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CHEMICAL COMPOSITION AND ANTIMICROBIAL ACTIVITY OF ESSENTIAL OILS FROM BLACK PEPPER, CUMIN, CORIANDER AND CARDAMOM AGAINST SOME PATHOGENIC MICROORGANISMS

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Abstract: Four popular spices black pepper (*Piper nigrum* L.), cumin (*Cuminum cyminum* L.), coriander (*Coriandrum sativum* L.) and cardamom (*Elettaria cardamomum*) were analyzed for their oil composition by GC-MS. Thirty compounds were identified in the black pepper oil and the main components were β-caryophyllene (20.225 %), sabinene (18.054 %), limonene (16.924 %), α-pinene (9.171 %) and α-phellandrene (5.968 %). Twenty five compounds were identified in the cumin oil – cuminaldehyde (30.834 %), 3-caren-10-al (17.223 %), β-pinene (14.837 %), γ–terpinene (11.928 %), 2-caren-10-al (8.228 %) and p-cymene (6.429 %). Twenty nine compounds were identified in the coriander oil – β-linalool (58.141 %), α-pinene (8.731 %), γ-terpinene (6.347 %) and p-cymene (5.227 %). Twenty nine compounds were identified in the cardamom oil – α-terpinyl acetate (39.032 %), eucalyptol (31.534 %), β-linalool (4.829 %), sabinene (4.308 %) and α-terpineol (4.127 %). The antimicrobial activity of essential oils against pathogenic (*Escherichia coli* ATCC 25922, *Escherichia coli* ATCC 8739, *Salmonella* sp. (clinical isolate), *Staphylococcus aureus* ATCC 6538P, *Proteus vulgaris* G) microorganisms by disc-diffusion method was examined. Gram-positive bacteria were more sensitive to the oils (inhibition zones being between 8 and 12.5 mm) and the minimum inhibitory concentration was more than 600 ppm; Gram-negative bacteria were less sensitive. The obtained essential oils are suitable for use as biopreservative agents.

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INTRODUCTION

The antimicrobial activity of plant essential oils is applied by mankind for various purposes since ancient times. They are used as spices in food preparation, forming the sensory profile and increasing the shelf life of the resulting foods. They facilitate the absorption of proteins, fats and carbohydrates. The antimicrobial and antioxidant properties of plants and the aromatic products derived from them are due to the different chemical substances in their composition - essential oils and glyceride oils, alkaloids, flavonoids, tannins, glycosides and other compounds (Dobreva, 2010; Souza et al., 2005; Suhaj et al., 2006). The fruits of black pepper (*Piper nigrum* L.), cumin (*Cuminum cyminum* L.), coriander (*Coriandrum sativum* L.) and cardamom (*Ellettaria cardamomum* L.) are some of the most used in food industry, due to the content of various bioactive substances. Black pepper (*Piper nigrum* L.), known as the "King" of spices, represents lianas of the family *Piperaceae*.

Its main components are the essential oil (1 – 6.4%) and pepper alkaloids (3-10%) (Georgiev & Stoyanova, 2005; Bagheri et al., 2014). The essential oil is obtained by distillation of the dried immature fruits. The essential oil of black pepper is nearly colorless to green-blue in color, it is an easy flowing liquid with the typical pepper smell with mild turpentine nuance and mild flavor. About 104 components have been identified in the essential oil of black pepper - mainly monoterpene (70 - 80%) and sesquiterpene (20 - 30%) carbohydrates and their oxygen derivatives (5 - 6%). From the monoterpene compounds limonene (8.7 - 26%), α- and β-phellandrene (0.2 - 27%), δ-3-caren (0.2 - 38%), sabinene (0.2 - 29%), α-pinene (0.3 - 13%), β-pinene (2 – 15.8%), ρ-cymene (0.1 – 9.7%), camphene, myrcene and others have been identified. From the sesquiterpene compounds β-caryophyllene (5.3 – 41.5%), β-bisabolene (0.6 - 3%), β-selinen (0.1 – 9.7%), β-farnesene and others have been identified. From the oxygen-containing compounds the content of linalool (0.07 – 1.0%) is the highest, and the rest of the oxygen-containing compounds are in amounts of 0.2 – 0.4%. The individual components vary widely depending on the origin and the variety of the raw material, its stage of maturity, the duration and conditions of storage (Georgiev & Stoyanova, 2005; Orav et al., 2004; Singh et al., 2004; Zachariah & Parthasarathy, 2008).

