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***Basic Study***

**Natural isothiocyanates of the genus *Capparis* as potential agonists of apoptosis and antitumor drugs**

Hanus L *et al*. Natural isothiocyanates

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**Abstract**

BACKGROUND

Using gas chromatography-mass spectrometry (GC/MS) analysis, we examined the composition of volatile components present in the yellow and green fruits, seeds, and jam of the scrambling shrub *Capparis cartilaginea* (*C. cartilaginea*). These plant samples were collected from Kibbutz Yotvata in Israel. In all the tested samples, isothiocyanates were identified. Utilizing the PASS program, we ascertained the biological activity of these isothiocyanates present in the *Capparis* genus. The study results highlighted that all isothiocyanates could potentially act as apoptosis agonists, making them strong candidates for antitumor drugs. This information holds significant value for the fields of medicinal chemistry, pharmacology, and practical medicine.

AIM

To investigate the volatile components present in the yellow and green fruits, seeds, and jam of the *C. cartilaginea* shrub using GC/MS analysis, to detect isothiocyanates in all the analyzed plant samples, and to assess the biological activity of these isothiocyanates utilizing the PASS program.

METHODS

We utilized two primary methods to analyze the volatile compounds present in the yellow and green fruits, seeds, and jams of the *C. cartilaginea*, native to Israel. We identified biologically active isothiocyanates in these samples. Their anticipated biological activities were determined using the PASS program, with the most dominant activities being apoptosis agonist, anticarcinogenic, and antineoplastic specifically for genitourinary cancer.

RESULTS

Fruits, seeds, and jams containing isothiocyanates, which exhibit antineoplastic and anticarcinogenic activities, could be suggested for cancer prevention and management. Specific isothiocyanates, with therapeutic potential in this realm, could be recommended as potent anticancer agents in practical medicine following clinical trials.

CONCLUSION

The discovery that isothiocyanates exhibit potent antineoplastic and anticarcinogenic activities was unexpected. Additionally, certain isothiocyanates demonstrated antifungal, antiviral (specifically against arbovirus), and antiparasitic properties.

**Key Words:** *Capparis cartilaginea*; Fruits; Seeds; Isothiocyanates; Apoptosis; Anticancer

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**Core Tip:** Using gas chromatography-mass spectrometry analysis, we examined the composition of volatile components present in the yellow and green fruits, seeds, and jam of the scrambling shrub *Capparis cartilaginea*. Fruits, seeds, and jams containing isothiocyanates, which exhibit antineoplastic and anticarcinogenic activities, could be suggested for cancer prevention and management. Specific isothiocyanates, with therapeutic potential in this realm, could be recommended as potent anticancer agents in practical medicine following clinical trials.

**INTRODUCTION**

The genus *Capparis*, part of the Capparidaceae family, comprises approximately 250 species[1-3]. The Cartilage caper is notably prevalent across tropical and subtropical regions in Asia, America, and Africa[4-6]. Recent findings suggest that the genus *Capparis* encompasses about 400 compounds, including glycosides, glucosinolites, flavonoids, terpenoids, tannins, steroids, and isothiocyanates[7,8]. There is substantial evidence indicating the therapeutic potential of these phytochemicals in treating and preventing various ailments such as inflammation, cancer, bacterial infections, ulcers, and diabetes[9-11].

This study explored the volatile compounds present in the yellow and green fruits, seeds, and jam of *Capparis cartilaginea* (*C. cartilaginea*), a species native to Israel. Furthermore, we were keen to examine the distribution of isothiocyanates in the essential oils of the *Capparis* genus from various global regions. Included is a table detailing the isothiocyanates identified within the *Capparis* genus, along with their anticipated biological activities as determined using the PASS software.

**MATERIALS AND METHODS**

***Plant materials and extraction***

The scrambling shrub *C. cartilaginea*, grown in Kibbutz Yotvata in Israel, was the source of the yellow and green fruits (Figure 1) harvested in 2019 for component analysis. The aromatic, juicy pulp of the fruit was available at the Kibbutz store, labeled as “*Jam of Tuvia Naor*”. Samples were taken from shrubs reaching heights of up to 3 meters. The fruit is globose-ellipsoid in shape, with a reddish hue, measuring (3-6) cm × (1.6-4) cm. Fresh biological materials underwent head space and solid phase microextraction gas chromatography-mass spectrometry (GC-MS) analysis, following the methods that we have previously detailed[12-14].

***General experimental procedures***

For the GC/MS analysis, we employed an Agilent 7890B GC combined with an Agilent 5977B MSD and a PAL 3 (RSI 85) chromatograph. The columns used were HP-5MS UI, 30 m × 0.25 mm with a film thickness of 0.25 μm, provided by Agilent Technologies, Inc. The analytical conditions were set with the column initially held at 35 °C for 5 min. Subsequently, the temperature was programmed to rise from 35 °C to 150 °C at a rate of 5 °C/min, then increasing by 15 °C/min to 250 °C, with a hold time of 90 min. The specific settings were as follows: Inlet temperature at 250 °C, detector temperature at 280 °C, split injection ratio of 1:5, initial temperature at 100 °C, and initial time set to 4.0 min. Helium was used as the carrier gas with a flow rate of 1 mL/min.

For compound detection and identification, we referenced various standards, retention times, and retention indices (Table 1). Additionally, we consulted multiple libraries: NIST/EPA/NIH Mass Spectral Library 2017, Wiley Registry of Mass Spectral Data 11th Edition, FFNSC3, © 2015, and the Adams EO library, Mass Spectral Library, containing 2205 compounds. In total, X volatile compounds were detected, with Y of them being positively identified. This identification was based on a comparison of their mass spectra and retention times, along with their Kovats retention indices, either to those of injected standards or by referencing the National Institute of Standards and Technology’s Mass Spectral Library database.

***Comparison of biological activities of natural isothiocyanates***

The principle that the chemical structure of natural or synthetic molecules dictates their biological activity has been recognized for over 150 years and is referred to as structure-activity relationships (SAR). This concept was first introduced by Brown and Fraser[15] in 1868. However, according to alternate sources[16], the SAR notion was earlier employed in the realm of toxicology. In this context, Cros determined the correlation between the toxicity of primary aliphatic alcohols and their water solubility as early as 1863.

In this particular study, we sourced PASS predictions for approximately 28 isothiocyanates derived from various plants. These PASS estimates are represented as Pa values. Each Pa value signifies the likelihood of a compound being categorized under “actives” for a given predicted biological activity. A higher Pa value denotes greater confidence in the anticipated biological activity[17,18].

**RESULTS**

Various components from leaves, buds, stems, aerial parts, and seeds of different plant species within the *Capparis* genus have been documented in the literature. Yet, no literature data was found pertaining to the study of yellow and green fruits or jam derived from *C. cartilaginea*. Based on our GC/MS findings, the primary constituents of the yellow fruits were identified as 2-butyl isothiocyanate (49.43%) and isopropyl isothiocyanate (48.74%), as visualized in the chromatogram (Figure 2A). A similar compositional profile was observed for the green fruits, with the dominant components being 2-butyl isothiocyanate (49.76%) and isopropyl isothiocyanate (46.68%), as shown in Table 2 and illustrated in the chromatogram (Figures 2B and 3).

The GC/MS analysis of the seeds from *C. cartilaginea* revealed dimethylsulfide as the predominant component, constituting 55.82%, while the content of 2-butyl isothiocyanate was notably lower at just 6.8%. These findings can be referenced in Table 3 and visualized in the chromatogram (Figure 2C). Furthermore, the GC/MS analysis of jam derived from *C. cartilaginea* indicated that its primary components were hexanedioic acid bis(2-ethylhexyl) ester at 61.99%, limonene (covering both isomers) at 8.51%, dimethyl sulfide at 3.85%, 2-butyl isothiocyanate at 3.29%, dodecanoic acid 1-methylethyl ester at 2.16%, and pentanoic acid, 2-ethylhexyl ester at 2.01% (Table 4). The molecular structures of these identified compounds are depicted in Figure 4. Tuvia Naor jam consists of the fruits of *C. cartilaginea* (or *Capparis inermis*, or a synonym for *Capparis sinaica*). Homemade jam Tuvia capparis Jam from the fruits of *C. cartilaginea* contains 36% fruit, sugar, apple, lemon, and flavors.

**DISCUSSION**

The experimental data reveals that all parts of plants from the *Capparis* genus contain isothiocyanates in varying concentrations. It was intriguing to discern which specific isothiocyanates were present in this genus. This curiosity stems from the fact that isothiocyanates are invaluable plant metabolites known for their broad spectrum of biological activities. Notably, certain isothiocyanates are incorporated into Tibetan and Chinese medicinal practices[19-21]. These naturally occurring molecules originate from glucosinolate precursors found in cruciferous vegetables[19,22-25].

Tables 5 and 6 provide a quantitative breakdown of the distribution of isothiocyanates across different plant species within the *Capparis* genus, collected from various global regions. While many articles discuss isothiocyanates, not all provide specific percentages, hence we have refrained from citing such articles. The molecular structures of isothiocyanates extracted from various *Capparis* species are illustrated in Figure 5.

Isothiocyanates, which originate from glucosinolate precursors in cruciferous plants, are recognized as some of the most potent chemoprophylactic agents. Numerous studies affirm that both natural and synthetic isothiocyanates possess anticarcinogenic properties, as they not only diminish the activation of carcinogens but also augment their detoxification[44-48]. Moreover, they demonstrate antitumor capabilities, influencing a myriad of pathways such as apoptosis, MAPK signaling, oxidative stress, and cell cycle progression[47-51].

The process through which natural isothiocyanates are formed *via* the hydrolysis of glucosinolates, facilitated by the enzyme β-thioglucosidase (known as myrosinase), is depicted in Figure 6. This biosynthetic mechanism is well-established, with isothiocyanates being identified in both plants and fungi[52-54]. Utilizing the PASS computer program, we computed the activity of natural isothiocyanates extracted from plants within the *Capparis* genus. The ensuing data is outlined in Table 7. As the table reveals, the primary properties pertaining to biological activity encompass apoptosis agonist, chemoprotective, chemosensitizer, and antineoplastic functions.

