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**Review Article :**

# Biotransformation of terpenoids by fungi and bacteria - A literature update

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## ABSTRACT

*Terpenenoids, which are naturally occurring organic compounds of plant and animal origin are presently gaining lot of scientific attention as potent antimicrobial agents. Monoterpenoids in plants have great ecological roles in acting as deterrents against feedings by herbivores, in defences against pathogens and as attractants for pollination. Sesquiterpenoids are also known to possess antibacterial properties with significant, pharmacological and clinical efficiency. Diterpenoids are also known to possess potent pharmacological activities. Several phytoextracts contain biologically active triterpenes which are found to possess anti-inflammatory, virostatic, hepatoprotective and antimycotic effects. Microbial transformation of terpenoids is being extensively studied to produce new metabolites with enhanced biological activity. The regio and stereo selective introduction of functional groups at unactivated carbon atom is achieved by biotransformation which is otherwise difficult with chemical methods. These terpenes and their derivatives can be utilized as chiral synthons for asymmetric synthesis. In present review we focus on the biotransformation of the various class of terpenoids by fungi and bacteria to obtain bioactive compounds from precursor torpene skeletons.*



## INTRODUCTION

Terpenoids are among the largest group of natural products found in plant and animal kingdom. A large group of plant families possess mono, sesqui, di and triterpenes. All of these are biogenetically derived from isoprene units ($C_5$) and belong to various skeletal classes [94].

Mono and sesquiterpenes also make up the composition of most of the essential oils which are largely used in perfumery and cosmetic industries, food flavors and condiments. They are also reported to possess antioxidant, hepatoprotective and anti-inflammatory activities [16, 28]. Industrially mono terpenoids have been proposed as substitute for chloro-fluoro hydrocarbons [64] and chlorinated solvents used for cleaning of electrical applications and metals [5]. Mono and sesquiterpenoids are also ecologically important as they act as attractant for pollinator, insert deterrents and anti-feedents and

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also as antimicrobial agents. Terpenoids are also used as insecticides and protection agents in storage and anti sprouting agents and also used for synthesis of high value compounds [16]. Diterpenoids have wide applications as pharmaceutical agents. These also act as anti cancer, anti tumor and cytotoxic agents [71]. Triterpenes and related steroidal compounds are involved in stabilization of cell membranes and regulation of enzymatic processes and metabolic pathways particularly in mammals [94].

The biotransformation of natural products is of interest to produce high value products from less useful materials and with interest to develop stereo selective and stereospecific methods for the formation of enantiomers with desired flavour and fragrance and pharmacological activity under mild conditions. Several reports are published on biotransformation of terpenoids by soluble and immobilized enzymes, cell culture extracts, bacteria, cyanobacterial fungi, yeast, algae and plant cell cultures. However whole cell bacterial, algal, fungal and plant cell cultures is simpler and inexpensive rather than purified enzymes [24]. In this communication we will restrict to the biotransformation studies on terpenoids by bacteria and fungi only. In whole cell cultures, the cell membranes and other factors protect the enzymatic reactions. Reaction products and reproducibility of biotransformation is difficult to control besides side reactions because of variants and different stage of cell growth.

Mostly, the biotransformation reactions are carried out in aqueous system which is favorable for growing fungal, bacterial, algal and plant cell cultures. The solubility of terpenoids in water is low hence biphasic systems with organic and aqueous phase have been used because of advantage of continues removal of products which favours the thermodynamic equilibrium of kinetically unfavorable reactions. Whole cell biotransformation in organic media have also been used but organic solvents sometimes can inactivate enzymes and effect the cell viability affecting the cell membrane [77]. Ionic liquids and super critical fluids are other non conventional media used for biotransformation studies [66, 100].

The value addition of monoterpene hydrocarbons by converting them to oxygenated mono terpenoids is a challenge at industrial scale because of their low solubility, high volatility antimicrobial activity and cytotoxicity [16]. The present review summarizes the use of fungal and bacterial strains for the biotransformation of various monoterpenoids, sesquiterpenoids, diterpenoids and triterpenes molecules.

**Biotransformation of monoterpene hydrocarbon and monoterpenoid**

The monoterpenoids are reported to possess various biological activities such as insecticide, antihelminthic, anticancer, antiinflammatory, antimicrobial and antioxidant potential [16, 88]. Intensive work has been done on the biotransformation of monoterpene and monoterpenoids by the various bacterial and fungal strains. Some of the major success stories are summarized in Table 1&2. Monoterpene hydrocarbons and oxygenated monoterpenoids make up the major portion of essential oils. Still there are several compounds which can be tried for biotransformation studies for converting them to useful products.