Cumin (*Cuminum cyminum* L.) is an annual herb of the family *Apiaceae*. The collected dry fruits during wax ripeness are processed. Their main ingredients which are used for their qualification are essential oils (2 to 6.1%) and glyceride oils (12-28%). The chemical composition of its essential oil is well

studied. There are approximately 66 identified ingredients, their amounts vary within wide ranges. The main components are: cumaldehyde (15.7 - 63%, rarely to 79.8%), ρ-mentadien-1,3-al-7 (2.2 -27.4%), ρ-mentadien 1,4-al-7 (0.3 -17.4%), β-pinene (0.8 to 21%), ρ-cymene (4.2 – 23.2%), γ-terpinene (1.5 - 23.9%), caryophyllene, sabine hydrate, α-terpineol, 1,8-cineole and others (Georgiev & Stoyanova, 2005; Al Juhaimi et al., 2013; Iacobellis et al., 2005) (Moghaddam et al., 2015; Mostafa et al., 2015).
Coriander (*Coriandrum sativum* L.) is a plant of the family *Apiaceae.* Its essential oil (0.8 – 2.2%) is prepared from the fruits collected during waxing or ripening (Ramadan et al., 2002). Around 283 components, most of which are in trace amounts are established in the essential oil, the major component being linalol (57 to 87.5%). The coriander essential oil also contains α- and β-pinene (0.2 – 8.5%), ρ-cymene (0.2 – 8.6%), limonene (0.2 – 6.3%), camphor (0.4 – 6.3%), γ-terpinene (0.7 – 35.4%), geraniol (0.3 – 5.1%), camphene, myrcene, α-terpineol and others (Georgiev & Stoyanova, 2005; Ramadan et al., 2002; Singh et al., 2004; Singh et al., 2006).
The cardamom essential oil is obtained by distillation of the dried unripened fruit of the tropical grass *Ellettaria cardamomum* (L.). The essential oil is easily movable colorless or pale yellow to yellow-green liquid with a spicy, warm and pleasant smell with balsamic, floral-woody nuance and with camphor hue. The yield is 3.5 to 8.4%. Approximately 68 components are identified in the oil, the main being 1,8-cineol (21 - 41%), α-terpinyl acetate (21-35%), α-terpineol (0.8 – 6.2%), limonene (1.7 – 3.7%), sabinene, ß-pinene (0.3 – 2.4%) and others. It is considered that the α-terpinyl acetate and some of the components in small amounts are responsible for the aroma of the oil (Georgiev & Stoyanova, 2005; Joshi et al., 2013; Savan et al., 2013).
The accumulation of essential oils occurs in typical plant formations called "receptacles". According to their location, the receptacles are divided into two groups: exogenous and endogenous. The essential oils of cereal raw materials are located in endogenous receptacles, allowing them to be stored for a long time without significant changes in the amount and composition of the oils (Dobreva, 2010).
The purpose of the present experiment was to determine the chemical composition and the antimicrobial activity of essential oils obtained from fruits of black pepper, cumin, coriander and cardamom against pathogens.

MATERIALS AND METHODS

Media

LBG – agar. Composition (g/dm^3): Tryptone - 10; yeast extract - 5; NaCl - 10; glucose – 10; agar - 15; pH = 7.5. Sterilization - 20 min at 121°C.

Saline solution with 1 % (v/v) Tween 80. Composition (g/dm^3): NaCl - 5; Tween 80 – 1cm^3/dm^3. Sterilization - 20 min at 121ºC.

Essential oils from fruits of black pepper, cumin, coriander and cardamom were used for the conduction of the experiments

Essential oil content was determined by water distillation in a modification of a laboratory glass apparatus of the British Pharmacopoeia (Balinova & Dyakov, 1974; Stoyanova et al., 2007).

The component composition of the oil was determined by gas chromatography with mass selective detector (GC-MS) (Morais et al., 2007): Apparatus: GC 7890 A / MSD 5975 C (Agilent Technologies); Conditions: 1) Oven Program: 40°C for 3 min then 5°C/min to 300°C for 5 min; Run Time: 60 min; 2) Front SS Inlet: He; Heater: 250°C; 3) Thermal Aux 2 (MSD Transfer Line); Heater: 150°C for 0 min; 4) Column: HP-5MS (5% Phenyl Methyl Silox); 325°C: 30 m x 250 μm x 0.25 μm; 5) Pressure: 6.9972 psi; 6) Flow: 1.0 mL/min.

