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Antioxidant and Hepatoprotective Potential of Essential Oils of Coriander (*Coriandrum sativum* L.) and Caraway (*Carum carvi* L.) (Apiaceae)

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Essential oils of *Coriandrum sativum* L. and *Carum carvi* L. fruits were analyzed by gas chromatography−mass spectrometry and assayed for their in vitro and in vivo antioxidant activity and hepatoprotective effect against carbon tetrachloride (CCl_4) damage. The in vitro antioxidant activity was evaluated as a free radical scavenging capacity (RSC), measured as scavenging activity of the essential oils on 2,2-diphenyl-1-picrylhydrazyl ($DPPH^•$) and OH radicals and effects on lipid peroxidation (LP) in two systems of induction. Some liver biochemical parameters were determined in animals pretreated with essential oils and later intoxicated with CCl_4 to assess in vivo hepatoprotective effect. Tested essential oils were able to reduce the stable $DPPH^•$ in a dose-dependent manner and to neutralize H_2O_2, reaching 50% neutralization with IC_{50} values of <2.5 μL/mL for *Carvi aetheroleum* and 4.05 μL/mL for *Coriandri aetheroleum*. Caraway essential oil strongly inhibited LP in both systems of induction, whereas coriander essential oil exhibited prooxidant activity. In vivo investigation conferred leak of antioxidative capacity of coriander essential oil, whereas the essential oil of caraway appeared promising for safe use in folk medicine and the pharmaceutical and food industries.

KEYWORDS: *Coriandrum sativum*; *Carum carvi*; essential oils; GC-MS; antioxidant activity; hepatoprotective effect

INTRODUCTION

Herbs and spices have been known since ancient times for their use in the preparation of foodstuffs to enhance their flavor and organoleptic properties. Nowadays, they have great potential in a growing nutrition industry because many plant-derived phytochemical preparations possess dual functionality in preventing lipid oxidation, a major cause of food quality deterioration and microbial spoilage. Their effectiveness against a wide range of microorganisms has been repeatedly demonstrated (*1*−*4*). Furthermore, biologically active natural compounds are of interest to the pharmaceutical industry for the control of human diseases of microbial origin and for the prevention of a wide range of diseases caused by lipid peroxidative damage (ischemia, coronary atherosclerosis, Alzheimer's disease, carcinogenesis, and aging processes) (*5*, *6*). Among various kinds of natural substances, essential oils from aromatic and medicinal plants and their compounds proved to be of special interest due to their strong in vitro antioxidant activity (*2*, *7*, *8*). This effect became even more interesting after synthetic food antioxidants, such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), were found to be tumorogenic (*9*, *10*). Therefore, the use of these chemicals is restricted in several countries as they may be dangerous to human health (*10*, *11*).

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Coriander (*Coriandrum sativum* L.) and caraway (*Carum carvi* L.) (Apiaceae) are well-known herbs widely used as spices, in folk medicine, and in the pharmacy and food industries. This usage mostly relates to their essential oil attributes. In traditional medicine they are recommended for spastic conditions of the gastrointestinal tract, flatulence, fullness, and loss of appetite due to their antispasmodic and antimicrobial actions (*12*). However, officinal medicine recommends their use only in dyspeptic problems. Even though coriander and caraway are widely used in phytotherapy, their use is sometimes restricted because allergic contact dermatitis may occur (*12*).

Although there are some data about antioxidative effects of coriander and caraway essential oils, this activity is usually attributed to existing phenolic compounds (*13*). However, there are very few data that describe the potential antioxidant properties related to chemically well-characterized essential oils of coriander and caraway (*1*), which are crucial in phytotherapy. Furthermore, the variations in biological activities of herbal drugs could be related to different compounds present in the plant material that is used (*14*).

With regard to all of this, in vitro and in vivo antioxidant effects of chemically characterized essential oils of coriander (*Coriandrum sativum* L.) and caraway (*Carum carvi* L.) (Apiaceae) are reported in the present study.

MATERIALS AND METHODS

Plant Material. Coriander and caraway fruits were obtained from the Institute for Studies on Medicinal Plants, Dr Josif Pančić, Belgrade,

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in 2008. Voucher specimens (Ph-CoS 56/08 and Ph-CaC 58/08) were confirmed (*15*) and deposited at the Herbarium of the Laboratory of Pharmacognosy, Department of Pharmacy, Faculty of Medicine, University of Novi Sad.

