

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Terpenes from Natural Products with Potential Anti-Inflammatory Activity

Roberto José Serrano Vega, Nimsi Campos Xolalpa,
Angel Josabad Alonso Castro,
Cuauhtémoc Pérez González, Julia Pérez Ramos and
Salud Pérez Gutiérrez

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.73215>

Abstract

The development and progression of many diseases is related with an inflammatory process, which could affect different organs or tissues. Currently, many drugs are used to treat inflammation. However, some of these compounds induce severe side effects. For this reason, the search of new therapeutic options for the treatment of inflammation is very desirable. Medicinal plants have been an interesting source for obtaining new active compounds, including several terpenes and terpenoids with anti-inflammatory activity. This book chapter includes 62 sesquiterpenes, 34 diterpenes, and 22 triterpenes with anti-inflammatory activity. The anti-inflammatory effect was evaluated using *in vitro*, *in vivo*, and both models. These terpenes were obtained from 44 plant species belonging to 25 botanical families. Eight of these species belong to the Asteraceae family and four to Lamiaceae family, respectively, and the other species belong to 13 different botanical families, one sesquiterpene was obtained from a sponge and two diterpenes were isolated from corals.

Keywords: Terpenes, terpenoids, anti-inflammatory activity, natural, products

1. Inflammation

Inflammation is a response of vascularized tissues to infections and tissue damage, and contributes to the beginning and progression of diseases such as Alzheimer, type 2

diabetes, obesity, stroke, and cancer [1, 2]. The symptomatology of inflammation is characterized by pain, redness, swelling, heat, and loss of function. Depending on the time of duration, inflammation might be categorized into acute and chronic. Acute inflammation is considered as a protective response and occurs within minutes, hours, or few days after exposure to infections and/or tissue damage. Acute inflammation is characterized by the exudation of fluid (edema), elevated blood flow, and migration of neutrophils [3]. Chronic inflammation occurs when the initial response fails to repair tissue damaged or when a noxious stimulus is persistent, and is characterized with more tissue destruction, fibrosis, long presence of lymphocytes [4]. Macrophages, dendritic cells, and mast cells initiate the inflammatory process secreting pro-inflammatory cytokines such as interleukin 6 (IL-6) and interleukin 8 (IL-8), tumor necrosis factor- α (TNF- α), and inducing the production of reactive oxygen species (ROS), which play an important role in the modulation of inflammation [5]. The long-term use of current drugs for the treatment of inflammation, including non-steroidal anti-inflammatory drugs (NSAIDs), the disease-modifying anti-rheumatic drugs (DMARDs), and steroids display several undesirable side effects such as gastric ulcers, nephrotoxicity, and hepatotoxicity, among others [6]. The search of new anti-inflammatory agents with less side effects is highly desirable. Furthermore, the efficient treatment of inflammation may be an interesting and effective way to prevent chronic diseases like cancer.

2. Terpenes

Natural products are a good source of anti-inflammatory compounds [7]. Terpenes, containing a C₅ isoprene unit, are the large group of natural compounds found mostly in higher plants, but also in lower invertebrates. There are approximately more than 50,000 terpenes that have been isolated from different plant species. Terpenes, composed of isoprene units (C₅H₈), play a variety of vital roles in plant species, including growth and development and defense against herbivores and environmental stress [8]. Terpenes possess a great variety of biological activities as antimicrobial, against cancer, malaria, and anti-inflammatory effects in acute and chronic inflammatory conditions like chronic obstructive pulmonary disease and osteoarthritis [9, 10].

Cyperus rotundus, a perennial plant, has several pharmacological activities, including antibacterial [11], antimutagenic [12], and anti-inflammatory [13]. Isocyperol, a sesquiterpene isolated from the rhizomes of *C. rotundus*, inhibited the production of NO and PGE₂, decreased the levels pro-inflammatory interleukins (IL-1 β and IL-6) and the monocyte chemotactic protein-1 (MCP-1), and suppressed the gene expression of iNOS and COX-2 in RAW-264

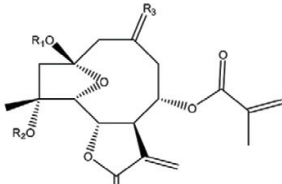
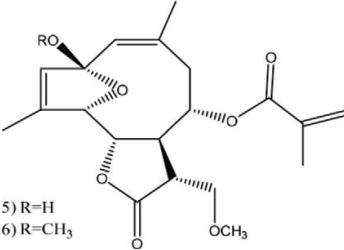
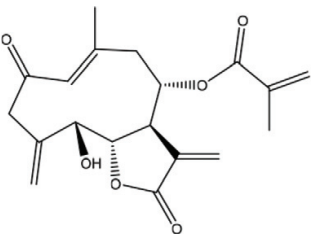
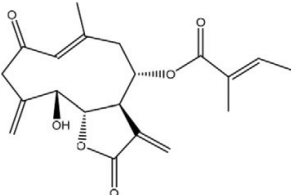
murine macrophages stimulated with lipopolysaccharide (LPS). In addition, isocyperol reduced the serum levels of NO, PGE₂, and IL-6 in LPS-induced septic shock in mice, via suppression of the NF- κ B and STAT3 signaling pathways [14]. *Dodonaea viscosa* induces gastroprotective [15], antibacterial [16], analgesic, and anti-inflammatory activities [17, 18]. Hawtriwaic acid, an ent-clerodane diterpene, was isolated from *D. viscosa* and showed anti-inflammatory activity on the murine ear edema induced with 12-O-tetradecanoylphorbol-13-acetate (TPA) by one or multiple applications. In both models, the compound diminished the edema [19]. Hawtriwaic acid at doses of 5, 10, and 20 mg/kg decreased knee inflammation in a murine model of monoarthritis induced with kaolin/carrageenan, by the reduction of serum levels of the pro-inflammatory interleukins IL-1 β , IL-6, and TNF- α , and the increase in the serum levels of the anti-inflammatory interleukin IL-10 [20]. Ursolic acid, a pentacyclic triterpene found in many plant species, was identified for the first time in 1920 in the epicuticular waxes of apples. Ursolic acid exerts cytotoxic effects in various cancer cells by the inhibition of the STAT3 signaling pathway [21] and the induction of apoptosis [22]. Ursolic acid has protective effects on lung, kidney, liver, and brain, exerts anabolic effects on skeletal muscle [23], and induces antinociceptive activity in abdominal constriction test induced by acetic acid and the formalin test in mice [24]. Ursolic acid decreased the paw edema induced with carrageenan in rats [25], decreased the ear edema induced with Croton oil in mice [26], reduced the levels of iNOS, COX-2, IL-1 β , IL-6, and TNF- α , and increased the level of IL-10 in macrophages stimulated with LPS [27].

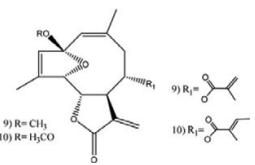
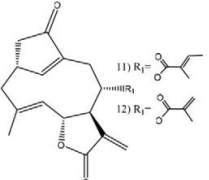
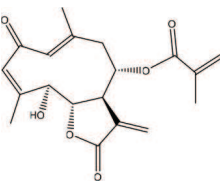
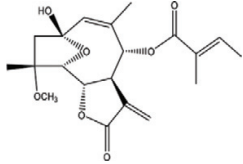
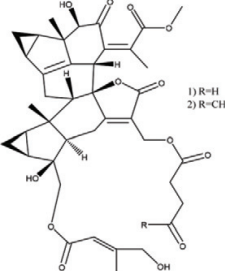
The sesquiterpenes, vernomelitensin and onopordopicrin, isolated from *Onopordum illyricum* and the triterpene, Sootepin F, obtained from *Gardenia sootepensis*, decreased each NF- κ B activity with IC₅₀ values of 3.6, 8.6, and 20.3 μ M, respectively [28, 29].

