Search for New Industrial Oils: XVI. Umbelliflorae—Seed Oils Rich in Petroselinic Acid

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ABSTRACT

Seed oils of the order Umbelliflorae, including those from the families Umbelliferae, Garryaceae, Araliaceae, Cornaceae, Davidiaceae, Nyssaceae and Alangiaceae, were analyzed for fatty acid composition by gas liquid chromatography (GLC) of their methyl esters. The characteristic fatty acid of the order, petroselinic acid, occurred in the Umbelliferae in amounts up to 85%. In the Araliaceae, the content was as high as 83% and in the Garryaceae as high as 81%. The other major acids were palmitic, oleic and linoleic acids, with small amounts of hexadecenoic, stearic, linolenic, and, in some cases, C_{20} acids. Petroselinic acid was determined by microscale ozonolysis of the C_{18} monoenoic esters and subsequent GLC of the ozonolysis products. The occurrence of high oil contents (up to 46%) combined with exceptionally high (up to 83%) single component purity is notable and emphasizes the potential of the Umbelliflorae as a raw material source for the chemical industry.

INTRODUCTION

The fatty acid compositions of a number of Umbelliferae seed oils have been investigated (1-7). In these reports, petroselinic (*cis*-6-octadecenoic) acid (PA) has generally been found to be the dominant constituent. The unusual position of the double bond in this fatty acid provides an opportunity for production, through cleavage of this bond, of valuable raw materials lauric and adipic acids. The U.S. has no domestic source of lauric acid and, in 1979, imported about 1 billion lb (8) of lauric-rich oils, about half of which goes into surfactants and the other half into edible products.

Although domesticated umbellifers currently could produce large amounts of petroselinic acid (20% of celery seed [66% PA at 30% oil], *Apium graveolens*, is petroselinic acid), many wild umbellifers such as *Bifora radians* can produce even greater amounts and should be investigated agronomically.

A North American shrub, *Garrya*, is of particular interest. Although the alkaloids of *Garrya* have been extensively characterized (9), the lipids have not been examined previously. We have found the seeds of this family to be rich in both petroselinic acid and oil content.

With these considerations in mind, the large variety of Umbelliflorae seed samples available in our collection were analyzed for the express purpose of identifying seed species containing large amounts of petroselinic acid.

EXPERIMENTAL PROCEDURES

Seeds were stored at 4 C from reception to time of anaysis (0-5 years). Seed samples were prepared for analysis and analyzed for oil and nitrogen content by standard AOCS methods (10). Oil compositional analyses were conducted as previously described (11). Methyl esters of the fatty acids were prepared (12) and analyzed by gas liquid and thin layer chromatography (GLC and TLC) (11,13). The esters were separated according to degree of unsaturation on TLC plates coated with a 1-mm thick layer of 20% $AgNO_3$ in Silica Gel G. Either benzene or a 50:50 mixture of benzene/chloroform was used as the developing solvent, which was allowed to move 15 cm. The monoenoid ester bands were scraped from the plate, and the esters were recovered from the adsorbent with diethyl ether. The ether was removed under nitrogen on a hot water bath and the esters, thus isolated, were analyzed by GLC as just described. The relative abundance of positional isomers in these esters was determined by ozonolysis-GLC procedures (7,14).

RESULTS AND DISCUSSION

Seed and oil analyses of Umbelliflorae samples are given in Table I. GLC of the esters from many samples revealed the presence of unusual compounds for which the equivalent chain lengths (ECL) (13) did not correspond to any species of the homologous series of straight-chain esters usually obtained from seed oils. These components were assumed to be part (or all) of the essential oils present in many umbelliferous seeds (15) and carried over into the ester preparations and usually eluted before the normal esters. Since we were unable to ascertain whether the ester samples contained representative proportions of the essential oils, the fatty acid compositions given were normalized to exclude these unusual constituents.

Petroselinic Acid (PA) Content

A limited number of samples each of the Nyssaceae, Cornaceae and Davidiceae was available for analysis, and PA was found in only one species within these families (*Aucuba japonica*). However, almost all species analyzed from the other families (Umbelliferae, Araliaceae, Garryaceae) contained PA. The range and average of PA in these 3 families are given in Figure 1, in which the Umbelliferae samples are also presented by tribes. Those tribes from which we obtained a fairly large number of samples appear to be quite similar in range and average and are consistent with the family plotted as a whole. The Dauceae and Saniculae tribes are represented primarily by *Daucus* and *Eryngium* species, respectively. These 2 genera are relatively high in PA and, therefore, their tribes have a higher average PA content.

In Figure 2, the distribution of PA in the Umbelliferae samples is given. Disregarding those samples which contained no or little PA, 2 separate maxima at 51-55% and 69-77% are apparent. When those tribes represented by more than 20 samples were plotted individually, they gave similar patterns. The Dauceae exhibited a single maximum at the higher range, again due to the paucity of genera other than *Daucus* representing this tribe.

As many of the Umbelliferae are already cultivated for food or food additives, they, as well as other members of the family, may have potential as industrial crops. This is especially true if those that have the desirable combination of high oil content in their seeds and high PA content in their oils also prove to have favorable agronomic characteristics. Table II lists the species in the Umbelliferae with the highest amount of petroselinic acid found in this study.

TABLE I

Composition of Umbelliflorae Seed

Sample no.[a]	Family and species	Component analyzed[d]	wt/1000 (g)	Dry basis % Oil	Dry basis % Protein	HBE[c]	RI	Fatty acid composition (%) IV	16:0	18:0	18:1[b,d]	18:1[b,d]	18:2	18:3	Others[e] #	Others[e] %
	Alangiaceae															
IN62166	*Alangium salviifolium* (L.F.) Wang	Seed	21.4	7.0	22.1	3.7			18.1	6.6		25.2	42.4	2.2	9	5.4
	Nyssaceae															
US47212	*Camptotheca acuminata* Decne.	S+P	38.4	14.0	12.4	1.6	1.4761	144	9.1	3.9		14.0	21.0	53.0	1	0.2
HE48819	*Nyssa aquatica* L.	Seed & endocarp	501.0	5.6	4.7	3.4			8.7	3.3		12.0	36.0	38.0	3	2.0
US41023	*Nyssa ogeche* Bartr. ex Marsh.	Seed	329.0	8.3	5.8				8.6	3.6		13.0	36.0	39.0	5	0.6
	Davidiaceae															
US62538	*Davidia involucrata* Baill.		120.0	39.5	6.4				4.8	1.5		18.5	32.1	42.0	6	1.1
	Cornaceae															
HE33788	*Aucuba japonica* Thunb.	S+P	287.0	0.8	8.8				17.7	1.0	33.3	13.8	10.2	11.5	3	12.2
–47100	*Cornus canadensis* L.	S+P	8.9	7.6	5.9	0.8			1.5	0.7		16.9	78.3	1.0	3	1.6
–22217	*Cornus florida* L.	S SC	12.0	43.3	35.3			139	7.1	2.4		17.4	72.6	0.4	1	0.1
PA46582	*Cornus macrophylla* Wall. ex Roxb.	S+P	59.8	6.6	5.2	1.8			12.8	3.4		27.9	52.5	2.0	7	1.4
TU41729	*Cornus mas* L.	Seed	30.5	7.3	4.1				7.6	3.5		16.0	68.7	1.5	7	2.6
KO49283	*Cornus officinalis* Sieb. + Zuuc.	Seed + endocarp	40.0	7.6	5.2	0.6			6.4	2.1		17.6	71.5	1.1	8	1.3
YU45139	*Cornus sanguinea* L.	S+P	7.4	17.7	6.4	1.1	1.4678	117	14.1	1.4		34.6	47.2	2.1	1	0.6
TU46117	*Cornus sanguinea* L. Subsp. *Australis* (C.A. Mey.) Jav.	S+P	65.0	19.5	7.8	1.6	1.4665	110	19.2	0.6		31.0	47.3		1	
	Garryaceae															
US62668	*Garrya congdonii* Eastw.		11.0	21.8	12.1				1.9	1.0	77.0	9.0	6.3	1.4	4	3.5
US62670	*Garrya fremontii* Torr.		13.2	34.3	8.6				1.8	1.0	81.7	8.7	4.4	0.6	4	2.4
US62671	*Garrya fremontii* Torr.		21.7	23.2	8.4				1.8	1.1	78.4	9.5	6.1	0.8	4	2.7
US62672	*Garrya lindheimeri* Torr.		40.0	21.5	11.2				2.0	1.7	80.5	8.0	4.3	1.0	4	2.4
US62699	*Garrya veatchii* Kell.		17.7	21.1	15.9				2.1	0.4	76.2	8.9	5.2	2.0	4	5.2
	Araliaceae TRIBE Schefflereae															
HE31265	*Acanthopanax spinosus* (L.F.) Miq.	Seed	3.0	36.6	30.6	0.7	1.4648	98	3.3	1.4	70.2	8.0	16.3		1	0.4
JA48889	*Dendropanax trifidus* (Thunb.) Makino	Seed	18.5	34.0	14.5	2.0	1.4625	84	3.7	0.8	83.3	3.7	7.3	0.7	2	0.4
HE48764	*Fatsia japonica* (Thunb.) Decne + Planch.	Seed	6.3	23.4					2.8	0.9	83.2	4.6	7.4	0.1	3	1.0
HE33784	*Hedera helix* L.	Seed	19.5	35.1	16.2	0.3	1.4630	97	2.8	1.7	79.3	7.7	8.0	0.1	2	0.4
PA47190	*Hedera nepalensis* K. Koch	Seed	14.7	22.6	17.4	2.1	1.4656	94	1.7	tr	75.9	15.6	6.7		1	0.1
JA48897	*Hedera rhombea* (Miq.) Bean	Seed	22.5	29.2	15.3	1.6	1.4686	138	8.4	3.1	1.5	11.2	75.1	0.2	3	0.5
HS42551	*Kalopanax septemlobus* (Thunb.) Koidz.	Seed	2.3	21.7	13.2	2.4	1.4644	90	7.2	1.6	63.2	10.0	16.3	0.3	3	1.5
	TRIBE Aralieae															
PA47440	*Aralia cachemirica* Decne.	S+P	7.9	22.0	14.1	1.3	1.4654	97	13.8	0.5	39.5	22.8	22.5	0.6	2	0.2
HE48799	*Aralia elata* (Miq.) Seem.	Seed	0.7	29.0	13.4	1.4	1.4650	99	2.8	0.9	70.0	7.6	18.0		3	0.4
US61095	*Aralia hispida* Vent.	Seed	5.1	15.6	4.7	1.0			2.4	0.6	45.4	11.3	38.7	0.4	7	1.2
–19765	*Aralia spinosa* L.	Seed	16.0	46.3	17.5		1.4624	96	2.8	1.1	71.1	10.2	14.3		1	0.5
	Umbelliferae Subfamily Hydrocotyloidea TRIBE Hydrocotyleae															
UR47346	*Hydrocotyl bonariensis* Lam.	S+P	1.2	14.6	10.6	1.4	1.4665	99	5.7	0.7	73.6	4.3	15.3	0.2	2	0.2
HE31261	*Trachymene caerulea* R. Grah.	S+P	1.9	37.4	22.5	0.1			4.8	1.8	76.3	6.6	8.4	0.5	3	1.5
	TRIBE Mulineae															