Benzyl isothiocyanate (9) has been extracted from *Capparis spinosa* (*C. spinosa*) components. Traditionally, fresh parts of this plant, particularly the flower buds, have been consumed as accompaniments to olives, cheese, and nuts. This plant stands out as one of the most cherished aromatic varieties native to the Mediterranean region. The fermentation of different parts of *C. spinosa* not only renders the capers consumable but also shapes their distinct taste, along with their organoleptic and nutritional attributes[54]. The biological activity of benzyl isothiocyanate is depicted in a 3D graph, as illustrated in Figures 7 and 8A.

Advanced ovarian cancer cannot be cured by surgery alone; chemotherapy is vital for its treatment. While isothiocyanates have been shown to inhibit carcinogen-induced tumorigenesis in animal models, their therapeutic potential in advanced ovarian cancer remains unexplored. Kalkunte *et al*[55] demonstrated that benzyl isothiocyanate, commonly found in cruciferous vegetables like broccoli, cabbage, and watercress, suppresses the proliferation of advanced ovarian cancer cells and triggers apoptosis. Preliminary studies indicate its potential in both preventing and treating various cancers. Given this evidence, more research is essential to confirm its efficacy in humans and to advance its potential as a prophylactic or therapeutic agent, maximizing therapeutic outcomes while minimizing toxicity in cancer treatments[47].

In our study, we examined the volatile components of yellow and green fruits from the scrambling shrub *C. cartilaginea*. Additionally, we delved into the composition of seeds and jam derived from *C. cartilaginea* using GC/MS analysis. We detected isothiocyanates in all plant samples studied. This research presents a comprehensive overview of isothiocyanates identified in the *Capparis* genus, gathered from various global regions. Through the PASS program, we ascertained the biological activities of these isothiocyanates. Our findings revealed that these compounds are promising apoptosis agonists with potential as potent antitumor agents. Furthermore, we identified additional biological activities. The insights provided in this study hold substantial practical relevance and could pave the way for medical applications. The term “chemoprotective” refers to the properties of a substance that helps protect cells and tissues from the toxic effects of chemicals or against the DNA damage that can lead to cancer. In other words, chemoprotective agents help prevent or reduce the risk of chemically induced diseases, including various forms of cancer. Chemoprotective properties can arise from a variety of mechanisms: (1) Antioxidant activity: Many chemoprotective agents can neutralize free radicals, reducing oxidative stress, which can cause DNA damage and potentially lead to cancer; (2) Detoxification: Certain substances can enhance the body’s detoxification processes, helping to remove or neutralize potential carcinogens before they can cause harm; (3) Enhancement of DNA repair: Some agents can boost the mechanisms that repair damaged DNA; (4) Inhibition of carcinogen activation: Some chemicals need to be activated in the body to become carcinogenic. Chemoprotective agents can inhibit the enzymes responsible for this activation; (5) Suppression of carcinogen binding to DNA: By preventing carcinogens from binding to DNA, chemoprotective agents can reduce the risk of mutations that might lead to cancer; and (6) Inhibition of tumor growth: Some agents can slow or stop the growth of tumors by affecting cell cycle progression, inducing apoptosis (programmed cell death) or suppressing the blood supply to tumors (anti-angiogenesis).

Natural foods, especially fruits, vegetables, and spices, are rich sources of chemoprotective compounds. Examples include the isothiocyanates from cruciferous vegetables, polyphenols from green tea, curcumin from turmeric, and resveratrol from grapes, among many others. In the context of cancer, chemoprotection can also refer to strategies or agents used to protect normal tissues from the harmful side effects of chemotherapy while allowing the drugs to act on cancer cells.

Ethyl-(2), allyl-(14), and 3-methyl-3-butenyl-isothiocyanates (17) exhibited a pronounced apoptosis agonist activity, with confidence levels exceeding 95%. The associated 3D graph (Figure 8B) visually represents their activities. Another visual representation can be observed in Figure 8C, where three specific isothiocyanates stand out due to their robust anti-*Helicobacter pylori* activity, which exhibits over 80% confidence. Among these, anticancer properties are the most prominent.

Furthermore, isothiocyanates labeled as 26, 27, and 28 provide compelling data, as illustrated in Figure 8D. Not only do these compounds demonstrate potent apoptosis agonist activity, surpassing 93% confidence, but they also show promise in treating periodontitis with a confidence level exceeding 70%.

“Anti-*Helicobacter pylori* activity” refers to the ability of a substance to inhibit or eradicate *Helicobacter pylori* bacteria. *Helicobacter pylori* is a type of bacteria that can infect the stomach and is known to be a main cause of peptic ulcers, and its persistent infection has also been linked to stomach cancer. Therefore, substances with anti-*Helicobacter pylori* activity may help in preventing or treating these conditions.

Substances with anti-*Helicobacter pylori* activity might function through various mechanisms, such as: (1) Inhibiting the growth or reproduction of the bacteria; (2) Killing the bacteria directly; and (3) Disrupting the mechanisms by which the bacteria cause disease (for instance, by neutralizing toxins produced by the bacteria).

Anti-*Helicobacter pylori* activity can be exhibited by antibiotics, as well as various other natural and synthetic compounds, and is an area of interest in pharmacology and medicinal chemistry due to the importance of managing infections by this bacterium. Research into substances with anti-*Helicobacter pylori* activity may yield new treatments for infections and possibly for preventing stomach ulcers and cancer.

Periodontitis refers to a serious gum infection that damages the soft tissue and destroys the bone that supports your teeth. It can lead to tooth loss or worse, if not treated. Periodontitis is common but largely preventable. It is usually the result of poor oral hygiene. Key points about periodontitis include: (1) Cause: It is primarily caused by bacteria that adhere to and grow on the tooth’s surfaces, along with an aggressive immune response against these bacteria; (2) Symptoms: Red or swollen gums, tender or bleeding gums, painful chewing, loose teeth, sensitive teeth, bad breath that does not go away, and receding gums or longer appearing teeth; (3) Risk factors: Periodontitis can be influenced by several factors including poor oral hygiene, tobacco use, diabetes, age, genetics, certain medications, and other conditions like decreased immunity; (4) Complications: If left untreated, periodontitis can result in tooth loss. It can also increase the risk of stroke, heart attack, and other health problems; and (5) Treatment: Treatment usually involves good dental hygiene practices, scaling, and root planning (deep cleaning) to remove the plaque and tartar, and in more severe cases, surgical treatments. Regular dental checkups and good oral hygiene can help prevent periodontal disease.

**CONCLUSION**

In our study, we examined the volatile components of yellow and green fruits from the scrambling shrub *C. cartilaginea*. Additionally, we delved into the composition of seeds and jam derived from *C. cartilaginea* using GC/MS analysis. We detected isothiocyanates in all plant samples studied. This research presents a comprehensive overview of isothiocyanates identified in the *Capparis* genus, gathered from various global regions. Through the PASS program, we ascertained the biological activities of these isothiocyanates. Our findings revealed that these compounds are promising apoptosis agonists with potential as potent antitumor agents. Furthermore, we identified additional biological activities. The insights provided in this study hold substantial practical relevance and could pave the way for medical applications.

**ARTICLE HIGHLIGHTS**

***Research background***

In the realm of medicinal chemistry, isothiocyanates are characterized by the -N=C=S functional group, which results from substituting the oxygen atom in the isocyanate group with sulfur. These compounds are predominantly found in plants and arise from the enzymatic conversion of metabolites, specifically glucosinolates. Notably, numerous plant-derived isothiocyanates have demonstrated anticarcinogenic properties. Their mechanism of action involves inhibiting the activation of carcinogens and bolstering their detoxification processes.

***Research motivation***

Our motivation to undertake this study stemmed from the noticeable lack of extensive literature regarding isothiocyanates in food sources. While some health research has touched upon the use of isothiocyanates, comprehensive investigations into their potential benefits remain limited. Consequently, we embarked on an in-depth *in silico* study of isothiocyanates to assess their preliminary therapeutic properties.

***Research objectives***

To investigate the composition of fruits, seeds, and jam derived from the scrambling shrub *Capparis cartilaginea* (*C. cartilaginea*) utilizing gas chromatography-mass spectrometry (GC-MS) analysis, and to conduct an *in silico* examination of the biological activity associated with the isolated isothiocyanates.

***Research methods***

For our investigation, we employed the following methods: GC/MS analysis: This technique allowed us to accurately identify and quantify the volatile components present in the samples from the scrambling shrub *C. cartilaginea*; PASS computer program: We utilized the PASS software, which boasts a comprehensive database of over one million natural and synthetic compounds, paired with more than 10000 documented biological activities. As per data from its official website, this German-developed program is a popular tool among the scientific community, with over 26000 researchers from 34 different countries using it on an annual basis.

***Research results***

Our investigation revealed that isothiocyanates exhibit a significant anticancer potential. Additionally, these compounds display other potential biological activities, including antiviral, antibacterial, and antifungal properties.

***Research conclusions***

The findings from our investigation are promising. We identified the presence of isothiocyanates in jams, seeds, and fruits, which demonstrated potential anti-cancer properties. Nevertheless, further *in vitro* and *in vivo* studies are essential to validate these preliminary results.

***Research perspectives***

Moving forward, the intention is to conduct more in-depth GC/MS and PASS *in silico* analyses on individual isothiocyanates extracted from jams, seeds, and fruits of the Capparis genus. This will provide a clearer understanding of the properties and potential therapeutic applications of these compounds.