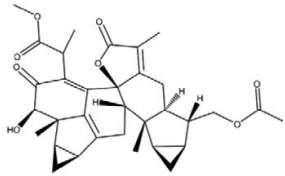
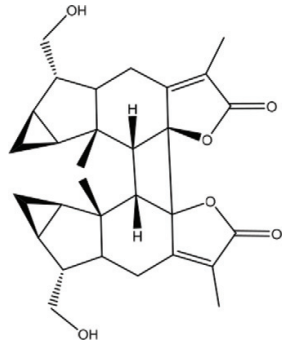
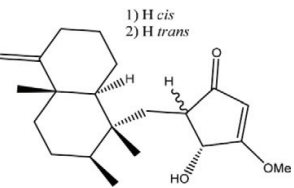
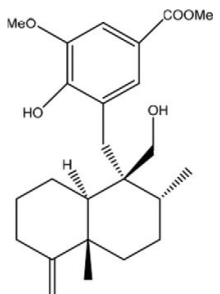
The pro-inflammatory enzymes: (1) inducible the nitric oxide synthase (iNOS), which is involved in the nitric oxide (NO) production, and the cyclooxygenase-2 (COX-2) involved in the prostaglandin production, are estimated in LPS-induced macrophages to evaluate the *in vitro* anti-inflammatory activity. IL-1 and TNF- α stimulate the production of NO. The inhibitory concentration 50 (IC₅₀) for these two pro-inflammatory enzymes has only been reported in some studies. The sesquiterpenes hydroxycostunolide (IC₅₀ = 0.68 μ M), costunolide (IC₅₀ 0.3 μ M), and artemorin (IC₅₀ = 0.16 μ M), obtained from *Inula montana*, showed similar or higher potency in the inhibition of NO, compared to that reported for the positive control dexamethasone (IC₅₀ = 0.45–4.33 μ M) [30]. Further studies are recommended to be performed with these sesquiterpenes. Toxicological studies to guarantee their safety in long-term studies are also necessary. The *in vivo* studies evaluate swelling, redness, and pain mainly in rodents.

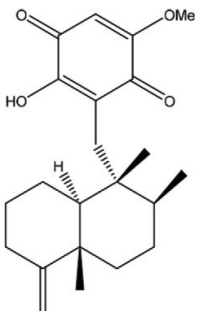
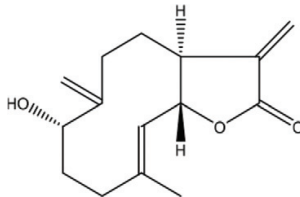
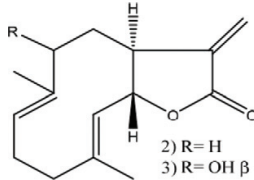
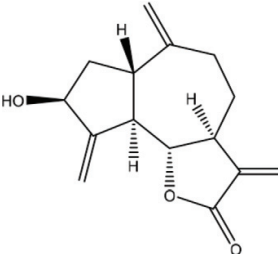
In the table is show the structure of 62 sesquiterpenes, 34 diterpenes, and 22 triterpenes with anti-inflammatory activity, isolated from 44 plant species, 1 sponge, and 2 corals.

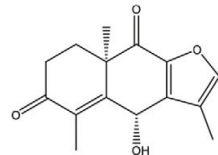
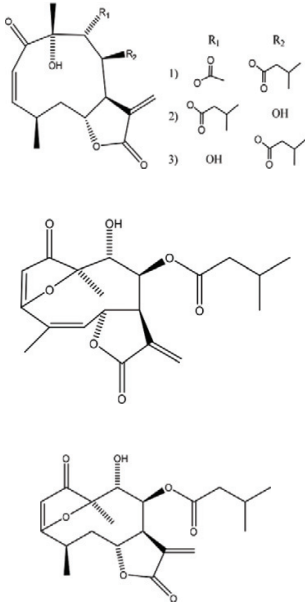
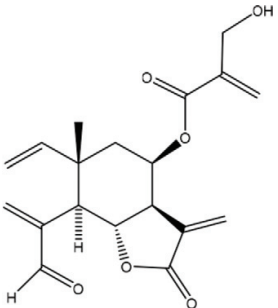
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.																		
Sesquiterpenes																							
<i>Datura metel</i> L.	1) 1 β ,5 α ,7 β -Guaiane-4 β ,10 α ,11-triol 2) 1 α ,5 α ,7 α -11- Guaiene-2 α ,3 β ,4 α ,10 α ,13-pentaol	<table><tr><td></td><td>1)</td><td>2)</td></tr><tr><td>R</td><td>H</td><td>OH</td></tr><tr><td>R₁</td><td>H</td><td>OH</td></tr><tr><td>R₂</td><td>OH α</td><td>OH β</td></tr><tr><td>R₃</td><td>H α</td><td>H β</td></tr><tr><td>R₄</td><td>C₃H₇O β</td><td>C₃H₅O α</td></tr></table>		1)	2)	R	H	OH	R ₁	H	OH	R ₂	OH α	OH β	R ₃	H α	H β	R ₄	C ₃ H ₇ O β	C ₃ H ₅ O α	LPS-stimulated BV2 microglia cells.	The compounds 1 and 2 , tested at a concentration of 80 μ M, each, inhibited the NO production by 37.5 and 46.0%, respectively.	[31]
	1)	2)																					
R	H	OH																					
R ₁	H	OH																					
R ₂	OH α	OH β																					
R ₃	H α	H β																					
R ₄	C ₃ H ₇ O β	C ₃ H ₅ O α																					
<i>Nardostachys chinensis</i> Batal.	Nardosinanone N		LPS-stimulated RAW 246.7 macrophages.	The compound tested at 30 μ M inhibited the protein expression of iNOS and COX-2.	[32]																		
<i>Chloranthus henryi</i> Hemsl.	Shizukaol B		LPS-stimulated BV2 microglia cells.	The compound (12.5–50 μ M) suppressed in concentration-dependent manner the protein expression of iNOS and COX ₂ , and decreased the production of NO, TNF- α , and IL-1 β .	[33]																		

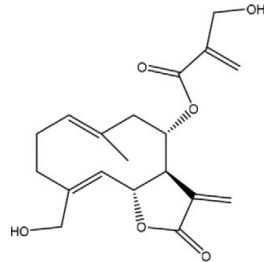
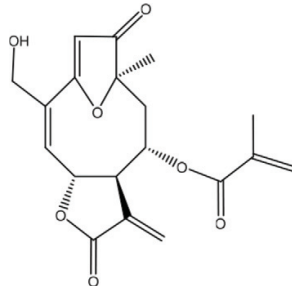
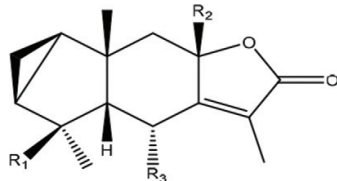
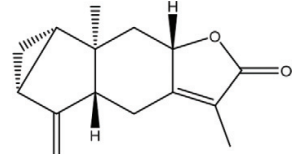
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Elephantopus mollis</i> Kunth.	1) 8- <i>O</i> -Methacryloyl-elephanpane	 <p>1) R₁ = H R₂ = H R₃ = CH₂ 2) R₁ = CH₃ R₂ = CH₃ R₃ = CH₂ 3) R₁ = H R₂ = CH₂CH₃ R₃ = CH₂ 4) R₁ = H R₂ = CH₃ R₃ = CH₂</p>	LPS-stimulated RAW 264.7 macrophages.	The compounds inhibited the NO production with the following IC ₅₀ values (μM): 1 (2.09), 2 (2.18), 3 (4.06), 4 (4.82), 5 (14.34), 6 (59.97), 7 (0.57), 8 (2.17), 9 (2.02), 10 (1.95), 11 (11.25), 12 (1.09) 13 (1.21), 14 (6.95), and the positive control indomethacin (127.88).	[34]
	2) 2,4-bis- <i>O</i> -Methyl-8- <i>O</i> -methacryloyl-elephanpane				
	3) 4- <i>O</i> -Ethyl-8- <i>O</i> -methacryloyl-elephanpane				
	4) 2,5-Epoxy-2β-hydroxy-4α-methoxy-8α-(2-methyl-propenyloxy)-10(14),11(13)-germacatrien-12,6α-olide				
	5) 2- <i>O</i> -Demethyl-tomenphantopin C	 <p>5) R = H 6) R = CH₃</p>			
	6) Tomenphantopin C				
	7) Molephantin A				
	8) Molephantin B				

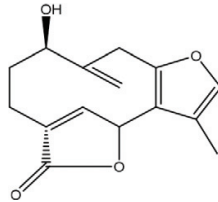
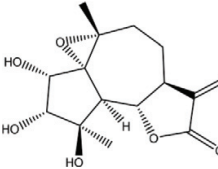
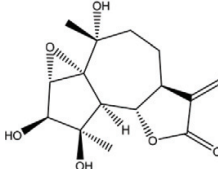
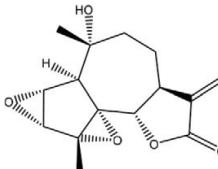
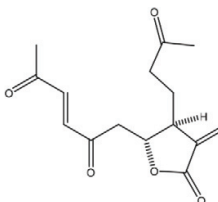
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
	9) 2 β -Methoxy-2-de-ethoxy-phantomolin 10) 2 β -Methoxy-2-deethoxy-8- <i>O</i> -deacyl-phantomolin-8- <i>O</i> -tiglate				
	11) Scabertopin 12) Isodeoxyelephantopi				
	13) Molephantin				
	14) 2, 5-Epoxy- 2 β -hydroxy-4 α -methoxy-8 α -[(<i>E</i>)-2-methylbut-2-enoyloxy] -4(15), 10(14), 11(13)-germacatrien-12,6 α -olide				
<i>Chloranthus holostegius</i> (Hand-Mazz) S. J. Pei & Shan.	1) Chololactone E 2) Chololactone F		LPS-stimulated RAW 264.7 macrophages.	All compounds reduced NO production with IC ₅₀ (μ M) values: 1 (8.5), 2 (6.9), 3 (3.5), 4 (4.4), and positive control dexamethasone (0.45).	[35]

