	1.9	17.1	24.2	52.0	192	
L. angustifolium	30	QC0412	0.14	9.9	5.4	23.8	13.5	47.3	167	1
		0417	0.11	8.9	5.0	15.9	11.3	58.9	187	26
		0418	0.10	8.7	7.9	34.4	14.0	34.9	145	19
		0419	0.12	10.4	3.1	16.0	10.4	60.1	188	17
		0420	0.12	6.6	2.3	25.0	23.0	43.1	173	27
		Mean	0.13	8.9	4.7	23.0	14.4	48.9	172	
L. arenicola	18 [a]	QC5501	0.01	7.9	2.5	18.1	39.1	32.4	167	4
L. aristatum	[e]	QC5601	0.04	6.9	3.4	21.6	63.4	4.7	140	4
		5602	0.04	8.7	3.3	16.8	63.6	7.6	144	4
		Mean	0.04	7.8	3.4	19.2	63.5	6.2	142	
L. australe	18	QC0505	0.11	5.5	1.7	20.9	24.7	47.2	183	19
L. austriacum	18	QC0609	0.13	5.0	3.1	16.5	28.8	46.6	185	12
		0610	0.14	5.5	1.2	16.8	24.6	51.8	192	20
		0611	0.17	3.4	1.4	18.7	22.1	54.4	196	28
		0612	0.13	9.0	2.0	23.6	22.1	43.3	171	19
		0613	0.14	3.8	2.4	15.7	24.4	53.7	195	13
		Mean	0.14	5.3	2.0	18.2	24.4	49.9	188	
L. campanulatum	28 [b]	QC4501	0.10	4.0	2.6	26.1	50.3	17.0	153	18
L. capitatum	28 [b]	QC4601	0.12	8.2	3.9	29.5	48.9	9.5	134	1
		4602	0.20	5.0	2.1	17.4	54.4	21.0	163	13
		Mean	0.16	6.6	3.0	23.4	51.6	15.3	149	
L. catharticum	16 [c]	QC4708	0.02	7.4	3.1	13.5	63.1	12.9	154	14
		4709	0.02	7.4	3.8	10.1	65.4	13.3	160	15
		4710	0.02	8.0	2.7	12.4	60.1	16.8	156	15
		4713	0.02	7.5	2.7	9.5	66.6	13.5	163	20
		4714	0.01	7.4	5.4	14.4	58.0	14.8	151	20
		4718	0.01	6.0	2.6	9.8	65.4	16.2	156	23
		4719	0.02	9.2	2.1	9.3	60.8	18.6	161	23
		4721	0.01	10.1	3.2	10.3	61.6	14.8	154	24
		4722	0.01	7.2	3.6	9.2	67.0	12.9	157	24
		4724	0.02	7.4	3.3	12.5	62.6	14.3	156	13
		Mean	0.02	7.8	3.3	10.2	63.1	14.8	157	
L. corymbiferum	30	QC1004	0.35	5.8	4.7	32.6	14.0	43.0	164	19
L. flavum	30 [b]	QC4802	0.09	6.0	2.0	19.8	54.5	17.6	157	21
		4803	0.11	4.7	1.7	22.0	50.8	20.7	160	28
		4804	0.09	9.7	2.4	34.4	47.2	5.8	126	19
		Mean	0.10	6.8	2.0	25.4	50.8	14.7	148	
L. gallicum	20	QC1602	0.01	6.1	3.3	8.5	30.4	51.6	194	1
		1604	0.01	8.2	2.2	5.7	29.7	54.2	197	2
		Mean	0.01	7.2	1.8	7.1	30.0	52.9	196	
L. grandiflorum	16	QC1707	0.24	11.0	3.3	23.7	15.9	46.1	168	25
		1709	0.24	9.9	4.6	23.1	15.0	47.4	169	19
		1710	0.24	7.1	2.9	15.5	15.6	58.9	194	13
		Mean	0.24	9.3	3.6	20.8	15.5	50.8	177	
L. hirsutum	16 [b]	QC1802	0.15	4.6	1.8	23.2	19.6	50.8	186	6
		1803	0.15	4.7	1.0	7.6	30.7	56.0	205	13
		Mean	0.15	4.7	1.4	15.4	25.1	53.4	196	