PA43347	*Bowlesia incana* Ruiz + Pav.	S+P	0.8	9.9	14.4	0.3	1.4663	112	18.3	2.7		25.2	53.3	0.1	4	0.2
	Subfamily Saniculoideae															
	TRIBE Saniculeae															
TU46848	*Actinolema eryngioides* Fenzl	S+P	5.8	40.4	16.8	1.4	1.4740	144	3.8	0.6	59.6	21.5	13.8		2	0.5
TU43458	*Actinolema macrolema* Boiss.	S+P	5.2	34.6	17.5	6.4	1.4765	140	6.6	1.7	43.7	26.9	18.9		3	1.3
TU42366	*Astrantia maxima* Pall.	S+P	2.8	39.2	28.9	0.6	1.4633	96	5.6	0.6	63.3	16.1	13.9		3	0.4
PA60588	*Eryngium caeruleum* Bieb.	S+P	0.9	21.3	12.1	0.7			8.0	1.1	50.5	15.9	23.2		6	1.6
SP46675	*Eryngium campestre* L.	S+P	1.4	26.7	25.9	1.5	1.4660	112	4.8	0.9	55.5	11.3	26.9		2	0.5
TU41345	*Eryngium creticum* Lam.	S+P	1.2	9.1	15.9	0.5	1.4661	101	5.8	2.4	54.2	13.6	22.6	0.1	4	0.9
UR47121	*Eryngium ebracteatum* Lam.	S+P	1.2	13.6	15.5	3.4	1.4719	122	5.8	1.6	70.1	8.6	13.5	0.1	1	0.1
UR43332	*Eryngium eburneum* Decne.	S+P	0.9	19.1	15.2	3.8	1.4742	116	5.4	1.9	73.8	4.7	13.2	0.3	3	0.6
UR47334	*Eryngium elegans* Cham. + Schlecht.	S+P	0.7	22.4	20.6	8.7	1.4666	124	4.1	1.1	76.3	4.3	13.9		1	0.1
–17315	*Eryngium giganteum* Bieb.	S+P	6.6	26.7	20.9		1.4644	108	4.1	0.1	54.2	14.0	26.8	0.2	2	0.3
TU43237	*Eryngium maritimum* L.	S+P	13.7	9.2	15.6	6.1	1.4878	118	8.2	1.2	46.6	10.8	30.5	0.8	3	2.0
UR43354	*Eryngium nudicaule* Lam.	Seed	0.5	34.2	35.6	0.2	1.4631	94	4.1	1.2	74.9	6.1	13.5	0.1	3	0.4
UR43808	*Eryngium pandifolium* Cham. + Schlecht	S+P	0.6	25.9	17.2	2.0	1.4643	93	5.0	0.8	75.2	5.2	13.5	0.1	1	0.1
UR43805	*Eryngium paniculatum* Cav. + Dombey ex Delar.	S+P	0.8	14.5	16.4	19.7	1.4672	92	4.2	0.6	77.7	4.5	12.5		1	0.3
HS40649	*Eryngium planum* L.	Seed	0.9	27.9	30.0	0.3	1.4677	124	5.2	0.9	30.3	14.9	47.1	0.4	1	1.0
UR47123	*Eryngium sanguisorba* Cham. + Schlecht.	S+P	0.3	25.7	18.3	2.3	1.4680	122	4.8	0.3	76.1	5.5	12.9		1	0.3
KO46738	*Sanicula chinensis* Bunge	S+P	4.2	25.2	23.6	2.1	1.4654	112	2.5	0.1	65.8	12.7	18.8		2	0.1
US47104	*Sanicula marilandica* L.	S+P	7.1	33.2	22.7	1.9	1.4652	110	2.6	0.2	55.5	15.1	26.3	0.1	1	0.1
	TRIBE Lagoeciae															
TU43253	*Lagoecia cuminoides* L.	Seed	0.4	24.5	26.7	0.4	1.4646	95	3.3	0.8	79.0	4.4	12.0		2	0.3
	Subfamily Apioideae															
	TRIBE Echinophoreae															
SP45597	*Echinophora spinosa* L.	S+P	13.0	33.6	27.5	1.5	1.4652	109	3.8	0.9	53.6	15.8	24.8	0.3	2	0.5
	TRIBE Scandicineae															
	Subtribe Scandicinae															
TU44706	*Anthriscus caucalis* Beib.	S+P	0.4	20.8	17.2	0.3	1.4637	97	4.2	0.6	68.9	6.4	19.3		3	0.4
19120	*Anthriscus cerefolium* (L.) Hoffm.	S+P	2.1	15.6	18.8	0.3	1.4648	108	8.1	1.1	48.8	6.6	34.5		3	0.4
YU43753	*Anthriscus cerefolium* (L.) Hoffm.	S+P	2.0	25.5	24.2	0.5	1.4654	102	4.0	1.5	70.2	9.6	14.0		3	0.7
KO46437	*Anthriscus nemorosa* (Beib.) Spreng.	S+P	3.6	17.6	22.1	1.1	1.4653	103	3.1	0.1	66.8	4.7	24.8	0.2	1	0.1
YU43643	*Anthriscus sylvestris* (L.) Hoffm.	S+P	3.0	21.8	21.1	0.3	1.4662	107	3.3	0.9	55.7	11.7	28.0	0.1	2	0.3
TU43475	*Chaerophyllum aromaticum* L.	S+P	16.0	15.9	23.8	11.2	1.4725	126	12.2	2.0		51.1	34.2	0.2		
YU46974	*Chaerophyllum aureum* L.	S+P	5.6	10.7	22.7	13.8	1.4722	135	9.0	1.7		37.9	51.0	0.3	1	0.1
YU45702	*Chaerophyllum bulbosum* L.	S+P	2.5	15.2	23.5	9.4	1.4716	136	9.4	1.9		25.6	61.5	0.3	3	0.7
YU45172	*Chaerophyllum coloratum* L.	S+P	7.8	14.2	19.4	19.7	1.4909	161	12.4	3.0		21.8	62.7			
TU46936	*Chaerophyllum crinitum* Boiss.	S+P	7.9	13.2	14.1	3.1	1.4672	114	6.7	0.9	18.1	37.4	36.2	0.1	2	0.5
PA45814	*Chaerophyllum reflexum* Lindl.	S+P	9.0	14.8	21.6	8.5	1.4699	113	12.1	2.3		48.5	36.6	0.1	1	0.4
US40922	*Chaerophyllum tainturieri* Hook	S+P	1.9	9.1	14.9	9.4	1.4714	126	7.2	0.8	34.1	29.4	27.6		1	0.8
PA45495	*Chaerophyllum villosum* Wall. ex DC.	S+P	6.0	5.6	19.4	10.2	1.4706	108	8.5	1.9		61.0	26.7	1.6	1	0.1
TU47743	*Grammosciadium platycarpum* Boiss. + Haussk.	S+P	28.3	22.0	14.3	2.4	1.4676	133	5.3	1.0	34.6	22.3	36.2	0.1	1	0.2
YU43703	*Myrrhis odorata* (L.) Scop.	S+P	40.5	12.6	24.1	0.9	1.4650	96	3.7	0.8	73.2	5.3	16.0	0.1	4	0.8
YU45099	*Myrrhoides nodosa* (L.) Cannon	S+P	12.3	8.3	16.3	11.5	1.4697	130	12.1	1.4	1.0	26.0	59.3		1	0.1