**Biotransformation of sesquiterpenoids**

Sesquiterpenoids are distributed abundantly and widely in nature and are of great therapeutic importance. They possess various biological activities such as anti-inflammatory, anti-tumoral, antifungal and antibacterial, antimalarial properties [89,90]. Some of the sesquiterpenoids which are biotransformed by the fungus and bacteria are discussed in Table 3.

## Table 1. Biotransformation of monoterpene hydrocarbon

| Compound | Organism responsible for biotransformation | Resulting compound | Ref no |
|---|---|---|---|
| limonene | *Nicotiana tabacum* | *cis*–Carveol; Carvone; *trans*-Carveol; Limonene,1-2 diol | 56 |
| Limonene | *Pseudomonas pudita* (DSM 12264) | Perillic acid | 88 |
| R-(+)-Limonene | *Pseudomonas pudita* (DSM 12264) | R(+)Perillic acid | 113 |
| R-(+)-Limonene | *Pleurotus sapidus* | *cis/trans* Carveol and Carvone | 98 |
| d-Limonene | *Cellulosimicrobium cellulans* (EB-8-4) | (+)-*trans*-Carveol | 122 |
| *β*-Myrcene | *Rhodococcus erythropolis* | Geraniol | 115 |
| *β*-Pinene | *Aspergillus niger* (NC1M 612) | *trans*-Pinocarveol | 31 |
| *β*-Pinene | *Armillariella mellea* | *trans*-Pinocarveol | 37 |
| *β*-Pinene | *Ganoderma applanatum* and *Pleurotus flabellatus* | 1,4-Cineol; 1,8-Cineol (eucalyptol); Myrtenol; Myrtenal | 8 |
| *β*-Pinene | *Pseudomonas sp.* | Borneol; Camphor; *β*-Isopropylpimelic acid | 32 111 |

## Table 2. Biotransformation of oxygenated monoterpenes

| Compound | Organism responsible for biotransformation | Resulting compound | Ref no |
|---|---|---|---|
| (?) -Menthone and (+) -pulegone | *Hormonema* isolate (UOFS Y-0067) | (+)-Neomenthol | 117 |
| Limonene-(1,2)-epoxide | *Rhodococcus erythropolis* (DCL14) | Limonene-(1,2)-diol | 25 |
| a) Nopol<br>b) Myrtenol<br>c) Nopinol | *Cephalosporium aphidicola* | (a) 4-*β M*ethoxynopol; 4-*β H*ydroxyoxynopol<br>(b) 4-*β,10*-Dihydroxypin-2-ene (c)Nopinone | 39 |
| (a) ±-*cis* –Nerolidol<br>(b) Nerylacetone | *Glomerella cingulate* | (a) (*Z*)-3,7,11-Trimethyl-1,6-dodecadien-3,10,11-triol<br>(b) (*Z*)-9,10-Dihydroxy-6-10-dimethyl-5-undecen-2-one | 92 |
| Geraniol and Nerol | *Penicillium italicum* | 6-Methyl-5-hepten-2-one | 29 30 |
| (-) -*cis*-myrtanol | *Glomerella cingulata* | (3S)-3-Hydroxy-*cis*-myrtanol; (4R)-4-Hydroxy-*cis*-myrtanol; 5-Hydroxy-*cis*-myrtanol . | 93 |
| (*RS*)-Linalool | a) *Fusarium* sp. (1D2)<br>b) *F. fujikuroi* | a) (*E*)- and (*Z*)-Furanlinalool oxides<br>b) 6-Methylhept-5-en-2-one | 104 |
| Geraniol | *Saccharomyces cerevisiae* | Citronellol<br>Linalool | 46<br>63 |
| Nerol | *Saccharomyces cerevisiae* | Geraniol | 127 |
| Linalool | *Saccharomyces cerevisiae* | *α*-Terpeniol | 131 |
| Geraniol | *Saccharomyces cerevisiae, Saccharomycesbayanus* | Linalool; *α*- Terpeniol | 45 |
| Geraniol | *Penicillium digitatum* | Citral | 123 |
| *α*-Pinene oxide | *Pseudomonas fluorescens* (NCIMB 11761) | Novalal | 132 |
| *α*-Pinene oxide | *P. rhodesiae* (CIP 107491) | Isonovalal | 41 42 |
| *α*-Pinene oxide | *P. rhodesiae* (CIP 107491) | Novalal (more)<br>Isonovalal(less) | 79 |
| Citronellol | *Pseudomonas spp.* | *cis*- and *trans*-Rose oxides | 102 |
| a) (*S*)-carvone<br>(*R*)-carvone | a) *M. circinelloides*<br>b) *L. theobromae*, *M. circinelloides* | a) Dihydrocarvone<br>b) *p*-Menthane-2,8,9-triols | 97 |