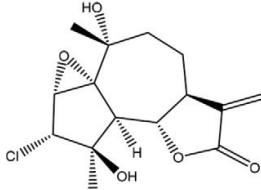
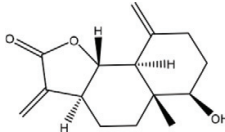
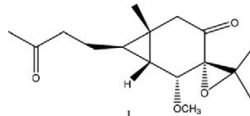
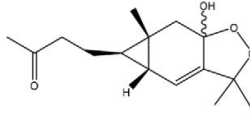
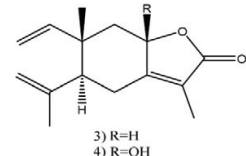
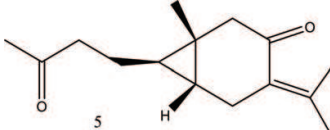
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Smenospongia cerebriformis</i> Duchassaing & Michelotti.	3) Chololactone G		LPS-stimulated BV2 microglial cells.	The compounds inhibited NO production 1 (IC ₅₀ 30.13 μM), 2 (IC ₅₀ 28.33 μM), 3 (IC ₅₀ 24.37 μM), 4 (IC ₅₀ 24.44 μM), and positive control l-NMMA (22.1 μM).	[36]
	4) Chololactone H				
	1) Smenohaimien A 2) Smenohaimien B				
	3) Smenohaimien E				

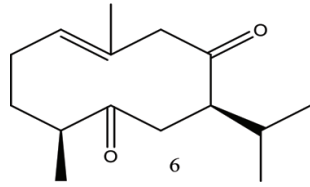
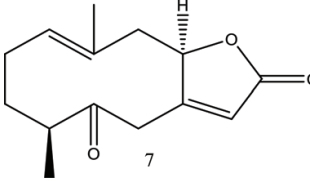
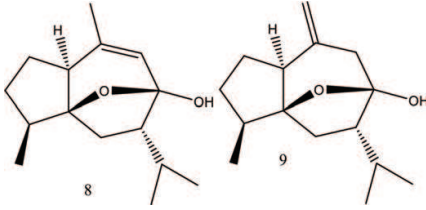
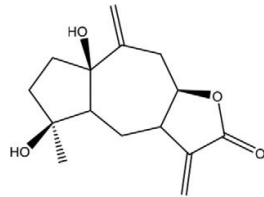
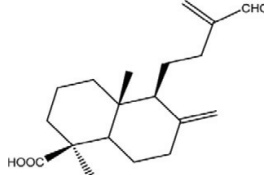
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
	4) Ilimaquinone				
<i>Inula montana</i> L.	1) Artemorin		LPS-stimulated RAW 264.7 macrophages.	The compounds inhibited the NO production with the following IC ₅₀ values (μM): 1 (0.16), 2 (0.3), 3 (0.68), and the positive control dexamethasone (4.33).	[30]
	2) Costunolide 3) 9β-Hydroxycostunolide				
<i>Ainsliaea yunnanensis</i> Franch.	Zaluzanin C		LPS-stimulated RAW 264.7 macrophages.	The compound (IC ₅₀ 6.54 μM) reduced the NO production with similar potency, compared to the positive control amino guanidine (IC ₅₀ 7.30 μM).	[37]

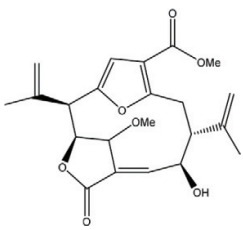
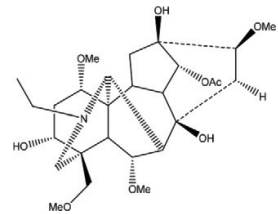
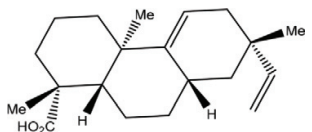
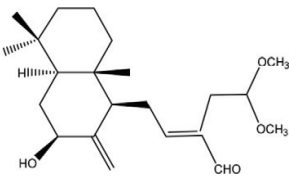
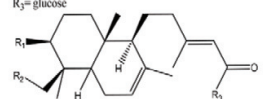
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Chloranthus japonicus</i> Siebold.	Chlorajaponol B		LPS-stimulated RAW 264.7 macrophages.	The compound decreased the NO production (IC ₅₀ 9.56 μM).	[38]
<i>Neurolaena lobata</i> (L.) Cass.	1) Neurolenin B 2) Neurolenin C 3) Neurolenin D 4) Lobatin B 5) 9α-Hydroxy-8β-isovalerynyloxycalculatolide		LPS-stimulated monocytes.	The compounds 1–5 are potent inhibitors of TNF-α production 1 (IC ₅₀ 2.32 μM), 2 and 3 (IC ₅₀ 1.10 μM), 4 (IC ₅₀ 0.17 μM), and 5 (IC ₅₀ 1.30 μM).	[39]
<i>Onopordum illyricum</i> L.	Vernomelitensin		Anti-NF-κB activity was evaluated in the NIH-3 T3-KBF-Luc cell line. The antiSTAT3 activity was analyzed in HeLa-STAT3-luc cell line. The activation of the Nrf2 pathway was analyzed in the HaCaT-ARE-Luc cell line. The protein concentration in the	Vernomelitensin decreased the activity of NF-κB (IC ₅₀ 3.6 μM), STAT3 (IC ₅₀ 27.9 μM), and Nrf2 (IC ₅₀ 1.1 μM) Onopordopicrin decreased the activity of NF-κB (IC ₅₀ 8.6 μM), STAT3 (IC ₅₀ 15.3 μM), and Nrf2 (IC ₅₀ 2.2 μM).	[28]

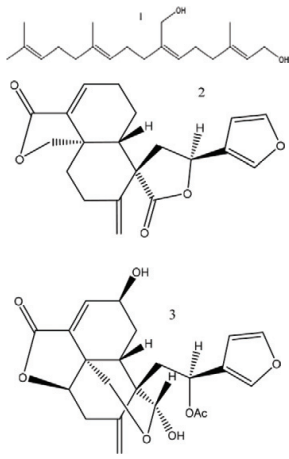
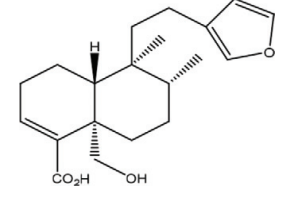
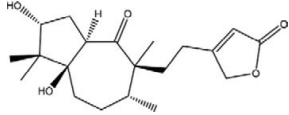
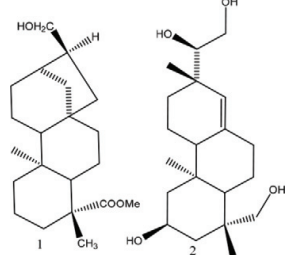
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
	Onopordopicrin		cell extracts were measured by the Bradford method (BioRad).		
<i>Lychnophora passerina</i> (Mart ex DC) Gardner.	Goyazensolide		Carrageenan-induced paw edema assay.	Goyazensolide (10 mg/kg orally) reduced carrageenan-induced paw edema assay in the second hour from the assay. This sesquiterpene lactone presented similar effect to indomethacin.	[40]
<i>Lindera strychnifolia</i> (Sieb. & Zucc.) Fern Vill.	1) Linderolide O 2) Linderolide P 3) Linderolide Q 4) Linderolide R	 1) R ₁ =OCH ₃ ; R ₂ =H 2) R ₁ =OH; R ₂ =OH; R ₃ =H 3) R ₁ =OH; R ₂ =OH; R ₃ =OH 4) R ₁ =OH; R ₂ =OH; R ₃ =OAc	LPS-stimulated RAW 264.7 macrophages.	The compounds inhibited the NO production with the following IC ₅₀ values (μM): 1 (6.3), 2 (9.6), 3 (14.6), 4 (12.8), 5 (15.4), 6 (9), and the positive control amino guanidine (18.4).	[41]
	5) Menelloide C				

