the water content of fresh fruits (75–90%) (see Table I).

It is obvious from the data obtained that most of these foods may have a considerable role in the design of pectin-rich diets if required for medical reasons.

Table III shows the PS content of fruits according to published literature. In general, there is good agreement between our results and published data. Slight variations can be ascribed to the fact that the data of the literature were obtained for fruits with skin while our data were obtained with peeled fruits. In the case of citrus fruit, most of the published data refer to whole fruit or albedo only. Since this portion of the citrus fruit is very rich in PS, the values collected in Table III are clearly higher than those reported in Table II. No information has been found on the PS content of dried, desiccated, or oleaginous fruits.

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LITERATURE CITED

Belo, P. S.; Lumen, B. O. *J. Agric. Food Chem.* **1981**, *29*, 370–373.
Campbell, L. A.; Palmer, G. H. In "Topic in Dietary Fiber Research"; Spiller, G. A.; Amen R. J., Eds.; Plenum Press: New York, 1978.
Dekker, R. F. H.; Richards, G. N. *J. Sci. Food Agric.* **1972**, *23*, 475–483.
Deuel, H.; Stutz, E. *Adv. Enzymol. Relat. Subj. Biochem.* **1958**, *20*, 341–383.
Hardinge, M. G.; Swarner, J. B.; Crooks, H. *J. Am. Diet. Assoc.* **1965**, *46*, 197–204.
Jenkins, D. J. A.; Leed, A. R.; Newton, C.; Cummings, J. H. *Lancet* **1975**, *May 17*, 1116–1117.
Jenkins, D. J. A.; Wolever, T. M. S.; Leeds, A. R.; Gassull, M. A.; Haisman, P.; Dilawari, J.; Goff, D. V.; Metz, G. L.; Alberti, K. G. M. M. *Br. Med. J.* **1978**, *1*, 1391–1394.
Kerstez, Z. I. "The Pectic Substances"; Interscience: New York, 1951.
Keys, A.; Grande, F.; Anderson, J. T. *Proc. Soc. Exp. Biol. Med.* **1961**, *106*, 555–558.
Koo, S. I.; Stanton, P. *Nutr. Rep. Int.* **1981**, *24* (2), 395–401.
Krause, M.; Bock, W. *Ernaehrungsforschung* **1973**, *18*, 111–123.
Labayle, D.; Chaput, J. C.; Buffer, C.; Rousseau, C.; François, P.; Etienne, J. P. *Nouv. Presse Med.* **1980**, *9*, 223–225.
Leeds, A. R.; Ebied, F.; Ralphs, D. N. L.; Metz, G. *Lancet* **1981**, *1*, 1075–1078.
McCready, R. M.; McComb, E. A. *Anal. Chem.* **1952**, *24*, 1986–1988.
Money, R. W.; Christian, W. A. *J. Sci. Food Agric.* **1950**, *1*, 8–12.
Palmer, G. H.; Dixon, D. G. *Am. J. Clin. Nutr.* **1966**, *18*, 437–442.
Pilnik, W.; Voragen, A. G. J. In "The Biochemistry of Fruits and Their Products"; Hulme, A. C., Ed.; Academic Press: London, 1970; Vol. I.
Ross, J. K.; Leklem, J. E. *Am. J. Clin. Nutr.* **1981**, *34*, 2068–2077.
Southgate, D. A. T. "Determination of Food Carbohydrates"; Applied Science Publishers: London, 1976.
Spiller, G. A.; Chernoff, M. C.; Hill, R. A.; Gates, J. E.; Nasar, J. J.; Shipley, E. A. *Am. J. Clin. Nutr.* **1980**, *33*, 754–759.
Surikova, V. V.; Kondrashevich, V. R.; Shklyar, G. A.; Bragadarova, Z. K. *Zdravookhr. Beloruss.* **1977**, *12*, 42–43.
Taton, J. *Diabetologia* **1981**, *21* (*3*), 335.
Williams, K. T.; Bevenue, A. *J. Agric. Food Chem.* **1954**, *2*, 472–474.
Worth, H. G. J. *Chem. Rev.* **1967**, *67*, 465–473.
Zilversmit, D. B. In "Nutrition, Lipids and Coronary Heart Disease. A Global View"; Levy, R. I.; Dennis, B. H.; Rifkind, B. M.; Ernst, N., Eds.; Raven Press: New York, 1979; Vol. I.