**Table 3. Biotransformation of sesquiterpenoids**

| Compound | Organism responsible for biotransformation | Resulting compound | Ref no |
|---|---|---|---|
| Caryophyllene | *Chaetomium cochliodes* (DSM1909) | 4,5-Epoxy-caryophyllene-7,12-diol | 1 |
| (-)-*α*-Bisabolol | *Glomerella cingulata* | (1S,3R,4R,7S,10S)-3,4-Dihydroxy-bisabolol oxide B | 91 |
| *β*-Selinene | *Glomerella cingulata* | (1S,6S,9S,10R**,**11RS)-1,11,13-Trihydroxy-*β* –selinene | 89 |
| *γ*-Gurjunene | *Glomerella Cingulata* | (1S,4S,7R,10R)- 5-Guaien-11,13- diol; (1S,4S,7R,10R)- 5-Guaien-10,11,13- triol. | 90 |
| Squamulosone | *Curvularia lunata* (ATCC 12017) | *2α*-Hydroxyaromadendr-1(10)-en-9-one; *2β*-Hydroxyaromadendr-1(10)-en-9-one; 13-Hydroxyaromadendr-1(10)-en-9-one; 14-Hydroxyaromadendr-1(10)-en-9-one | 22 |
| *5α*-Hydroxycaryophylla-4(12), 8(13)-diene | *Macrophomina phaseolina* | *4β*-Methoxycaryophyllene-*5α,* (11S)-14-diol; *4β*-Methoxycaryophyllene-*5α, (11R)*-15-diol; Caryophyllene-*5α, (11R)*-15-diol | 95 |
| Santonin | *Aspergillus niger* (ATCC 9142), *Mucor plumbeus* (ATCC 4740), *Whetzelinia sclerotiorum* ATCC 18687 *Cunninghamella echinulata* (ATCC 8688a) | *11β,13*-Dihydroxysantonin ,6,7-dehydosantonin; 3,6-Dihydroxy-9-keto-9,10-seco-selina-1,3,5(10)-trien-12-oic acid-12,6-lactone; *11β*-Hydroxysantonin, 14-hydroxysantonin, 3,6,9-trihydroxy-9,10-seco-selina-1,3,5(10)-trien-12-oic acid-12,6-lactone | 69 |
| a) Confertifolin b) Isodrimenin | *Rhizopus oryzae* | a) C-*3β P*roducts (80%) b) C-*3β P*roducts(53%); C-*7α H*ydroxyl metabolite | 87 |
| 1,1,4-Trimethyl tricyclo95.4.0.0)undec-7-en-9-one | *Rhizopus oryzae* | C-12 and C-13 Monohydroxylated metabolite | 52 |
| (1*R*,2*R*,4*S*)-1,7-Dimethyl-4- (1-methylethyl) tricyclo[4.4.0.0] dec-6-en-8-one | *Rhizopus oryzae* | *β*-Cyperone | 68 |
| Valencene | *Pleurotus sapidus* | Nootkatone | 43 |
| Cadinanes | *Beauveria bassiana* (ATCC 7159) | Insecticidal derivatives of cadinanes | 7 |
| Patchoulol | *Pithomyces* species | Regioselective 10-hydroxylation of patchoulol | 114 |
| (-)-Maalioxide | *Aspergillus cellulosae* | *1β*-Hydroxymaalioxide | 51 |
| (-)-Maalioxide | *Aspergillus niger* | *7β*-Hydroxymaalioxide *1β,9β- and 1β,12*-Dihydroxy derivatives | 51 |
| (-)-Maalioxide | *Mucor plumbeus* | *9β*-Hydroxymaalioxide; *1β*-Hydroxymaalioxide; *7β*-Hydroxymaalioxide | 121 |

## Biotransformation of diterpenoids

Diterpenoids are also found in nature and possess potent anticancer activity. These also possess antimicrobial, trypanosomicidal and antiviral activities. Although the isolation of the diterpenoids from nature is very difficult still extensive work is going on to isolate diterpenoid because of their important properties [6, 71*, 112]*. Some of the diterpenoids which are transformed either by the bacteria or the fungus are presented in Table 4.