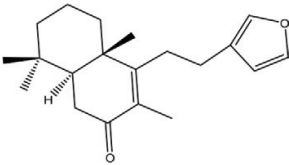
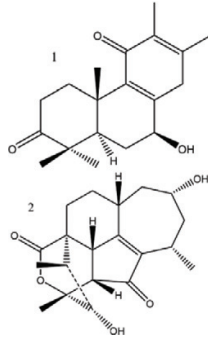
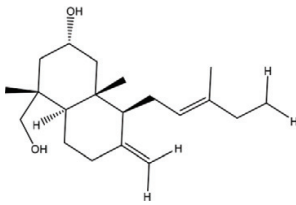
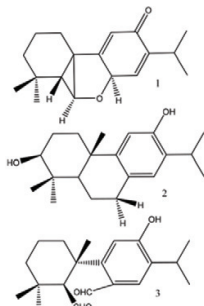
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Artemisia austroyunnanensis</i> Y. Ling & Y. R. Ling.	6) Parvigemone		LPS-stimulated RAW 264.7 macrophages.	The compounds inhibited the NO production with the following IC ₅₀ values (μM): 1 (4.20), 2 (10.67), 3 (5.10), 4 (8.77), 5 (4.21), 6 (2.57), and the positive control L-NMMA (24.95).	[42]
	1) Austroyunnane B				
	2) Austroyunnane C				
	3) Austroyunnane D				
	4) Artecaninhydrate				

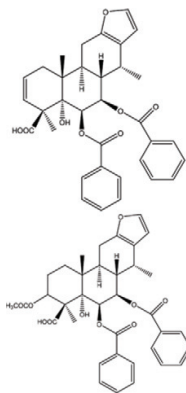
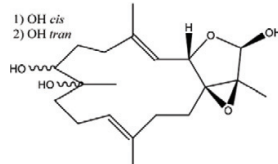
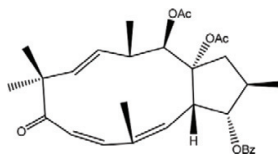
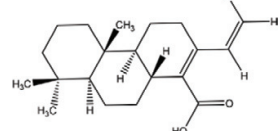
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.			
<i>Curcuma wenyujin</i> Y. H. Chen & C. Ling.	5) 3 α - Chloro-4 β ,10 α -dihydroxy-1 β ,2 β -epoxy-5 α ,7 α H-guai-11(13)-en-12,6 α -olide		LPS-stimulated RAW 264.7 macrophages.	The compounds inhibited the NO production with the following IC ₅₀ values (μM): 1 (47.05), 2 (25.36), 3 (30.62), 4 (59.97), 5 (34.69), 6 (24.18), 7 (14.50), 8 (22.36), 9 (17.26), and the positive control hydrocortisone (64.34).	[43]			
	6) 15,16-Reynosin							
	1) 7 α ,11-Epoxy-6 α -methoxy-carabran-4,8-dione							
	2) 8,11-Epidioxy-8-hydroxy-4-oxo-6-carabren							
	3) Isogermafurenolid							
	4) Hydroxyisogermafurenolid							
	5) Curcumenone							
	6) Neocurdione							
	7) Curdionolide B							
	8) Isocurcumol							
	9) 4-Epicurcumol							

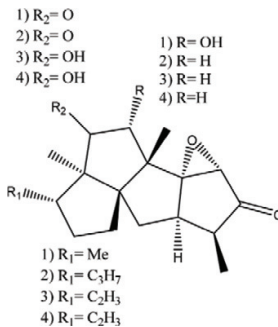
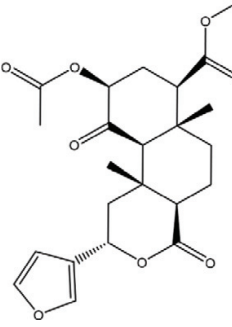
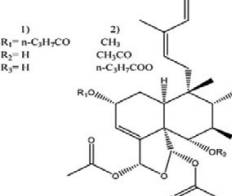
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
		   			
<i>Pulicaria undulata</i> (L.) C.A. Mey.	1 β ,4 β -Dihydroxy-5 α H,7 α H,8 α -guaia-10(14),11(13)-dien-8 α ,12-olide		LPS-stimulated RAW 264.7 macrophages.	The compound inhibited the NO production with IC ₅₀ 7.2 μ M.	[44]
Diterpenes					
<i>Thuja orientalis</i> L.	15-nor-14-Oxolabda-8(17),13(16)-dien-19-oic acid		LPS-stimulated RAW 264.7 macrophages.	The compound reduced the expression of iNOS and COX-2 (IC ₅₀ 1: 3.56 μ M). Curcumin was used as a positive control.	[45]

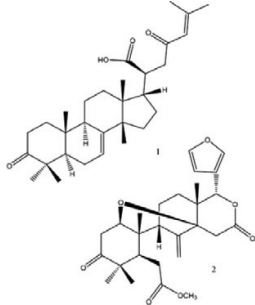
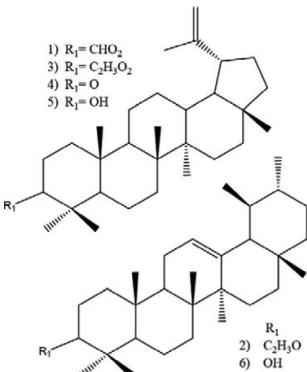
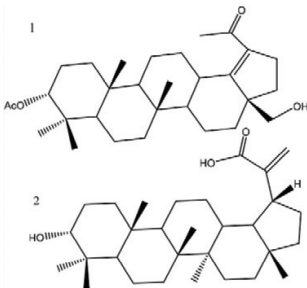
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Pseudopterogorgia acerosa</i> Pallas.	Pseudopterane		LPS-stimulated peritoneal macrophages.	This compound (25 μ M) inhibited the expression and secretion of TNF- α , IL-6, IL-1 β , NO, IP-10, COX-2 iNOS and monocyte chemoattractant protein-1 (IC ₅₀ = 12.25).	[46]
<i>Aconitum laciniatum</i> (Brühl) Stapf.	14-O-Acetylneoline		TNBS-induced colitis model in mice.	At doses 10, 20 and 50 μ g/mouse showed significant protection against different parameters of colitis inflammation.	[47]
<i>Aconitum koreanum</i> Rapaics.	Acanthoic acid		LPS-stimulated RAW 264.7 peritoneal macrophages. Ear edema in mice induced by TPA.	The compound (10 μ M) decreased the levels of IL-1 β , IL-18, TNF- α , and IFN- γ . Decreased ear edema (0.5 μ g/ear), and indomethacin was used as the positive control (0.5 μ g/ear).	[48]
<i>Hedychium coronarium</i> J. Koenig.	7 β -Hydroxycalcaratarin A		Measurement of superoxide anion generation.	Inhibition (IC ₅₀ 4.52 μ g/mL) of superoxide anion generation by human neutrophils.	[49]
<i>Physalis angulata</i> L.	1) Physangulatoside A 2) Physangulatoside F	 1) R ₁ =H R ₂ =glucose R ₃ =glucose 2) R ₁ =H R ₂ = β -D-glucopyranosyl (1 \rightarrow 2)- β -D-glucopyranosyl R ₃ =glucose	LPS-stimulated RAW 264.7 macrophages.	Compounds displayed inhibitory effects against NO production with IC ₅₀ values of 15.9 μ M and 60.7 μ M, respectively.	[50]

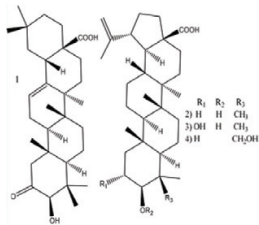
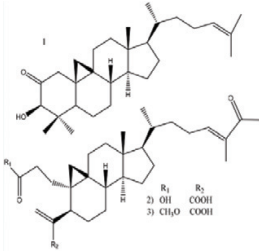
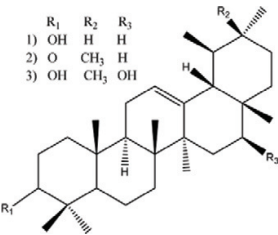
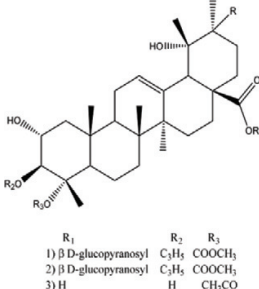
Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Croton stellatopilosus</i> H. Ohba.	1) Plaunotol 2) Plaunolide 3) Plaunol E		LPS-stimulated RAW 264.7 macrophages.	Plaunotol, plaunolide and plaunol E showed IC ₅₀ values of 3.41, 17.09, and 2.79 μM, respectively. Plaunotol suppressed expression of the iNOS gene. Plaunolide decreased the expression of the COX-1, COX-2 and iNOS genes. Plaunol E inhibited the expression of the COX-2.	[51]
<i>Dodonaea viscosa</i> Jacq.	Hawtriwaic acid		Kaolin/carrageenan-induced monoarthritis model. Ear edema induced with TPA.	After 10 days of treatment with different doses of hawtriwaic acid (5, 10, 20 mg/kg) decreased knee inflammation in a range of 40–70%. Hawtriwaic acid decreased the levels of proinflammatory cytokines IL-1β, IL-6, and TNF-α.	[20]
<i>Callicarpa randaiensis</i> Hayata.	Randainins D		Measurement of superoxide anion generation.	The compound exhibited moderate inhibition of superoxide anion generation with an IC ₅₀ value of 21.5 μM.	[52]
<i>Siegesbeckia pubescens</i> (Makino) Makino.	1) Methyl ent-16αH-17-Hydroxy-kauran-19-oate 2) Kirenol		LPS-stimulated BV2 microglia cells.	Each compound, tested at 100 μM, decreased the expression of iNOS and COX-2 by 20.5% and 22.5%, respectively.	[53]

Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Leonurus japonicus</i> Houtt.	Hispanone		Inhibition of superoxide anion generation and elastase release.	The compound decreased the superoxide anion with $IC_{50} = 8.48 \mu M$.	[54]
<i>Cephalotaxus lanceolata</i> K.M. Feng.	1) Lanceolatin C 2) Gongshanolide		LPS-stimulated RAW 264.7 macrophages.	The compounds decreased the NO production with IC_{50} values of $10.79 \mu M$ and $12.73 \mu M$, respectively.	[55]
<i>Ocimum labiatum</i> (N.E. Br.) A.J. Paton.	Labda-8(17),12E,14-triene-2R,18-diol		Cytometric bead array (CBA) technique. The effect on phytohemagglutinin (PHA)-induced nitric oxide (NO) production in peripheral blood mononuclear cells (PBMCs) was also assessed.	The compound tested at $25 \mu g/ml$ inhibited the production of pro-inflammatory cytokines IL-2, IL-4, IL-6, and IL-17A. The compound decreased the NO production with IC_{50} value of $70 \mu M$.	[56]
<i>Cunninghamia konishii</i> Hayata.	1) Konishone 2) Hinokiol 3) 12-Hydroxy-6,7-secoabieta-8,11,13-triene-6,7-dial		LPS-stimulated RAW 264.7 macrophages.	The compounds inhibited the NO production with the following IC_{50} values (μM): 1 (9.8), 2 (7.9), and 3 (9.3).	[57]

Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Caesalpinia pulcherrima</i> (L.) Sw.	1) Pulcherrimin B 2) Pulcherrimin D		Evaluated via the oxidative burst assay using a luminol-amplified chemiluminescence technique.	The compounds inhibited the production of reactive oxygen species with IC ₅₀ values of 15.30 μM and 8 μM, respectively.	[58]
<i>Lobophytum crassum</i> von Merenzeller.	1) Lobocrasol A 2) Lobocrasol B		Were evaluated using NF-κB luciferase and reverse transcription polymerase chain reaction (RT-PCR).	Significantly inhibited TNF-α induced NF-κB transcriptional activity in HepG2 cells in a dose-dependent, with IC ₅₀ values of 6.30 and 6.63 μM.	[59]
<i>Euphorbia helioscopia</i> L.	Jatrophone		LPS-stimulated BV-2 microglial cells.	The compound inhibited the NO production (IC ₅₀ = 73.7 μM).	[60]
<i>Erythrophleum ivorense</i> A. Chev.	Erythroivorensin		The carrageenan paw edema model in chicken.	The compound (300 mg/kg orally) showed anti-inflammatory effect with similar activity compared to diclofenac (100 mg/Kg).	[61]

Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Crinipellis species</i> .	1) Crinipellin E 2) Crinipellin F 3) Crinipellin G 4) Crinipellin H	 <p>1) $R_2 = O$ 2) $R_2 = O$ 3) $R_2 = OH$ 4) $R_2 = OH$</p> <p>1) $R = OH$ 2) $R = H$ 3) $R = H$ 4) $R = H$</p> <p>1) $R_1 = Me$ 2) $R_1 = C_3H_7$ 3) $R_1 = C_2H_3$ 4) $R_1 = C_2H_3$</p>	LPS/IFN- γ induced CXCL10 promoter activity in transiently transfected human MonoMac6 cells.	Reduce the inducible expression of pro-inflammatory genes in LPS/IFN- γ stimulated human MonoMac6 cells (IC ₅₀ values of 15, 1.5, 1.3, and 3.15 μM , respectively).	[62]
<i>Salvia divinorum</i> Epling & Játiva.	Salvinorin A		Calcium ionophore-stimulated peritoneal macrophages, and in carrageenan-induced pleurisy in rats.	Inhibited the production of leukotrienes. In carrageenan-induced pleurisy in rats, Salvinorin A significantly inhibited LTB ₄ production in the inflammatory exudates, along with reducing the phlogistic process in the lung.	[63]
<i>Casearia sylvestris</i> Sw.	1) Caseargrewiin F 2) Casearin B	 <p>1) $R_1 = n-C_3H_7CO$ $R_2 = H$ $R_3 = H$</p> <p>2) CH_3 CH_2CO $n-C_3H_7COO$</p>	Carrageenan-induced paw edema.	At doses 10 and 100 mg/kg showed a significant reduction of the carrageenan-induced paw edema in rats compared to indomethacin.	[64]

Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
Triterpenes					
<i>Anopyxis klaineana</i> Pierre (Engl.).	1) 3,23-Dioxotirucalla-7,24-dien-21-oic acid 2) Methyl angolensate		The PGE ₂ assay method, sequential competitive enzyme immunoassay with RAW 264.7.	The IC ₅₀ values were 3.63 μM and 10.23 μM for compounds 1 and 2, respectively. Cortisone was used as reference standard.	[65]
<i>Bursera copallifera</i> (DC.) Bullock.	1) 3-Epilupeol formiate 2) α-Amyrin acetate 3) 3-Epilupeol acetate 4) Lupenone 5) 3-Epilupeol 6) α-Amyrin		TPA-induced ear edema in mice, and LPS-stimulated RAW 264.7 macrophages.	The anti-inflammatory effect (1 mg/ear) on ear edema induced by TPA were: 1) 55.14%, 2) 62.12%, 3) 49.35%, 4) 57.25%, 5) 66.39, and 6) 25%. The compounds inhibited the NO production with IC ₅₀ values (μM): 1 (43.31), 2 (22.57), 3 (31.13), 4 (20.8), 5 (15.5), and 6 (8.98).	[66]
<i>Euonymus carnosus</i> Hemsl.	1) 3α-Acetoxy-28-hydroxy-30-norlupane-18(19)-en-20-one 2) 3α-Hydroxylup-20(29)-en-30-oic acid		LPS-stimulated BV-2 microglial cells.	The compounds inhibited the NO production with IC ₅₀ values (μM): 1 (5.99) and 2 (8.47).	[67]

Scientific name	Terpene	Structure	Anti-inflammatory assay	Results	Ref.
<i>Chaenomeles sinensis</i> (Thouin) Koehne.	1) Sinenic A acid 2) 3 β -O-cis-Feruloyl-2 α ,19 α -dihydroxy-urs-12-en-28-oic acid 3) 3 β -O-cis-caffeoylbetulin 4) Betulinic acid		LPS-stimulated microglia BV2 cells.	The compounds inhibited the NO production with the following IC ₅₀ values (μ M): 1 (17.8), 2 (4.5), 3 (14.5), and 4 (13.4).	[68]
<i>Gardenia sootepensis</i> Hutch.	1) Sootepin F 2) Sootepin G 3) Sootepin H		LPS-stimulated macrophages RAW 264.7.	The compounds inhibited the NO production with the following IC ₅₀ values (μ M): 1 (43.6), 2 (18.4), and 3 (15). The compounds inhibited the NF-kB activity with the following IC ₅₀ values (μ M): 1 (20.3), 2 (>100), and 3 (42.3).	[29]
<i>Protium paniculatum</i> Engl.	1) α -Amyrin 2) α -Amyrone 3) Maniladiol		LPS-stimulated J774A.1 macrophages.	The compounds tested at 1 μ g/ml inhibited the NO production by 98.34% 1, 99.86% 2, and 96.05% 3).	[69]
<i>Quercus serrata</i> var. <i>brevipetiolata</i> (A. DC.) Nakai.	1) 3,23-O-Methyl butyrate-2,3,19,23-tetrahydroxy-urs-12-en-28-oic acid β -D-glucopyranosyl ester 2) 3,23-O-Methyl butyrate-2,3,19,23-tetrahydroxy-olean-12-en-28-oic acid β -D-glucopyranosyl ester 3) 23-Acetoxy-2,3,19-trihydroxyurs-12-en-28-oic acid		LPS-induced NO production and interleukins pro-inflammatory.	The compounds inhibited the NO production with the following IC ₅₀ values (μ M): 1 (8.2) μ M, 2 (12.8), and 3 (19.1).	[70]