The identified components were arranged according to the retention time and their quantity is given in percentages.

Determination of microbiological indicators of spices

- Mesophilic aerobic and facultative anaerobic bacteria, according to BS EN ISO 4833:2004;
- Yeasts and molds, according to BDS EN ISO 21527-2:2011;
- *Escherichia coli*, according to ISO 16649-2:2001;
- *Enterobacteriaceae*, according to BS EN ISO 21528-2:2011;
- Sulphite-reducing bacteria, according to ISO 15213:2003;
- *Salmonella* sp. bacteria, according to EN ISO 6579:2003;
- Coagulase-positive staphylococci, according to BDS EN ISO 6888-1:2005 + A1:2005.

Determination of the antimicrobial activity against pathogenic microorganisms.

- Test microorganisms: *Escherichia coli* ATCC 25922, *Escherichia coli* ATCC 8739, *Salmonella* sp. (clinical isolate), *Staphylococcus aureus* ATCC 6538P, *Proteus vulgaris* G. All strains are deposited in the culture collection of the Department "Microbiology" at the University of Food Technologies, Plovdiv, Bulgaria.
- Preparation of the suspensions of the test pathogenic microorganisms. The test pathogenic microorganisms were cultured on LBG-agar at 37±1°C for 24-48 hours. Using sterile loop biomass of the developed test pathogenic

microorganisms was suspended in sterile saline solution in order to obtain suspensions of the test pathogenic microorganisms.

- The antimicrobial activity was studied by the disc-diffusion method.

Sterile melted LBG-agar medium was poured in Petri dishes and after the hardening of the agar, the dishes were spread plated with suspensions of the test pathogenic microorganisms. Decimal dilutions of the essential oils in saline solution containing 1 % (v/v) Tween 80 were prepared. The experiments were conducted with dilutions 1×, 10× and 100× in order to determine the MIC (minimal inhibitory concentration). The used paper discs were 6 mm in diameter. 6 μL of the corresponding dilution were pipetted on the corresponding paper discs. Paper discs soaked in distilled water were used as blanks. The results were recorded as diameters of the inhibition zones (IZ) around the paper discs, in millimeters, after 24–48 hours of incubation of the Petri dishes at optimal temperature for the growth of the corresponding test-microorganism (at 30 °C for the saprophytic microorganisms and at 37°C for the pathogenic microorganisms) (Jirovetz et al., 2006). The MIC was defined as the lowest concentration of the essential oil at which the microorganism did not demonstrate visible growth (Randrianarivelo et al., 2009).

The experiments were performed in quadruplicate. The mean values and the standard deviations were calculated using MS Office Excel 2010. The MICs, in ppm, were calculated on the basis of the obtained results in accordance with CLSI. *Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria That Grow Aerobically; Approved Standard—Ninth Edition*.

RESULTS AND DISCUSSIONS

Microbiological indicators

The antimicrobial activity of spices and their effect on food products is determined by several factors: the type, composition and quantity of the spice; the types of microorganisms and degree of contamination; the composition of the medium; the processing and storage conditions of the resulting foodstuffs (Zachariah & Parthasarathy, 2008).

Although they are being added in small amounts to enhance the color and flavor of food, spices can cause microbial spoilage or turn food into an unsafe product for the health of the consumer. They carry themselves saprophytic and pathogenic microflora. The microflora of the fruits of black pepper, cumin, coriander and cardamom is given in Table 1. They all carried a significant amount of saprophytic microorganisms (over 10^3-10^6 cfu/g), as well as molds and yeasts (over 10^2-10^3 cfu/g).

It is typical for spices to be significantly contaminated. But essential oils have strong antimicrobial and antioxidant properties, thus they are successfully applied as natural preservatives in food.