– Continued –

[a]Two letter prefix indicates source of seed. IN = India; US = USA; HE = Herbst Bros., NY; PA = Pakistan; TU = Turkey, KO = Korea; JA = Japan; UR = Uruguay; SP = Spain; HS = Harry Saier, MI; YU = Yugoslavia; TA = Tanzania; IS = Israel; ME = Mexico; SA = Union of South Africa; ET = Ethiopia; – = unknown.

[b]S+P = seed + pericarp, S-SC = seed seedcoat.

[c]HBE = hydrogen bromide equivalent; RI = refractive index; IV = iodine value; PA = petroselinic acid.

[d]$18:1^6$ = petroselinic acid; $18:1^9$ = oleic acid.

[e]Other fatty acid methyl esters eluting from GC columns; # = number of components.

TABLE I- Continued

Sample no.[a]	Family and species	Component analyzed[d]	wt/1000 (g)	Dry basis		HBES[e]	RI	IV	Fatty acid composition (%)							
				% Oil	% Protein				16:0	18:0	18:1[b,d]	18:1[b,d]	18:2	18:3	Others[c] #	Others[c] %
US47075	*Osmorhiza aristata* (Thunb.) Makino var. *Lava* (Royle) Const. + Shan	S+P	10.5	7.3	20.1	1.9			4.4	0.4	50.8	7.8	36.3		3	0.2
US41907	*Osmorhiza chilensis* Hook. + Arn.	S+P	6.3	8.5	24.7	1.2	1.4645	96	3.9	0.3	72.6	7.3	15.2		2	0.7
US49447	*Osmorhiza longistylis* (Torr.) DC.	S+P	11.7	6.0	24.7	0.8			3.8	1.4	52.7	5.9	35.1		4	1.1
US41014	*Osmorhiza occidentalis* (Nutt.) Torr.	S+P	13.7	10.4	20.8	0.4	1.4663	106	2.8	0.9	58.6	11.5	25.8	0.2	2	0.2
TU44587	*Scandix iberica* Bieb.	S+P	15.2	4.4	18.2	1.7	1.4660	103	11.1	0.9	16.3	43.1	27.8	0.4	2	0.3
YU45198	*Scandix macrorhyncha* C.A Mey.	S+P	10.0	6.5	16.0	1.0	1.4643	95	6.8	0.9	52.1	18.0	21.5	0.2	2	0.3
PA43791	*Scandix pecten-veneris* L. Subtribe Caucalinae	S+P	10.4	7.0	14.3	0.4	1.4657	99	6.3	1.5	55.7	14.3	21.0	0.4	3	0.8
TU46153	*Astrodaucus orientalis* (L.) Drude	S+P	3.6	15.8	17.0	2.3	1.4670	98	3.1	0.3	56.9	21.1	17.9		2	0.3
TA61210	*Caucalis incognita* Norman	S+P	6.1	19.1	19.2	1.1	1.4632	101	3.6	0.4	79.8	4.2	10.0	0.2	7	1.8
YU45683	*Caucalis platycarpos* L.	S+P	27.0	16.0	16.2	0.5	1.4642	95	3.0	0.5	69.2	11.8	15.3		1	0.1
TU44702	*Lisaea heterocarpa* (DC.) Boiss.	S+P	8.8	15.7	14.4	0.2	1.4645	98	4.0	1.7	50.1	22.0	21.1	0.2	4	0.9
TU41247	*Lisaea papyracea* Boiss.	S+P	26.7	17.2	12.4	0.1	1.4646	104	3.2	0.7	53.4	17.8	24.1		2	0.8
YU43425	*Orlaya grandiflora* (L.) Hoffm.	S+P	12.4	11.0	16.4	4.0	1.4706	100	4.0	1.0	62.2	16.6	15.6		2	0.5
PA46282	*Psammogeton biternatum* Edgew.	S+P	0.4	31.6	20.4	1.4	1.4691	115	4.6	1.9	62.2	13.6	17.6		2	0.1
YU45211	*Torilis arvensis* (Huds.) Link	S+P	3.0	20.5	21.2	1.3	1.4652	102	4.0	0.6	73.6	7.8	13.7		1	0.2
IS42104	*Torilis arvensis* (Huds.) Link Subsp. *Neglecta* (Spreng. ex Schult.) Thell.	S+P	1.6	23.0	19.9	0.2	1.4652	106	4.6	0.7	73.8	7.2	13.3		1	0.3
TU43556	*Torilis japonica* (Houtt.) DC.	S+P	1.7	22.8	26.3	1.3	1.4660	105	3.5	1.3	73.8	5.7	14.4	0.7	2	0.4
PA42795	*Torilis leptophylla* (L.) Reichb. F.	S+P	1.7	14.4	16.7	0.8	1.4627	90	4.5	0.7	81.7	3.1	9.7		1	0.1
US33101	*Torilis nodosa* (L.) Gaertn.	S+P	4.0	11.2	20.6	2.0	1.4634	90	5.0	0.6	79.2	3.4	11.6		1	0.1
YU45793	*Turgenia latifolia* (L.) Hoffm. TRIBE Coriandreae	S+P	12.4	36.4	24.8	1.2	1.4646	106	3.8	1.0	56.0	13.3	24.7	0.5	3	0.7
US40924	*Bifora americana* (DC.) Benth. + Hook.	S+P	9.4	17.9	9.1		1.4658	100	3.0	1.0	72.0	6.1	11.6		3	6.0
YU45733	*Bifora radians* Bieb.	S-SC	5.0	49.5	19.6	1.1	1.4627	98	4.4	0.7	74.9	7.9	7.8	12.0	1	0.2
YU45792	*Bifora testiculata* (L.) Spreng. ex Schult.	S-SC.	4.2	41.5	21.9	0.9	1.4627	88	3.6	0.8	81.1	5.7	8.2		1	0.2
TU43232	*Coriandrum sativum* L. TRIBE Smyrnieae	S+P	7.4	22.0	15.0	0.3	1.4644	98	3.9	1.2	71.8	9.4	13.2		3	0.5
TU42340	*Conium maculatum* L.	S+P	4.0	17.5	20.6	0.2	1.4650	102	4.0	0.7	56.3	15.1	23.0	0.1	2	0.6
YU43704	*Grafia golaka* (Hacq.) Reichb.	S+P	3.4	34.5	27.9	0.3	1.4665	119	3.0	0.2	44.2	11.1	40.5	0.1	1	0.3
TU46828	*Heptaptera anacolea* (Boiss.) Tutin	S+P	49.1	12.2	23.8	7.3			10.1	2.1		54.2	31.9	0.4	3	1.2
IS43186	*Heptaptera anisoptera* (DC.) Tutin	Seed	13.9	13.1	30.7	10.6	1.5054	100	9.3	2.5	1.2	45.5	39.4		2	2.2
TU47712	*Heptaptera ciliata* (Boiss. + Bal.) Tutin	S+P	10.9	17.1	18.7	5.7	1.5428	123	12.3	1.2	9.2	38.8	38.2	0.3		
PL42701	*Hippomarathrum bossieri* Reut. + Hausskn.	S+P	15.5	20.2	15.4	1.6	1.4825	82	2.7	2.2	49.0	25.2	20.4		2	0.5
YU45767	*Hippomarathrum cristatum* (DC.) Boiss.	S+P	37.8	8.6	12.2	13.2		82	7.1	1.3	54.4	16.9	19.8	0.3		
TU46810	*Hippomarathrum microcarpum* (Bieb.) Fedtsch.	S+P	20.8	14.1	12.3	38.8			15.0	5.3	6.5	20.5	37.8	6.5	5	8.4