3. Conclusion

This book chapter indicates that there has been an increase in the search of terpenes with anti-inflammatory activity in recent years. This fact indicates that terpenes are a topic of interest. The possible mechanisms involved in the anti-inflammatory effects of the terpenes are pointing out on the inhibition of NF- κ B, TNF- α , PGE2, and pro-inflammatory cytokines such as IL-6. NF- κ B is one of the current targets for the development of new anti-inflammatory drugs [71]. In addition, the molecular targets of terpenes are highly desirable to find target-specific anti-inflammatory drugs. The mechanism of action of many terpenes remains to be studied. The combination of terpenes with high anti-inflammatory activity and with studied mechanism of action and currently used drugs could be another strategy for further anti-inflammatory therapy.

Author details

Roberto José Serrano Vega¹, Nimsi Campos Xolalpa¹, Angel Josabad Alonso Castro², Cuauhtémoc Pérez González¹, Julia Pérez Ramos¹ and Salud Pérez Gutiérrez^{1*}

*Address all correspondence to: msperez@correo.xoc.uam.mx

1 Universidad Autónoma Metropolitana-Xochimilco, Delegación Coyoacan, Ciudad de México, México

2 Departamento de Farmacia, División de Ciencias Naturales y Exactas, Universidad de Guanajuato, Guanajuato, GTO, México

References

- [1] Shafi O. Inverse relationship between Alzheimer's disease and cancer, and other factors contributing to Alzheimer's disease: A systematic review. *BMC Neurology*. 2016;**16**(1): 236. DOI: 10.1186/s12883-016-0765-2
- [2] Ben-Neriah Y, Karin M. Inflammation meets cancer, with NF-[kappa] B as the match-maker. *Nature Immunology*. 2011;**12**:715-723. DOI: 10.1038/ni.2060
- [3] Markiewski MM, Lambris JD. The role of complement in inflammatory diseases from behind the scenes into the spotlight. *The American Journal of Pathology*. 2007;**171**(3):227-240. DOI: 10.2353/ajpath.2007.070166
- [4] Yang HZ, Wang JP, Mi S, Liu HZ, Cui B, Yan HM, Lu W. TLR4 activity is required in the resolution of pulmonary inflammation and fibrosis after acute and chronic lung injury. *The American Journal of Pathology*. 2012;**180**:275-292. DOI: 10.1016/j.ajpath.2011.09.019

- [5] Gordon S. Alternative activation of macrophages. *Nature Reviews Immunology*. 2016; **3**(1):23-36. DOI: 10.1038/nri978
- [6] Pereira-Leite C, Nunes C, Jamal SK, Cuccovia IM, Reis S. Nonsteroidal anti-inflammatory therapy: A journey toward safety. *Medicinal Research Reviews*. 2016;**37**:802-859. DOI: 10.1002/med.21424
- [7] Javadi B, Sahebkar A. Natural products with anti-inflammatory and immunomodulatory activities against autoimmune myocarditis. *Pharmacological Research*. 2017;**124**:34-42. DOI: 10.1016/j.phrs.2017.07.022
- [8] Mewalal R, Rai DK, Kainer D, Chen F, Külheim C, Peter GF, Tuskan GA. Plant-derived terpenes: A feedstock for specialty biofuels. *Trends in Biotechnology*. 2017;**35**(3):227-240. DOI: 10.1016/j.tibtech. 2016-08.003
- [9] Rufino A, Ribeiro M, Judas F, Salgueiro L, Lopes M, Cavaleiro C, Mendes A. Anti-inflammatory and chondroprotective activity of (+)- α -pinene: Structural and enantiomeric selectivity. *Journal of Natural Products*. 2014;**77**(2):264-269. DOI: 10.1021/np400828x
- [10] Ma J, Xu H, Wu J, Qu C, Sun F, Xu S. Linalool inhibits cigarette smoke-induced lung inflammation by inhibiting NF- κ B activation. *International Immunopharmacology*. 2015; **29**(2):708-713. DOI: 10.1016/j.intimp.2015.09.005
- [11] Kilani S, Sghaier M, Limem I, Bouhlef I, Boubaker J, Bhouri W, Skandrani I, Neffatti A, Ben-Ammar R, Dijoux-Franca M, Ghedira K, Chekir-Ghedira L. In vitro evaluation of antibacterial, antioxidant, cytotoxic and apoptotic activities of the tubers infusion and extracts of *Cyperus rotundus*. *Bioresource Technology*. 2008;**99**(18):9004-9008. DOI: 10.1016/j.biortech.2008.04.066
- [12] Kilani S, Ammar R, Bouhlef I, Abdelwahed A, Hayder N, Ben-Chibani J, Mahmoud A, Ben-Chibani L, Chekir-Ghedira K. Investigation of extracts from (Tunisian) *Cyperus rotundus* as antimutagens and radical scavengers. *Environmental Toxicology and Pharmacology*. 2005;**20**(3):478-484. DOI: 10.1016/j.etap.2005.05.012
- [13] Dang G, Parekar R, Kamat S, Scindia A, Rege N. Antiinflammatory activity of *Phyllanthus emblica*, *Plumbago zeylanica* and *Cyperus rotundus* in acute models of inflammation. *Phytotherapy Research*; **25**(6):904-908. DOI: 10.1016/S0014-5793(01)03293-8
- [14] Seo Y, Jeong M, Lee K, Jang DS, Choi J. Isocyperol, isolated from the rhizomes of *Cyperus rotundus*, inhibits LPS-induced inflammatory responses via suppression of the NF- κ B and STAT3 pathways and ROS stress in LPS-stimulated RAW 264.7 cells. *International Immunopharmacology*. 2016;**38**:61-69. DOI: 10.1016/j.intimp.2016.05.017
- [15] Arun M, Asha V. Gastroprotective effect of *Dodonaea viscosa* on various experimental ulcer models. *Journal of Ethnopharmacology*. 2008;**118**(3):460-465. DOI: 10.1016/j.jep.2008.05.026
- [16] Khurram M, Khan M, Hameed A, Abbas N, Qayum A, Inayat H. Antibacterial activities of *Dodonaea viscosa* using contact bioautography technique. *Molecules*. 2009;**14**(3):1332-1341. DOI: 10.3390/molecules14031332