Table 1. Microbiological indicators of the dry fruits of black pepper, cumin, coriander and cardamom

Parameter	Method of examination	Black pepper	Cumin	Coriander	Cardamom
		cfu/g	cfu/g	cfu/g	cfu/g
Mesophilic aerobic and facultative anaerobic bacteria	BDS EN ISO 4833:2004	$1.5x10^6$	$4x10^3$	$7.2x10^5$	$1.1x10^6$
Yeasts and molds	BDS EN ISO 21527-2:2011	$8x10^2$	$4x10^2$	$3x10^3$	$2x10^2$
Escherichia coli	ISO 16649-2:2001	< 10	< 10	< 10	< 10
Enterobacteriaceae	БДС EN ISO 21528-2:2011	< 10	< 10	< 10	< 10
Sulphite-reducing bacteria	ISO 15213:2003	< 10	< 10	< 10	< 10
Salmonella sp.	BDS EN ISO 6579:2003	Not foumd in 25g			
Coagulase-positive staphylococci	BDS EN ISO 6888-1:2005 +A1:2005	< 100	< 100	< 100	< 100

Chemical composition

Essential oils are complex mixtures of volatile compounds derived from a large number of plants. Their content in plants is a very small part (less than 5% of the dry matter content of the plant) and consists primarily of carbohydrate terpenes and terpenoids (Asbahani et al., 2015). The content of essential oil in the fruits of black pepper is between 1% and 6.4% (Georgiev & Stoyanova, 2005; Bagheri et al., 2014). The cumin essential oil content is up to 10%, the coriander essential oil content is from 0.8% to 2.2%, and the cardamom essential oil content is 3.5 – 8.4% (Georgiev & Stoyanova, 2005; Ramadan et al., 2002; Mostafa et al., 2015). The chemical composition of the obtained essential oils of black pepper, cumin, coriander and cardamom are presented in Table 2.

30 compounds, 14 of them being over 1% and the other 16 - less than 1% were identified in the essential oil of black pepper. The monoterpene and

sesquiterpene carbohydrates prevailed. The monoterpene carbohydrates were represented mainly by sabinene (18.054%), limonene (16.924%), α-phelandrene (5.968%) and α- and β-pinene (9.171% and 3.419%, respectively); sesquiterpene carbohydrates – by β-caryophyllene (20.225%); aromatic compounds – by p-cymene (1.874%) (Table 2).

Table 2. Component composition of oils from the fruits of black pepper, cumin, coriander and cardamom

#	Name	RI	Black pepper	Cardamom	Cumin	Coriander
			% of TIC	% of TIC	% of TIC	% of TIC
1	α-thujene	928	2.512	0.222	0.375	0.109
2	α-pinene	939	9.171	1.839	1.126	8.731
3	camphene	954	0.183	0.103	0.048	1.132
4	sabinene	971	18.054	4.308	nd	0.566
5	β-pinene	979	3.419	1.491	14.837	0.895
6	β-myrcene	991	1.582	0.088	0.708	0.913
7	α-phellandrene	1003	5.968	nd	0.082	nd
8	p-cymene	1024	1.874	0.096	6.429	5.227
9	β-phellandrene	1027	0.433	nd	0.055	nd
10	limonene	1030	16.924	0.072	0.565	2.526
11	eucalyptol	1032	nd	31.534	0.232	0.112
12	β-ocimene	1046	0.109	0.112	nd	nd
13	γ-terpinene	1055	0.152	0.611	11.928	6.347
14	terpinolene	1088	0.367	0.104	0.079	0.333
15	β-linalool	1092	0.373	4.829	0.063	58.141
16	camphor	1144	0.103	nd	nd	4.048
17	borneol	1169	nd	nd	nd	0.196
18	pinocarvone	1175	0.096	nd	nd	0.132
19	terpinene-4-ol	1179	0.461	1.313	0.148	0.243
20	α-terpineol	1189	0.062	4.127	1.746	0.376
21	cis-geraniol	1215	nd	0.128	nd	0.055
22	cis-citral	1220	nd	0.242	nd	0.071
23	linalyl anthranilate	1226	nd	1.896	nd	nd
24	trans-geraniol	1232	nd	0.859	nd	2.018
25	trans-citral	1240	nd	0.414	nd	0.067
26	cumaldehyde	1242	nd	nd	30.834	nd
27	phelandral	1258	nd	nd	0.206	nd
28	thymol	1266	nd	nd	nd	0.049
29	2-caren-10-al	1285	nd	nd	8.228	nd
30	3-caren-10-al	1293	nd	nd	17.223	nd

