Gamma-Linolenic Acid and Tocopherol Contents in the Seed Oil of 47 Accessions from Several *Ribes* Species

Fernando D. Goffman*,† and Stefania Galletti‡

Institute of Agronomy and Plant Breeding, Georg-August-University of, Von-Siebold-Strasse 8, 37075 Göttingen, Germany, and Istituto Sperimentale per la Frutticoltura, Italian Ministry for Agricultural and Forestry Politics, Pergine Valsugana (TN), Italy

Gamma-linolenic acid is an essential fatty acid for humans with delta-6-desaturase deficiency; it is a precursor of prostaglandins, prostacyclins, and tromboxanes; and it has antiinflammatory and antitumoral effects. Tocopherols are natural antioxidants with biological activity, heart/vascular, and cancer protective properties. The oil, gamma-linolenic acid, and tocopherol contents, as well as tocopherol composition, were investigated in the seed oil of a collection of 47 accessions belonging to various species of the genus *Ribes*. Differences for oil content among species were not significant. The highest total tocopherol content was found in *R. nigrum* (mean, 1716 mg kg^{-1} oil), followed by *R. rubrum* (mean, 1442 mg kg^{-1} oil). *R. grossularia* showed the lowest values for this trait (mean, 786 mg kg^{-1} oil). The three species also differed strongly for tocopherol composition. *R. rubrum* was distinguished by a higher concentration of delta-tocopherol (mean, 20.2%); *R. grossularia* displayed the highest percentage of gamma-tocopherol (mean, 70.0%), and *R. nigrum* showed the highest concentration for alpha-tocopherol (mean, 34.8%), the most biologically active among the four tocopherols. Regarding gamma-linolenic acid, the highest content was found in *R. nigrum*, which exhibited up to 15.8% of this essential fatty acid in the oil. *R. grossularia* and *R. rubrum* showed mean gamma-linolenic acid contents of 8% and 6.2%, respectively. The present study indicated that seeds of *Ribes* species, especially *R. nigrum*, could be used as sources of gamma-linolenic acid and natural vitamin E.

Keywords: *Gamma-linolenic acid, oil quality, Ribes, tocopherol, vitamin E*

INTRODUCTION

Gamma-linolenic acid (C18:3, *n*-6) is an essential fatty acid for humans with a deficiency of delta-6-linolenic acid desaturase, which is normally produced through desaturation of alpha-linolenic acid in the liver. Gamma-linolenic acid is an indispensable compound for humans because it is an intermediate for the biosynthesis of compounds such as prostaglandins, prostacyclins, and tromboxanes (*1*). In cases of delta-6 desaturase deficiency, gamma-linolenic acid must be supplied in the diet. In addition, several studies demonstrated that dietary gamma-linolenic acid has many health benefits. It shows antiinflammatory and antiproliferative effects (*2, 3*), reduces body fat content and facilitates fatty acid beta-oxidation in the liver (*4*), and acts as an effective cytotoxic agent against superficial bladder cancer (*5*).

Current commercial sources of gamma-linolenic acid are evening primrose (*Oenothera biennis* L.) and borage (*Borago officinalis* L.) oils. The level of gamma-linolenic acid in evening primrose oil varies from 7 to 10% of total fatty acids, whereas in borage oil it ranges from 17 to 25% (*6*−*8*). *Ribes* species (currants and gooseberries) also constitute one of the richest sources of gamma-linolenic acid yet described. In particular, black currant (*R. nigrum*) oil contains up to 19% of this essential fatty acid (*9*). This species is also characterized by a pulp rich in antioxidant components, such as polyphenols and anthocyanins (up to 1% and 0.3% of fresh fruit, respectively), as well as vitamin C (up to 0.1%), which make this fruit very interesting for both dietary quality and industrial extraction of active principles (*10*).

In addition to essential fatty acids, seed oils are excellent sources of vitamin E (tocopherols). Tocopherols are natural antioxidants with biological activity. They occur as a family of four derivatives (alpha-, beta-, gamma-, and delta-tocopherol), differing in the methylation of the chroman headgroup. The main biochemical function of the tocopherols is believed to be the protection of polyunsaturated fatty acids against peroxidation (*11*, *12*). Furthermore, there is evidence that tocopherols may reduce the risk of many different heart-vascular diseases, cancer, and other diseases (*13*, *14*).