**REFERENCES**

1 **Shahrajabian MH**, Sun W, Cheng Q. Plant of the Millennium, Caper (Capparis spinosa L.), chemical composition and medicinal uses. *Bull Natl Res Cent* 2012; **45**: 131-142 [DOI: 10.1186/s42269-021-00592-0]

2 **Tlili N**, Elfalleh W, Saadaoui E, Khaldi A, Triki S, Nasri N. The caper (Capparis L.): ethnopharmacology, phytochemical and pharmacological properties. *Fitoterapia* 2011; **82**: 93-101 [PMID: 20851750 DOI: 10.1016/j.fitote.2010.09.006]

3 **Mohammad SM**, Kashani HH, Azarbad Z. Capparis spinosa L. propagation and medicinal uses. *Life Sci J* 2012; **9**: 684-686

4 **Jacobs M**. The genus Capparis (Capparaceae) from the Indus to the Pacific. *Blumea: Biodiversity, Evolution and Biogeography of Plants* 1964; **12**: 385-541

5 **Cornejo X**. New combinations in South American Capparaceae. *Harvard Papers in Botany* 2008; **13**: 117-120 [DOI: 10.3100/1043-4534(2008)13[117:NCISAC]2.0.CO;2]

6 **Ge SX**, Hu SJ, Shi HL, Han FY, Li MJ, Ren LL. The first record of the genus Belenois (Lepidoptera: Pieridae) from China. *Biodivers Data J* 2021; **9**: e61332 [PMID: 33519265 DOI: 10.3897/BDJ.9.e61332]

7 **Nabavi SF**, Maggi F, Daglia M, Habtemariam S, Rastrelli L, Nabavi SM. Pharmacological Effects of Capparis spinosa L. *Phytother Res* 2016; **30**: 1733-1744 [PMID: 27406313 DOI: 10.1002/ptr.5684]

8 **Annaz H**, Sane Y, Bitchagno GTM, Ben Bakrim W, Drissi B, Mahdi I, El Bouhssini M, Sobeh M. Caper (Capparis spinosa L.): An Updated Review on Its Phytochemistry, Nutritional Value, Traditional Uses, and Therapeutic Potential. *Front Pharmacol* 2022; **13**: 878749 [PMID: 35935860 DOI: 10.3389/fphar.2022.878749]

9 **Kdimy A**, El Yadini M, Guaadaoui A, Bourais I, El Hajjaji S, Le HV. Phytochemistry, Biological Activities, Therapeutic Potential, and Socio-Economic Value of the Caper Bush (Capparis Spinosa L.). *Chem Biodivers* 2022; **19**: e202200300 [PMID: 36064949 DOI: 10.1002/cbdv.202200300]

10 **Omara T**, Kagoya S, Openy A, Omute T, Ssebulime S, Kiplagat KM, Bongomin O. Antivenin plants used for treatment of snakebites in Uganda: ethnobotanical reports and pharmacological evidences. *Trop Med Health* 2020; **48**: 6 [PMID: 32071543 DOI: 10.1186/s41182-019-0187-0]

11 **Kulisic-Bilusic T**, Schmöller I, Schnäbele K, Siracusa L, Ruberto G. The anticarcinogenic potential of essential oil and aqueous infusion from caper (Capparis spinosa L.). *Food Chem* 2012; **132**: 261-267 [PMID: 26434289 DOI: 10.1016/j.foodchem.2011.10.074]

12 **Abu-Lafi S**, Dembicki JW, Goldshlag P, Hanuš LO, Dembitsky VM. The use of the 'Cryogenic' GC/MS and on-column injection for study of organosulfur compounds of the Allium sativum. *J Food Comp Anal* 2004; **17**: 235-245 [DOI: 10.1016/j.jfca.2003.09.002]

13 **Dembitsky VM**, Goldshlag P, Srebnik M. Occurrence of p-nonylphenol isomers in wild species of Cichorium endivia subsp. divaricatum. *J Chem Ecol* 2002; **28**: 1623-1628 [PMID: 12371814 DOI: 10.1023/A:1019980513949]

14 **Dembitsky VM**, Abu-Lafi S, Hanus LO. Occurrence of sulfur-containing fatty acids in Allium sativum. *Nat Prod Common* 2007; **2**: 771-774 [DOI: 10.1177/1934578X0700200713]

15 **Brown AC**, Fraser TR. The connection of chemical constitution and physiological action. *Trans Roy Soc Edinburg* 1868; **25**: 224-242 [DOI: 10.1017/S0080456800028155]

16 **Cros AFA**. Action de l'Alcohol Amylique Sur l'Organisme. University of Strasbourg. 1863

17 **Dembitsky VM**. Microbiological aspects of unique, rare, and unusual fatty acids derived from natural amides and their pharmacological profile. *Microbiol Res* 2022; **13**: 377-417 [DOI: 10.3390/microbiolres13030030]

18 **Dembitsky VM**. Hydrobiological aspects of fatty acids: Unique, rare, and unusual fatty acids incorporated into linear and cyclic lipopeptides and their biological activity. *Hydrobiology* 2022; **1**: 331-432 [DOI: 10.3390/hydrobiology1030024]

19 **Dinkova-Kostova AT**, Kostov RV. Glucosinolates and isothiocyanates in health and disease. *Trends Mol Med* 2012; **18**: 337-347 [PMID: 22578879 DOI: 10.1016/j.molmed.2012.04.003]

20 **Guerrero-Alonso A**, Antunez-Mojica M, Medina-Franco JL. Chemoinformatic Analysis of Isothiocyanates: Their Impact in Nature and Medicine. *Mol Inform* 2021; **40**: e2100172 [PMID: 34363333 DOI: 10.1002/minf.202100172]

21 **Palliyaguru DL**, Yuan JM, Kensler TW, Fahey JW. Isothiocyanates: Translating the Power of Plants to People. *Mol Nutr Food Res* 2018; **62**: e1700965 [PMID: 29468815 DOI: 10.1002/mnfr.201700965]

22 **Vanduchova A**, Anzenbacher P, Anzenbacherova E. Isothiocyanate from Broccoli, Sulforaphane, and Its Properties. *J Med Food* 2019; **22**: 121-126 [PMID: 30372361 DOI: 10.1089/jmf.2018.0024]

23 **Abbaoui B**, Lucas CR, Riedl KM, Clinton SK, Mortazavi A. Cruciferous Vegetables, Isothiocyanates, and Bladder Cancer Prevention. *Mol Nutr Food Res* 2018; **62**: e1800079 [PMID: 30079608 DOI: 10.1002/mnfr.201800079]

24 **Esteve M**. Mechanisms Underlying Biological Effects of Cruciferous Glucosinolate-Derived Isothiocyanates/Indoles: A Focus on Metabolic Syndrome. *Front Nutr* 2020; **7**: 111 [PMID: 32984393 DOI: 10.3389/fnut.2020.00111]

25 **Kołodziejski D**, Koss-Mikołajczyk I, Abdin AY, Jacob C, Bartoszek A. Chemical Aspects of Biological Activity of Isothiocyanates and Indoles, the Products of Glucosinolate Decomposition. *Curr Pharm Des* 2019; **25**: 1717-1728 [PMID: 31267852 DOI: 10.2174/1381612825666190701151644]

26 **Gramosa NV**, Lemos TLG, Braz-Filho R. Volatile constituents isolated from Capparis flexuosa of Brazil. *J Essential Oil Res* 1997; **9**: 709-712 [DOI: 10.1080/10412905.1997.9700819]

27 **Rahnavard R**, Razavi N. A review on the medical effects of Capparis spinosa L. *Adv Herbal Med* 2016; **2**: 44-53

28 **Al-Shayeb A**. Chemical composition of essential oil and crude extract fractions and their antibacterial activities of Capparis spinosa L. and Capparis cartilaginea Decne from Jordan. 2012

29 **Bakr RO**, EI Bishbishy MH. Profile of bioactive compounds of Capparis spinosa var. aegyptiaca growing in Egypt. *Rev Bras Farmacogn* 2016; **26**: 514-520 [DOI: 10.1016/j.bjp.2016.04.001]

30 **Hamed AR**, Abdel-Shafeek KA, Abdel-Azim NS, Ismail SI, Hammouda FM. Chemical Investigation of Some Capparis Species Growing in Egypt and their Antioxidant Activity. *Evid Based Complement Alternat Med* 2007; **4**: 25-28 [PMID: 18227928 DOI: 10.1093/ecam/nem110]

31 **Alipour F**, Nabigol A, Nabizadeh E. Variation in volatile organic compounds in fruits of Iranian Capparis spinosa L. accessions. *Saudi J Biol Sci* 2021; **28**: 4664-4667 [PMID: 34354453 DOI: 10.1016/j.sjbs.2021.04.077]

32 **El-Naser Z**. Analysis of essential oil of Capparis spinosa L. leaves and interaction between Pieris brassicae L. (Lepidopteran) which attack caper and natural enemy Cotesia glomerata (L.). *Int J Chem Tech Res* 2016; **9**: 477-485

33 **Moharram BA**, Al-Mahbashi HM, Saif-Ali R, Ali Aqlan F. Phytochemical, anti-inflammatory, antioxidant, cytotoxic and antibacterial study of Capparis cartilaginea Decne fromyemen. *Int J Pharm Pharm Sci* 2018; **10**: 38-44 [DOI: 10.22159/ijpps.2018v10i6.22905]

34 **Júnior UL**, Ali A, Rehman R, Nisar S. A comprehensive review on phytochemistry and biological activities of Della (Capparis decidua). 2019

35 **Grimalt M**, Sánchez-Rodríguez L, Hernández F, Legua P, Carbonell-Barrachina AA, Almansa MS, Amorós A. Volatile profile in different aerial parts of two Caper cultivars (Capparis spinosa L.). *J Food Quality* 2021: 1-9 [DOI: 10.1155/2021/6620776]

36 **Alkhaibari AM**, Alanazi AD. Chemical Composition and Insecticidal, Antiplasmodial, and Anti-Leishmanial Activity of Capparis spinosa Essential Oil and Its Main Constituents. *Evid Based Complement Alternat Med* 2022; **2022**: 6371274 [PMID: 35154348 DOI: 10.1155/2022/6371274]

37 **Mugo NW**. Anti-ulcerogenic activity of leaf extract of Capparis cartilaginea Decne on ethanol and indomethacin-induced peptic ulcers in Wistar rats. Jomo Kenyatta University of Agriculture and Technology, Thesis, Juja, Kenya. 2012

38 **Rajesh E**, Sankari LS, Malathi L, Krupaa JR. Naturally occurring products in cancer therapy. *J Pharm Bioallied Sci* 2015; **7**: S181-S183 [PMID: 26015704 DOI: 10.4103/0975-7406.155895]

39 **Iranshahi M**. A review of volatile sulfur-containing compounds from terrestrial plants: biosynthesis, distribution and analytical methods. *J Essential Oil Res* 2012; **24**: 393-434 [DOI: 10.1080/10412905.2012.692918]