TU43246	*Hippomarathrum pauciradiatum* (Heldr. + Halacsy) Heldr + Halacsy	Seed	18.2	31.3	36.9	10.4	1.4800	89	4.5	0.4	66.0	13.8	14.7	0.2	1	0.4
KO47563	*Pleurospermum camtschaticum* Hoffm.	S+P	4.9	36.9	26.5	1.2	1.4666	116	2.4	0.1	53.8	6.6	36.3		2	0.7
TU46914	*Prangos acaulis* (DC.) Bornm.	Seed	16.9	25.3	35.8	14.1	1.4731	93	9.3	0.4	52.7	20.3	16.2		1	1.1
TU46908	*Prangos asperula* Boiss.	Seed	80.5	26.0	36.4	1.7	1.4661	98	5.6	0.7	53.6	17.4	22.0		1	0.5
TU46911	*Prangos ferulacea* (L.) Lindl.	Seed	19.5	31.8	29.9	7.0	1.4786	97	5.3	0.3	59.2	14.7	19.6		1	0.8
TU47691	*Prangos ferulacea* (L.) Lindl.	S+P	36.1	28.5	34.9	33.2	1.4769	113	6.1	0.8	50.8	20.5	20.1	0.1	2	1.5
PA44006	*Prangos pabularia* Lindl.	S+P	16.1	27.0	33.0	7.7	1.4702	96	6.2	0.8	52.0	15.1	25.2		1	0.6
TU46909	*Prangos pabularia* Lindl.	Seed	49.2	28.7	32.9	7.8	1.4855	108	8.4	0.8	51.8	9.0	28.9		1	0.9
TU46912	*Prangos uloptera* DC.	Seed	22.9	33.6	26.1	18.8	1.4821	96	4.9	0.8	61.6	8.5	21.9	1.7	1	0.3
PA47824	*Scaligeria aitchisonii* H. Wolff	S+P	1.5	17.4	16.6	1.5	1.4641	94	3.8	0.8	75.0	5.6	13.7	0.3	1	0.6
TU42191	*Scaligeria meifolia* (Fenzl) Boiss.	Seed	0.8	26.4	28.4	1.1	1.4913	221	6.5	0.5	56.4	15.1	20.8	0.2	1	0.3
YU47626	*Smyrnium cordifolium* Boiss.	S+P	9.0	26.6	21.4	7.0	1.4896	172	13.9	1.2	19.3	20.5	2.9			
TU43474	*Smyrnium creticum* Mill.	S+P	1.0	22.7	18.5	2.9	1.4686	107	6.3	0.5	60.1	14.7	17.2		2	1.1
YU45173	*Smyrnium olusatrum* L.	S+P	36.7	16.6	17.9	8.8	1.4732	134	7.6	0.5	69.1	7.7	14.2		1	0.7
TU46023	*Smyrnium olusatrum* L.	S+P	33.6	21.2	19.0	2.7	1.4747	140	5.9	0.4	67.1	14.9	11.2		1	0.4
YU43747	*Symrnium perfoliatum* L.	S+P	7.5	16.6	17.9	7.3	1.4714	130	7.8	0.8	49.8	23.2	18.0	0.1	1	0.2
TU44257	*Smyrnium rotundifolium* Mill.	S+P	6.5	15.5	18.4	9.8	1.4774	152	8.4	0.2	44.7	24.9	21.2	0.1	1	0.3
US42817	*Tauschia hartwegii* (Gray) F. Macbr.	S+P	21.8	16.3	21.9	1.1	1.4746	82	3.0	0.5	80.6	5.3	9.9		2	0.4
	TRIBE Apieae															
	Subtribe Apiinae															
TU43216	*Ammi majus* L.	S+P	0.7	19.4	19.1	4.3	1.4630	88	4.0	1.1	57.8	28.2	7.6		1	0.4
US46343	*Ammi topalii* Beauverd	S+P	0.4	19.5					4.8	0.3	47.5	29.5	10.1	1.3	4	6.3
TU41179	*Ammi visnaga* (L.) Lam.	S+P	0.7	15.3	17.3	0.3	1.4675	93	3.8	0.4	69.4	9.7	15.8		2	0.8
US47347	*Ammoselinum giganteum* Coult. + Rose	S+P	1.4	25.7	13.3	2.4	1.4749	109	4.2	0.4	62.2	7.6	25.7		4	0.3
US40809	*Ammoselinum popei* Torr. + Gray	S+P	2.7	7.8	13.1	0.5	1.4838	110	4.4	1.4	60.8	6.4	26.4		1	0.5
—13392	*Apium graveolens* L.	S+P	0.4	30.4	23.3		1.4694	102	6.1	0.5	65.7	7.7	17.8	0.2	2	2.0
UR44799	*Apium leptophyllum* (Pers.) F. Muell.	S+P	0.2	32.4	19.9	1.4	1.4650	90	2.5	0.9	86.5	1.3	7.9		2	0.4
UR42669	*Apium sellowianum* H. Wolff	S+P	0.9	25.6	20.2	2.0	1.4801	102	6.0	1.1	66.7	7.1	18.8		1	0.2
US61598	*Berula erecta* (Huds.) Cov.	S+P	3.0	21.8	17.0	0.8	1.4695	88	4.7	1.3	48.7	18.0	24.5	0.7	8	1.9
TU46000	*Bunium paucifolium* DC.	S+P	9.5	22.2	17.4	1.6	1.4738	140	3.8	0.3	73.2	5.8	15.1	0.5	2	1.1
PA43051	*Bunium persicum* (Boiss.) B. Fedtsch.	S+P	1.4	13.6	19.9	1.5	1.4695	106	6.0	0.1	56.0	13.9	23.0	0.4	2	0.2
TU42168	*Bupleurum croceum* Fenzl	S+P	2.6	9.5	14.9	0.6	1.4647	94	5.4	0.6	44.6	33.7	13.2	0.4	3	1.2
TU41276	*Bupleurum beldreichii* Boiss. + Bal.	S+P	2.0	8.2	15.1	0.3	1.4649	99	5.8	0.9	50.0	19.1	23.3	0.3	2	0.5
PA44128	*Bupleurum lanceolatum* Wall. ex DC.	S+P	4.7	21.4	20.6	1.6	1.4679	98	5.2	0.3	57.2	18.5	18.1		2	0.5
IS42967	*Bupleurum lancifolium* Hornem.	S+P	12.2	6.8	10.3	0.8	1.4630	87	7.0	1.0	41.6	39.3	10.8		1	0.2
TU46887	*Bupleurum lancifolium* Hornem.	S+P	10.0	8.8	12.6	1.9			7.3	2.0	48.2	33.4	8.2		1	0.4
KO44420	*Bupleurum longiradiatum* Turcz	S+P	2.4	27.9	20.1	1.1	1.4718	116	2.5	0.2	59.7	4.0	33.2	0.1	2	0.2
TU46886	*Bupleurum odontites* L.	S+P	0.2	11.6					6.9	0.5	63.5	11.4	13.1	3.6	2	0.9
PA44272	*Bupleurum tenue* Buch.-Ham. ex D. Don	S+P	0.8	17.5	18.2	0.8	1.4670	101	5.9	1.1	54.5	16.8	20.8	0.6	2	0.2
IN61016	*Carum bulbocastrum* (L.) Koch	S+P	1.4	11.7	20.4	2.4			5.7	1.6	52.3	14.8	24.0	0.7	2	0.9

Continued

[a]Two-letter prefix indicates source of seed. IN = India; US = USA; HE = Herbst Bros., NY; PA = Pakistan; TU = Turkey; KO = Korea; JA = Japan; UR = Uruguay; SP = Spain; HS = Harry Saier, MI; YU = Yugoslavia; TA = Tanzania; IS = Israel; ME = Mexico; SA = Union of South Africa; ET = Ethiopia; — = unknown.