Because of the nutritional and antioxidative properties of the tocopherols, not only the gamma-linolenic acid content, but also the tocopherol content and composition, should be taken into acount in the formulation of gamma-linolenic acid containing products. The aim of the present study was to investigate the levels of gamma-linolenic acid and tocopherols, and the tocopherol composition in 47 accessions of several *Ribes* species.

MATERIALS AND METHODS

Plant Material. Fifteen accessions from *Ribes grossularia*, 10 from *R. nigrum*, 21 from *R. rubrum,* and one from the interspecific hybrid *R. nigrum* x *R. hirtellum* were grown at the Istituto Sperimentale per la Frutticoltura, Pergine Val-

* To whom correspondence should be addressed. Fax: ++541 14 514 8739. E-mail: fgoffman@mail.agro.uba.ar.

† Georg-August-University.

‡ Italian Ministry for Agricultural and Forestry Politics.

10.1021/jf0006729 CCC: $20.00
Published on Web 12/13/2000

Table 1. Origin and Description of the 47 Evaluated Accessions of *Ribes* Species

species/accession	origin[a]	description
R. grossularia (red-black gooseberries)		
Achilles	UK	late ripening, large fruit, very high yield
Captivator	Ontario, Canada	mid season ripening, large fruit, equal in size
Hinnonmaki Rod	Finland	early ripening, medium size fruits, very productive
Maiherzog	Germany[b]	mid season ripening, good yield
May Duke	UK	old cultivar, early ripening, medium-large fruits
Rokula	Belgium	mid season ripening, large fruits
Rosko	NL	mid season ripening, high yield, large round fruit
Rote Triumph	UK[b]	old cultivar, mid season ripening
Whinham‘s Industry	UK	early-mid ripening, large fruits, medium yield
R. grossularia (yellow gooseberries)		
Goudbal	NL	early ripening, large fruits, excellent flavor
Hinnonmaki Gul	Finland	mid season ripening, excellent flavor
Invicta	England, UK	early ripening, very high yield, large fruits
Lady Delamere	UK	old cultivar, early-mid season ripening, high yield
Mucurines	Belgium	late ripening, good yield
White Smith	England, UK	old cultivar, early-mid season ripening, large fruits
Ribes nigrum (black currants)		
Andega	France	mid season ripening, medium yield, high quality
Baldwin Hilltop	England, UK	mid-late ripening, good yield
Ben Lomond	Scotland, UK	mid-late ripening, high yield
Ben Nevis	Scotland, UK	late ripening, high yield
Black Reward	England, UK	late ripening, large fruit
Tenah	Wageningen, NL	early mid season ripening, high yield
Titania	Balsgard, Sweden	late ripenning, very high yield, large fruits
Troll	France	new cultivar, early-mid season ripening
Tsema	Wageningen, NL	early ripening, good yield
Typhon	France	new cultivar, early ripening, high yield, large fruits
Ribes rubrum (red currants)		
Augustus	NL	late ripening, high yield, tart flavor
Cassa	NL	mid season ripening, tightly packed fruits
Fay's Prolific	New York, USA	early mid season ripening, medium productive
Heinemann's Rote S.	Germany	old cultivar, late ripening, good yield, tart flavor
Jonkheer van Tets	Schellenkhout, NL	old cultivar, very early ripening, good yield
London Market	England, UK	late ripening, high yield, medium fruits
Prince Albert	England, UK	very late ripening, medium to very productive
Red Lake	Minnesota, USA	mid-early ripening, good yield, large fruits
Rolan	NL	mid season ripening, very high yield
Rondom	NL	late ripening, medium fruits, tart flavor
Roodneus	NL	late ripening, high to very high yield
Rosetta	NL	late ripening, extremely productive, large fruits
Rotet	NL	late-mid season ripening, very high yield
Rovada	Wageningen, NL	very late ripening, high yield, large fruits
Stanza	NL	mid season to late ripening, high yield, small fruits
Ribes rubrum (white currants)		
Bar le Duc	France	large fruits
Blanka	Bojnice, Slovakia	late ripening, high yield, large tightly packed fruits
Primus	Bojnice, Slovakia	late ripening, small fruits, high vitamin C content
Werdavia	Germany	medium yield, medium fruits, tart flavor
Witte Parel	Europe[b]	old cultivar
Zitavia	Germany	early ripening, large fruits, good flavor
R. nigrum x *R. hirtellum* (jostaberries)		
Josta	Hannover, Germany	ripening in mid season, mid yield, thornless