Essential Oil Isolation. Plant material was submitted to hydrodistillation according to *European Pharmacopoea 6* (*16*), using *n*-hexane (Merck, Darmstadt, Germany) as a collecting solvent. The solvent was removed under vacuum, and the quantities of essential oils were determined gravimetrically.

Essential Oils Analysis. Qualitative and quantitative analyses of the essential oils were carried out using a Hewlett-Packard 5973-6890 GC-MS system operating in EI mode at 70 eV, equipped with a split−splitless injector (200 °C) and a flame ionization detector (FID) (250 °C). Helium was used as carrier gas (1 mL/min), and the capillary columns used were a HP 5MS (30 m × 0.25 mm; film thickness = 0.25 μm). The temperature program was from 60 to 280 °C at a rate of 3 °C/min, and split ratio was 1:10. The identification of individual compounds was made by comparison of their retention times and mass spectra with those obtained from authentic samples (Carl Roth GmbH, Karlsruhe, Germany) and/or the NIST/NBS and Wiley library spectra as well as with literature data (*17*).

Antioxidant Activity. Antioxidant properties of examined essential oils were evaluated as both free radical scavenging capacity (RSC) and protective effect on lipid peroxidation (LP).

RSC was evaluated by measuring the scavenging activity of examined essential oils on H_2O_2 and the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical.

The scavenging activity on H_2O_2 was carried out using the method of Ruch et al. with slight modifications (*18*). The 40 mM solution of H_2O_2 was freshly prepared in 0.05 M KH_2PO_4−K_2HPO_4 phosphate buffer (PB) (pH 7.4). Samples (ranging from 10 to 50 μL for both essential oils) were mixed with 3.4 mL of PB and 0.6 mL of 40 mM H_2O_2. The absorbance of the resulting solutions and the blank (4 mL of PB) was recorded spectrophotometrically at 230 nm using an Agilent Technologies 8453 spectrophotometer. The percent of H_2O_2 neutralization was calculated by using following equation:

$$\%\ H_2O_2\ \text{neutralization} = [(A_{\text{blank}} - A_{\text{sample}})/A_{\text{blank}}] \times 100$$

The DPPH assay was performed as described before (*2*). The percent of DPPH-RSC was calculated by using the following equation:

$$\text{RSC}\ (\%) = 100 \times (A_{\text{blank}} - A_{\text{sample}}/A_{\text{blank}})$$

The IC_{50} values of neutralization of H_2O_2 and DPPH radical (concentrations of essential oils that cause 50% neutralization) were determined by regression analysis from the obtained RSC values.

Rapid Screening for Scavenging Compounds of Essential Oils. For fast screening of compounds responsible for antioxidant activity of the investigated essential oils (10 μL of each), the dot-blot test on TLC silica gel F_{254} aluminum plates (Merck) stained with the free radical DPPH$^{\bullet}$ was used according to the method described before (*2*). Compounds of essential oils responsible for scavenging activity were identified comparing the DPPH-TLC chromatogram with the control plate and literature data (*19*).

Determination of Lipid Peroxidation (*LP*). The extent of LP was determined by measuring the color of adduct, produced in the reaction of 2-thiobarbituric acid (TBA) and malondialdehyde (MDA), as an oxidation product in the peroxidation process of membrane lipids, by the TBA assay (*2*). The commercial preparation of liposomes PRO-LIPO S (Lucas-Meyer, Hamburg, Germany), pH 5−7, was used as a model system of biological membranes. The series of concentrations of tested essential oils ranging from 10 to 50 μL were used in Fe^{2+}/ascorbate and Fe^{2+}/H_2O_2 systems of induction. For each sample five replicates were recorded. The percentage of LP inhibition was calculated by using the equation

$$I\ (\%) = (A_0 - A_1)/A_0 \times 100$$

where A_0 is the absorbance of the control reaction (no essential oil added) and A_1 is the absorbance of tested oils reaction in the presence of inhibitor.