40 **Marcinkowska MA**, Jeleń HH. Role of Sulfur Compounds in Vegetable and Mushroom Aroma. *Molecules* 2022; **27** [PMID: 36144849 DOI: 10.3390/molecules27186116]

41 **Lucarini E**, Micheli L, Di Cesare Mannelli L, Ghelardini C. Naturally occurring glucosinolates and isothiocyanates as a weapon against chronic pain: potentials and limits. *Phytochem Rev* 2022; **21**: 647-665 [DOI: 10.1007/s11101-022-09809-0]

42 **Fahey JW**, Zalcmann AT, Talalay P. The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry* 2001; **56**: 5-51 [PMID: 11198818 DOI: 10.1016/s0031-9422(00)00316-2]

43 **Brown KK**, Hampton MB. Biological targets of isothiocyanates. *Biochim Biophys Acta* 2011; **1810**: 888-894 [PMID: 21704127 DOI: 10.1016/j.bbagen.2011.06.004]

44 **Traka M**, Mithen R. Glucosinolates, isothiocyanates and human health. *Phytochem Rev* 2009; **8**: 269-282 [DOI: 10.1007/s11101-008-9103-7]

45 **Wu X**, Zhou QH, Xu K. Are isothiocyanates potential anti-cancer drugs? *Acta Pharmacol Sin* 2009; **30**: 501-512 [PMID: 19417730 DOI: 10.1038/aps.2009.50]

46 **Mitsiogianni M**, Koutsidis G, Mavroudis N, Trafalis DT, Botaitis S, Franco R, Zoumpourlis V, Amery T, Galanis A, Pappa A, Panayiotidis MI. The Role of Isothiocyanates as Cancer Chemo-Preventive, Chemo-Therapeutic and Anti-Melanoma Agents. *Antioxidants (Basel)* 2019; **8** [PMID: 31003534 DOI: 10.3390/antiox8040106]

47 **Dinh TN**, Parat MO, Ong YS, Khaw KY. Anticancer activities of dietary benzyl isothiocyanate: A comprehensive review. *Pharmacol Res* 2021; **169**: 105666 [PMID: 33989764 DOI: 10.1016/j.phrs.2021.105666]

48 **Coscueta ER**, Sousa AS, Reis CA, Pintado MM. Phenylethyl Isothiocyanate: A Bioactive Agent for Gastrointestinal Health. *Molecules* 2022; **27** [PMID: 35164058 DOI: 10.3390/molecules27030794]

49 **Tarar A**, Peng S, Cheema S, Peng CA. Anticancer Activity, Mechanism, and Delivery of Allyl Isothiocyanate. *Bioengineering (Basel)* 2022; **9** [PMID: 36135016 DOI: 10.3390/bioengineering9090470]

50 **Kyriakou S**, Trafalis DT, Deligiorgi MV, Franco R, Pappa A, Panayiotidis MI. Assessment of Methodological Pipelines for the Determination of Isothiocyanates Derived from Natural Sources. *Antioxidants (Basel)* 2022; **11** [PMID: 35453327 DOI: 10.3390/antiox11040642]

51 **El Omari N**, Bakrim S, Bakha M, Lorenzo JM, Rebezov M, Shariati MA, Aboulaghras S, Balahbib A, Khayrullin M, Bouyahya A. Natural Bioactive Compounds Targeting Epigenetic Pathways in Cancer: A Review on Alkaloids, Terpenoids, Quinones, and Isothiocyanates. *Nutrients* 2021; **13** [PMID: 34835969 DOI: 10.3390/nu13113714]

52 **Plaszkó T**, Szűcs Z, Vasas G, Gonda S. Effects of Glucosinolate-Derived Isothiocyanates on Fungi: A Comprehensive Review on Direct Effects, Mechanisms, Structure-Activity Relationship Data and Possible Agricultural Applications. *J Fungi (Basel)* 2021; **7** [PMID: 34356918 DOI: 10.3390/jof7070539]

53 **Poveda J**, Díaz-González S, Díaz-Urbano M, Velasco P, Sacristán S. Fungal endophytes of Brassicaceae: Molecular interactions and crop benefits. *Front Plant Sci* 2022; **13**: 932288 [PMID: 35991403 DOI: 10.3389/fpls.2022.932288]

54 **Sonmezdag AS**, Kelebek H, Selli S. Characterization of Aroma-Active Compounds, Phenolics, and Antioxidant Properties in Fresh and Fermented Capers (Capparis spinosa) by GC-MS-Olfactometry and LC-DAD-ESI-MS/MS. *J Food Sci* 2019; **84**: 2449-2457 [PMID: 31476250 DOI: 10.1111/1750-3841.14777]

55 **Kalkunte S**, Swamy N, Dizon DS, Brard L. Benzyl isothiocyanate (BITC) induces apoptosis in ovarian cancer cells in vitro. *J Exp Ther Oncol* 2006; **5**: 287-300 [PMID: 17024969]

**Footnotes**

**Institutional review board statement:** The study was conducted *in silico* and did not include humans or animals, so a statement from the Institutional Review Board was not necessary.

**Conflict-of-interest statement:** All the authors report no relevant conflicts of interest for this article.

**Data sharing statement:** The study was conducted only in a computational environment and the data and three-dimensional structures used are available in public online databases.

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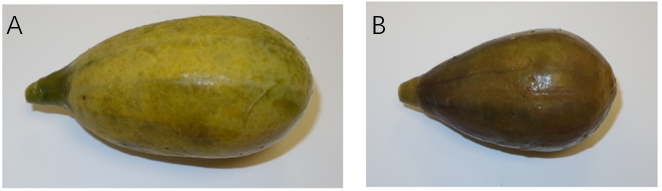
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Grade D (Fair): 0