31	myrtenyl acetate	1327	nd	nd	0.111	0.084
32	α-terpinyl acetate	1333	nd	39.032	0.171	0.078
33	neryl acetate	1342	nd	0.169	nd	0.051
34	geranyl acetate	1350	nd	0.804	nd	3.906
35	α-longipinene	1352	0.995	nd	nd	nd
36	β-longipinene	1396	0.692	nd	nd	nd
37	β-caryophyllene	1419	20.225	0.142	0.093	0.265
38	α-trans-bergamotene	1435	1.281	nd	0.054	nd
39	α-humulene	1454	2.063	nd	0.062	nd
40	α-terpinyl propionate	1466	nd	nd	nd	0.242
41	β-eudesmene	1478	nd	0.411	nd	nd
42	γ-curcumene	1483	0.752	0.325	nd	nd
43	α-zingiberene	1494	nd	0.152	nd	nd
44	α-muurolene	1498	0.402	nd	nd	nd
45	β-bisabolene	1506	1.667	0.149	nd	nd
46	γ-cadinene	1513	0.786	nd	nd	nd
47	δ-cadinene	1524	1.985	nd	nd	nd
48	±-trans-nerolidol	1565	nd	1.391	nd	nd
49	caryophyllene oxide	1574	nd	0.312	0.082	0.042
50	(-)-spathulenol	1619	1.039	nd	nd	nd
51	α-bisabolol	1675	0.695	nd	nd	nd

* RI-Relative Index; TIC-Total Ion Current; nd-no detect

25 components, 8 of them being over 1%, the remaining 17 - in a concentration less than 1% were identified in the essential oil of cumin. Monoterpene carbohydrates, aromatic compounds, monoterpene oxygen derivatives and sesquiterpene carbohydrates prevailed in the composition of the essential oil. From the monoterpene carbohydrates the main substances were β-pinene (14.837%) and γ-terpinene (11.928%); from the aromatic conpounds – cumaldehyde (30.834%) and p-cymene (6.429%); from the monoterpene oxygen derivatives - 2- and 3-caren-10-al (8.228% and 17.223%) and from the sesquiterpene carbohydrates - β-caryophyllene (0.093%) (Table 2).

29 components were identified in the coriander essential oil. 9 of the substances were in a concentration more than 1%, and the remaining 20 were all in concentrations less than 1%. The monoterpene oxygen derivatives, followed by the monoterpene carbohydrates and the aromatic compounds prevailed in the composition of the oil, the content of sesquiterpene carbohydrates was below 1%. The predominant monoterpene oxygen

derivatives were β-linalool (58.141%), geranyl acetate (3.906%) and geraniol (2.018%); the prevailing monoterpene carbohydrates were γ-terpinene (6.347%), α-pinene (8.731%) and limonene (2.526%), and the predominant aromatic compounds were p-cymene (5.227%) and camphor (4.048%) (Table 2).

29 components were identified in the cardamom essential oil. 9 of the substances were in a concentration more than 1%, and the remaining 20 were all in concentrations less than 1%. The monoterpene oxygen derivatives and the monoterpene carbohydrates prevailed in the essential oil. The monoterpene oxygen derivatives were represented mainly by β-linalool (4.829%) α-terpinyl acetate (39.032%), eucalyptol (31.534%) and α-terpineol (4.127%); the monoterpene carbohydrates – by sabinene (4.308%) (Table 2).

The biological function of the chemical components is not limited by their antimicrobial activity, some of them have antioxidant (limonene, pinene), antitumor (linalool, borneol), anti-inflammatory (sabinene, pinene) and analgesic function (citral) (Asbahani et al., 2015; Miracle et al., 2013; Marija et al., 2014; Nishijima et al., 2014; Singh et al., 2010; Valente et al., 2013). Typical for camphor are its antispasmodic, diuretic, antirheumatic and sedative effects (Valente et al., 2013). The geraniol has insecticidal, antimicrobial, antitumor and antioxidant function and the β-caryophyllene has anticolitis, anti-inflammatory and antispasmodic activities (Asbahani et al., 2015; Chen et al., 2010). Due to the content of different bioactive substances the essential oils obtained from the fruits of black pepper, cumin, coriander and cardamom are some of the most used in food industry.

The content of flavoring substances in the essential oils of the four spices used in the present work does not differ from data in literature.