[b]S+P = seed + pericarp, S-SC = seed-seedcoat.

[c]HBE = hydrogen bromide equivalent; RI = refractive index; IV = iodine value; PA = petroselinic acid.

[d]$18{:}1^{6}$ = petroselinic acid; $18{:}1^{9}$ = oleic acid.

[e]Components other than fatty acid methyl esters eluting from GC columns; # = number of components.

TABLE I—Continued

Sample no.[a]	Family and species	Component analyzed[d]	wt/1000 (g)	Dry basis		HBE[c]	RI	Fatty acid composition (%)								
				% Oil	% Protein			IV	16:0	18:0	18:1[6 d]	18:1[9 d]	18:2	18:3	Others[e] #	Others[e] %
YU47059	*Carum carvi* L.	S+P	2.0	19.4	21.5	1.6	1.4700	135	5.2	1.1	35.4	24.1	33.9		2	0.2
41018	*Cicuta douglasii* (DC.) Coult. + Rose	S+P	3.9	16.9	25.4	1.6	1.4790	129	4.6	1.1	39.3	14.8	39.5	0.7		
US40862	*Cicuta maculata* L.	S+P	2.6	15.9	23.8	0.3	1.4642	96	4.1	0.4	58.1	18.2	18.9		1	0.4
ME41021	*Cicuta mexicana* Coult. + Rose	S+P	4.1	32.6	16.2	1.8	1.4830	151	4.7	1.2	52.9	18.0	22.0	0.8	2	0.4
PA46506	*Cuminum cyminum* L.	S+P	2.4	32.0	21.4	4.9	1.4682	108	3.1	1.0	52.2	15.4	27.9		2	0.3
41586	*Deverra aphylla* (Chem. + Schlecht.) DC.	S+P	2.3	27.1	19.8	0.7	1.4784	100	3.2	0.2	84.7	3.4	8.0		1	0.4
TU46799	*Foeniculum vulgare* Bernh.	S+P	1.2	11.6	20.1	26.5	1.4834	132	7.7	3.6	48.2	2.3	38.7	0.8	1	0.5
YU45312	*Petroselinum crispum* (Mill.) A.W. Hill	S+P	1.6	25.7	22.0	1.3	1.4765	115	3.7	1.1	71.5	5.3	8.5	9.3	1	0.4
SA19108	*Pimpinella anisum* L.	S+P	2.6	23.9	19.6		1.4715	97	4.7	1.1	48.9	21.7	21.2	0.5	3	1.1
PA47490	*Pimpinella diversifolia* DC.	S+P	1.2	29.4	23.1	9.4	1.4668	111	4.4	0.1	75.4	6.0	13.5		2	0.5
TU44707	*Pimpinella kotschyana* Boiss.	S+P	0.4	18.4	13.6		1.4981	178	10.8	1.0	37.5	20.8	28.6	1.0		
IS42976	*Pimpinella peregrina* L.	S+P	0.5	19.8	22.1	22.5	1.4719	109	5.7	1.2	70.2	6.6	15.6	0.6	1	0.1
YU46975	*Pimpinella saxifrage* L.	S+P	2.4	29.0	23.6	12.1	1.4720	131	4.5	0.5	46.6	16.6	31.4	0.1	1	0.2
PA46594	*Pimpinella stewartii* (Duan) F. Nasir	S+P	0.6	25.2	20.2	4.3	1.4726	116	9.2	1.1	54.5	9.6	24.8	0.2	3	0.5
KO45863	*Pimpinella thellungiana* H. Wolff var. *Gustavobegiana* (Kroidz.) Kitam.	S+P	1.0	24.2	27.3	10.0	1.4794	111	4.3	0.9	42.2	14.1	37.8	0.4	1	0.1
YU46976	*Pimpinella tragium* Vill.	S+P	1.0	27.0	23.1	16.7	1.4740	123	4.2	0.5	52.8	14.0	27.8	0.3	2	0.3
IS42032	*Ridolfia segetum* (L.) Moris	S+P	0.5	12.0	21.2	6.4	1.4713		4.9	0.3	76.1	10.4	7.5		2	0.7
KO48307	*Sium latifolium* L.	S+P	0.9	25.2	20.5	5.5	1.4718	138	4.2	0.6	34.5	13.1	46.9	0.4	1	0.1
KO4421	*Sium sisarum* L.	S+P	1.0	26.2	19.3	2.7	1.4700	128	4.8	0.6	31.1	15.7	47.0	0.4	1	0.2
US48409	*Spermolepis echinata* (Nutt.) Heller	S+P	0.6	28.3	18.1	3.2	1.4685	106	3.5	0.8	65.9	10.7	17.8		6	2.6
US40909	*Spermolepis inermis* (Nutt.) Math. + Const.	Seed	0.5	5.1	17.5	1.8			3.9	0.8	67.8	19.7	0.1		2	1.0
ET46532	*Trachyspermum ammi* (L.) Sprague Subtribe Seselinae	S+P	1.5	28.5	21.6	6.1	1.4710	121	4.5	1.6	61.4	9.7	22.7		1	0.1
YU45264	*Anethum graveolens* L.	S+P	1.7	19.0	16.3	1.2	1.4660	113	3.3	0.6	81.6	7.8	5.8	0.1	2	0.6
US51613	*Anethum graveolens* L.	S+P	2.6	17.8	20.7	1.4	1.4706	121	4.0	0.5	78.0	8.6	8.4	0.1	1	0.2
YU43691	*Athamanta cretensis* L.	S+P	5.0	25.8	25.9	1.5	1.4742	119	5.8	0.8	33.5	20.1	24.3	15.0	3	0.3
KO45853	*Cnidium monnieri* (L.) Cusson	S+P	0.3	39.2	17.4	0.8	1.4680	110	2.1	0.8	58.2	4.5	32.6	0.5	2	0.4
YU45165	*Crithmum maritimus* L.	S+P	1.6	37.0	21.8	3.3	1.4649	98	5.4	1.4	67.3	9.9	14.6		1	1.0
17354	*Foeniculum vulgare* Mill.	S+P	4.3	24.0	19.7		1.4636	91	5.0	1.2	72.9	8.7	11.0	0.2	2	0.5
SP46662	*Foeniculum vulgare* Mill. Subsp. *Piperitum* (Ucria) Coutinho	S+P	3.0	21.7	22.6	1.2	1.4694	96	4.2	0.4	80.1	2.9	11.5	0.1	1	0.3
YU44967	*Ligusticum lucidum* Mill.	S+P	4.8	31.9	27.4	15.4	1.4783	91	3.9	0.4	62.4	16.1	17.1			
US40995	*Ligusticum porteri* Coult. + Rose	S+P	4.2	23.9	26.4	0.8	1.4694	108	4.3	1.1	58.7	11.7	22.8	0.7	1	0.7
US40890	*Limnosciadium pumilum* (Engelm. + Gray) Math. + Const.	S+P	3.8	16.2	12.5	1.2	1.4764	113	3.4	0.3	83.0	3.9	9.2		1	0.1
YU43692	*Meum athamanticum* Jacq.	S+P	6.4	18.5	26.3	1.6	1.4773	131	5.3	0.5	57.9	10.4	20.8	0.7	3	4.3
YU45789	*Oenanthe aquatica* (L.) Poir.	S+P	2.6	22.8	12.2	19.2	1.4804	126	3.5	0.8	59.0	8.9	27.1	0.4		
UR43157	*Oenanthe globulosa* L.	S+P	15.2	8.8	9.6	16.0	1.4720	117	4.9	0.5	74.3	4.4	13.5	0.9	1	0.5
SP42617	*Oenanthe lachenalii* C.C. Gmel	S+P	0.9	22.1	17.6	11.0	1.4664	100	4.1	0.5	68.4	7.5	19.0	0.1	1	0.1
TU44369	*Oenanthe pimpinelloides* L.	S+P	1.8	16.0	13.2	9.7	1.4696	112	3.1	0.5	58.3	10.5	27.4		1	0.2
YU45163	*Oenanthe pimpinelloides* L.	S+P	2.0	11.6	12.0	9.2	1.4711	104	4.3	0.6	72.6	6.3	16.0		1	0.2
TU46158	*Oenanthe silaifolia* Bieb.	S+P	1.7	11.7	16.4	3.4	1.4679	116	4.3	0.8	32.8	22.7	38.2	0.7	2	0.5