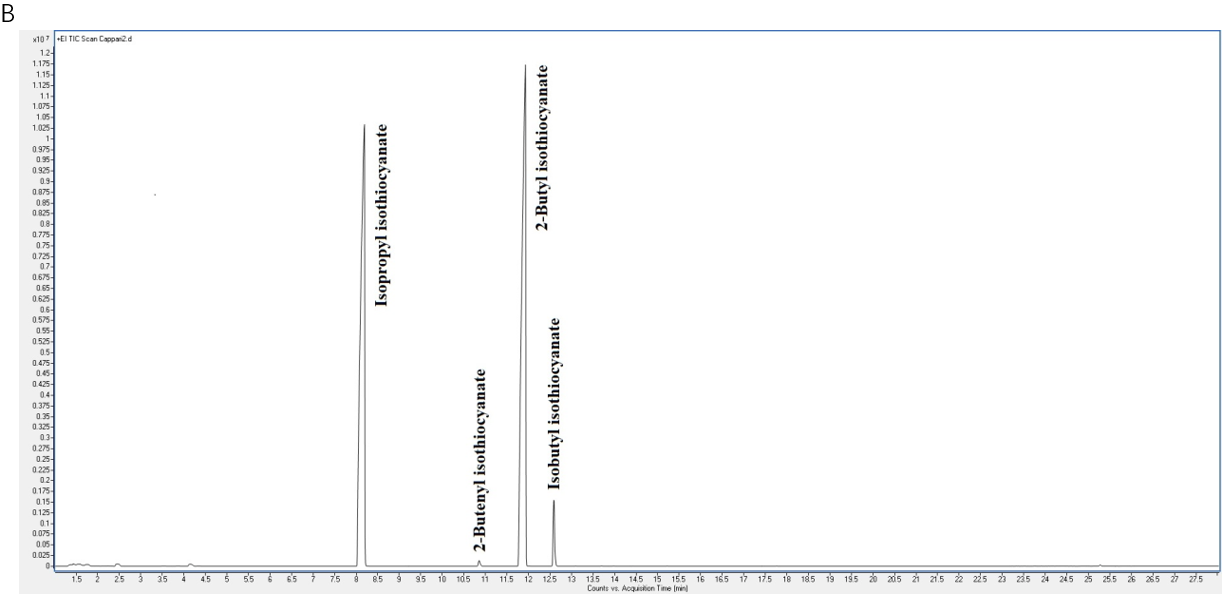
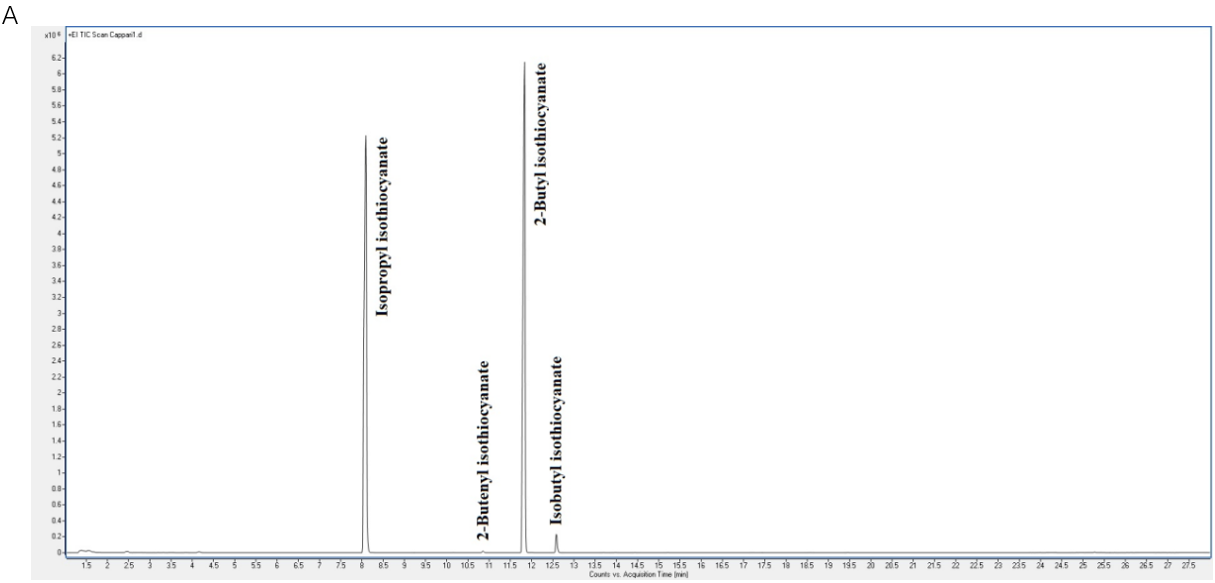
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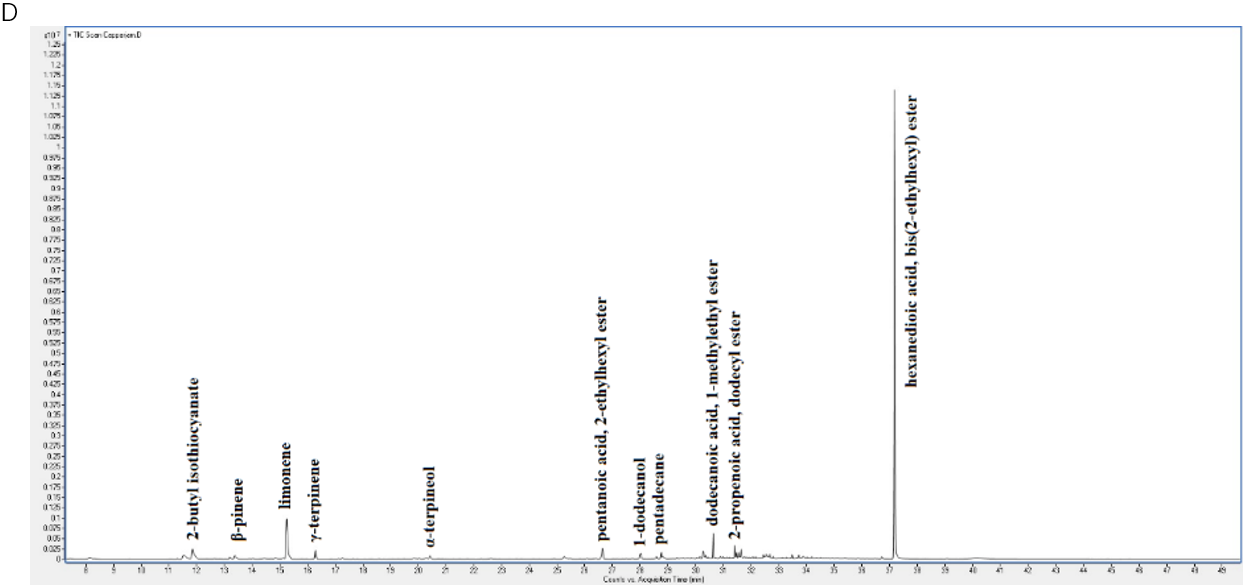
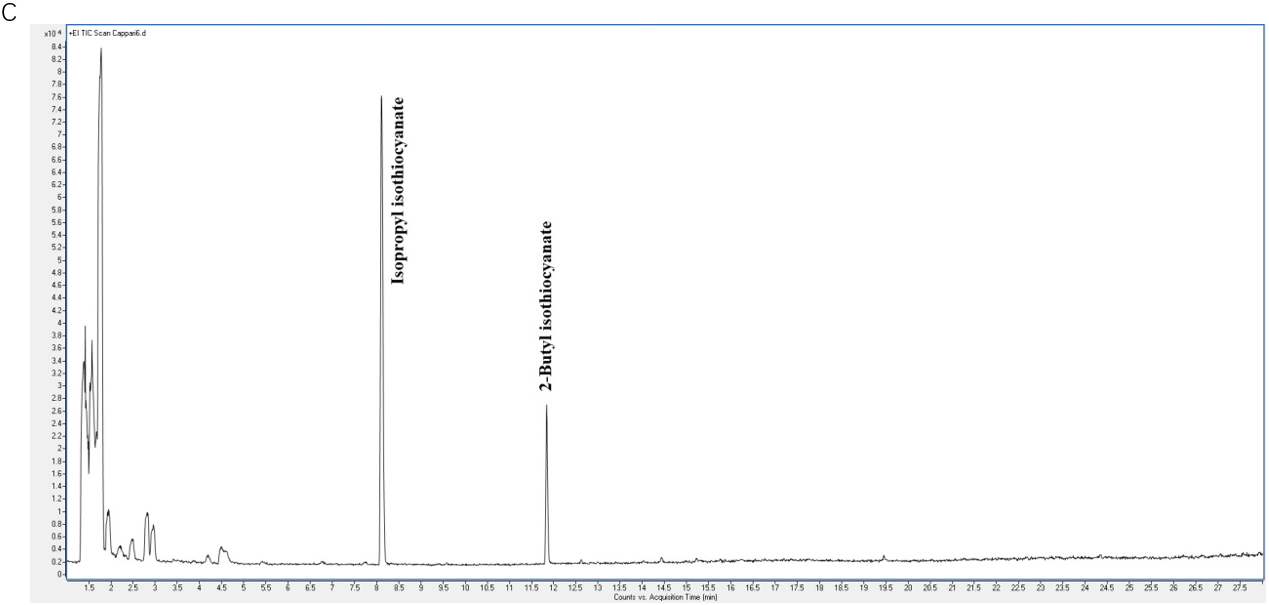
**P-Reviewer:** Gupta S, Brazil; Zhang J, China **S-Editor:** Wang JJ **L-Editor:** Wang TQ **P-Editor:**

**Figure Legends**



**Figure 1** **Yellow and** **green fruits harvested from the scrambling shrub *Capparis cartilaginea* contain a different set of components.** A: Yellow fruit; B: Green fruit.

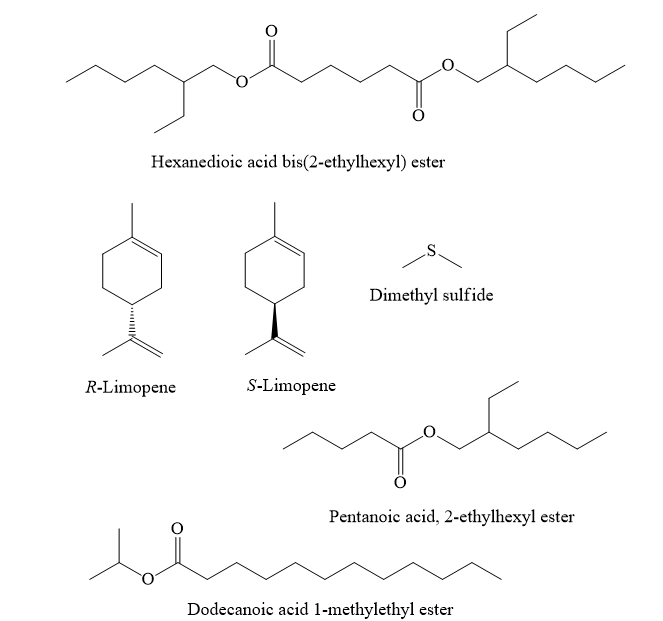




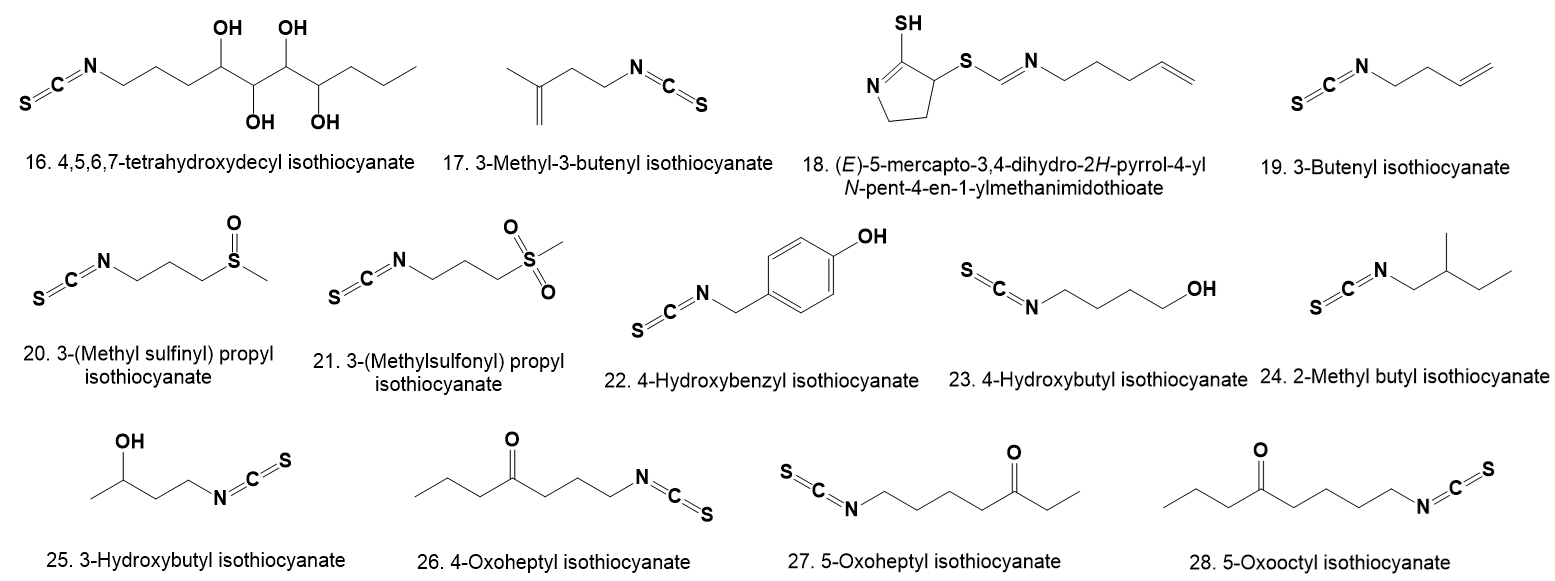
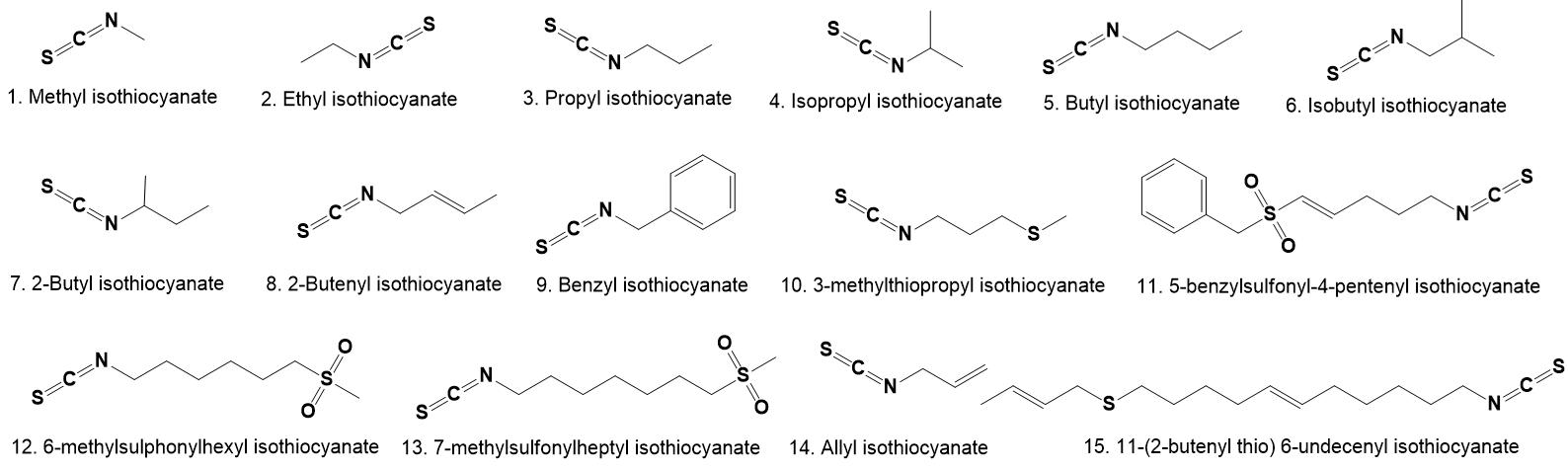
**Figure 2 Gas chromatography-mass spectrometry chromatogram of compounds which were identified from yellow and green fruits, seeds, and jam of *Capparis cartilaginea*.** A: Yellow fruits; B: Green fruits; C: Seeds; D: Jam.