L. hologynum	18	QC2002	0.11	5.7	1.8	21.6	22.2	28.7	184	19
L. holstii	[e]	QC5401	0.01	7.4	4.0	9.5	77.6	1.5	146	1
		5403	0.02	8.3	2.9	14.4	69.7	4.7	145	7
		Mean	0.02	7.9	3.5	11.9	73.6	3.1	146	
L. hudsonoides	[e]	QC5701	0.06	8.4	3.8	24.7	56.6	6.5	136	4
L. lewisii	18 [b]	QC2405	0.15	4.8	1.5	16.5	16.2	61.2	201	8
		2407	0.15	8.3	2.7	10.8	9.3	68.9	205	22
		Mean	0.15	6.6	2.1	13.7	12.8	65.1	203	
L. monogynum		QC5301	0.28	6.6	1.6	9.3	22.1	60.4	201	10
		5302	0.28	7.1	3.0	10.5	12.9	66.5	204	22
		Mean	0.28	6.9	2.3	9.9	17.5	63.5	203	
L. marginale		QC2505	0.01	6.9	2.4	20.7	30.1	39.4	172	25
L. maritimum	18 [d]	QC2604	0.11	7.1	1.5	25.3	22.7	43.3	174	19
L. medium	36	QC5801	0.02	7.3	2.6	12.2	65.3	12.5	157	4
var *texanum*		5802	0.02	6.1	3.0	8.1	72.4	10.5	159	4
var *texanum*		5803	0.03	9.0	4.0	7.2	68.3	11.5	154	4
var *texanum*		5804	0.02	8.0	4.1	6.9	69.5	11.5	155	4
var *texanum*		5805	0.02	5.5	2.8	7.5	76.3	7.9	159	4
var *texanum*		5806	0.02	7.8	2.8	9.2	62.4	17.8	162	4
var *texanum*		5807	0.02	9.0	4.3	7.4	66.9	12.4	154	4
var *texanum*		5808	0.02	6.6	3.9	7.2	73.8	8.4	155	4
var *texanum*		5809	0.02	6.4	3.0	5.2	75.8	9.6	160	4
		Mean	0.02	6.6	3.4	7.9	70.0	11.3	157	
L. muelleri	30	QC2902	0.10	6.3	2.1	27.4	21.6	42.5	171	19
L. narbonense	18	QC3005	0.12	5.0	2.2	26.1	24.1	42.6	175	19
L. nervosum	30	QC3102	0.38	5.8	4.4	29.9	14.3	45.5	169	19
L. pallescens	30	QC3203	0.44	10.1	3.6	26.9	15.6	43.9	164	19
L. perenne	18 [b]	QC3310	0.13	4.7	2.3	21.9	27.3	43.6	179	1
		3311	0.36	6.3	2.9	24.3	19.2	47.3	177	3
		3312	0.38	5.7	3.7	19.5	17.5	53.6	186	12
		3313	0.15	5.0	1.6	16.4	21.4	55.5	196	16
		3315	0.15	3.4	2.7	19.2	16.4	58.3	197	22
		3316	0.15	4.9	1.5	13.0	15.4	64.8	206	22
		Mean	0.22	5.0	2.5	19.1	19.5	53.9	190	
L. pratense	18 [a]	QC5901	0.17	5.8	2.7	21.3	18.0	52.3	186	4
		5902	0.17	4.9	4.2	15.2	18.6	57.1	194	4
		Mean	0.17	5.4	3.5	18.3	18.3	54.7	190	
L. rigidum		QC6001	0.09	8.4	4.1	20.6	55.7	11.2	143	4
var *berlanderi*		6002	0.10	7.8	4.7	17.6	60.2	9.7	144	4
filifolium	18	6003	0.10	9.5	4.5	17.9	65.7	2.4	135	4
filifolium		6004	0.07	9.3	3.6	13.0	69.8	4.3	143	4
rigidum	30	6005	0.08	10.5	3.5	22.4	56.4	7.3	135	4
rigidum		6006	0.08	7.5	3.1	20.3	58.4	10.6	146	4
		6007	0.07	5.3	2.2	12.3	59.3	20.9	167	22
		Mean	0.08	8.3	3.7	17.7	60.7	9.0	145	