[a] Abbreviations: UK, United Kingdom; NL, The Netherlands. [b] Probable origin.

sugana, (TN), Italy, and their fruit production was collected in July 1999. They represent a very divergent collection of cultivars of *Ribes* spp., including old varieties and present day accessions from Europe, USA ,and Canada (Table 1). The field design of the experiment was a randomized complete block with one replication. From each plot, four plants were harvested at commercial maturity. The fruit seeds were separated from the pulp through a sieve under running water and dried in a ventilated oven at 30 °C overnight. They were stored at 5 °C until chemical analysis.

Reagents. Isooctane and *tert*-butylmethyl ether were of HPLC grade (Merck, Darmstadt, Germany). Petrolether (40 °C) was of analytical grade (>98%) (Merck). Methanol, $NaHSO_4$, and sodium methylate were also of analytical grade (Fluka, Neu-Ulm, Germany).

Oil Content and Fatty Acid Analysis. Seeds were ground in a Retsch Grinder fitted with a 0.25-mm screen. Seed oil content was determined by weighting on milled samples of about 500 mg by Soxhlet extraction with light petrolether (boiling point, 40 °C). Extraction time was 12 h. Oil content was expressed as wt %/wt (dry weight basis). Fatty acid composition of seed oils was analyzed by gas−liquid chromatography of fatty acid methyl esters according to Thies (*15*). About 200 mg of milled seeds was extracted and transmethylated for 20 min at 20 °C with 1 mL of a 0.5 M solution of sodium methylate in methanol. Isooctane (0.5 mL) and 0.2 mL

Table 2. Means[a] and Ranges for Oil, Tocopherol Composition, Total Tocopherol, and Gamma-Linolenic Acid Contents in Seeds of *Ribes* Species

species	oil[c] (%)	Tocopherols[b] (%)				total-T[d]	γ-C18:3[e] (%)
		α-T	β-T	γ-T	δ-T		
R. grossularia							
mean ($n = 15$)	20.7 a	23.5 b	0.0 b	70.0 a	6.5 b	786 c	8.0 b
range	16.2−26.4	16.3−37.6	0.0−0.0	59.4−79.4	3.0−15.4	559−1191	5.6−11.3
R. nigrum							
mean ($n = 10$)	20.3 a	34.8 a	0.0 b	60.2 b	5.0 b	1716 a	13.8 a
range	17.2−22.3	29.2−43.7	0.0−0.0	53.6−65.1	2.5−8.6	1228−2458	11.9−15.8
R. rubrum							
mean ($n = 21$)	19.0 a	17.8 c	1.7 a	60.2 b	20.2 a	1442 b	6.2 c
range	11.2−23.6	9.1−35.8	0.0−4.3	44.5−68.8	12.0−31.2	857−2481	3.3−7.2
R. nigrum x *R. hirtellum*[f]	18.5	43.5	0.0	53.6	3.0	1360	8.3

[a] Means within a column followed by the same letter do not differ significantly at $P = 0.05$ level as determined by Scheffe's test. [b] Tocopherols, expressed as % of total tocopherols. Abbreviations: α-T, alpha-tocopherol; β-T, beta-tocopherol; γ-T, gamma-tocopherol; δ-T, delta-tocopherol; total-T, total tocopherol; γ-C18:3, gamma-linolenic acid. [c] Oil content, expressed as wt %/wt. [d] Total tocopherol content, as mg kg^{-1} oil. [e] gamma-linolenic acid, as % of total fatty acids. [f] Only one accession; not included in the Scheffe's test.

of 5% (wt/v) of $NaHSO_4$ in water were added in that order. Samples were centrifuged, and 2.5 μL of the upper phase was injected into the gas chromatograph. Analyses were performed on a Perkin-Elmer gas chromatograph model 8600 (Perkin-Elmer Corporation, Norwalk, CT) equipped with a fused silica capillary column FFAP, 25 m × 0.25 mm i.d. with 0.25 μm film thickness (Macherey & Nagel GmbH + Co KG, Düren, Germany). Separation was done isothermically: the oven, detector, and injector temperatures were 200, 250, and 250 °C, respectively. The carrier gas was hydrogen at a pressure of 100 kpa. The samples (2 μL) were injected at a split rate of 1:70.