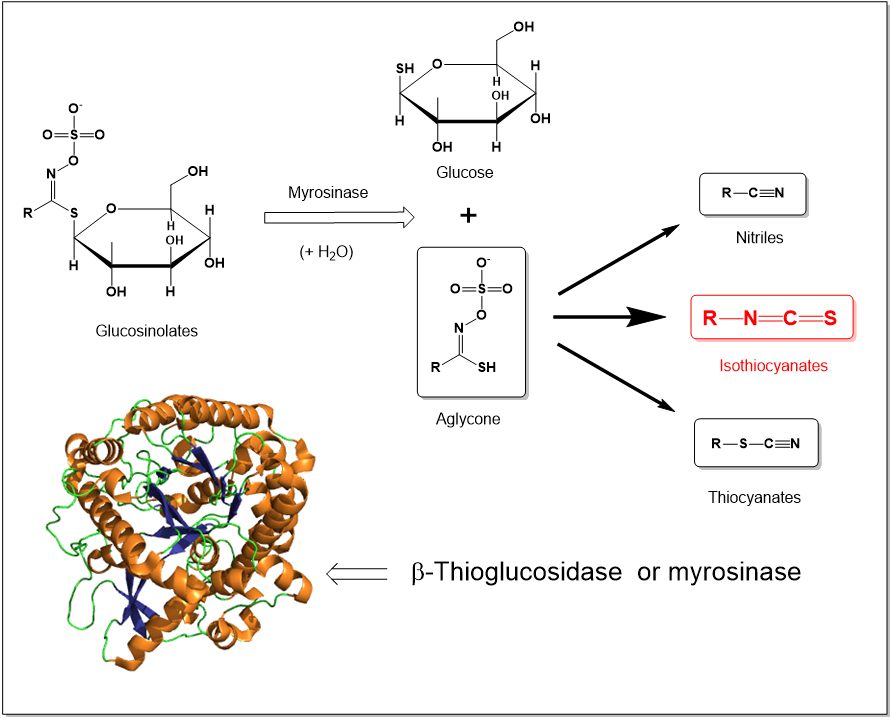
**Figure 3 Seeds of the scrambling shrub *Capparis cartilaginea*.**



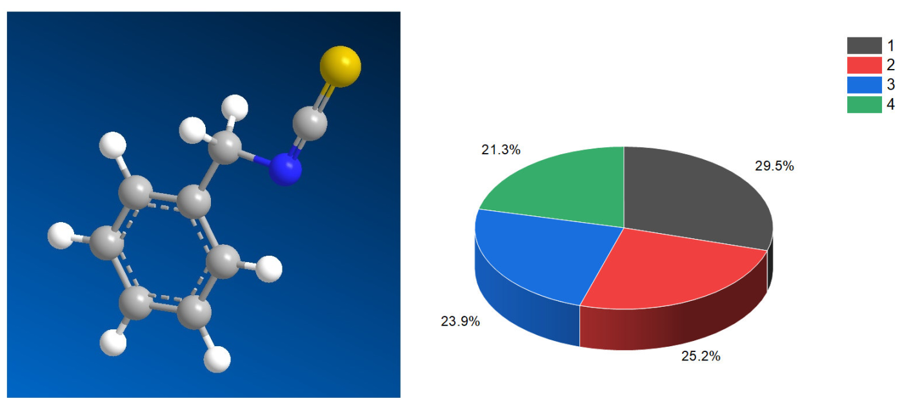
**Figure 4 Major metabolites that have been identified in *Capparis cartilaginea* jam.**



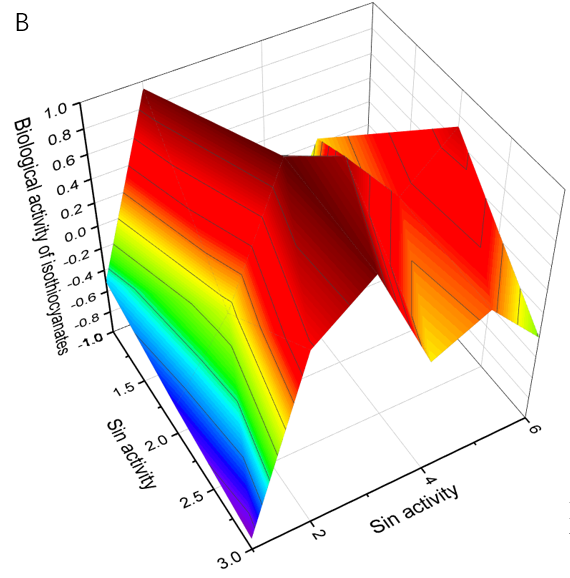
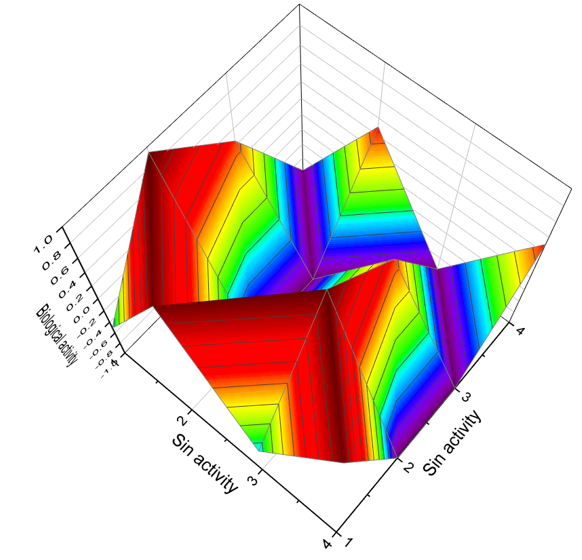
**Figure 5 Isothiocyanates found in plant extracts of the genus *Capparis*.** These compounds were identified by gas chromatography-mass spectrometry and other physical-chemical methods[26-43].

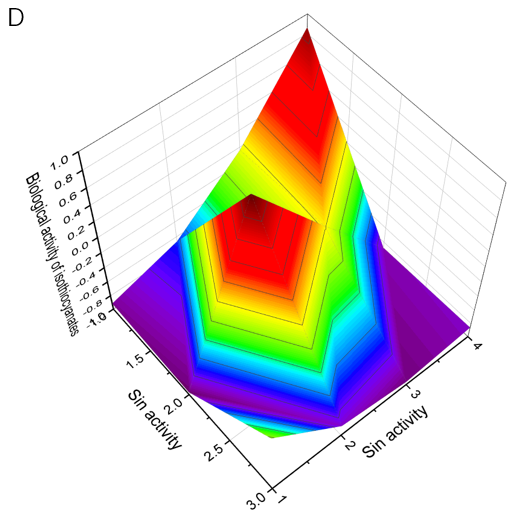
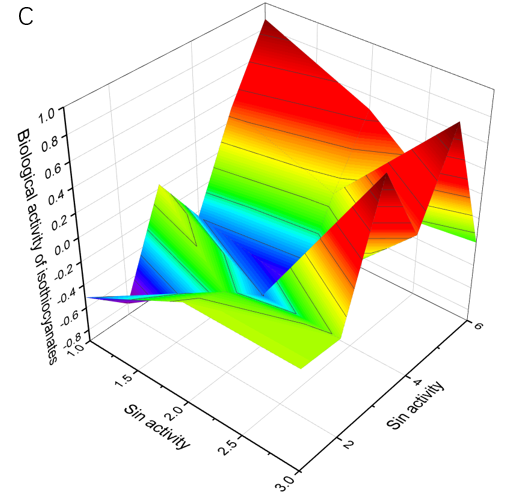


**Figure 6 Myrosinase (or β-thioglucosidase) which catalyzes the hydrolysis of glucosinolates to isothiocyanates, thiocyanates, nitriles, and other metabolites.**



**Figure 7 3D model (left) and percentage distribution of the dominant biological activity on the example benzyl isothiocyanate (9), which has a wide range of anticancer properties.** Where activities are indicated under the numbers: (1) Apoptosis agonist (29.5%); (2) Antineoplastic (25%); (3) Chemoprotective (23.9%); and (4) Chemosensitizer (21.3%). The nitrogen atom is highlighted in blue, and sulfur atom is highlighted in brown.