Animals and Experimental Design. Male NMRI mice, body weight 25−35 g, were obtained form Luis Pasteur Institute (Novi Sad, Serbia) and housed in individual cages for 1 week prior to experimental procedures. There were 12 animals per cage. They had free access to pelleted food and water. Temperature of the environment was 24 ± 3 °C, and the animals were housed on a 12 h day−night cycle. All animals were divided in three principal groups according to oral pretreatment: control group pretreated with saline and groups pretreated with daily doses (DD) of essential oil of coriander and caraway, during 5 consecutive days. Each of these groups was divided into two subgroups with regard to later application of CCl_4. There were six animals in each group. Human DDs of essential oil of coriander and caraway recommended by German Commission E Monographs (*12*) were adapted for the experimentation on mice by using the following conversion equation for human equivalent dose (HED) (*20*):

$$\text{HED (mL/kg)} = \text{animal dose (mL/kg)} \times [\text{animal weight (kg)}/\text{human weight (kg)}]^{0.33}$$

Calculated DDs of coriander and caraway essential oils were 0.03 and 0.13 g/kg, respectively. Essential oils were applied by peroral gavage, in the form of emulsion prepared with Tween 80 (Wiler-PCCA, Ontario, Canada). The last dose of essential oils was applied 24 h before the animals were sacrificed, whereas the single dose of CCl_4 in olive oil (1:1, 2 mL/kg) was applied intraperitoneally 20 h before the animals were sacrificed. After decapitation, blood samples were collected and centrifuged (3000 rpm, 10 min) for serum aliquot, whereas livers were perfused with saline, removed, and weighed; both were stored at −20 °C until further analysis. The experimental procedures were approved by the Ethical Committee for Animal Use in Experiments, University of Novi Sad.

Tissue Preparation and Biochemical Assays. Liver samples were thawed on ice, weighed, and homogenized (1:4, w/v) in ice-cold 50 mM Tris-HCl buffer (pH 7.4) containing 250 mM saccharose for the analyses of liver biochemical parameters. Liver homogenates were made on ice using a Potter-Elvehjem apparatus attached to a rotatory device (6−8 strokes at 1000 rpm).

The content of reduced glutathione (GSH), the activities of peroxidase (Px), catalase (CAT), gluthatione peroxidase (GSH-Px), and xanthine oxidase (XOD), and the extent of lipid peroxidation (LPx) in liver tissue samples were spectrophotometrically assayed (*21*). Plasma activities of aspartate transaminase (AST) and alanine transaminase (ALT) were measured using a specrophotometric method of a commercial assay kit (Randox Laboratories Ltd., Crumlin, U.K.).

Statistics. All data were reported as mean values ± standard deviation (SD). Values representing concentrations of investigated essential oils that cause 50% neutralization/inhibition (IC_{50}) were determined by the regression analysis of obtained RSC values and that of the inhibition of LP (Microsoft Excel program for Windows, v. 2003). Results obtained in in vivo investigations were analyzed by one-way ANOVA. Post hoc analysis of each mean treatment was compared to the controls using LSD, and differences were considered to be significant when $P < 0.05$.

RESULTS AND DISCUSSION

Content and Composition of Essential Oils. The contents of essential oil in coriander and caraway fruits were 0.89 and 5.8%, respectively (v/w in dry matter). The percentage composition of the essential oils is presented in **Table 1**. The total numbers of chemical constituents identified in essential oils were 14 for coriander and 12 for caraway, representing 99.9 and 96.7% of the total oil content, respectively. In both essential oils oxygenated monoterpenes were the main class of constituents (94.3% for coriander and 86.6% for caraway). The main compounds of *Coriandrum sativum* essential oil were linalool (74.6%), camphor (5.9%), geranyl acetate (4.6%), and *p*-cymene (4%). Carvone (78.8%) and limonene (10.1%) were identified as the main constituents of *Carum carvi* essential oil. The obtained results of the chemical composition of the investigated essential oils are in accordance with the earlier published data (*1*).

In Vitro Antioxidant Activity. The antioxidant potential of different plant extracts and pure compounds can be measured using numerous in vitro assays. Each of these tests is based on one feature of the antioxidant activity, such as the ability to scavenge free radicals, the inhibition of lipid peroxidation, or chelation of the transition metal ions (TMI). However, a single method is not recommended for the evaluation of antioxidant activities of different plant products due to their complex compositions (*22*). Therefore, the antioxidant effects of plant products must be evaluated by

