Definite Influence of Location and Climatic Conditions on the Fatty Acid Composition of Sunflower Seed Oil

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Percentages of linoleic, oleic and stearic acids present significant differences between growing areas, whereas palmitic acid content remains practically constant, or at least presents no significant relation to the growing area. Nevertheless, palmitic acid appears to follow a pattern that relates its content to the total content of the other three major fatty acids. Seeds grown in the northern part of Spain presented a higher linoleic content than seeds grown in the South, which is in agreement with the general theory found in prior studies. Although there is an inverse correlation between oleic and linoleic content, we have found that the total content of both is neither constant nor independent of temperature, and increases when temperature and oleic acid increase. However, stearic content increases when the combination of linoleic and oleic acid decreases, suggesting a total constant value for the combination of these three acids. The average temperature of the area during development of the seed and the local climatic conditions have the greatest influence over fatty acid composition, while the seed variety presents limited influence.

KEY WORDS: Climate, fatty acid correlation, geographic location, latitude, linoleic acid, oleic acid, sunflower seed, temperature.

A correlation between geographic latitude and fatty acid composition has been recognized for many oilseed crops. The relationship between geographic location in Spain and fatty acid composition of sunflower seed oil was studied for the 1988 crop. It was found that not only latitude, but also local climatic conditions and temperature at time of planting, blooming and maturing, play an important role in the relative composition of the fatty acids linoleic, oleic and stearic, while palmitic acid content remains about constant.

The final fatty acid composition of the sunflower seed oil obtained from mature seeds is more a function of the geographical location and climatic conditions than of the variety being planted, unless planting seeds are hybrids where genetic manipulation addressed the fatty acid composition rather the total oil content. In general, there is a correlation between latitude and fatty acid composition, but only because of the influence of latitude on the climatic conditions. When other factors affect local climate, or the biological cycle of the plant takes place in a different time of the year, the general relationship between geographic location and fatty acid composition is altered.

In 1964, Kinman and Earle (1) reported that "the linoleic acid content of oil from northern grown seed was much higher than for the same varieties grown in the South". In a further study, Putt *et al.* (2) concluded statistically that the variation in fatty acid composition was due to both variety and location. Temperature at the time of synthesis of oil should also be considered (3,4) since low temperatures appear to produce high linoleic acid oils. In a further article, Kinman (5) introduced the genetic factor, indicating that "it may be possible to breed hybrids which will produce high linoleic acid oils even in the southern states".

The pressure to reduce cholesterol in human diets has promoted edible oils containing highly unsaturated fatty acids, like linoleic acid. This raises the concern that high linoleic acid sunflower oil could not be produced from seeds grown below a certain latitude, and therefore would reduce its marketability.

The purpose of this study was to investigate the expected correlation between latitude and linoleic acid content of sunflower seed grown in Spain, and its correspondence to the general theory.

EXPERIMENTAL PROCEDURES

Samples were taken at each purchasing point of the company and properly labeled. The oil content was determined by nuclear magnetic resonance and indicated on the label. When a significant range of oil content was observed for the same area, samples were made in two groups, one for the higher and another for the lower oil content. All samples were analyzed in the laboratory of the Sevilla Crushing Plant of Cargill España, S.A. After samples were combined by areas of production, the oil was extracted from the entire seed (kernel and hull), according to the AOCS Official Method Ai 3-75 (6).

The percentages of linoleic, oleic, stearic and palmitic acids were determined by gas chromatography according to the AOCS Official Method Ce 1-62 (7). The chromatograph was a Perkin-Elmer unit 3920 B (Perkin Elmer, Norwalk, CT), with an integrator 3380 A and a column GP 5% DEGS-PS Supelcoport 100/200 (Supelco, Inc., Bellefonte, PA). Working conditions were 180°C column, 230°C injection, 205°C detector (FID) and nitrogen as a carrier.

Samples of planting seeds from all major producers in Spain were also analyzed for oil content (clean seed, dry basis) and fatty acid composition. Also, several samples were ranked by oil content, and percent of hull was determined in each of the seed samples.

RESULTS AND DISCUSSION

Table 1 shows the composition of the four main fatty acids for the average results obtained in each province. Table 2 is based on Table 1 and lists the total percentages of different combinations of some of those four fatty acids, the ratio linoleic to oleic acid and the total oil content for each province.