**Figure 8 3D graphs.** A: 3D graph shows a wide range of biological activities and predicted pharmacological activities of benzyl isothiocyanate (9). This compound is characterized as an agonist of apoptosis. In addition, it exhibits antitumor properties and is an inhibitor of the development of the Gram-negative microaerophilic helical bacterium *Helicobacter pylori* (*H. pylori*). The *H. pylori* infection is known to be an important public health problem worldwide, with a prevalence of 45% to 84%. The *H. pylori* bacteria enter the digestive tract and can cause ulcers in the lining of the stomach or in the upper part of the small intestine, and patients can develop chronic gastritis, atrophic gastritis, intestinal metaplasia, dysplasia, stomach cancer, or peptic ulcer disease. Amoxicillin is commonly used to treat this infection, and it appears that isothiocyanates may be a potential drug for *H. pylori* infection; B: 3D graph shows the predicted and calculated biological activity of isothiocyanates (compound numbers: 2, 14, and 17) showing the highest degree of confidence. All presented natural isothiocyanates have a dominant activity as an apoptosis agonist with a confidence of more than 96%. The second activity that characterizes these isothiocyanates is chemoprotective; C: 3D graph shows the predicted and calculated anti-*H. pylori* activity of isothiocyanates (compound numbers: 5, 8, and 20) showing the highest degree of confidence, more than 82.2%; D: 3D graph shows the predicted and calculated activity of isothiocyanates against periodontitis (compound numbers: 26, 27, and 28) showing the highest degree of confidence, more than 73%.

**Table 1 Composition of components that were identified from yellow fruits of** ***Capparis cartilaginea***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Peak** | **RT** | **Area** | **%** | **Compound** | **RI** |
| 1 | 2.477 | 67563.26 | 0.16 | Isopropylnitrile | 623 |
| 2 | 4.145 | 48903.53 | 0.11 | N-methylene-ethenamine | 727 |
| 3 | 8.089 | 20864469.13 | 48.74 | Isopropyl isothiocyanate | 837 |
| 4 | 10.846 | 55386.82 | 0.13 | 2-butenyl isothiocyanate | 887 |
| 5 | 11.832 | 21159669.73 | 49.43 | 2-butyl isothiocyanate | 920 |
| 6 | 12.578 | 597488.12 | 1.40 | Isobutyl isothiocyanate | 926 |
| 7 | 25.268 | 17767.47 | 0.04 | Benzyl isothiocyanate | 1359 |

RT: Retention time; RI: Retention index.

**Table 2 Composition of components that were identified from green fruits of *Capparis cartilaginea***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Peak** | **RT** | **Area** | **%** | **Compound** | **RI** |
| 1 | 1.756 | 283022.83 | 0.19 | Dimethylsulfide | 520 |
| 2 | 2.453 | 308033.24 | 0.21 | Isobutyronitrile | 626 |
| 3 | 3.864 | 23282.6 | 0.02 | Sec-butyl cyanate | 689 |
| 4 | 4.145 | 284696.04 | 0.19 | N-methylene-ethenamine | 727 |
| 5 | 6.991 | 10973.58 | 0.01 | Ethyl isothiocyanate | 796 |
| 6 | 8.193 | 68423753.03 | 46.68 | Isopropyl isothiocyanate | 837 |
| 7 | 10.59 | 6355.8 | 0.00 | Propyl isothiocyanate | 881 |
| 8 | 10.854 | 393825.2 | 0.27 | 2-butenyl isothiocyanate | 887 |
| 9 | 11.929 | 72938834.61 | 49.76 | 2-butyl isothiocyanate | 920 |
| 10 | 12.586 | 3848951.24 | 2.63 | Isobutyl isothiocyanate | 926 |
| 11 | 25.276 | 70246.54 | 0.05 | Benzyl isothiocyanate | 1359 |

RT: Retention time; RI: Retention index.

**Table 3 Composition of components that were identified from seeds of *Capparis cartilaginea***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Peak** | **RT** | **Area** | **%** | **Compound** | **RI** |
| 1 | 1.779 | 557486.8 | 55.82 | Dimethylsulfide | 520 |
| 2 | 2.493 | 18043.82 | 1.81 | Isobutyronitrile | 626 |
| 3 | 2.822 | 41394.08 | 4.14 | 3-methylbutanal | 652 |
| 4 | 2.958 | 31612.69 | 3.17 | 2-methyl-butanal | 662 |
| 5 | 8.112 | 280745.6 | 28.11 | Isopropyl isothiocyanate | 837 |
| 6 | 11.84 | 67963.7 | 6.80 | 2-butyl isothiocyanate | 920 |
| 7 | 12.618 | 1561.57 | 0.16 | Isobutyl isothiocyanate | 926 |

RT: Retention time; RI: Retention index.

**Table 4 Composition of components that were identified from jam of *Capparis cartilaginea***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Peak** | **RT** | **Area** | **%** | **Compound** | **RI** |
| 1 | 1.788 | 272484.92 | 3.85 | Dimethyl sulfide | 520 |
| 2 | 2.453 | 59609.49 | 0.84 | Isobutyronitrile | 626 |
| 3 | 2.814 | 96185.08 | 1.36 | 3-methyl-butanal | 652 |
| 4 | 2.926 | 34760.26 | 0.49 | 2-methyl-butanal | 662 |
| 5 | 4.161 | 145138.02 | 2.05 | N-methylene-ethenamine | 727 |
| 6 | 8.113 | 85740.89 | 1.21 | Isopropyl isothiocyanate | 837 |
| 7 | 11.824 | 232997.63 | 3.29 | 2-butyl isothiocyanate | 920 |
| 8 | 12.61 | 6608.49 | 0.09 | Isobutyl isothiocyanate | 926 |
| 9 | 13.347 | 77903.33 | 1.10 | β-pinene | 979 |
| 10 | 13.981 | 7385.93 | 0.10 | β-myrcene | 991 |
| 11 | 14.806 | 8950.21 | 0.13 | α-terpinene | 1018 |
| 12 | 15.079 | 5640.69 | 0.08 | P-cymene | 1025 |
| 13 | 15.215 | 601965.53 | 8.51 | Limonene | 1030 |
| 14 | 15.296 | 13202.57 | 0.19 | Eucalyptol | 1032 |
| 15 | 16.249 | 112624.11 | 1.59 | γ-terpinene | 1060 |
| 16 | 17.219 | 7218.34 | 0.10 | Terpinolene | 1088 |
| 17 | 20.402 | 11884.14 | 0.17 | α-terpineol | 1189 |
| 18 | 25.261 | 57235.71 | 0.81 | 2-(2-butoxyethoxy)-ethanol acetate | 1366 |
| 19 | 26.638 | 142269.27 | 2.01 | Pentanoic acid, 2-ethylhexyl ester | 1404 |
| 20 | 28.014 | 76710.10 | 1.08 | 1-dodecanol | 1473 |
| 21 | 28.59 | 25321.22 | 0.36 | Pentadecane | 1500 |
| 22 | 30.152 | 13471.82 | 0.19 | Diphenyl sulfide | 1552 |
| 23 | 30.264 | 83985.94 | 1.19 | Hexadecane | 1600 |
| 24 | 30.45 | 11616.10 | 0.16 | Octadecanal | 1357 |
| 25 | 30.636 | 152595.56 | 2.16 | Dodecanoic acid 1-methylethyl ester | 1618 |
| 26 | 31.408 | 80674.69 | 1.14 | 2-propenoic acid dodecyl ester | 1675 |
| 27 | 31.473 | 41016.71 | 0.58 | Heptadecane | 1700 |
| 28 | 31.547 | 53606.2 | 0.76 | (1-methyldecyl)-benzene | 1708 |
| 29 | 31.64 | 73991.74 | 1.05 | (1-methyldecyl)-benzene | 1735 |
| 30 | 32.189 | 9636.895 | 0.14 | 2-methyl-octadecane | 1863 |
| 31 | 32.449 | 27402.23 | 0.39 | Nonadecane | 1900 |
| 32 | 33.491 | 19861.16 | 0.28 | Hexadecanoic acid methyl ester | 1926 |
| 33 | 33.732 | 28833.81 | 0.41 | Hexadecanoic acid | 1968 |
| 34 | 34.021 | 9930.393 | 0.14 | Heneicosane | 2100 |
| 35 | 37.182 | 4384622 | 61.99 | Hexanedioic acid bis(2-ethylhexyl) ester | 2398 |

RT: Retention time; RI: Retention index.

**Table 5 Production of main isothiocyanates in essential oils of the genus *Capparis* collected in different world regions**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Species, tissues** | **Collected place** | **1** | **2** | **4** | **5** | **6** | **7** | **8** | **12** | **13** | **17** | **Ref.** |
| *C. flexuosa*, leaves | Brazil |  |  |  | 11.2 |  |  |  |  |  | 79.3 | [26] |
| *C. spinosa*, leaves and flower buds | Croatia | 92.1 |  |  | 0.4 |  | 0.3 |  |  |  |  | [11,27] |
| *C. spinosa*, leaves | Jordan | 25.6 |  | 28.9 |  |  |  |  |  |  |  | [28] |
| *C. cartilaginea*, leaves | Jordan | 31.8 | 2.5 | 18.2 |  | 5.4 |  |  |  |  |  | [28] |
| *C. spinosa var. aegyptiaca* | Egypt | 24.7 |  | 12.4 | 3.2 |  |  |  |  |  |  | [29] |
| *C. cartilaginea*, leaves | Egypt |  |  |  | 65.0 |  |  |  | 29.9 |  |  | [30] |
| *C. deserti*, leaves | Egypt |  |  |  | 68.7 |  |  |  | 20.0 |  |  | [30] |
| *C. spinosa*, fruits | Iran |  |  | 13.7 | 10.6 |  |  |  |  | 15.6 |  | [31] |
| *C. cartilaginea*, yellow fruits | Israel |  |  | 48.7 |  | 1.4 | 49.4 | 0.1 |  |  |  | This study |
| *C. cartilaginea*, green fruits | Israel |  | 0.1 | 46.7 |  | 2.6 | 49.8 | 0.3 |  |  |  | This study |
| *C. cartilaginea*, seeds | Israel |  |  | 28.1 |  | 0.2 | 6.8 |  |  |  |  | This study |
| *C. cartilaginea*, jam | Israel |  |  | 1.2 |  | 0.1 | 3.3 |  |  |  |  | This study |
| *C. spinosa*, leaves | Syria | 25.6 |  | 28.9 |  | 16.6 |  | 2.2 |  |  |  | [32] |
| *C. ovata*, buds | Turkey | 4.5 | 1.5 |  | 0.1 | 0.2 |  |  |  |  |  | [33] |
| *C. ovata*, leaves | Turkey | 20.0 | 1.6 |  | 0.5 | 0.3 |  |  |  |  |  | [33] |
| *C. cartilaginea*, leaves | Yemen |  |  | 69.4 | 26.9 | 3.3 |  |  |  |  |  | [34] |