Table 1. Chemical Composition of *Carum carvi* and *Coriandrum sativum* Essential Oils

peak	component	RI[a]	*Carvi aetheroleum* (%)	*Coriandri aetheroleum* (%)	identification method[b]
	monoterpene hydrocarbons		**10.1**	**5.6**	
1	*p*-cymene	1025		4.0	MS
2	limonene	1029	10.1	0.1	GC-MS
4	γ-terpinene	1060		1.2	GC-MS
	oxygenated monoterpenes		**86.6**	**94.3**	
3	1,8-cineole	1031	0.6		GC-MS
5	*trans*-linalool oxide	1073		0.9	GC-MS
6	*cis*-linalool oxide	1087		0.9	GC-MS
7	linalool	1097		74.6	GC-MS
8	*cis*-limonene oxide	1137	1.8		GC-MS
9	β-terpineol	1144		0.5	MS
10	camphor	1146		5.9	GC-MS
11	menthone	1153	1.2		GC-MS
12	borneol	1169		1.2	GC-MS
13	menthol	1172	0.4		GC-MS
14	terpinene-4-ol	1177		0.4	GC-MS
15	dihydrocarvone	1201	0.8		MS
16	*trans*-carveol	1217	1.3		GC-MS
17	*cis*-carveol	1229	0.6		GC-MS
18	carvone	1243	78.8		GC-MS
19	*trans*-geraniol	1253		2.8	GC-MS
20	*cis*-carvone oxide	1263	0.3		MS
21	*trans*-anethole	1285	0.4	1.8	GC-MS
22	isomenthone	1295	0.1		GC-MS
23	geranyl acetate	1381		4.6	GC-MS
25	α-terpineol	1819		0.7	GC-MS
	oxygenated sesquiterpenes				
24	caryophyllene oxide	1583	0.3		MS
	amount of identified compounds		**96.7**	**99.9**	

[a] Retention indices relative to C_9-C_{24} *n*-alkanes on the HP 5MS column. [b] GC, identification based on retention times of authentic compounds on HP 5MS column; MS tentatively identified on the basis of computer matching of the mass spectra of peacks with the NIST/NBS and Wiley libraries and those reported by Adams (*17*).

Table 2. Percentage of Neutralization of H_2O_2 by Essential Oils of *Carum carvi* and *Coriandrum sativum*

	concentrations					
source	2.5 μL/mL	5 μL/mL	7.5 μL/mL	10 μL/mL	12.5 μL/mL	IC_{50} (μL/mL)
Carum carvi	89.27 ± 0.005	67.24 ± 0.04	63.62 ± 0.006	74.37 ± 0.03	97.15 ± 0.007	<2.5
Coriandrum sativum	18.99 ± 0.4	52.86 ± 0.08	68.28 ± 0.04	56.16 ± 0.08	27.35 ± 0.4	4.05

Table 3. Percentage of Neutralization of DPPH of Essential Oils of *Carum carvi* and *Coriandrum sativum* in the DPPH Assay

	concentrations							
source	2.5 μL/mL	5 μL/mL	7.5 μL/mL	10 μL/mL	12.5 μL/mL			IC_{50} (μL/mL)
Carum carvi	34.69 ± 0.1	58.75 ± 0.01	73.71 ± 0.01	85.41 ± 0.01	91.57 ± 0.009			4.1
	concentrations							
source	12.5 μL/mL	18.75 μL/mL	25 μL/mL	50 μL/mL	75 μL/mL	100 μL/mL	125 μL/mL	IC_{50} (μL/mL)
Coriandrum sativum	10.32 ± 0.02	17.07 ± 0.01	23.52 ± 0.01	47.36 ± 0.01	62.27 ± 0.02	87.35 ± 0.01	88.15 ± 0.01	53.5

combining two or more different in vitro assays to obtain relevant data. With respect to this, the antioxidant properties of the examined essential oils were evaluated, both as RSC and as protective effect on LP.

Free Radical Scavenging Capacity. The DPPH radical is one of the most commonly used substrates for fast evaluation of antioxidant activity because of its stability (in radical form) and the simplicity of the assay. On the other hand, although hydrogen peroxide is a non-free radical species, it is the source of the very toxic hydroxyl radical. Also, hydrogen peroxide can cross membranes and may slowly oxidize a number of cell compounds. Thus, the elimination of hydrogen peroxide is important for both human health and the protection of pharmaceuticals and foodstuffs.

The ability of the examined essential oils to scavenge hydrogen peroxide is shown in **Table 2**. Assessed essential oils were able to neutralize H_2O_2, reaching 50% neutralization with an IC_{50} of < 2.5 μL/mL for *Carvi aetheroleum* and 4.05 μL/mL for *Coriandri aetheroleum*. The unusual neutralization curve of hydrogen peroxide, exhibited by both essential oils, could be explained partially by their chemical composition. The presence of phenolic constituents such as *trans*-anethole (**Table 1**) or some other compounds can interfere with hydrogen peroxide wavelength (260 nm) and produce false-positive results, especially at higher concentrations of tested essential oils.