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TABLE 1

Average Composition of Basic Fatty Acids of Samples Taken from Sunflower Seed Growing Provinces in Spain (Qty. refers to Number of Locations and/or Parcels Sampled)

No.	Province	Qty.	Linoleic	Oleic	Stearic	Palmitic
1	Palencia	14	70.23	15.73	5.58	6.88
2	Soria	861	69.70	15.21	6.35	7.04
3	Segovia	118	69.13	16.56	5.70	6.94
4	Burgos	263	68.98	16.41	6.00	6.90
5	Valladolid	43	68.87	16.91	5.45	7.08
6	Teruel	82	68.86	16.23	5.59	7.10
7	Salamanca	108	68.67	17.27	5.19	7.10
8	Zamora	85	68.59	17.35	5.46	7.01
9	Avila	60	68.50	17.26	5.76	6.92
10	Logroño	3	66.98	19.83	4.57	6.12
11	Valencia	239	66.53	20.32	4.61	7.01
12	Zaragoza	143	66.44	19.95	5.24	6.86
13	Lérida	107	66.38	20.16	4.95	6.66
14	Albacete II	209	66.05	20.54	4.63	7.20
15	Navarra	45	65.69	21.72	4.26	6.84
16	Guadalajara	655	64.94	20.80	5.17	7.38
17	Cuenca	2340	63.80	22.79	4.71	7.16
18	Huesca	1004	62.81	23.43	4.93	7.09
19	Albacete I	810	62.52	24.32	4.60	7.34
20	Granada	11	61.58	25.57	4.33	6.95
21	Madrid	33	59.91	26.40	4.55	7.44
22	Ciudad Real	145	59.09	26.70	4.77	7.58
23	Cáceres	152	58.65	27.13	4.43	7.98
24	Toledo	363	58.20	27.45	4.44	7.55
25	Gerona	102	57.80	29.85	3.95	6.87
26	Badajoz	1486	56.57	29.41	4.28	8.06
27	Málaga	907	55.71	32.35	3.48	7.06
28	Barcelona	22	55.22	30.41	4.88	7.35
29	Cádiz	227	55.17	32.34	3.66	7.40
30	Huelva	478	53.63	33.46	3.82	7.52
31	Sevilla	1773	52.85	34.64	3.89	7.17
32	Córdoba	422	50.88	36.45	3.89	7.32
33	Jaén	148	48.67	39.16	3.22	7.41

The average content of linoleic acid for each sunflower seed growing area is represented in Figure 1, and the results are grouped into four main ranges. It shows clearly that below parallel 38 the average linoleic content is very low, with the exception of Granada, which reaches 62%. Above parallel 40, especially in Castilla, linoleic acid content is much higher, and reaches values close to 70%.

The effect of geographic location in Spain on the fatty acid composition appears to be in agreement with previous findings. The variation of fatty acid composition with planting location and with climatic conditions during the growing season was indicated by Kinman and Earle in 1964 (1) and by Cummins *et al.* in 1967 (8). In 1968, Earle *et al.* (9) concluded that "kernel oil from seed raised in northern United States or southern Canada typically contains about 70% linoleic acid". This situation was confirmed in 1971, for hybrid and open-pollinated varieties, in a well-documented article by Robertson *et al.* (10), and summarized by Robertson in 1972 (11).

Therefore, as was expected, seeds grown in the northern part of Spain presented a higher linoleic acid content than seeds grown in the South. The samples analyzed showed a clear inverse correlation between oleic and linoleic acids. The higher the linoleic content, the lower the oleic. This was constant for all samples analyzed. The ratios of linoleic to oleic, for all samples representing a certain growing area, give a straight line on a chart.

Although most of the time temperature is a direct consequence of geographical location, orographic variations and microclimatic conditions may determine acute differences within the same latitude.

It has been clearly established by several investigators that reduced temperature during sunflower seed growth promotes an increase in the proportion of linoleic acid vs oleic acid (3,4,10,12–14).

The mechanism involved appears to be the direct effect of temperature on the activity of desaturase enzymes converting oleic to linoleic acid, and on the solubility of oxygen, which seems to play a regulatory function in that activity (12, 14).