- [17] Khalil N, Sperotto J, Manfron M. Antiinflammatory activity and acute toxicity of *Dodonaea viscosa*. *Fitoterapia*. 2006;**77**(6):478-480. DOI: 10.1016/j.fitote.2006.06.002
- [18] Getie M, Gebre-Mariam T, Rietz R, Höhne C, Huschka C, Schmidtke M, Neubert RHH. Evaluation of the anti-microbial and anti-inflammatory activities of the medicinal plants *Dodonaea viscosa*, *Rumex nervosus* and *Rumex abyssinicus*. *Fitoterapia*. 2003;**74**(1):139-143. DOI: 10.1016/S0367-326X(02)00315-5
- [19] Salinas-Sánchez D, Herrera-Ruiz M, Pérez S, Jiménez-Ferrer E, Zamilpa A. Anti-inflammatory activity of hautriwaic acid isolated from *Dodonaea viscosa* leaves. *Molecules*. 2012;**17**(4):4292-4299. DOI: 10.3390/molecules17044292
- [20] Salinas-Sánchez D, Zamilpa A, Pérez S, Herrera-Ruiz M, Tortoriello J, González-Cortazar M, Jiménez-Ferrer E. Effect of hautriwaic acid isolated from *Dodonaea viscosa* in a model of kaolin/carrageenan-induced monoarthritis. *Planta Medica*. 2015;**81**(14):1240-1247. DOI: 10.1055/s-0035-1546197
- [21] Pathak A, Bhutani M, Nair A, Ahn K, Chakraborty A, Kadara H, Aggarwal B. Ursolic acid inhibits STAT3 activation pathway leading to suppression of proliferation and chemosensitization of human multiple myeloma cells. *Molecular Cancer Research*. 2007; **5**(9):943-955. DOI: 10.1158/1541-7786.MCR-06-0348
- [22] Wand X, Zhang F, Yang L, Mei Y, Long H, Zhang X. Ursolic acid inhibits proliferation and induces apoptosis of cancer cells in vitro and in vivo. *Journal of Biomedicine and Biotechnology*. 2011;**2011**:1-8. DOI: 10.1155/2011/419343
- [23] Woźniak Ł, Skąpska S, Marszałek K. Ursolic acid-a pentacyclic triterpenoid with a wide spectrum of pharmacological activities. *Molecules*. 2015;**20**(11):20614-20641. DOI: 10.3390/molecules201119721
- [24] Vasconcelos M, Royo V, Ferreira D, Crotti A, Silva M, Carvalho J, Bastos JK, Cunha WR. In vivo analgesic and anti-inflammatory activities of ursolic acid and oleanoic acid from *Miconia albicans* (Melastomataceae). *Zeitschrift für Naturforschung*. 2006;**61**(7–8):477-482. DOI: 0939-5075/2006/0700-0477
- [25] Baricevic D, Sosa S, Della-Loggia R, Tubaro A, Simonovska B, Krasna A, Zupancic A. Topical anti-inflammatory activity of *Salvia officinalis* L. leaves: The relevance of ursolic acid. *Journal of Ethnopharmacology*. 2001;**75**(2):125-132. DOI: 10.1016/S0378-8741(00)00396-2
- [26] González-Chávez M, Ramos-Velázquez C, Serrano-Vega R, Pérez-González C, Sánchez-Mendoza E, Pérez-Gutiérrez S. Anti-inflammatory activity of standardized dichloromethane extract of *Salvia connivens* on macrophages stimulated by LPS. *Pharmaceutical Biology*. 2017; **55**(1):1467-1472. DOI: 10.1080/13880209.2017.1305423
- [27] Zerín T, Lee M, Jang W, Nam K, Song H. Anti-inflammatory potential of ursolic acid in mycobacterium tuberculosis-sensitized and Concanavalin A-stimulated cells. *Molecular Medicine Reports*. 2016;**13**(3):2736-2744. DOI: 10.3892/mmr.2016.4840

- [28] Formisano C, Sanna C, Ballero M, Chianese G, Sirignano C, Rigano D, Taglialatela-Scafati O. Anti-inflammatory sesquiterpene lactones from *Onopordum illyricum* L.(Asteraceae), an Italian medicinal plant. *Fitoterapia*. 2017;**116**:61-65. DOI: 10.1016/j.fitote.2016.11.006
- [29] Youn UJ, Park EJ, Kondratyuk TP, Sripisut T, Laphookhieo S, Pezzuto JM, Chang LC. Anti-inflammatory triterpenes from the apical bud of *Gardenia sootepensis*. *Fitoterapia*. 2016;**114**:92-97. DOI: 10.1016/j.fitote.2016.08.012
- [30] Garayev E, Herbette G, Di Giorgio C, Chiffolleau P, Roux D, Sallanon H, Baghdikian B. New sesquiterpene acid and inositol derivatives from *Inula montana* L. *Fitoterapia*. 2017;**120**:79-84. DOI: 10.1016/j.fitote.2017.05.011
- [31] Mai NT, Cuc NT, Anh HLT, Nhiem NX, Tai BH, Yen PH, Oh H. Two new guaiane sesquiterpenes from *Datura metel* L. with anti-inflammatory activity. *Phytochemistry Letters*. 2017;**19**:231-236. DOI: 10.1016/j.phytol.2017.01.011
- [32] Shen XY, Yu Y, Chen GD, Zhou H, Luo JF, Zuo YH, Dai Y. Six new sesquiterpenoids from *Nardostachys chinensis* Batal. *Fitoterapia*. 2017;**119**:75-82. DOI: 10.1016/j.fitote.2017.04.004
- [33] Pan LL, Xu P, Luo XL, Wang LJ, Liu SY, Zhu YZ, Liu XH. Shizukaol B, an active sesquiterpene from *Chloranthus henryi*, attenuates LPS-induced inflammatory responses in BV2 microglial cells. *Biomedicine & Pharmacotherapy*. 2017;**88**:878-884. DOI: 10.1016/j.biopha.2017.01.152
- [34] Wu ZN, Zhang YB, Chen NH, Li MJ, Li MM, Tang W, Wang GC. Sesquiterpene lactones from *Elephantopus mollis* and their anti-inflammatory activities. *Phytochemistry*. 2017;**137**: 81-86. DOI: 10.1016/j.phytochem.2017.01.020
- [35] Shen CP, Luo JG, Yang MH, Kong LY. Sesquiterpene dimers from the roots of *Chloranthus holostegius* with moderate anti-inflammatory activity. *Phytochemistry*. 2017;**137**:117-122. DOI: 10.1016/j.phytochem.2017.02.016
- [36] Van Kiem P, Hang DT, Nhiem NX, Tai BH, Anh HLT, Van Cuong P, Subedi L. Sesquiterpene derivatives from marine sponge *Smenospongia cerebriformis* and their anti-inflammatory activity. *Bioorganic & Medicinal Chemistry Letters*. 2017;**27**(7):1525-1529. DOI: 10.1016/j.bmcl.2017.02.040
- [37] Fang X, Xu XK, Wang GW, Zeng RT, Tian XH, Shi ZR, Zhang WD. Guaianolide sesquiterpenoids from *Ainsliaea yunnanensis*. *Phytochemistry*. 2017;**139**:47-55. DOI: 10.1016/j.phytochem.2017.04.001
- [38] Zhuo ZG, Wu GZ, Fang X, Tian XH, Dong HY, Xu XK, Shen YH. Chlorajaponols A-F, sesquiterpenoids from *Chloranthus japonicus* and their in vitro anti-inflammatory and anti-tumor activities. *Fitoterapia*. 2017;**119**:90-99. DOI: 10.1016/j.fitote.2017.04.009
- [39] Walshe-Roussel B, Choueiri C, Saleem A, Asim M, Caal F, Cal V, Arnason JT. Potent anti-inflammatory activity of sesquiterpene lactones from *Neurolaena lobata* (L.) R. Br. ex Cass., a Q'eqchi'Maya traditional medicine. *Phytochemistry*. 2013;**92**:122-127. DOI: 10.1016/j.phytochem.2013.05.004

- [40] de Albuquerque Ugoline BC, de Souza J, Ferrari FC, Ferraz-Filha ZS, Coelho GB, Saúde-Guimarães DA. The influence of seasonality on the content of goyazensolide and on anti-inflammatory and anti-hyperuricemic effects of the ethanolic extract of *Lychnophora passerina* (Brazilian arnica). *Journal of Ethnopharmacology*. 2017;**198**:444-450. DOI: 10.1016/j.jep.2017.01.017
- [41] Liu Q, Jo YH, Kim SB, Jin Q, Hwang BY, Lee MK. Sesquiterpenes from the roots of *Lindera strychnifolia* with inhibitory effects on nitric oxide production in RAW 264.7 cells. *Bioorganic & Medicinal Chemistry Letters*. 2016;**26**(20):4950-4954. DOI: 10.1016/j.bmcl.2016.09.012
- [42] Chi J, Li BC, Dai WF, Liu L, Zhang M. Highly oxidized sesquiterpenes from *Artemisia austro-yunnanensis*. *Fitoterapia*. 2016;**115**:182-188. DOI: 10.1016/j.fitote.2016.10.013
- [43] Xia G, Zhou L, Ma J, Wang Y, Ding L, Zhao F, Qiu F. Sesquiterpenes from the essential oil of *Curcuma wenyujin* and their inhibitory effects on nitric oxide production. *Fitoterapia*. 2015;**103**:143-148. DOI: 10.1016/j.fitote.2015.03.021
- [44] Hegazy MEF, Nakamura S, Tawfik WA, Abdel-Azim NS, Abdel-Lateff A, Matsuda H, Pará PW. Rare hydroperoxyl guaianolide sesquiterpenes from *Pulicaria undulata*. *Phytochemistry Letters*. 2015;**12**:177-181. DOI: 10.1016/j.phytol.2015.03.019
- [45] Kim TH, Li H, Wu Q, Lee HJ, Ryu JH. A new labdane diterpenoid with anti-inflammatory activity from *Thuja orientalis*. *Journal of Ethnopharmacology*. 2013;**146**(3):760-767. DOI: 10.1016/j.jep.2013.02.001
- [46] González Y, Doens D, Santamaría R, Ramos M, Restrepo CM, de Arruda LB, Fernández PL. A pseudopterane diterpene isolated from the octocoral *Pseudopterogorgia acerosa* inhibits the inflammatory response mediated by TLR-ligands and TNF- α in macrophages. *PloS One*. 2013;**8**(12):e84107. DOI: 10.1371/journal.pone.0084107.g003
- [47] Wangchuk P, Navarro S, Shepherd C, Keller PA, Pyne SG, Loukas A. Diterpenoid alkaloids of *Aconitum laciniatum* and mitigation of inflammation by 14-O-acetylneoline in a murine model of ulcerative colitis. *Scientific Reports*. 2015;**5**:12845. DOI: 10.1038/srep12845
- [48] Través PG, Pimentel-Santillana M, Rico D, Rodríguez N, Miethke T, Castrillo A, Boscá L. Anti-inflammatory actions of acanthoic acid-related diterpenes involve activation of the PI3K p110 γ/δ subunits and inhibition of NF- κ B. *Chemistry & Biology*. 2014;**21**(8):955-966. DOI: 10.1016/j.chembiol.2014.06.005
- [49] Chen JJ, Ting CW, Wu YC, Hwang TL, Cheng MJ, Sung PJ, Chen JF. New labdane-type diterpenoids and anti-inflammatory constituents from *Hedychium coronarium*. *International Journal of Molecular Sciences*. 2013;**14**(7):13063-13077. DOI: 10.3390/ijms140713063
- [50] Sun CP, Yuan T, Wang L, Kang N, Zhao F, Chen LX, Qiu F. Anti-inflammatory labdane-type diterpenoids from *Physalis angulate*. *RSC Advances*. 2016;**6**(80):76838-76847. DOI: 10.1039/c6ra16424b