In the DPPH test the ability of essential oils to act as donors of hydrogen atoms or electrons in the transformation of DPPH into

its reduced form (DPPH-H) was measured spectrophotometrically (**Table 3**). Assessed essential oils were able to reduce the stable DPPH radical to yellow-colored DPPH-H, reaching 50% of reduction with an IC_{50} of 4.1 μL/mL for *Carvi aetheroleum* and 53.5 μL/mL for *Coriandri aetheroleum* in a dose-dependent manner.

Identification of the essential oil constituents most responsible for the RSC was accomplished by comparing the resulting TLC dot-blot chromatogram with the control TLC and GC-MS analysis (**Tables 4** and **5**; see also Figures 2 and 3 in the Supporting Information). It seems that the most active compounds of *Carum carvi* essential oil were *trans*-anethole and certain monoterpene alcohols (carveole and its isomers). However, time-dependent scavenging activity was observed for several compounds. New dots corresponding to carvone and its isomers appeared 1 and 24 h after spraying. As for the *Coriadrum sativum* essential oil, monoterpene hydrocarbons (mainly *p*-cymene) and *trans*-anethole, exhibited free radical scavenging activity immediately after spraying, whereas camphor did it 24 h later. Linalool proved to be a leading component in stabilization of the DPPH radical in a time-dependent manner. These findings are in correlation with earlier published data on antioxidant/prooxidant activities of selected essential oil components and its prooxidant effects in some model systems that were used (*7*, *8*).

Protective effects of essential oil on LP have been evaluated by TBA assay in two systems of induction, Fe^{2+}/ascorbate and Fe^{2+}/H_2O_2 (**Figure 1**). Inhibition of LP was determined by measuring the formation of secondary components (MDA and other thiobarbituric acid reactive species (TBARS)) of the oxidative process, using liposomes as a model of biological membranes. Using this model it is possible to obtain some indications of the real applicability of the oil. In the Fe^{2+}/ascorbate system, *Carum carvi* essential oil expressed a strong and partly dose-dependent antioxidant capacity (IC_{50} < 2.5 μL/mL) with the highest inhibition of 68.11% at a dose of 5 μL/mL. However, *Coriandrum sativum* essential oil showed a decrease of LP contrary to dose rise and an IC_{50} value was not reached. In the Fe^{2+}/H_2O_2 system of induction (Fenton's reaction) the caraway essential oil showed quite weak inhibitory effect on LP with the maximum at dose of 5 μL/mL (33.67%), whereas coriander essential oil proved to have significant, dose-dependent prooxidant activity. *Carum carvi* essential oil exhibited high antioxidant activity, which was found to be in correlation with the content of monoterpene alcohols and ketones. It also proved to have inhibitory effect on LP in both systems of induction, with a stronger effect in the Fe^{2+}/ascorbate system. On the contrary, *Coriandrum sativum* essential oil exhibited lower

Table 4. DPPH Scavenging Active Compounds in *Carum carvi* Essential Oil Identified by Means of TLC Dot-Blot Technique

compound	R_f value	just after spraying	1 h after spraying	24 h after spraying
trans-anethole	0.81	+	+	+
carveole isomers	0.1	+	+	+
carvone	0.59	−	+	+
menthol	0.21	−	+	+

Table 5. DPPH Scavenging Active Compounds in *Coriandrum sativum* Essential Oil Identified by Means of TLC Dot-Blot Technique

compound	R_f value	just after spraying	1 h after spraying	24 h after spraying
p-cymene	0.9	+	+	+
trans-anethole	0.77	+	+	+
geranyl acetate	0.71	+	+	+
camphor	0.59	−	−	+
linalool	0.32	−	+[a]	+[a]

[a] Linalool caused stabilization of DPPH radical.