Tocopherol Analysis. About 50 mg of milled seeds was weighed and placed in a 5-mL volumetric test tube. Isooctane (2 mL) was added and the tube contents were mixed. Samples were extracted overnight at room temperature in darkness. A 5-μL aliquot of the upper layer was injected into the HPLC. Analyses of tocopherol content and composition were performed by HPLC as described by Thies (*16*), with a fluorescence detector (Ex at 295 nm and Em at 330 nm), a C-18 diol column (250 × 3 mm), and isooctane/*tert*-butyl-methyl ether (94:6, v/v) as eluent at a flow rate of 0.7 mL/min. Identification and quantification of tocopherols were done using alpha-, beta-, gamma-, and delta-tocopherol from Merck (Darmstadt, Germany) as external standards. Total tocopherol contents were expressed as mg kg^{-1} oil.

RESULTS AND DISCUSSION

Results of oil, gamma-linolenic, and total tocopherol contents, and tocopherol composition, given as average, minimum, and maximum, are given in Table 2. Within each species, no significant differences for the analyzed compounds were found between fruit color groups. *Ribes* species did not significantly differ for oil content. But considering all analyzed accessions, a medium variation was observed for this trait, which was in the range from 11.2 to 26.4 wt %/wt. Large significant differences were detected among species for total tocopherol content and composition. The highest total tocopherol content was found in *R. nigrum* (mean, 1716 mg kg^{-1} oil). This value is similar to those of wheat and corn germ oils, which currently are the most important sources of natural vitamin E. *R. grossularia* showed the lowest value for total tocopherol content (mean, 786 mg kg^{-1} oil) and *R. rubrum* exhibited a medium to high total tocopherol content (mean, 1442 mg kg^{-1} oil) with a broad variation, ranging from 857 to 2481 mg kg^{-1} oil.

Tocopherol composition differed significantly among the studied *Ribes* species and was characteristic for each of them. *R. rubrum* was clearly distinguished from the other two species by a higher concentration of delta-tocopherol (mean, 20.2%) and the presence of beta-tocopherol. On average, delta-tocopherol accounted for up to 6.5% of total tocopherols in *R. grossularia* and *R. nigrum*, and the beta-derivative was not detected. *R. grossularia* displayed the highest percentage of gamma-tocopherol (mean, 70.0%), whereas *R. nigrum* showed the highest concentration for the alpha-derivative (mean, 34.8%). This large variation found for tocopherol pattern can be used to create cultivars with improved tocopherol composition in *Ribes*. A higher proportion of alpha-tocopherol is desirable in *Ribes* species for increasing their vitamin E content, because this derivative is the most biologically active of the four tocopherols (*17*). *R. nigrum* appears to be the best candidate for this aim among the studied *Ribes* species. The interspecific hybrid *R. nigrum* x *R. hirtellum* (cv. Josta) showed a high level of alpha-tocopherol (43.5%) with a relatively high total tocopherol content next to *R. nigrum*. This similarity between both species was expected, because new forms of Josta were developed by backcrossing to the black currant parent.

On the other hand, the tocopherol profile clearly separates the three *Ribes* species from each other and therefore appears to have chemotaxonomic importance in this genus. The significance of tocopherols as chemotaxonomic markers was already demonstrated in Brassicaceae (*18*), Onagraceae (*19*), Boraginaceae (*20*), and in the genus *Linum* (*21*) and genus *Orobanche* (*22*).

With regard to gamma-linolenic acid, the highest content was recorded in *R. nigrum*, which widely surpassed the two other species, exhibiting up to 15.8% of this essential fatty acid in the oil. *R. grossularia* and *R. rubrum* showed mean gamma-linolenic contents of 8% and 6.2%, respectively. Although earlier investigations have shown *R. nigrum* seed oil as the richest source of gamma-linolenic acid within the genus *Ribes* (*19*, *23*), by analyzing wild berries from *R. nigrum*, *R. alpinum*, and *R. spicatum* spp. *lapponicum*, Johansson et al. (*24*) found the highest proportion (16.1%) in the latter species, revealing the potential to discover further variability for this trait by screening other *Ribes* species or genotypes.