- [51] Premprasert C, Tewtrakul S, Plubrukarn A, Wungsintaweeikul J. Anti-inflammatory activity of diterpenes from *Croton stellatopilosus* on LPS-induced RAW264. 7 cells. *Journal of Natural Medicines*. 2013;**67**(1):174-181. DOI: 10.1007/s11418-012-0668-5
- [52] Cheng HH, Cheng YB, Hwang TL, Kuo YH, Chen CH, Shen YC. Randainins A–D, based on unique diterpenoid architectures, from *Callicarpa randaiensis*. *Journal of Natural Products*. 2015;**78**(8):1823-1828. DOI: 10.1021/acs.jnatprod.5b00012
- [53] Lee M, Kim SH, Lee HK, Cho Y, Kang J, Sung SH. *ent*-kaurane and *ent*-pimarane diterpenes from *Siegesbeckia pubescens* inhibit lipopolysaccharide-induced nitric oxide production in BV2 microglia. *Biological & Pharmaceutical Bulletin*. 2013;**37**(1):152-157. DOI: 10.1248/bpb.b13-00233
- [54] Qin J, Li HM, Gao LH, Liu D, Li RT, Lee KH. New labdane diterpenoids from *Leonurus japonicus* and their anti-inflammatory activity. *Phytochemistry Letters*. 2014;**10**:313-317. DOI: 10.1016/j.phytol.2014.10.027
- [55] He YR, Shen YH, Shan L, Yang X, Wen B, Ye J, Zhang WD. Diterpenoid lanceolatins A–G from *Cephalotaxus lanceolata* and their anti-inflammatory and anti-tumor activities. *RSC Advances*. 2015;**5**(6):4126-4134. DOI: 10.1039/c4ra10665b
- [56] Kapewangolo P, Omolo JJ, Bruwer R, Fonteh P, Meyer D. Antioxidant and anti-inflammatory activity of *Ocimum labiatum* extract and isolated labdane diterpenoid. *Journal of Inflammation*. 2015;**12**(1):4. DOI: 10.1186/s12950-015-0049-4
- [57] Chen YC, Li YC, You BJ, Chang WT, Chao LK, Lo LC, Kuo YH. Diterpenoids with anti-inflammatory activity from the wood of *Cunninghamia konishii*. *Molecules*. 2013;**18**(1):682-689. DOI: 10.3390/molecules18010682
- [58] Erharuyi O, Adhikari A, Falodun A, Jabeen A, Imad R, Ammad M, Gören N. Cytotoxic, anti-inflammatory, and leishmanicidal activities of diterpenes isolated from the roots of *Caesalpinia pulcherrima*. *Planta Medica*. 2016;**83**(01/02):104-110. DOI: 10.1016/j.bjp.2016.12.008
- [59] Thao NP, Luyen BTT, Ngan NTT, Song SB, Cuong NX, Nam NH, Van Minh C. New anti-inflammatory cembranoid diterpenoids from the Vietnamese soft coral *Lobophytum crissum*. *Bioorganic & Medicinal Chemistry Letters*. 2014;**24**(1):228-232. DOI: 10.1016/j.bmcl.2013.11.033
- [60] Chen H, Wang H, Yang B, Jin DQ, Yang S, Wang M, Guo Y. Diterpenes inhibiting NO production from *Euphorbia helioscopia*. *Fitoterapia*. 2014;**95**:133-138. DOI: 10.1016/j.fitote.2014.03.010
- [61] Armah FA, Annan K, Mensah AY, Amponsah IK, Tocher DA, Habtemariam S. Erythroivorenin: A novel anti-inflammatory diterpene from the root-bark of *Erythrophloeum ivorense* (a Chev.). *Fitoterapia*. 2015;**105**:37-42. DOI: 10.1016/j.fitote.2015.06.001
- [62] Rohr M, Oleinikov K, Jung M, Sandjo LP, Opatz T, Erkel G. Anti-inflammatory tetraquinane diterpenoids from a *Crinipellis* species. *Bioorganic & Medicinal Chemistry*. 2017;**25**(2):514-522. DOI: 10.1016/j.bmc.2016.11.016

- [63] Rossi A, Pace S, Tedesco F, Pagano E, Guerra G, Troisi F, Izzo AA. The hallucinogenic diterpene salvinorin A inhibits leukotriene synthesis in experimental models of inflammation. *Pharmacological Research*. 2016;**106**:64-71. DOI: 10.1016/j.phrs.2016.01.032
- [64] Pierri EG, Castro RC, Vizioli EO, Ferreira CM, Cavaleiro AJ, Tininis AG, Santos AG. Anti-inflammatory action of ethanolic extract and clerodane diterpenes from *Casearia sylvestris*. *Revista Brasileira de Farmacognosia*. 2017;**27**:495-501. DOI: 10.1016/j.bjp.2016.12.008
- [65] Mireku EA, Kusari S, Eckelmann D, Mensah AY, Tolantsi FM, Spteller M. Anti-inflammatory tirucallane triterpenes from *Anopyxis kaineana* Pierre (Engl.), (Rhizophoraceae). *Fitoterapia*. 2015;**106**:84-91. DOI: 10.1016/j.fitote.2015.08.007
- [66] Romero-Estrada A, Maldonado-Magaña A, González-Christen J, Bahena SM, Garduño-Ramírez ML, Rodríguez-López V, Alvarez L. Anti-inflammatory and antioxidative effects of six pentacyclic triterpenes isolated from the Mexican copal resin of *Bursera copallifera*. *BMC Complementary and Alternative Medicine*. 2016;**16**(1):422-432. DOI: 10.1186/s12906-016-1397-1
- [67] Zhou J, Wei XH, Chen FY, Li CJ, Yang JZ, Ma J, Zhang DM. Anti-inflammatory pentacyclic triterpenes from the stems of *Euonymus carnosus*. *Fitoterapia*. 2017;**118**:21-26. DOI: 10.1016/j.fitote.2017.01.015
- [68] Chun SK, Lalita S, Joonseok O, Sun YK, Sang UC, Kang R. Bioactive triterpenoids from the twigs of *Chaenomeles sinensis*. *Journal of Natural Products*. 2017;**80**:1134-1140. DOI: 10.1021/acs.jnatprod.7b00111
- [69] de Almeida PDO, Boleti APA, Rüdiger AL, Lourenço GA, da Veiga Junior VF, Lima ES. Anti-inflammatory activity of triterpenes isolated from *Protium paniculatum* oil-resins. *Evidence-Based Complementary and Alternative Medicine*. 2015, Article ID: 293768. DOI: 10.1155/2015/293768
- [70] Huang J, Wang Y, Li C, Wang X, He X. Triterpenes isolated from acorns of *Quercus serrata* Var. *Brevipetiolata* exert anti-inflammatory activity. *Industrial Crops and Products*. 2016;**91**:302-309. DOI: 10.1016/j.indcrop.2016.07.033
- [71] Killeen MJ, Linder M, Pontoniere P, Crea R. NF- κ B signaling and chronic inflammatory diseases: Exploring the potential of natural products to drive new therapeutic opportunities. *Drug Discovery Today*. 2014;**19**(4):373-378. DOI: 10.1016/j.drudis.2013.11.002