Figure 1 shows three distinct sunflower seed growing areas between parallels 40 and 43. The average temperature of the area during development of the seed and the microclimate conditioned by height (mountain) or sea (Mediterranean border) are even more of a determinant than latitude itself. This explains the deviations observed for Granada (higher linoleic content than expected based on the latitude), or Barcelona-Gerona, where the influence

TABLE 2

Complement of Table 1 Showing: A, Total Percent Linoleic + Oleic Acids; B, Ratio of Percent Contents of Linoleic to Oleic; C, Total Percent Linoleic + Oleic + Stearic Acids; D, Total Percent Linoleic + Oleic + Stearic + Palmitic; and E, Total Fat Content (Clean Seed, Dry Basis)

No.	Province	A	B	C	D	E
1	Palencia	85.96	4.47	91.54	98.42	52.52
2	Soria	84.91	4.59	91.26	98.30	48.56
3	Segovia	85.69	4.18	91.39	98.33	50.09
4	Burgos	85.39	4.22	91.39	98.29	49.85
5	Valladolid	85.78	4.09	91.32	98.40	48.50
6	Teruel	85.09	4.25	90.68	97.78	49.73
7	Salamanca	85.94	4.00	91.13	98.23	49.71
8	Zamora	85.94	3.96	91.40	98.41	50.49
9	Avila	85.76	3.99	91.52	98.44	49.47
10	Logroño	86.81	3.38	91.38	97.50	51.10
11	Valencia	86.85	3.28	91.46	98.47	49.81
12	Zaragoza	86.39	3.37	91.63	98.49	50.40
13	Lérida	86.54	3.34	91.49	98.15	49.42
14	Albacete II	86.59	3.35	91.22	98.42	44.40
15	Navarra	87.41	3.06	91.67	98.51	53.33
16	Guadalajara	85.74	3.22	90.91	98.29	49.67
17	Cuenca	86.59	2.81	91.30	98.46	48.39
18	Huesca	86.24	2.69	91.17	98.26	50.28
19	Albacete I	86.84	2.65	91.44	98.78	48.29
20	Granada	87.15	2.41	91.48	98.43	49.70
21	Madrid	86.31	2.31	90.86	98.30	48.74
22	Ciudad Real	85.79	2.22	90.56	98.14	48.46
23	Cáceres	85.78	2.16	90.21	98.19	48.16
24	Toledo	85.65	2.14	90.09	97.64	47.79
25	Gerona	87.65	1.99	91.60	98.47	51.39
26	Badajoz	85.98	1.93	90.26	98.32	48.69
27	Málaga	88.06	1.74	91.54	98.60	49.76
28	Barcelona	85.63	1.82	90.51	97.86	50.10
29	Cádiz	87.51	1.73	91.17	98.57	49.58
30	Huelva	87.09	1.61	90.91	98.43	49.72
31	Sevilla	87.49	1.53	91.38	98.55	48.27
32	Córdoba	87.33	1.40	91.22	98.54	49.13
33	Jaén	87.83	1.25	91.05	98.46	48.66

of the Mediterranean sea changes the expected pattern.

In our findings, temperature during the time elapsed between flowering and ripening is perhaps the most important factor influencing fatty acid composition. Table 3 shows the existing relationship in Spain between linoleic content and minimum temperature at the time of seed growing. For the first two groups the growing takes place during July, August and September, and for the second two groups (southern) during June, July and August.

The literature supports a strong correlation between linoleic and oleic acid contents, and a relationship between this correlation and temperature. Canvin (3) had already indicated in 1965 that the enzymes that convert oleic to linoleic acid are inactivated at high temperatures, which prevents extensive formation of linoleic acid.

The contents of linoleic and oleic acid seem to be complementary, and the increase of one results in a similar decrease of the other (12,15). Rodrigues (13) indicated that this correlation is true for the kernels, but less manifest for the hulls, and concluded that although the final contents of oleic and linoleic acids are "strongly influenced by temperature", the sum of both acids (about 87%) is independent of temperature. However, we found that even the sum of linoleic and oleic acids is temperature dependent, and increases when temperature and oleic acid content increase.

The saturated fraction includes mainly stearic and palmitic acids, along with other minor constituents, and although this fraction shows "a continuous content decrease or remains constant during seed ripening" (16), the correlation of linoleic and oleic acids has shown some association with stearic (2).

In the study of fatty acid composition as influenced by seed position, Zimmerman and Fick (17) reported that the level of stearic acid, although to a lesser extent, may also change with the oleic and linoleic acid contents. However, in our findings, the direction of variation of stearic content in relation to linoleic content is just the opposite to the one found by Zimmerman and Fick.