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Seasonal and Regional Variation in the Quantitative Composition of Cold-Pressed Lemon Oil from California and Arizona

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Cold-pressed peel oils from California and Arizona lemons were analyzed by glass capillary gas chromatography. Thirty-eight components were determined in early-, mid-, and late-season desert and coastal fruit by using the internal standard method. Several of these, including β-pinene, limonene, neral, geranial, nonanal, linalool, and geranyl acetate, showed large variations in concentration as a function of either maturity or geographic origin of the fruit. Climatic differences between the two growing regions are presumed to be most responsible for the compositional differences observed.

About one-fourth of the world's lemon crop is now produced in the United States ("Citrus Fruit Industry Statistical Bulletin", 1981). Virtually all of this production is confined to the citrus growing regions of California and Arizona. Currently, 40–50 million, 38-lb cartons of lemons per year are harvested in these regions. On average, about half of this crop is not suitable for the fresh fruit market, being either incorrectly sized or cosmetically defective, and is diverted to the processing plant. Cold-pressed lemon oil is the most valuable commodity derived from this "products fruit".

Although Argentina and Brazil are steadily increasing their processing capacity, lemon oil from California and Arizona still represents about 40% of world production. Because of cooperative marketing agreements, most of this oil is blended prior to sale, usually to meet the specifications of the Food Chemicals Codex or other user specifications. Large-scale bulking and blending eliminates or minimizes yearly variation in physicochemical and organoleptic properties.

Recently, we applied the technique of glass capillary gas chromatography to the quantitative analysis of a typical, blended, cold-pressed lemon oil derived from California and Arizona fruit (Staroscik and Wilson, 1982). The concentrations of 37 components were determined and the results compared to those obtained earlier by packed-

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Table I. Seasonal and Regional Variation in the Composition (Weight Percent) of California-Arizona Lemon Oil

	coastal			desert		
component[a]	early	mid	late	early	mid	late
heptanal	0.004	0.004	0.004	tr	tr	tr
α-thujene	0.45	0.44	0.44	0.34	0.36	0.35
α-pinene	2.11	2.14	2.15	1.41	1.50	1.49
camphene	0.07	0.08	0.07	0.03	0.03	0.03
sabinene	2.48	2.61	2.68	1.09	1.11	1.17
β-pinene	15.62	17.29	16.58	5.38	6.07	6.44
6-methyl-5-hepten-2-one	tr	tr	tr	tr	tr	tr
myrcene	1.28	1.22	1.33	1.77	1.74	1.74
octanal	0.14	0.14	0.10	0.04	0.09	0.09
α-phellandrene	0.04	0.04	0.04	0.04	0.04	0.04
3-carene	0.004	0.004	0.006	tr	tr	tr
α-terpinene	0.32	0.32	0.28	0.26	0.27	0.26
p-cymene	0.03	0.03	0.03	0.02	0.02	0.03
limonene	60.36	58.47	59.92	76.48	75.74	76.30
γ-terpinene	9.78	9.74	9.39	7.80	8.03	7.90
octanol	0.02	0.02	0.03	0.03	0.01	0.01
terpinolene	0.39	0.38	0.36	0.37	0.36	0.35
linalool	0.13	0.15	0.21	0.20	0.12	0.09
nonanal	0.21	0.27	0.21	0.06	0.06	0.06
citronellal	0.09	0.08	0.08	0.06	0.09	0.09
terpinen-4-ol	0.07	0.16	0.10	0.06	0.06	0.05
α-terpineol	0.17	0.27	0.26	0.23	0.13	0.09
decanal	0.07	0.07	0.05	0.02	0.05	0.06
octyl acetate	0.006	0.007	0.004	tr	0.002	0.003
nerol	0.02	0.04	0.04	0.05	0.02	0.02
neral	0.74	0.89	1.07	0.84	0.54	0.41
carvone	0.006	0.008	0.006	0.007	0.007	0.008
geraniol	0.03	0.05	0.04	0.02	0.02	0.03
geranial	1.21	1.44	1.70	1.28	0.88	0.68
nonyl acetate	0.02	0.02	0.01	0.002	0.002	0.002
citronellyl acetate	0.03	0.02	0.01	0.01	0.03	0.04
neryl acetate	0.51	0.57	0.60	0.32	0.51	0.55
geranyl acetate	0.61	0.72	0.61	0.15	0.21	0.24
dodecanal	0.03	0.03	0.02	0.007	0.01	0.02
caryophyllene	0.23	0.23	0.26	0.27	0.22	0.21
trans-α-bergamotene	0.40	0.40	0.35	0.34	0.42	0.41
α-humulene	0.02	0.02	0.02	0.02	0.02	0.02
β-bisabolene	0.61	0.62	0.53	0.50	0.62	0.61
total hydrocarbons	94.39	94.03	94.44	96.12	96.55	97.35
total aldehydes[b]	2.49	3.07	3.23	2.31	1.72	1.41
total aldehydes[c]	2.6	2.9	3.2	2.3	1.8	1.4