TABLE II (Continued)

Species	Chrom No. (2n)	Accession No.	Weight (g) 100 seeds	% Fatty acids					Iodine value [f]	Origin [g]
				Palmitic	Stearic	Oleic	Linoleic	Linolenic		
L. rupestre	36	QC6101	0.02	7.0	2.6	7.2	79.1	4.3	154	4
L. schiedeanum	36	QC6201	0.02	9.2	3.5	9.4	72.5	5.3	147	4
		6202	0.02	8.7	1.5	7.9	78.7	5.2	157	4
		Mean	0.02	8.9	2.5	8.7	75.6	5.3	152	
L. striatum		QC6302	0.02	9.5	3.6	11.5	64.8	10.5	149	4
		6303	0.02	10.6	3.5	12.6	65.3	8.0	144	4
		Mean	0.02	10.1	3.5	12.0	65.0	9.3	147	
L. strictum	18 [b]	QC3705	0.02	7.9	2.5	8.7	41.2	39.7	182	11
L. sulcatum	30	QC3802	0.03	8.9	3.6	6.8	71.1	9.7	154	4
		3803	0.03	8.2	2.7	5.7	66.5	16.9	164	22
		Mean	0.03	8.6	3.2	6.3	68.8	13.3	159	
L. tenue	30	QC4002	0.34	6.9	3.8	32.0	12.6	44.7	166	19
L. tenuifolium	18 [b]	QC3903	0.05	4.8	2.2	7.9	83.7	1.4	155	1
		3904	0.06	6.3	2.1	7.2	82.6	1.8	153	24
		3905	0.05	5.0	2.5	7.5	78.3	4.7	155	28
		3907	0.05	7.0	1.3	8.8	81.4	1.5	152	24
		Mean	0.05	5.8	2.0	8.4	81.5	2.4	154	
L. thracicum	18	QC6501	0.11	4.7	2.0	23.3	21.8	48.2	183	19
L. vernale	[e]	QC6401	0.05	7.7	5.0	18.0	63.1	6.1	140	4
L. viscosum	16 [b]	QC6801	0.05	6.9	2.4	9.9	29.6	51.2	193	13
L. usitatissimum	30									
var Abyssinian yellow			0.36	7.0	4.0	15.0	18.0	56.0	199	
Cawnpore			0.64	7.0	4.0	39.0	15.0	35.0	156	

[a] Osborne, W. P., and W. H. Lewis, Chromosome Numbers of Linum from the Southern United States and Mexico, SIDA *1*(2):63–68 (1962).
[b] Ray, C., Cytological Studies on the Glax Genus, Linum. Amer. J. Botany. *31*(4),241–248 (1944).
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[d] Nagao, S., Cytogenetics in the Genus Linum, Jap. J. Genetics *17*(2),109–116 (1941).
[e] Not reported.
[f] Computed from fatty acid composition.
[g] Numbers correspond to serial number in Table I.

crops. In rapeseed, samples from single plants of the variety "Liho" had a range of 6 to 50% in erucic acid content. In safflower, mutant types were found with 75% oleic and 15% linoleic acid in contrast to 20% oleic and 70% linoleic acid in the commercial varieties grown in California. Thus, when single plants from the species studied are analyzed, the variability in fatty acid composition and the potential for selection of pure lines with divergent oil composition will probably be greater than present data indicate.

Whether the species studied constitute valuable germplasm depends on the success with which interspecific crosses can be made, especially with cultivated flax, *Linum usitatissimum*, Lin. Such crosses in flax are possible only among species having the same chromosome number. Consequently, the transfer of genes determining fatty acid composition to the cultivated varieties from species with chromosome number other than 2n = 30 depends on the success with which appropriate cytogenetic techniques, proven effective on other species, can be applied on flax.

Among the species studied, 10 had a mean linolenic acid content of less than 10%; 6 others ranged from 11–17%. These 16 species all had a high linolenic acid content (50.3–81.5%). By contrast, 2 species had over 63% linolenic acid, which is somewhat higher than that of most cultivated varieties. In terms of linolenic acid content, the remaining 25 species analyzed were distributed almost evenly between these two extremes.

Variability in oil composition within species, in which more than one seed collection was made, was considerable. Since most of the wild species of flax are cross-pollinated, especially the ones with 2n = 18 and heterostylic flowers, it is expected that a major portion of that variability is of genetic origin. Determinations of the chromosome number were made on 20 of the species analyzed; for the rest, the data were obtained from the literature. It is evident that fatty acid composition is not correlated with chromosome number.

In addition to its significance from plant breeding aspects, variability in fatty acid composition has been looked upon with interest from a biochemical systematics point of view. The number of seed collections as well as the locations sampled are not the same in each of the species listed in Table II. Therefore, the data on fatty acid composition are suggestive rather than representative of their mean composition if their overall, worldwide distribution we to be specified. The 43 species listed in Table I plus 10 whose composition was reported earlier (4) were arranged in Figure 1 on the basis of their linolenic acid content to illustrate one way of dividing the *Linum* species into two broad categories: 1) Species with high linolenic, low linoleic and low oleic acid content (the three major unsaturated acids only were considered). 2) Species with high linoleic, low linolenic and low oleic acid content. The first catgory includes the cultivated species, *L. usitatissimum*; the data of two of its varieties are included in Figure 1. These varieties are: Abyssinian yellow and Cawnpore and they represent extremes in linolenic acid content with 56 and 35% linolenic acid, respectively. Since the seed collections made include only part of the variability available in the entire genus, the data were not analyzed statistically. It is obvious, however, from Figure 1 that a positive correlation exists between iodine value and linolenic acid content, and a negative correlation between linolenic and linoleic acid content.