The mean values for oil, gamma-linolenic acid, and tocopherol traits from each studied accession, classified by species and fruit color, are presented in Table 3.

Table 3. Means for Oil, Total Tocopherol, and Gamma-Linolenic Acid Contents, and Tocopherol Composition of the 47 Analyzed Accessions of *Ribes* Species

species/accession	n[b]	oil[c] (%)	Tocopherols[a] (%) α-T	β-T	γ-T	δ-T	total-T[d]	γ-C18:3[e] (%)
R. grossularia (red-black gooseberries)								
Achilles	3	18.7	24.3	0.0	71.4	4.5	750	9.7
Captivator	4	18.2	28.2	0.0	63.3	8.6	790	9.9
Hinnonmaki Rod	3	23.1	16.9	0.0	77.3	5.3	595	11.3
Maiherzog	4	24.2	18.0	0.0	76.2	5.8	598	7.5
May Duke	4	26.4	16.3	0.0	79.4	4.3	559	8.0
Rokula	4	16.2	19.9	0.0	64.9	15.4	1191	6.8
Rosko	4	21.3	20.8	0.0	71.2	8.1	870	7.2
Rote Triumph	2	19.6	23.1	0.0	70.0	6.6	772	8.5
Whinham's Industry	3	19.5	24.9	0.0	70.2	4.8	811	9.1
R. grossularia (yellow gooseberries)								
Goudbal	4	19.8	23.2	0.0	70.1	6.8	766	5.8
Hinnonmaki Gul	4	20.6	17.2	0.0	73.8	9.0	715	5.6
Invicta	4	19.9	37.6	0.0	59.4	3.0	892	8.1
Lady Delamere	4	20.9	27.5	0.0	68.9	3.5	719	8.1
Mucurines	4	21.9	33.8	0.0	62.7	3.4	946	7.1
White Smith	3	19.7	20.6	0.0	70.9	8.5	817	8.0
Ribes nigrum (black currants)								
Andega	4	21.9	30.4	0.0	60.9	8.6	1676	12.0
Baldwin Hilltop	4	21.1	31.7	0.0	60.5	7.6	1419	13.9
Ben Lomond	4	22.1	29.6	0.0	63.6	6.9	1500	14.1
Ben Nevis	4	20.9	32.6	0.0	63.2	4.2	1599	14.6
Black Reward	4	21.9	32.0	0.0	63.4	4.6	1478	15.8
Tenah	4	18.0	29.2	0.0	65.1	5.8	1228	13.5
Titania	4	22.3	36.5	0.0	59.8	3.7	1756	11.9
Troll	4	18.1	40.8	0.0	56.6	2.5	2159	14.8
Tsema	4	19.1	41.4	0.0	55.6	2.9	1887	14.1
Typhon	4	17.2	43.7	0.0	53.6	2.7	2458	13.0
Ribes rubrum (red currants)								
Augustus	4	22.4	21.8	2.6	57.5	18.1	1272	5.8
Cassa	3	19.0	17.8	2.6	56.1	23.4	1736	4.7
Fay's Prolific	4	20.4	15.6	1.7	58.7	24.2	1359	5.8
Heinemann's Rote S.	4	19.3	18.3	2.3	59.4	19.8	1030	6.5
Jonkheer van Tets	4	20.1	19.0	2.7	63.1	15.5	1219	4.1
London Market	4	22.2	13.4	2.9	66.0	17.7	1101	6.3
Prince Albert	4	16.7	17.2	0.6	56.8	25.1	857	6.9
Red Lake	4	19.4	12.7	2.0	53.9	31.2	1759	4.9
Rolan	4	17.3	19.6	1.2	60.3	19.0	1323	6.1
Rondom	4	11.2	35.8	4.3	44.5	15.2	2481	7.0
Roodneus	4	17.9	24.3	2.7	61.0	12.0	1610	3.3
Rosetta	4	18.9	13.0	1.5	67.6	17.9	1473	6.6
Rotet	4	16.4	25.2	1.2	57.6	15.7	1200	7.2
Rovada	4	15.3	19.8	4.1	55.7	20.4	1558	5.3
Stanza	4	18.3	24.9	2.4	59.2	13.7	1352	5.2
Ribes rubrum (white currants)								
Bar le Duc	4	22.2	10.9	0.0	65.9	23.2	1594	7.1
Blanka	4	23.6	18.1	0.8	59.5	21.6	1315	8.8
Primus	4	18.0	10.3	0.6	61.5	27.7	1402	6.8
Werdavia	4	19.1	17.2	0.0	68.8	14.0	1415	7.4
Witte Parel	3	20.1	10.7	0.0	66.1	23.2	1824	6.1
Zitavia	4	21.0	9.1	0.0	65.9	24.8	1409	7.4
R. nigrum x *R. hirtellum* (jostaberries)								
Josta	4	18.5	43.4	0.0	53.6	2.9	1360	8.3