Table 6. Effects of Caraway (CA) and Coriander (CO) Essential Oils Treatment on Biochemical Parameters of Liver Tissue Homogenate after CCl_4 Application

		groups[a]		
parameter	units	CCl_4	CA + CCl_4	CO + CCl_4
LPx	nmol/mg of protein	2.82 ± 1.0 a	1.72 ± 0.8	1.57 ± 0.3
GSH	nmol/mg of protein	0.80 ± 0.2 a	1.04 ± 0.3 a	1.24 ± 0.2 a
GSH-Px	nmol/mg of protein/min	1.08 ± 0.3	1.76 ± 0.2 b	1.24 ± 0.2
Px	nmol/mg of protein/min	2.96 ± 0.5 a	2.51 ± 0.4 a	1.98 ± 0.4 a
CAT	nmol/mg of protein/min	7.38 ± 2.3 a	7.33 ± 1.3 a	6.96 ± 1.0 a
XOD	nmol/mg of protein/min	2.58 ± 0.8	2.26 ± 0.8	2.36 ± 0.4
proteins	mg/g of liver tissue	516.7 ± 144.9a	521.2 ± 138.3 a	616.2 ± 116.6 a

[a] a, $p < 0.05$ versus control group; b, $p < 0.05$ versus CCl_4 group.

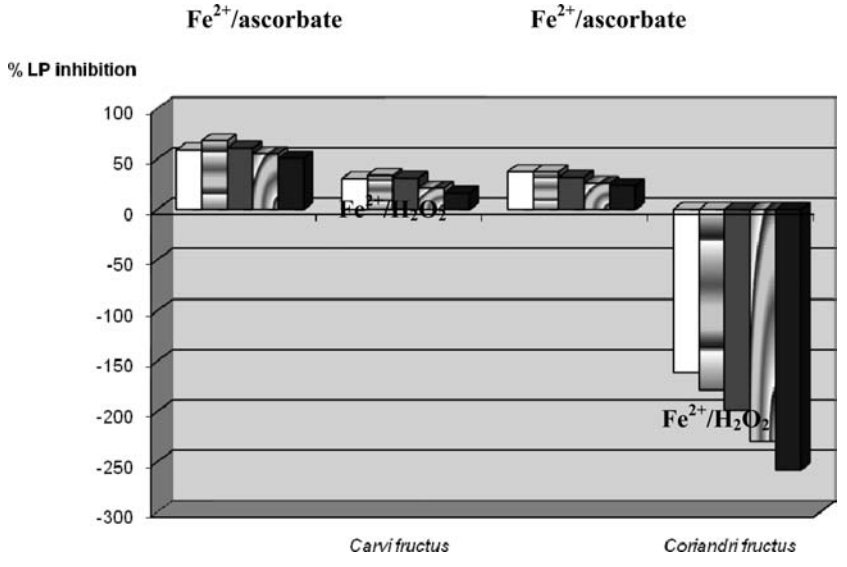

Figure 1. Inhibition of lipid peroxidation (LP) in Fe^{2+}/ascorbate and Fe^{2+}/H_2O_2 systems of induction by the essential oils of *Carum carvi* and *Coriandrum sativum* in the TBA assay.

Table 7. Effects of Caraway (CA) and Coriander (CO) Essential Oil Treatment on Aspartate (AST) and Alanine Transaminase (ALT) in Animals without and after CCl_4 Application

		groups[a]					
parameter	units	control	CA	CO	CCl_4	CA + CCl_4	CO + CCl_4
AST	U/L	88.9 ± 26.0	120.2 ± 17.3	145.0 ± 26.3 a	229.3 ± 38.0 a	173.2 ± 94.7 a	245.0 ± 26.3 a
ALT	U/L	51.2 ± 29.6	101.0 ± 59.0	126.2 ± 10.1 a	119.4 ± 31.3	103.0 ± 69.0	125.2 ± 28.0 a

[a] a, $p < 0.05$ versus control group.

RSC and even prooxidant activity on LP in the Fe^{2+}/H_2O_2 system of induction.

In Vivo Antioxidant Activity. The examined essential oils of caraway and coriander changed in vivo biochemical parameters of liver in mice. A single acute application of CCl_4 brought about characteristic changes in biochemical parameters of liver tissue, too. It caused statistically significant increases in LPx and activity of Px and decreases in the content of GSH and activities of CAT and GSH-Px (**Table 6**). The application of CCl_4 resulted in high values of ALT and AST in all groups, too (**Table 7**).