From top to bottom of Table 1, the difference between highest and lowest content of linoleic (−21.56) and oleic (+23.43) acids are almost compensated by

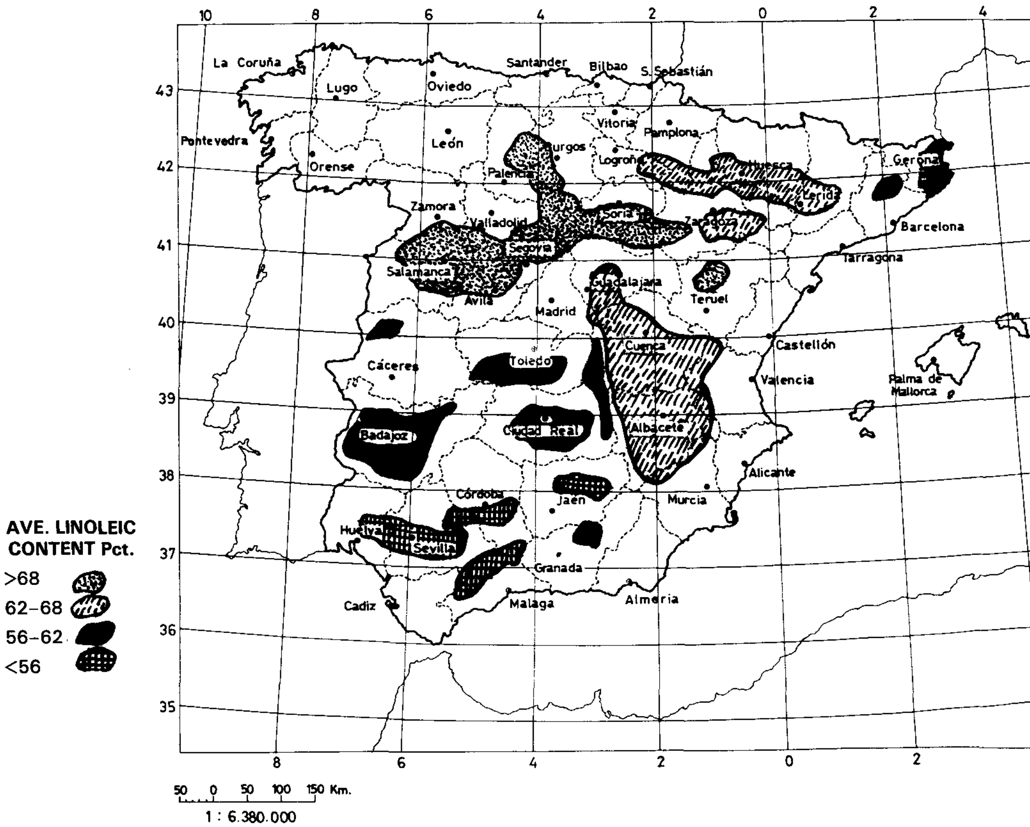

FIG. 1. Major sunflower seed growing areas in Spain.

TABLE 3

Linoleic Content Related to the Low Average Temperature of the Area, During the Time Elapsed Between Flowering and Ripening

Area	Average linoleic content	Average of minimum temperature °C
Avila-Burgos-León-Salamanca-Segovia-Soria-Valladolid-Zamora	69.08	10.7
Albacete (First Crop)-Cuenca	63.16	12.8
Badajoz-Ciudad Real-Toledo	57.95	15.5
Cádiz-Córdoba-Huelva-Jaén-Málaga-Sevilla	52.82	18.3

the variation of stearic (−2.36) acid. This seems to indicate that when linoleic content decreases, oleic content increases at a slightly faster rate, which is partially compensated by the reduction of stearic acid. Or, perhaps we should say that the rate of conversion of oleic acid into linoleic is slightly compensated by the conversion of stearic into oleic acid. In other words, the results of Table 1 might suggest that stearic acid is also desaturated into oleic acid at the same time and by the same mechanism as the oleic acid is desaturated into linoleic acid.

Therefore, the correlation linoleic-oleic is not the only one. We have observed the same inverse correlation between oleic and stearic acid, indicating that the higher the content of linoleic, the higher the content of stearic acid.