[a] Tocopherols, expressed as % of total tocopherols. Abbreviations: α-T, alpha-tocopherol; β-T, beta-tocopherol; γ-T, gamma-tocopherol; δ-T, delta-tocopherol; total-T, total tocopherol; γ-C18:3, gamma-linolenic acid. [b] *n*, number of analyzed plants. [c] Oil content, expressed as wt %/wt. [d] total tocopherol content, as mg kg^{-1} oil. [e] gamma-linolenic acid, as % of total fatty acids.

Among all accessions, the highest oil contents were found in the red-black accessions of *R. grossularia* cvs. Hinnonmaki Rod, Maiherzog, and May Duke, and in *R. rubrum* cv. Blanka, which exhibited values over 23% of oil. All cultivars from *R. grossularia* showed values below 1000 mg total tocopherol kg^{-1} oil, with the exception of the accession Rokula. But Rokula appears to be distinct from the other *R. grossularia* cultivars, exhibiting the lowest oil content (16.2%) and a different tocopherol profile with the highest percentage of delta-tocopherol (15.4%). All black currants showed total tocopherol contents over 1200 mg kg^{-1} oil and more than 11% of gamma-linolenic acid. The black currants cultivars Troll, Tsema, and Typhon exhibited the highest values for alpha-tocopherol concentration (>40%) and total tocopherol contents (>1800 mg kg^{-1} oil) with a relatively high gamma-linolenic acid content (>13%), appearing therefore to be the most interesting genetic

Table 4. Correlations among Oil, Gamma-Linolenic Acid, and Tocopherol Contents[a] and the Tocopherol Composition in 47 Accessions of *Ribes* spp.

	α-T	β-T	γ-T	δ-T	total-T	γ-C18:3
oil	−0.21 NS	−0.42**	0.60**	−0.21 NS	−0.42**	0.18 NS
α-T		0.21 NS	−0.42**	−0.73**	0.34*	0.62**
β-T			0.51**	0.52**	0.31*	0.55**
γ-T				−0.30*	−0.74**	0.02 NS
δ-T					0.21 NS	−0.61**
total-T						0.23 NS

[a] Oil content expressed as % (wt/wt); individual tocopherols, % of total tocopherols; gamma-linolenic acid, % of total fatty acids; and total tocopherol contents, mg kg^{-1} oil. Abbreviations: α-T, alpha-tocopherol; β-T, beta-tocopherol; γ-T, gamma-tocopherol; δ-T, delta-tocopherol; total-T, total tocopherol; γ-C18:3, gamma-linolenic acid. *,** Significant at 0.05 and 0.01 probability levels, respectively; NS, nonsignificant.

material for improvement of the mentioned traits. One accession of *R. rubrum* (Rondom) was characterized by a very high total tocopherol content (2481 mg kg^{-1} oil), but this was a result of its extremely low oil content (11.2%), which was the lowest among all studied accessions. The other *R. rubrum* cultivars exhibited a medium to high total tocopherol content and similar low values for gamma-linolenic acid content.