The essential oil of coriander increased LPx and the activity of Px without statistically significant changes of other antioxidative liver enzymes (**Table 8**). The observed rise in the content of GSH is more distinctive for extracts containing polyphenolic components than for essential oils (*23*). Significant elevation of serum ALT and AST activities compared to control (**Table 7**) correlated with the noted noxious effect of coriander essential oil intake on liver function. The addition of carbon tetrachloride in the group pretreated with essential oil of coriander initiated/potentiated oxidative processes, manifested by the fall of the activity of CAT and the decrease in GSH content (**Table 6**). The activity of Px was elevated, but the LPx remained unchanged. The levels of ALT and AST remained high (**Table 7**). Although in many papers coriander was described as an important spice in the prevention of oxidative damage, these research studies were related to various fruit and leaf extracts, not to essential oil (*23*−*25*). Wangensteen et al. (*13*) found that both coriander essential oil and lipophilic extract of coriander seed were weak or inactive in DPPH scavenging activity and explained it by the lack of hydrogen-donating capacity.

Underlying results of in vitro and in vivo prooxidative action of *Coriandrum sativum* essential oil correlate to findings of the investigation of linalool, the dominant component of this oil. It caused induction of the peroxisomal enzymes in rat liver (*26*), the process connected to hepatomegaly and liver tumors (*27*). Also, biological transformation of linalool involves reactive oxidation−epoxidation, catalyzed by CYP2D6 (*28*). This process results in the formation of an electrophilic product, 6,7-epoxylinalool, which can cause oxidative tissue damage.

Pretreatment with caraway essential oil did not produce a prooxidative effect in liver despite increased Px activity (**Table 8**). Decrease in the activity of XOD after caraway pretreatment was statistically significant, too. The addition of CCl_4 to this group significantly decreased the content of GSH and the activity of CAT, whereas the activities of GSH-Px, Px, and AST rose (**Tables 6** and **7**). Irrespective of CCl_4 potential in the formation of lipid peroxidation products, in the caraway group LPx remained unchanged compared to both control and CCl_4 groups.

The in vitro and in vivo effects of *Carum carvi* essential oil can be attributed to its principle compound, carvone. The possibility of carvone to induce anticarcinogenic and antioxidative glutathione *S*-transferase (GST) speaks in favor of a carvone protective effect (*29*). Stimulation of GST activity is a detoxifying mechanism to eliminate noxious substances. Although CCl_4 decreased GSH levels, the overall effects of the detoxifying system (GST, GSH, and GSH-Px) on the prevention of LPx prevailed.

Table 8. Effects of Caraway (CA) and Coriander (CO) Essential Oils Treatment on Biochemical Parameters of Liver Tissue Homogenate

		groups[a]		
parameter	units	control	CA	CO
LPx	nmol/mg of protein	1.70 ± 0.2	1.85 ± 0.6	2.64 ± 0.8 a
GSH	nmol/mg of protein	2.32 ± 0.7	2.90 ± 0.5	4.02 ± 1.6
GSH-Px	nmol/mg of protein/min	1.30 ± 0.3	1.92 ± 0.3	1.66 ± 0.2
Px	nmol/mg of protein/min	0.36 ± 0.08	3.05 ± 0.79 a	2.80 ± 0.09 a
CAT	nmol/mg of protein/min	9.88 ± 1.1	10.57 ± 2.8	10.84 ± 1.4
XOD	nmol/mg of protein/min	3.37 ± 0.9	2.46 ± 0.7 a	4.17 ± 0.9
proteins	mg/g of liver tissue	354.6 ± 47.6	391.2 ± 28.4	370.0 ± 70.9

[a] a, $p < 0.05$ versus control group.

In general, results of this study confirmed both in vitro and in vivo antioxidant properties of caraway essential oil in tested doses. They indicate that caraway essential oil could serve not only as flavor agent but also as safe antioxidant and antiseptic supplement in preventing deterioration of foodstuffs, beverage products, and pharmaceuticals. This essential oil and it components appear to be promising for safe use in folk medicine and the pharmaceutical and food industries. On the contrary, the use of coriander fruit and its essential oil (especially that with linalool as a dominant component) should be restricted due to its strong prooxidant activity on LP in the Fe^{2+}/H_2O_2 system of induction. The real population exposure to these oils with regard to all beneficial and adverse effects (including potential interactions with other pharmaceuticals) remains unknown and should be the scope of further investigation.

Supporting Information Available: TLC dot-blot chromatograms of examined essential oils of caraway and coriander with the compounds most responsible for antiradical activity (Figures 2 and 3). This material is available free of charge via the Internet at http://pubs.acs.org.

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