[a] The components are listed in order of their retention on SE-54. [b] Sum of aldehyde in Table I. [c] Determined by the hydroxylamine method ("Food Chemicals Codex", 1981) and calculated as citral.

column methods. Here, we apply the same technique to study the effect of fruit maturity and climate on the composition of peel oil from the two principal lemon growing regions of these states.

MATERIALS AND METHODS

Cold-pressed lemon oil was extracted at a citrus processing plant in either Yuma, AZ, or Corona, CA. Each sample represents a composite of 1 day's production. The Arizona plant processes only desert fruit, while the California plant processes both desert and coastal fruit, as well as a minor amount of fruit from the interior valley. Though there was no practical way to control the type of fruit delivered to the California plant on a given day, it was possible to retrospectively select composite samples from days on which a minimum of 95% of the lemons processed were from the coastal region. In this way, lemon oils from early- (May 15, 1980), mid- (July 16, 1980), and late-season (Oct 3, 1980) coastal and early- (Sept 26, 1980), mid- (Dec 15, 1980), and late-season (March 14, 1981) desert fruit were obtained.

After extraction, composite samples were checked for angular rotation at 25 °C and total aldehydes by the hydroxylamine method ("Food Chemicals Codex", 1981).

The method for analytical gas chromatography has been described (Staroscik and Wilson, 1982). Oil samples and the calibration mixture were injected in triplicate and the results averaged. The chromatographic system was recalibrated at the start of each day and after completion of each set of sample replicates.

RESULTS AND DISCUSSION

Marked compositional differences exist between cold-pressed lemon oil obtained from desert fruit and that from fruit grown in the coastal region. Of the 38 components listed in Table I, several show enough variation in concentration to significantly affect either the physicochemical or organoleptic properties of their respective sources. Most apparent is the variation in the relative amounts of β-pinene and limonene. These two hydrocarbons are the main contributors to the optical rotation displayed by lemon oil (Stanley et al., 1961). The characteristically lower angular rotations (at 25 °C) of the early- (+54.8°), mid- (+51.0°), and late-season (+53.8°) coastal lemon oils compared to the early- (+74.5°), mid- (+73.9°), and late-season (+73.8°) desert oils are undoubtedly due to the much greater percentage of β-pinene in the former.