Xavier and Rogers (5) have suggested a classification of some *Linum* species in the following groups on the basis of pollen and general morphology:

Group I: *L. lewisii*, *L. rupestre*, *L. arenicola*, *L. usitatissimum*, *L. catharticum*, and *L. bahamense.*

Group II: *L. medium* var *texanum*, *L. striatum*, and *L. virginianum.*

Group III: *L. intercursum*, *L. westii*, *L. floridanum*, and *L. medium* var *medium.*

Group IV: *L. rigidum* and *L. sulcatum.*

Group I is characterized by the largest array of primative features; Groups II and III are intermediate; Group IV combines the largest number of advanced features. The data on fatty acid composition would not lead to a similar grouping of

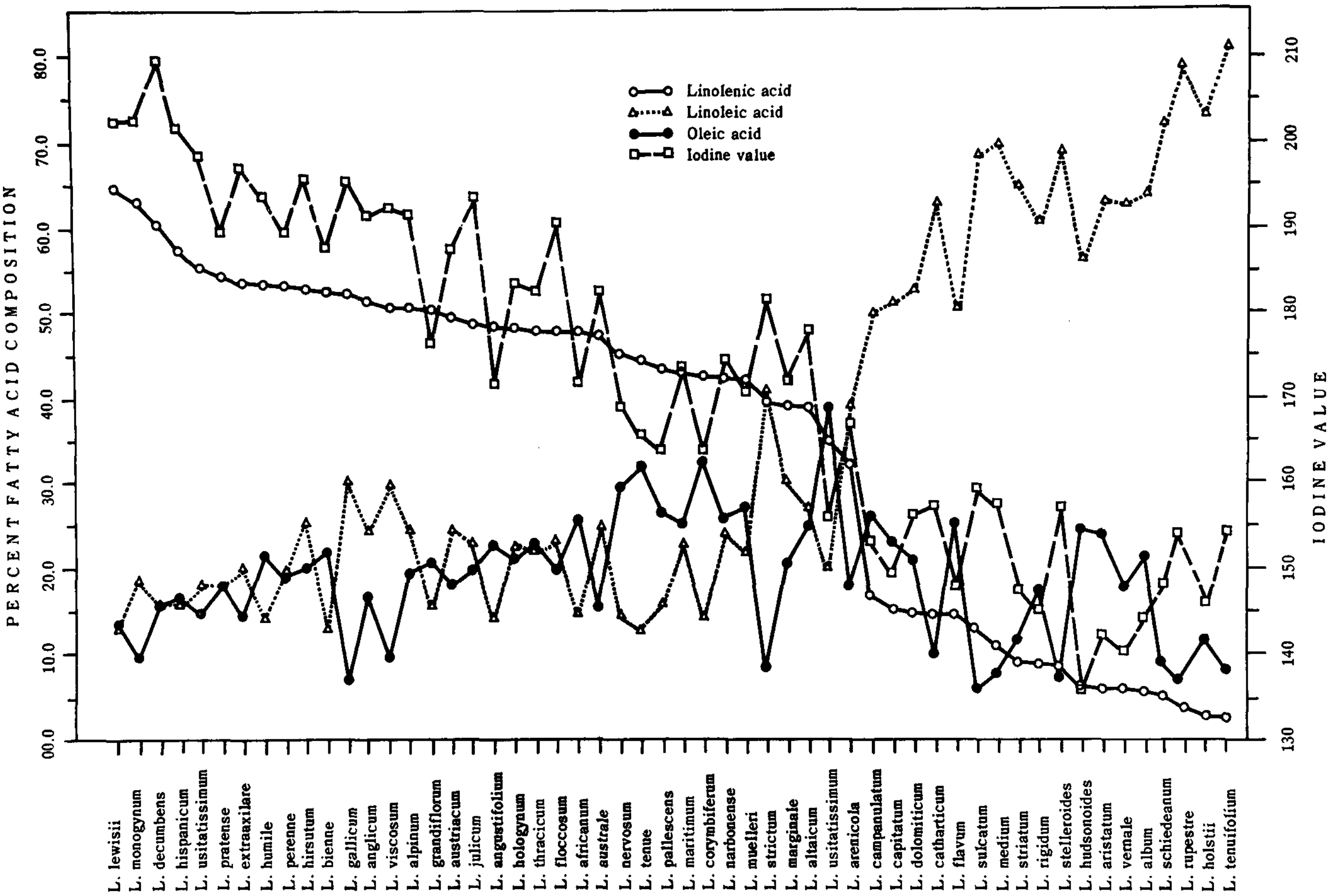

FIG. 1. Iodine value and unsaturated fatty acid composition of 43 *Linum* species arranged in order of decreasing linolenic acid.

these species. If anything, they would merely support the statement made by Xavier and Rogers, that "the usual treatment of *Linum* as one genus is too conservative."

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