Antimicrobial activity

The results from the determination of the antimicrobial effect of essential oils obtained from the fruits of black pepper, cumin, coriander and cardamom are presented in Table 3. All oils exhibited antimicrobial activity against the investigated test organisms. Gram-positive bacteria were more sensitive to the activity of the essential oils, the measured zones of inhibition were between 8 and 10 mm, the minimum inhibitory concentration was greater than 600 ppm. The tested Gram-negative bacteria showed zones of inhibition between 8 and 12.5 mm, with a minimum inhibitory concentration of 6 ppm. The observed difference in the sensitivity of the different test-microorganisms to the examined essential oils was due to the difference in the structure and composition of the cell wall of both groups of bacteria. The presence of an outer membrane in Gram-negative bacteria hinders the diffusion of essential oils through the membrane into the cytoplasm of the cell, which makes them more resistant to the action of the oils. The results obtained for the different resistance of Gram-positive and Gram-negative bacteria to inhibitors of microbial growth were consistent with literature data (Randrianarivelo et al., 2009; Souza et al., 2005). The small differences in the zones of inhibition for one and the same test microorganism of the four essential oils can be explained by the variation of the content of aromatic compounds and the different component composition.

The antimicrobial activity of the oil of black pepper is due to the carbohydrates sabinene, cymene, limonene, linalool and bisabolol. In coriander oil the components responsible for the antimicrobial activity are sabinene, cymene, limonene, linalool, borneol, geraniol, thymol and citral. In cumin oil the antimicrobial activity is due to cymene, limonene and linalol, in cardamom oil - to sabinene, cymene, limonene, linalool, geraniol and citral (Asbahani et al., 2015).

Table 3. Antimicrobial activity of essential oils from the fruits of black pepper, cumin, coriander and cardamom.

Test-microorganism	Black pepper		Cumin		Coriander		Cardamom	
Pathogenic microorganisms	IZ, mm	MIC, ppm	IZ, mm	MIC, ppm	IZ, mm	MIC, ppm	IZ, mm	MIC, ppm
Staphylococcus aureus ATCC 6538P	9.50± 0.47	60	9.00± 0.47	60	10.00 ±0.48	>600	9.00± 0.48	600
Proteus vulgaris G	9.00± 0.47	>600	9.00± 0.47	600	9.00± 0.47	60	8.00± 0.48	600
Salmonella sp.	9.00± 0.48	>600	8.00± 0.48	600	10.00 ±0.40	>600	8.00± 0.40	600
Escherichia coli ATCC 8739	9.00± 0.47	60	10.00 ±0.48	>600	10.00 ±0.47	60	10.00 ±0.47	>600
Escherichia coli ATCC 25922	9.00± 0.48	6	9.00± 0.47	60	12.50 ±0.40	60	8.00± 0.47	60

IZ – inhibition zone; MIC – Minimal Inhibitory Concentration

The resulting oils can be used as food flavorings in the production of sausages, vegetable, meat and fish canned food, chutneys, mayonnaise, ketchup, salad dressings, processed cheese, beverages, candies and more. They also have potential application in perfumery and cosmetics, in the manufacture of perfumes, cosmetics, soaps and shampoos. They are used as natural pesticides as well. They are also widely used in medicine because of their multilateral physiological effect. Most of them have common medicinal properties, which are manifested differently depending on the component composition.

CONCLUSIONS

Traditional spices are characterized by high level of contamination, but essential oils, on the contrary, clearly possess antimicrobial and antioxidant properties and may be administered in small amounts. The predominant components in the examined essential oils obtained from the fruits of black pepper were the monoterpene (53.536%) and sesquiterpene carbohydrates (22.099%); cumin - monoterpene carbohydrates (26.765%), followed by aromatic compounds (37.263%) and monoterpene oxygen derivatives (25.451%); coriander - monoterpene oxygen derivatives (64.065%), followed by monoterpene carbohydrates (17.604%) and aromatic compounds (9.275%); cardamom - monoterpene oxygen derivatives (79.522%). The essential oils exhibited pronounced antimicrobial activity against Gram-positive bacteria as compared to Gram-negative bacteria. This is due to the difference in the structure and composition of the cell wall of bacteria belonging to both groups and the different component composition of the essential oils. Their antimicrobial activity allows their application as natural preservatives, helping increase food safety.

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