YU45166	*Portenschlagiella ramosissima* (Portens.) Tutin	S+P	2.2	38.8	19.2	2.8	1.4815	159	6.0	0.2	52.3	15.6	25.1		3	0.5
YU44961	*Selinum carvifolia* (L.) L.	S+P	1.2	24.3	22.5	8.6	1.4684	105	3.6	0.2	53.0	9.5	33.5			
IN61886	*Selinum wallichianum* (DC.) E. Nasir	S+P	1.8	16.8	29.3	2.2			3.5	1.5	64.6	4.1	23.5	0.5	8	2.1
SP45543	*Seseli cantabricum* Lange	S+P	9.8	14.9	26.6	3.3	1.4756	88	6.3	1.2	35.1	37.1	19.6	0.3	1	0.2
YU43690	*Seseli libanotis* (L.) W. Koch Subsp. *libanotis*	S+P	1.2	26.4	27.9	3.3	1.4742	124	3.5	1.1	45.6	14.8	34.7		1	0.2
TU46203	*Silaum silaus* (L.) Schinz + Thell.	S+P	3.1	14.1	22.1	4.5	1.4687	127	5.8	0.6	13.2	27.2	52.6	0.3		
	TRIBE Peucedaneae															
	Subtribe Angelicinae															
US40993	*Angelica ampla* A. Nels.	S+P	3.9	26.0	29.5	5.2	1.4830	105	4.1	3.3	38.0	16.8	37.1		2	0.9
US46347	*Angelica archangelica* L.	Seed	3.6	28.4	28.0	2.1	1.4737	116	4.5	1.5	42.7	13.3	35.0	2.7	3	0.3
KO48299	*Angelica cartilaginomarginata* (Makino) Nakai	S+P	1.4	28.7	27.4	2.9	1.4715	125	3.6	0.6	43.3	19.0	33.1		1	0.2
KO47550	*Angelica dahurica* (Fisch.) Benth. + Hook.	S+P	2.6	22.2	26.6	2.7	1.4725	121	3.7	0.3	39.1	16.6	40.0		1	0.3
KO44417	*Angelica decursiva* (Miq.) Frach. + Sav.	S+P	3.6	21.8	28.6	6.1	1.4731	112	3.8	0.8	39.9	18.8	34.9		3	1.8
US45524	*Angelica lucida* L.	S+P	6.0	18.2	16.7	19.8	1.4827	111	3.5	0.4	40.8	13.0	42.1		1	0.1
TU43504	*Angelica sylvestris* L.	Seed	1.4	32.2	28.1	1.7	1.4750	114	4.6	0.8	42.1	18.6	33.2	0.2	3	0.4
YU45025	*Angelica sylvestris* L.	S+P	2.4	24.7	26.9	2.2	1.4743	120	4.7	1.1	44.9	10.4	38.3		1	0.3
KO44419	*Angelica takesbimana* Nakai	S+P	4.2	19.0	19.4	2.3	1.4677	98	5.6	0.9	64.8	4.0	23.6		1	0.6
HS40662	*Levisticum officinale* Koch	S+P	2.0	14.7	20.0	1.0	1.4762	118	4.6	1.3	42.8	14.1	34.8	0.9	2	1.3
KO47551	*Ostericum sieboldii* (Miq.) Nakai	S+P	2.6	25.1	27.7	1.3	1.4688	117	3.7	0.2	50.8	12.1	32.8		1	0.2
	Subtribe Peucedaninae															
PA42845	*Ducrosis anethifolia* (DC.) Boiss.	S+P	2.7	11.6	13.4	28.1	1.4683	106	6.6	1.7	66.4	11.8	10.7	1.3	2	1.5
TU43444	*Ferula assa-foetida* L.	S+P	25.3	10.4	20.1	1.0	1.4675	90	3.8	1.0	76.5	5.3	12.8	0.1	1	0.5
IS42076	*Ferula communis* L.	S+P	15.5	9.2	28.3	1.0	1.4781	70	4.3	1.1	78.1	4.4	10.5	0.9	1	0.7
YU45167	*Ferula comminus* L. Subsp. *Glauca* Rouy + Camus	S+P	23.2	13.7	23.3	9.3	1.4806	79	7.7	0.9	70.8	8.8	11.8	0.2	1	0.2
US41059	*Ferula galbaniflua* Boiss. + Buhse	S+P	23.0	46.9	13.1	3.1	1.5128	132	7.7	0.3	52.4	14.3	25.1	0.1	1	0.1
PA42843	*Ferula oopoda* (Boiss. + Buhse) Boiss.	S+P	16.1	19.1	25.4	5.0	1.4851	133	5.2	0.6	52.4	13.3	27.8	0.1	1	0.4
PA42846	*Ferula ovina* (Boiss.) Boiss.	S+P	11.9	19.1	21.4	1.9	1.4875	86	6.6	1.3	23.1	26.2	42.1	0.4	1	0.3
YU45168	*Ferulago galbanifera* (Mill.) W. Koch	S-SC	20.0	36.3	26.2	5.9	1.4762	94	6.1	1.0	50.1	18.8	23.9			
TU47732	*Ferulago longistylis* Boiss.	Seed	37.8	22.0	35.1	11.9			6.0	1.2	52.5	16.1	24.1	0.1		
US42814	*Lomatium californicum* (Nutt.) Math. + Const.	S+P	22.5	20.4	19.1	0.8	1.4776	108	3.4	0.6	68.5	6.6	18.6	0.4	2	1.7
US42820	*Lomatium dasycarpum* (Torr. + Gray) Coult. + Rose	S+P	8.8	18.4	16.6	7.6	1.4742	105	4.7	1.4	71.4	6.8	15.6			
US40871	*Lomatium daucifolium* (Nutt.) Coult. + Rose	S+P	2.6	17.6	22.1	0.9	1.4768	120	3.1	1.1	64.3	10.7	19.7		2	0.7
US19696	*Lomatium macrocarpum* (Hook. + Arn.) Coult. + Rose	Seed	8.7	23.5	23.9		1.4879	101	3.5	2.1	71.6	5.8	15.5		3	1.3
US42771	*Lomatium marginatum* (Benth.) Coult. + Rose	S+P	9.2	7.3	17.9	0.7	1.4650	95	4.0	0.5	60.5	19.6	13.7	1.0	4	0.6
–32940	*Lomatium nudicaule* (Pursh) Coult. + Rose	S+P	24.4	19.4	18.1	1.2	1.4640	95	4.3	1.1	67.2	18.5	7.9	0.4	1	0.5
US45169	*Opopanax chironium* (L.) W. Koch	S+P	10.7	19.8	16.7	14.6	1.4915	116	9.0	2.0		62.2	27.3	0.1	2	0.4

— *Continued* —

[a]Two-letter prefix indicates source of seed. IN = India; US = USA; HE = Herbst Bros., NY; PA = Pakistan; TU = Turkey; KO = Korea; JA = Japan; UR = Uruguay; SP = Spain; HS = Harry Saier, MI; YU = Yugoslavia; TA = Tanzania; IS = Israel; ME = Mexico; SA = Union of South Africa; ET = Ethiopia; – = unknown.

[b]S+P = seed + pericarp, S-SC = seed-seedcoat.

[c]HBE = hydrogen bromide equivalent; RI = refractive index; IV = iodine value; PA = petroselinic acid.

[d]$18{:}1^{6}$ = petroselinic acid: $18{:}1^{9}$ = oleic acid.

[e]Components other than fatty acid methyl esters eluting from GC columns; # = number of components.