Apparently, palmitic showed no consistent association with any of the other three acids (2), and its

TABLE 4

Fatty Acid Composition and Oil Content of Major Commercial (Planting) Seeds in Spain

	Seed producer			
Analysis	I	II	III	IV
Oil content				
range	49.4–54.9	50.7–55.3	46.1–52.3	49.5–55.9
average	51.82	52.55	49.05	52.60
Linoleic				
range	39.7–61.3	45.7–63.7	50.8–55.6	50.8–58.0
average	53.86	54.13	53.18	55.73
Oleic				
range	26.0–47.9	20.8–42.5	29.3–36.9	30.2–36.6
average	33.35	32.49	33.04	32.36
Stearic				
range	4.2–5.7	3.6–6.5	4.7–6.5	3.6–4.2
average	4.88	4.62	5.32	3.87
Palmitic				
range	5.3–6.8	5.9–7.7	5.6–6.7	6.2–6.5
average	6.17	6.73	6.03	6.37

	Seed produce			
Analysis	V	VI	VII	VIII
Oil content	52.50	53.00	48.90	53.30
Linoleic	57.06	57.82	66.95	57.05
Oleic	29.53	29.96	19.47	30.59
Stearic	4.18	3.41	5.54	4.63
Palmitic	6.94	7.25	5.84	6.06

level might be changed "without appreciably altering the others" (17). But in spite of these findings, there seems to be some sort of correlation. Table 2 shows that palmitic content is almost constant within a rather narrow range, with minor random variations that suggest a certain compensation to the content of the other three acids, to reach a total value for all four acids of about 98.4%. This is in agreement with analysis results of Robertson *et al.* (10, Table 2), Robertson (11, Table 2), and Earle *et al.* (9, Table 2), for both high-oil seed and large (birdfeed) seed.

Another apparently important factor influencing fatty acid composition is the variety of the seed and its genetics. Although Putt *et al.* (2) had found statistically significant variations in fatty acid composition due to both variety and location, some investigators indicated that "fatty acid composition is not apparently influenced significantly by variety" (9), "or that environmental conditions influence the fatty acid composition much more than the genotype of the variety" (10), as previously indicated by Kinman and Earle (12).

Table 4 shows the basic fatty acid composition and oil content of the larger selling planting seeds in Spain. The first four brands account for more than 90% of the total planted seeds. Nevertheless, linoleic acid content of northern growing areas in Spain greatly exceed the upper limit shown by those seeds.

Therefore, we have concluded that fatty acid composition of the samples analyzed in our study showed a uniform pattern related to the area rather than to the variety planted. In other words, these results suggest that the original fatty acid composition of the planting seed will be at least partly modified based on the area where it is planted.

The total wax content in sunflower seed is usually associated with the hull content. Total wax or hull contents could be expected to maintain a certain relationship with geographical location or growing conditions. We have found, as shown in Table 5, that the higher the oil content, the lower the percentage of hull in the seed, which is more dependent of the variety of the seed than of the growing conditions. Apparently both location and hybrid were found to influence the amount of hull and wax content of the hulls, but not the wax content of the oil (18).

TABLE 5

Correlation Between Oil Content and Percent of Hull in Sunflower Seed for Several Locations in Spain

Location	Province	Total samples	Oil %	Hull %
Quintanar del Puente	Palencia	10	52.0	22.5
Las Cabezas	Sevilla	61	51.2	24.3
San Pedro Gallos	Segovia	11	50.9	25.5
Puentepinillo	Soria	73	50.4	25.7
Almazán	Soria	235	49.4	23.9
Mollina	Málaga	109	49.4	25.1
Montellano	Sevilla	290	49.3	26.2
Almazán	Soria	125	48.1	24.8
Castro del Rio	Córdoba	80	48.0	26.1
Carmona	Sevilla	431	47.9	25.7
Los Corrales	Sevilla	19	47.2	27.2
Alameda	Málaga	45	47.1	27.1
Almazán	Soria	83	47.0	27.2
Lerma	Burgos	33	46.5	26.8
Gomara	Soria	51	46.1	26.4
Almazán	Soria	79	45.0	26.5
Carmona	Sevilla	66	44.7	27.8

ACKNOWLEDGEMENTS

We thank the analysts of the Sevilla Crushing Plant of Cargill España, S.A. for their cooperation and the extra work load caused by this study.

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[Received August 22, 1989, accepted April 12, 1990]