Citral (neral plus geranial) is the main contributor to lemon flavor and aroma, and commercially, the concentration of citral is by far the most important factor in determining the value of a lemon oil sample. For routine evaluation, citral is usually determined by the hydroxylamine titration method ("Food Chemicals Codex", 1981), which is nonspecific and actually determines total aldehydes calculated as citral. We found that both early-season desert and coastal oils had approximately the same citral content. However, as their respective seasons progress, oil from coastal fruit enjoyed a large increase in citral (1.95 → 2.77%, determined chromatographically), while oil from desert fruit suffered a large loss (2.12 → 1.09%). As indicated in Table I, total aldehyde concentration showed a similar pattern. The correlation between total aldehyde concentration determined by glass capillary gas chromatography and that determined by the hydroxylamine method was unexpectedly good and should probably not be anticipated for other essential oils without experimental verification.

Large seasonal or regional variation is seen in the amounts of linalool, nonanal, and geranyl acetate, among others. While no work has been reported relating the concentrations of these minor components to lemon flavor quality, a comprehensive work on citrus science (Shaw, 1977) suggests that relative amounts of these substances will affect organoleptic properties. Coastal oils are richer in oxygenated components, which usually have a stronger sensory impact, the desert oils being higher in total hydrocarbons.

Influence of Variables on Oil Composition. Our samples were composites representative of a 24-h production period at a citrus processing plant. Typically, culls from at least 20 packinghouses arrived during that interval. While the geographic origin of the fruit was known, the many other variables associated with the fruit's origin could not be controlled. Hence, a thoroughly systematic explanation of the compositional differences observed is not possible. However, we can speculate on the relative contributions of the variables involved.

Two horticultural varieties (cultivars) of *Citrus limon*, Lisbon and Eureka, account for essentially all lemons grown commercially in California and Arizona. Coastal fruit is composed of nearly equal numbers of these two varieties, but desert plantings are almost exclusively Lisbon. For each variety several selections have been identified and propagated on several disease-resistant rootstocks. Soils can range from sand to clay. Average tree age is somewhat greater in the coastal than in the desert region.

Though all of the above factors may affect the chemical composition of the cold-pressed oil, we feel that climatic effects are of greatest importance in the present study. A detailed description of the climatic characteristics of the California and Arizona citrus growing regions has been given by Burke (1967). Briefly, the coastal region, which extends about 25 miles inland from Mexico to Santa Barbara, has a mild, Mediterranean climate. Cool summers, mild winters, fogs, and high humidity characterize this area. The desert region of southeastern California and around Yuma, AZ, has much higher average temperatures, very low humidity, and more intense solar radiation. The growing region near Phoenix, AZ, is somewhat cooler and more humid than that near Yuma but still definitely desert. Other authors (Swisher, 1966; Hodgson, 1967) have emphasized the importance of environmental factors over varietal differences in determining the chemical composition and morphology of the lemon. Despite the uncontrolled variables in the present study, the distinct difference in geographical, and hence climatic, origin of the fruit seems to correlate well with the distinct differences in chemical composition of the expressed oils.

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LITERATURE CITED

Burke, J. H. In "The Citrus Industry"; Reuther, W.; Webber, H. J.; Batchelor, L. D., Eds.; University of California: Berkeley, CA, 1967; Vol. 1, Chapter 2.

"Citrus Fruit Industry Statistical Bulletin"; Sunkist Growers, Inc.: Ontario, CA, 1981.

"Food Chemicals Codex", 3rd ed.; National Academy Press: Washington, DC, 1981; p 168.

Hodgson, R. W. In "The Citrus Industry"; Reuther, W.; Webber, H. J.; Batchelor, L. D., Eds.; University of California: Berkeley, CA, 1967; Vol. 1, Chapter 4.

Shaw, P. E. "Citrus Science and Technology"; Nagy, S.; Shaw, P. E.; Veldhuis, M. K., Eds.; Avi Publishing Co.: Westport, CT, 1977; Vol. 1, Chapter 11.

Stanley, W. L.; Ikeda, R. M.; Cook, S. *Food Technol. (Chicago)* **1961**, *15*, 381.

Staroscik, J. A.; Wilson, A. A. *J. Agric. Food Chem.* **1982**, *30*, 507.

Swisher, H. E. *Perfum. Essent. Oil Rec.* **1966**, 771.

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