TABLE I—Continued

Sample no.[a]	Family and species	Component analyzed[d]	wt/1000 (g)	Dry basis		HBE[c]	RI	Fatty acid composition (%)								
				% Oil	% Protein			IV	16:0	18:0	18:1[6 d]	18:1[9 d]	18:2	18:3	Others[e] #	Others[e] %
TU41257	*Opopanax hispidus* (Friv.) Griseb.	S+P	7.5	15.6	23.8	4.5	1.4674	97	6.1	1.4	40.0	16.6	35.2	0.1	3	0.5
US41910	*Pastinaca sativa* L.	S+P	2.3	28.8	15.5	0.2	1.4661	92	4.0	1.1	58.2	15.8	20.6		1	0.2
TU43542	*Pastinaca sativa* L. Subsp. *Urens* (Req. ex Godr.) Celak.	S+P	2.3	28.7	18.1	1.1	1.4727	90	5.7	1.2	60.1	12.3	20.5		1	0.1
YU45072	*Peucedanum aegopodioides* (Boiss.) Vandas	S+P	2.0	18.1	22.6	0.7	1.4668	106	3.5	0.6	56.0	12.2	26.5		1	1.2
YU45229	*Peucedanum austriacum* (Jacq.) Koch	S+P	5.3	16.0	18.5	3.1	1.4705	95	3.7	0.3	64.8	8.9	21.9		1	0.2
SA41556	*Peucedanum capense* Sond.	S+P	3.4	20.3	13.1	7.9	1.4777	92	2.7	1.4	83.1	2.8	9.6		1	0.4
KO48306	*Peucedanum elegans* Komar.	S+P	3.9	28.0	20.1	4.5	1.4726	110	3.6	0.4	54.2	15.4	25.8		1	0.1
SA41530	*Peucedanum ferulaceum* Thunb.	S+P	3.0	22.3	14.0	15.9	1.4819	96	3.3	0.5	74.0	14.0	7.7		1	0.3
SP46664	*Peucedanum hispanicum* (Boiss.) Endl.	S+P	1.2	22.7	22.8	9.5	1.4823	105	4.2	0.8	50.1	21.6	23.1		1	0.1
YU46977	*Peucedanum oligophyllum* (Griseb.) Vandas	S+P	3.4	25.1	20.1	1.5	1.4655	100	2.7	0.4	70.3	9.3	16.8	0.1	1	0.3
YU45023	*Peucedanum oreoselinum* (L.) Moench	S+P	4.0	26.6	22.4	2.1	1.4736	99	4.6	0.4	56.2	15.0	22.8	0.3	2	0.7
KO47562	*Peucedanum terebinthaceum* (Fisch.) Fisch. ex Turcz.	S+P	2.1	25.7	25.6	2.2	1.4706	124	3.3	0.5	45.5	10.6	39.1	0.5	2	0.4
YU43696	*Peucedanum verticillare* (L.) Koch ex DC.	S+P	3.8	19.6	21.8	10.0	1.4816	91	3.8	1.0	45.9	11.8	37.1	0.1	1	0.1
US40964	*Polytaenia nuttallii* DC. Subtribe Tordyliinae	S+P	6.4	26.6	14.4	18.2	1.4929	125	4.4	0.9	39.6	19.6	33.6		2	2.0
IS44120	*Ainsworthia trachycarpa* Boiss.	S+P	0.2	7.8	21.9	0.6	1.4581		4.9	1.6	75.8	6.5	9.6	0.1	2	1.3
TU46670	*Ainsworthia trachycarpa* Boiss.	S+P		27.7	19.7	0.4	1.4549	64	5.3	1.3	74.2	9.4	9.6		1	0.2
PA44790	*Heracleum candicans* Wall. ex DC.	S+P	6.0	19.5	23.4	2.0	1.4666	94	4.0	0.2	66.6	8.7	20.2		1	0.1
US41042	*Heracleum lanatum* Michx.	Seed	4.0	21.0	29.3	3.9			4.2	1.4	34.9	19.5	38.3	0.4	1	0.3
PA47826	*Heracleum pinnatum* C.B. Clarke	S+P	3.2	21.7	19.6	1.2	1.4649	99	3.7	0.8	57.6	16.6	20.1	0.1	2	0.7
TU42739	*Heracleum platytaenium* Boiss.	S+P	22.2	19.0	19.5	1.9	1.4696	94	5.3	1.1	52.3	14.7	25.6	0.1	3	0.7
TU46098	*Heracleum sphondylium* L.	S+P	14.0	23.9	17.2	1.3	1.4609	82	5.0	0.6	56.3	12.2	24.9	0.4	2	0.5
YU43699	*Heracleum sphondylium* L. Subsp. *Montanum.* (Schleicher ex Gaud.) Briq.	S+P	7.8	21.2	21.5	2.8	1.4702	103	5.2	1.1	47.4	14.4	31.7			
YU45389	*Heracleum sphondylium* L. Subsp. *Orsinii* (Guss.) H. Neumayer	S+P	7.1	15.9	20.8	6.6	1.4679	90	4.4	0.5	55.6	14.2	24.6	0.1	3	0.4
HU45788	*Heracleum sphondylium* L. Subsp. *Sibricum* (L.) Simonakai	S+P	10.3	19.8	21.6	6.7	1.4670	92	4.6	1.1	51.6	13.0	29.1		2	0.4
YU45751	*Malabaila involucrata* Boiss.	S+P	3.7	8.0	14.1	0.7	1.4584	83	4.9	2.0	62.2	13.3	16.5	0.2	1	0.8
TU46844	*Malabaila lasiocarpa* Boiss.	S+P	5.8	12.0	12.2	1.0	1.4607	91	7.3	0.8	53.0	20.3	17.3		2	1.2
TU41202	*Malabaila secacul* (Mill.) Boiss.	S+P	5.6	16.0	16.8	0.2	1.4575	85	3.9	1.5	47.0	13.4	32.6	0.4	3	1.1
IS42106	*Synelcosiadium carmelii* (Labill.) Boiss.	S+P	8.9	8.7	15.8	0.3	1.4599	82	4.4	2.5	78.6	5.1	7.9	0.1	1	0.9
TU44601	*Tordylium aegyptiacum* (L.) Lam	S-SC	4.7	21.8	21.5	0.4	1.4635	93	3.0	0.5	76.8	5.3	13.7		3	0.7
YU43617	*Tordylium maximum* L.	S+P	5.2	18.9	16.1	0.1	1.4614	90	3.8	0.8	70.8	10.0	13.7		2	0.5
PA47356	*Zosima absinthiifolia* (Vent.) Link	S+P	7.0	20.1	15.8	1.2	1.4632	89	5.9	0.6	45.5	21.7	25.2	0.3	3	0.9
	TRIBE Laserpitieae															
SP46230	*Laserpitium gallicum* L.	S+P	13.2	13.0	15.5	2.5	1.4673	98	5.4	0.4	60.2	12.5	20.5	0.1	1	0.1