**Table 6 Production of main isothiocyanates in essential oils of the genus *Capparis* collected in different world regions**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Species, tissues** | **Collected place** | **1** | **4** | **5** | **6** | **Ref.** |
| *C. decidua*, leaf | Pakistan |  | 11.0 | 6.3 |  | [34] |
| *C. spinosa*, leaves | Spain | 87.2 |  | 0.1 | 0.8 | [35] |
| *C. spinosa*, stems | Spain | 86.6 |  | 0.1 | 0.4 | [35] |
| *C. spinosa*, flower buds | Spain | 65.3 |  |  |  | [35] |
| *C. spinosa*, aerial parts | Saudi Arabia | 31.6 |  | 1.1 |  | [36] |
| *C. cartilaginea*, leaves | Kenya | 31.8 |  |  | 3.2 | [37] |

**Table 7 Predicted biological activity of isothiocyanates derived from essential oils of the genus *Capparis***

|  |  |  |
| --- | --- | --- |
| **No** | **Anticancer properties. Pa1** | **Anti-infectives properties. Pa1** |
| 1 | Apoptosis agonist (0.963) | Anti-schistosomal (0.759) |
| Chemoprotective (0.871) | Antiviral (arbovirus) (0.638) |
| Antineoplastic (0.794) | Anti-seborrheic (0.614) |
| 2 | Apoptosis agonist (0.965) | Anti-*Helicobacter pylori* (0.853) |
| Chemoprotective (0.890) | Anti-seborrheic (0.749) |
| Chemosensitizer (0.798) | Anti-schistosomal (0.711) |
| Antineoplastic (0.789) | Antiparasitic (0.537) |
| 3 | Apoptosis agonist (0.956) | Anti-*Helicobacter pylori* (0.816) |
| Chemoprotective (0.866) | Anti-seborrheic (0.690) |
| Chemosensitizer (0.779) | Antiviral (arbovirus) (0.635) |
| Antineoplastic (0.743) | Anti-schistosomal (0.612) |
| 4 | Apoptosis agonist (0.914) | Anti-*Helicobacter pylori* (0.720) |
| Chemoprotective (0.819) | Anti-schistosomal (0.687) |
| Chemosensitizer (0.726) | Anti-seborrheic (0.684) |
| 5 | Apoptosis agonist (0.956) | Anti-*Helicobacter pylori* (0.816) |
| Chemoprotective (0.858) | Antiviral (arbovirus) (0.690) |
| Chemosensitizer (0.778) | Anti-schistosomal (0.594) |
| Antineoplastic (0.751) | Antiparasitic (0.570) |
| 6 | Apoptosis agonist (0.951) | Anti-*Helicobacter pylori* (0.804) |
| Chemoprotective (0.850) | Anti-seborrheic (0.731) |
| Chemosensitizer (0.765) | Anti-schistosomal (0.665) |
| Antineoplastic (0.720) | Antiparasitic (0.524) |
| 7 | Apoptosis agonist (0.867) | Antiviral (arbovirus) (0.654) |
| Chemoprotective (0.782) | Anti-seborrheic (0.650) |
| Chemosensitizer (0.694) | Anti-*Helicobacter pylori* (0.624) |
| 8 | Apoptosis agonist (0.955) | Anti-*Helicobacter pylori* (0.822) |
| Chemoprotective (0.839) | Antiparasitic (0.680) |
| Antineoplastic (0.833) | Anti-helmintic (0.632) |
| Chemosensitizer (0.791) | Antifungal (0.568) |
| 9 | Apoptosis agonist (0.965) | Anti-*Helicobacter pylori* (0.629) |
| Antineoplastic (0.825) | Anti-schistosomal (0.598) |
| Chemoprotective (0.782) |  |
| Chemosensitizer (0.696) |  |
| 10 | Apoptosis agonist (0.933) | Anti-*Helicobacter pylori* (0.739) |
| Chemoprotective (0.847) |  |
| Antineoplastic (0.728) |  |
| Chemosensitizer (0.722) |  |
| 11 | Apoptosis agonist (0.884) | Anti-*Helicobacter pylori* (0.679) |
| Chemoprotective (0.812) |  |
| Antineoplastic (0.714) |  |
| Chemosensitizer (0.661) |  |
| 12 | Apoptosis agonist (0.956) | Anti-*Helicobacter pylori* (0.703) |
| Chemoprotective (0.825) |  |
| Chemosensitizer (0.741) |  |
| Antineoplastic (0.740) |  |
| Antineoplastic (genitourinary cancer) (0.581) |  |
| 13 | Apoptosis agonist (0.856) | Anti-*Helicobacter pylori* (0.703) |
| Chemoprotective (0.825) |  |
| Chemosensitizer (0.741) |  |
| Antineoplastic (0.740) |  |
| Antineoplastic (genitourinary cancer) (0.581) |  |
| 14 | Apoptosis agonist (0.959) | Anti-*Helicobacter pylori* (0.792) |
| Chemoprotective (0.867) | Antiparasitic (0.609) |
| Chemosensitizer (0.787) | Anti-helmintic (0.581) |
| Antineoplastic (0.775) | Antis-chistosomal (0.574) |
| 15 | Apoptosis agonist (0.923) | Anti-*Helicobacter pylori* (0.659) |
| Chemoprotective (0.817) | Antifungal (0.658) |
| Antineoplastic (0.771) | Antiparasitic (0.560) |
| Chemosensitizer (0.728) |  |
| 16 | Apoptosis agonist (0.919) | Anti-*Helicobacter pylori* (0.752) |
| Chemoprotective (0.821) | Antiviral (arbovirus) (0.730) |
| Antineoplastic (0.751) | Antifungal (0.678) |
| Chemosensitizer (0.747) | Antiparasitic (0.672) |
| 17 | Apoptosis agonist (0.953) | Anti-*Helicobacter pylori* (0.753) |
| Chemoprotective (0.830) | Antifungal (0.533) |
| Antineoplastic (0.781) |  |
| Chemosensitizer (0.754) |  |
| 18 | Antineoplastic (myeloid leukemia) (0.805) | Anti-eczematic (0.606) |
| Chemosensitizer (0.742) |  |
| 19 | Apoptosis agonist (0.952) | Anti-*Helicobacter pylori* (0.769) |
| Chemoprotective (0.847) | Anti-eczematic (0.610) |
| Chemosensitizer (0.764) | Antifungal (0.575) |
| Antineoplastic (0.753) | Anti-schistosomal (0.502) |
| 20 | Apoptosis agonist (0.955) | Anti-*Helicobacter pylori* (0.901) |
| Chemoprotective (0.911) | Anti-ulcerative (0.611) |
| Antineoplastic (0.781) |  |
| Chemosensitizer (0.694) |  |
| Anticarcinogenic (0.573) |  |
| Chemopreventive (0.559) |  |
| 21 | Apoptosis agonist (0.851) | Anti-*Helicobacter pylori* (0.691) |
| Chemoprotective (0.839) |  |
| Chemosensitizer (0.747) |  |
| Antineoplastic (0.733) |  |
| Antineoplastic (genitourinary cancer) (0.627) |  |
| 22 | Apoptosis agonist (0.951) | Anti-seborrheic (0.775) |
| Antineoplastic (0.820) | Antifungal (0.543) |
| Chemoprotective (0.752) | Anti-*Helicobacter pylori* (0.542) |
| Chemosensitizer (0.673) |  |
| Preneoplastic conditions treatment (0.559) |  |
| 23 | Apoptosis agonist (0.929) | Anti-*Helicobacter pylori* (0.780) |
| Chemoprotective (0.832) | Antiviral (arbovirus) (0.626) |
| Chemosensitizer (0.771) | Antiparasitic (0.589) |
| Antineoplastic (0.762) | Anti-helmintic (0.559) |
| Preneoplastic conditions treatment (0.515) |  |
| 24 | Apoptosis agonist (0.932) | Anti-*Helicobacter pylori* (0.736) |
| Chemoprotective (0.819) | Anti-schistosomal (0.579) |
| Chemosensitizer (0.742) | Antifungal (0.550) |
| Antineoplastic (0.675) | Antiviral (arbovirus) (0.531) |
| Preneoplastic conditions treatment (0.541) | Antiparasitic (0.529) |
| 25 | Apoptosis agonist (0.930) | Anti-*Helicobacter pylori* (0.715) |
| Chemoprotective (0.828) | Antiviral (arbovirus) (0.639) |
| Antineoplastic (0.792) | Antifungal (0.620) |
| Chemosensitizer (0.754) |  |
| 26 | Apoptosis agonist (0.938) | Periodontitis treatment (0.752) |
| Chemoprotective (0.827) | Anti-*Helicobacter pylori* (0.739) |
| Antineoplastic (0.740) | Antifungal (0.622) |
| Chemosensitizer (0.736) | Antiviral (arbovirus) (0.599) |
| Preneoplastic conditions treatment (0.593) |  |
| 27 | Apoptosis agonist (0.937) | Periodontitis treatment (0.727) |
| Chemoprotective (0.820) | Anti-*Helicobacter pylori* (0.718) |
| Antineoplastic (0.742) | Antifungal (0.644) |
| Chemosensitizer (0.728) | Antiviral (arbovirus) (0.563) |
| Preneoplastic conditions treatment (0.563) |  |
| 28 | Apoptosis agonist (0.934) | Periodontitis treatment (0.751) |
| Chemoprotective (0.823) | Anti-*Helicobacter pylori* (0.733) |
| Antineoplastic (0.740) | Antifungal (0.639) |
| Chemosensitizer (0.732) | Antiviral (arbovirus) (0.621) |
| Preneoplastic conditions treatment (0.613) |  |

1Only activities with Pa > 0.5 are shown.