Table 4 shows the correlation coefficients (r) among oil, gamma-linolenic, and tocopherol traits in the 47 accessions of *Ribes*. Oil and total tocopherol contents were significant negatively correlated. That could be explained by a dilution or concentration effect of the tocopherols in the oil, i.e., higher oil contents lead to a reduction of the concentration of tocopherols in oil and viceversa. Alpha-tocopherol was strongly negative correlated with delta-tocopherol ($r = -0.73$**) and positively correlated with total tocopherol and gamma-linolenic acid contents. These positive correlations of alpha-tocopherol were more related to taxonomic characteristics than to relationships between these compounds. *R. nigrum*, for example, characterized by high total tocopherol and gamma-linolenic acid contents, showed the highest percentage of alpha-tocopherol, which was typical for this species. Gamma-tocopherol percentage was highly negative correlated with total tocopherol content ($r = -0.74$**) and positively correlated with oil content. A possible explanation of this fact could be that the *Ribes* cultivars which displayed a high proportion of gamma-tocopherol, as those from *R. grossularia*, exhibited a low total tocopherol content. Moreover, the positive correlation detected between oil content and gamma-tocopherol proportion ($r = 0.60$**) could have indirectly caused the negative correlation observed between gamma-tocopherol percentage and total tocopherol content. Other studies carried out in corn germ oil (*25*) and rapeseed (*26*) also found a positive correlation between oil content and gamma-tocopherol, suggesting a possible relationship between both components.

The present study demonstrated that *Ribes* species have great potential as sources of gamma-linolenic acid and tocopherols, containing relatively high amounts of these compounds if compared to other vegetable sources. The highest values registered for both gamma-linolenic acid and tocopherol content in *R. nigrum* suggests this species as the most promising of all evaluated *Ribes* spp., therefore being recommended for further investigations in this area. It should be noted that this species is mainly processed to obtain juices and jellies, therefore eliminating the seeds, which could be recovered and processed as byproduct at low cost. The variation found for gamma-linolenic acid, tocopherol content, and composition do not necessarily represent that of the whole population of the studied *Ribes* species, indicating the possibility to find genotypes exhibiting higher or lower values of the analyzed traits by screening additional plant materials.

ACKNOWLEDGMENT

The authors gratefully acknowledge the technical assistance of Uwe Ammermann and Nicole Ritgen.

LITERATURE CITED

(1) Paccalin, J.; Dabadie, H.; Bernard, M.; Mendy, F.; Spielmann, D.; Delhaye, N. Intérêt d'une nouvelle plante oleagineuse: l'onagre. Apport en acide gamma-linolenique et troubles de la désaturation en pathologie. *Med. Nutr.* **1985**, *21*, 132−136.
(2) Johnson, M. M.; Swan, D. D.; Surette, M. E.; Stegner, J.; Chilton, T.; Fonteh, A. N.; Chilton, F. H. Dietary supplementation with gamma-linolenic acid alters fatty acid content and eicosanoid production in healthy humans. *J. Nutr.* **1997**, *127*, 1435−1444.
(3) Fan, Y. Y.; Chapkin, R. S. Importance of dietary gamma-linolenic acid in human health and nutrition. *J. Nutr.* **1998**, *128*, 1411−1414.
(4) Takada, R.; Saitoh, M.; Mori, T. Dietary gamma-linolenic acid-enriched oil reduces body fat content and induces liver enzyme activities relating to fatty acid beta-oxidation in rats. *J. Nutr.* **1994**, *124*, 469−474.
(5) Solomon, L. Z.; Jennings, A. M.; Hayes, M. C.; Bass, P. S.; Birch, B. R.; Cooper, A. J. Is gamma-linolenic acid an effective intravesical agent for superficial bladder cancer? In vitro cytotoxicity and in vivo tolerance studies. *Urol. Res.* **1998**, *26*, 11−15.
(6) Muuse, B. G.; Essers, M. L.; van Soest, L. J. M. Oenothera species and Borago officinalis: Sources of gamma-linolenic acid. *Neth. J. Agr. Sci.* **1988**, *36*, 357−363.
(7) Simon, J. E.; Beaubaire, N.; Weller, S. C.; Janick, J. Borage: a source of gamma-linolenic acid. In *Advances in New Crops*; Janick, J., Simon, J. E., Eds. Timber Press: Portland, OR, 1990.
(8) Goffman, F. D.; Velasco, L.; Becker, H. C. Gamma-linolenic acid and Vitamin E content of 36 Boraginaceae species. In *Proceedings of the 6th Symposium on Renewable Resources for the Chemical Industry and 4th European Symposium on Industrial Crops and Products*, Bonn, Germany, 1999a.
(9) Traitler, H.; Winter, H.; Richli, U.; Ingenbleek, Y. Characterization of gamma-linolenic acid in *Ribes* seed. *Lipids* **1984**, *19*, 923−928.
(10) Albasini, A.; Melegari, M.; Costantino, L.; Rastelli, G. Contenuti in componenti di natura polifenolica, vitamina C, macro e microelementi in "piccoli frutti". In *Proceedings of the I Convegno Internazionale S. I. S. A. Gli Alimenti Montani*, S. Michele all'Adige (TN), Italy, 1996.
(11) Beringer, H.; Dompert, W. U. Fatty acid and tocopherol-pattern in oil seeds. *Fat Sci. Technol.* **1976**, *78*, 228−231.