YU45224	*Laserpitium krapfii* Crantz Subsp. *Krapfii*	S+P	6.5	18.0	19.4	2.8	1.4661	99	4.1	0.4	63.3	14.0	18.0		1	0.1
YU45384	*Laserpitium latifolium* L.	S+P	7.2	16.1	21.5	2.9	1.4657	95	4.1	0.6	65.7	10.7	18.5		2	0.3
YU43701	*Laserpitium peucedanoides* L.	Seed	3.0	35.5	31.4	1.6	1.4643	100	3.7	0.7	59.0	16.1	20.3		1	0.1
YU43700	*Laserpitium siler* L.	S+P	8.9	21.6	25.4	2.0	1.4700	116	4.1	0.2	70.4	6.5	18.4	0.1	1	0.1
SP46237	*Thapsia villosa* L.	S+P	7.4	16.8	33.3	2.4	1.4656	100	3.9	0.4	77.5	3.4	14.3	0.2	1	0.2
	TRIBE Dauceae															
TU41240	*Artedia squamata* L.	S+P	10.1	9.5	11.2	0.2	1.4637	92	3.8	0.6	72.4	11.3	11.7		1	0.1
IS44115	*Daucus aureus* Desf.	S+P	2.2	22.6	18.5	0.2	1.4638	91	4.4	0.8	75.7	7.4	11.1		4	0.6
IS43196	*Daucus broteri* Ten.	S+P	2.0	18.6	18.9	6.9	1.4690	100	6.1	0.3	75.1	5.3	11.6	0.5	1	1.0
US42274	*Daucus carota* L.	S+P	0.6	27.2	22.4	1.1	1.4664	102	3.6	0.7	71.2	11.6	12.2		3	0.3
SP46650	*Daucus carota* L. Subsp. *Maritimus* (Lam.) Baty.	S+P	1.0	17.7	16.9	5.7	1.4805	188	6.1	0.2	69.8	12.4	10.6			
IS42102	*Daucus carota* L. Subsp. *Maximus* (Desf.) J. Bail	S+P	0.8	18.9	19.1	12.0	1.4629	150	3.8	1.1	72.5	9.9	10.8	0.3	1	0.9
SP46404	*Daucus crinitus* Desf.	S+P	1.2	[illegible]	21.0	0.6	1.4643	91	5.0	0.1	74.3	9.7	10.8			
TU41712	*Daucus guttatus* Sibth. + SM.	S+P	0.8	23.3	20.9	0.5	1.4683	105	4.2	2.6	65.0	15.9	11.6	0.1	2	0.6
IS46439	*Daucus littoralis* Sibth. + SM.	S+P	3.6	10.4	11.2	2.4	1.4667	95	5.5	0.3	79.7	4.2	9.5		2	0.4
SP44109	*Daucus muricatus* (L.) L.	S+P	6.0	11.1	17.8	0.6	1.4645	92	5.1	1.1	74.8	7.4	10.8		2	0.7
US40878	*Daucus pusillus* Michx.	S+P	1.0	22.7	21.4	0.2	1.4737	117	4.3	1.5	70.6	9.6	13.4	0.1	3	0.3
UR43312	*Daucus pusillus* Michx.	S+P	1.7	22.0	19.2	0.7	.14723	116	4.2	0.2	80.1	4.3	10.8		1	0.1
SP44110	*Daucus setifolius* Desf.	S+P	4.0	16.1	28.9	12.8	1.4761	106	9.1	1.5	50.9	12.6	25.1		3	0.7

[a]Two-letter prefix indicates source of seed. IN = India; US = USA; HB = Herbst Bros., NY; PA = Pakistan; TU = Turkey; KO = Korea; JA = Japan; UR = Uruguay; SP = Spain; HS = Harry Saier, MI; YU = Yugoslavia; TA = Tanzania; IS = Israel; ME = Mexico; SA = Union of South Africa; ET = Ethiopia; = unknown.

[b]S+P = seed + pericarp; S-SC = seed-seedcoat.

[c]HBE = hydrogen bromide equivalent; RI = refractive index; IV = iodine value; PA = petroselinic acid.

[d]18:1* = petroselinic acid; 18:1[9] = oleic acid.

[e]Components other than fatty acid methyl esters eluting from GC columns; # = number of components.

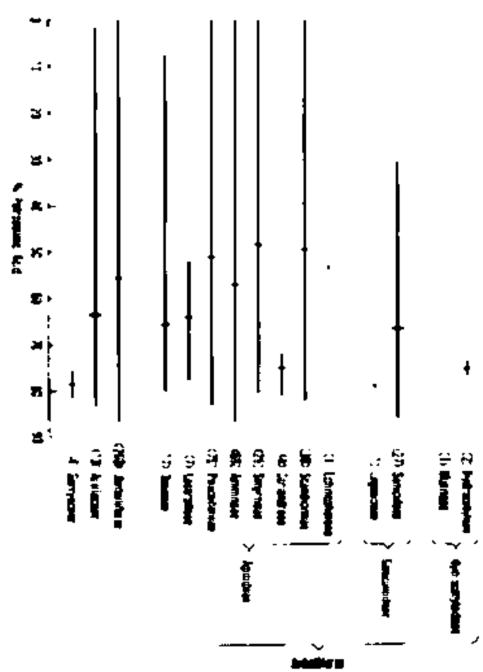

FIG. 1. Range and mean average of petroselinic acid in the Umbelliferae (by tribes) and Araliaceae seed oils.

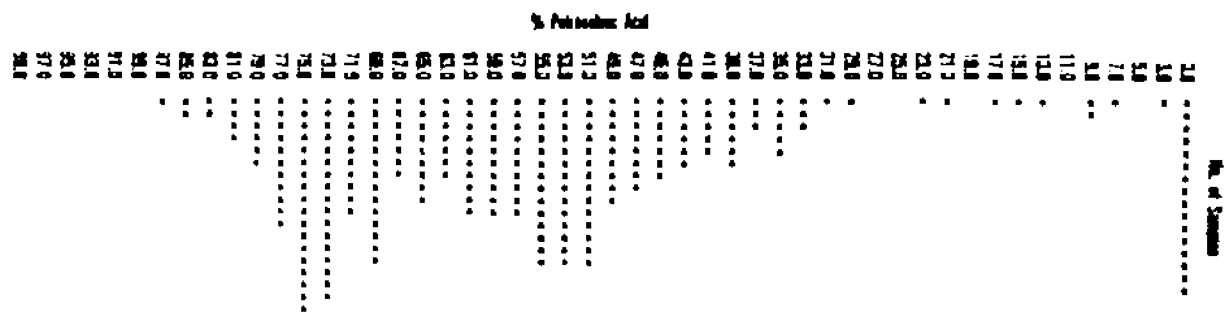

FIG. 2. Distribution of petroselinic acid in the Umbelliferae as % of seed oil. Mean average = 57%.

TABLE II

Richest Sources of Petroselinic Acid

Species family	% 18:1[6] m	% Oil	% 18:1[6] in seed
Bifora radiana (Umbelliferae)	75	50	37
Bifora testiculata (Umbelliferae)	81	42	34
Aralia spinosa (Araliaceae)	71	46	33
Trachymene caerulea (Umbelliferae)	76	37	29
Dendropanax trifidus (Araliaceae)	83	34	28
Apium leptophyllum (Umbelliferae)	87	32	28
Garrya fremontii (Garryaceae)	81	34	28
Hedera helix (Araliaceae)	79	35	28
Acanthopanax spinosus (Araliaceae)	70	37	26
Eryngium nudicaule (Umbelliferae)	75	34	26
Crithmum maritimum (Umbelliferae)	67	37	25
Astrantia maxima (Umbelliferae)	53	38	25
Ferula galbaniflua (Umbelliferae)	52	47	25
Actinolema eryngioides (Umbelliferae)	60	40	24

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Effects of Various Parameters on the Formation of Radiolysis Products in Model Systems

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ABSTRACT

Effects of various parameters on the formation of radiolysis products in tripalmitin, palmitic acid, oleic acid, caprylic acid and capric acid were investigated. A greater yield of primary and recombination products was observed in palmitic acid compared to that of oleic acid. In general, higher amounts of recombination products are formed in both acids when irradiated at room temperature than at −45 C. In the short chain acids, the yield of the hydrocarbon recombination product was enhanced in the liquid state. In contrast, the ketone recombination product was formed in greater amounts from solid capric acid than from liquid caprylic acid. In the absence of oxygen, a linear relationship was obtained between the dose and the yield of radiolysis products in tripalmitin. In the presence of oxygen, a considerable increase in the formation of γ-palmitolactone, n-3 and n-2 alkanes was observed at room temperature.

INTRODUCTION

Much of our knowledge regarding radiation chemistry of fats is based on model systems made from known compounds. Such systems have included free fatty acids (1), methyl esters (2) and triglycerides (3,4). The radiolytic behavior of these systems are similar and include such mechanisms as decarboxylation, dehydrogenation, polymerization and cleavage at all points of the alkyl chain.

Most of the early work on the effect of radiation in lipids was done in the presence of oxygen. Consequently, the changes taking place in the fat were partly the result of irradiation-induced oxidation (5). Little difference, however, between the radiolytic compounds identified under vacuum and in the presence of oxygen could be detected if analysis is conducted immediately after radiation. Nevertheless, storage of irradiated items in air has produced a variety of typical decomposition products (4).

In the previous publication, the effects of radiation parameters on the formation of some relatively small molecular weight (MW) volatile compounds have been reported (6). In the present study, the effects of various parameters (dose, temperature, oxygen, chemical nature and physical state) on the formation of the major primary and recombination radiolysis products in tripalmitin, palmitic acid, oleic acid, caprylic and capric acids were investigated.