(12) Kamal-Eldin, A.; Andersson, R. A multivariate study of the correlation between tocopherol content and fatty acid composition in vegetable oils. *J. Am. Oil Chem. Soc.* **1997**, *74*, 375−380.

(13) Burton, G. W.; Ingold, K. U.; Cheeseman, K. H.; Slater, T. F. Application of denterated alpha-tocopherols to the biokinetics and bioavailability of vitamin E. *Free Radical Res. Commun.* **1990**, *11*, 99−107.

(14) Borek, C. The role of vitamin E in cancer prevention. In *Vitamin E in Health and Disease*. Packer, L., Fuchs, J., Eds. Marcel Dekker: New York, 1993.

(15) Thies, W. Schnelle und einfache Analysen der Fettsäurezusammensetzung in einzelnen Raps-Kotyledonen I. Gaschromatographische und papierchroma-tographische Methoden. *Z. Pflanzenzüchtg.* **1971**, *65*, 181−202.

(16) Thies, W. Entwicklung von Ausgangsmaterial mit erhöhten alpha- oder gamma-Tocopherol-Gehalten im Samenöl für die Körnerraps-Züchtung. I. Quantitative Bestimmung der Tocopherole durch HPLC. *Angew. Bot.* **1997**, *71*, 62−67.

(17) Pongracz, G.; Weiser, H.; Matzinger, D. Tocopherole-Antioxidantien der Natur. *Fat Sci. Technol.* **1995**, *97*, 90−104.

(18) Goffman, F. D.; Thies, W.; Velasco, L. Chemotaxonomic value of tocopherols in Brassicaceae. *Phytochemistry* **1999b**, *50*, 793−798.

(19) Velasco, L.; Goffman, F. D. Tocopherol and fatty acid composition of twenty-five species of Onagraceae Juss. *Bot. J. Linnean Soc.* **1999a**, *129*, 359−366.

(20) Velasco, L.; Goffman, F. D. Fatty acids and tocopherols in the seeds of 36 species of Boraginaceae and their chemotaxonomic significance. *Phytochemistry* **1999b**, *52*, 423−426.

(21) Velasco, L.; Goffman, F. D. Tocopherol, plastochromanol and fatty acid pattern in the genus *Linum*. *Plant Syst. Evol.* **2000**, *221*, 77−88.

(22) Velasco, L.; Goffman, F. D.; Pujadas-Salvà, A. Contribution of fatty acids and tocochromanols to the systematics of *Orobanche* L. *Phytochemistry* **2000**, *54*, 295−300.

(23) Traitler, H.; Wille, H. J.; Studer, A. Fractionation of polyunsaturated fatty acids from various natural oil sources. *Fat Sci. Technol.* **1986**, *88*, 378−382.

(24) Johansson, A.; Laakso, P.; Kallio, H. Characterization of seed oils of wild, edible Finnish berries. *Z. Lebensm.-Unters. Forsch. A* **1997**, *204*, 300−307.

(25) Levy, R. D. *Genetics of vitamin E content in corn grain*. Ph.D. Thesis, University of Illinois, Urbana-Champaign, IL, 1973.

(26) Goffman, F. D.; Becker, H. C. Genetic variation of tocopherol content in a germplasm collection of *Brassica napus* L. *Euphytica*, in press.

Received for review May 31, 2000. Revised manuscript received October 13, 2000. Accepted October 16, 2000.

JF0006729