## Biotransformation of triterpene

Squalene which is the simplest triterpene is found predominantly in the fish liver oils, plant oils and in mammalian fats. The triterpenes usually consist of the oleanane, ursane, lupine and dammarane –euphane type skeletons.These are reported to possess various biological activities such as anti- inflammatory, analgesic, antibacterial, antifungal, immmunomodulatary, antimycotic and hepatoprotective activity [94]. Table 5 presents the biotransformation of some of the triterpenes which are biotransformed by the various fungus and bacteria

**Table4 - Biotransformation of diterpenoids**

| Compound | Organism responsible for biotransformation | Resulting compound | Ref no |
|---|---|---|---|
| Stemodin | *Rhizopus oryzae* | Shift in the position of hydroxylation | 86 |
| a) 13R,14R,15-Trihydroxylabd-7-ene b) 13R,14R,15-Trihydroxylabd-8(17)-ene | *Debaryomyces hansenii* | a)(13R,14R,15-Trihydroxy-6-oxolabd-8-ene) b)(7*α*,13R,14R,15-Tetrahydroxy-labd-8(17)-ene) | 50 |
| a) 13R,14R,15-Trihydroxylabd-7-ene b) 13R,14R,15-trihydroxylabd-8,17-ene | *Aspergillus niger* | a)(3*β*,13R,14R,15-Tetrahydroxy-labd-7-ene) b)(7*α*,13R,14R,15-Tetrahydroxy-labd-8(17)-ene); (3R,14R,15-3-Oxotetrahydroxy-labd-7-ene) | 50 |
| 15(13? 12)Abeo-13b-hydroxystemaran-2-one | *Rhizopus oryzae* | 15(13? 12)Abeo-*7β,13β*-dihydroxystemaran-2-one | 85 |
| Ent-kaur-16-en-19-oic acid | *Rhizopus Stolonifer* | Ent-16b,17-dihydroxy-kauran-19-oic acid. | 112 |
| Stemodin | *Mucor plumbeus* (ATCC 4740) | *2α,6β,1*3-Trihydroxystemodane; *2α,3β,13*-Trihydroxystemodane; *2α,11β,13*-Trihydroxystemodane; *2α,13,14*-Trihydroxystemodane | 12 |
| Stemodinone | *Mucor plumbeus* (ATCC 4740) | *6α,13*-Dihydroxystemodan-2-one; *6α,12α,13*-Trihydroxystemodan-2-one | 12 |
| *7α*,19-Dihydroxy-ent-atis-16-ene | *Gibberella fujikuroi* | 19-Hydroxy-7-oxo-ent-atis-16-ene13(R); 19-Dihydroxy-7-oxo-ent-atis-16-ene; *7α ,11β,19*-Trihydroxy-ent-atis-16-ene; 7*α* ,16*β*,19-Trihydroxy-ent-atis-16-ene | 44 |
| Imbricatolic acid | *a) Aspergillus n* *b) Rhizopus nigricans* | a) 1*α*-Hydroxyimbricatolic acid b) 15-Hydroxy-8,17-epoxylabdan-19-oic acid | 57 |
| Stemodin and Stemodinone | *Beauveria bassiana* (ATCC 7159) | C-18 Hydroxylated products of stemodin and stemodinone | 6 |
| Stemodin | *a) Cunninghamella echinulata* var. *Elegans* *b) Phanerochaete chrysosporium* | a)*7α*-Hydrox*y, 7β*-h*ydroxy and 3β*-hydroxy derivatives *b) 7 β*-Hydroxy, *3β-hydroxy and 11β*-hydroxyderivatives | 70 |
| Ent-*16β*-19-dihydroxykaurane | *Cephalosporium aphidicola* | *11 β alcohol* | 48 |
| Sclareolide | *C. aphidicola*. | 3-Oxosclareolide; 3-*β*-Hydroxysclareolide; *3β,6β*-Dihydroxysclareolide | 49 |
| Isosteviol | *Fusarium verticilloides* | Ent-*7β*-hydroxy-16-ketobeyeran-19-oic acid; Ent-*12α*-hydroxy-16-ketobeyeran-19-oic acid. | 27 |
| Ent-16-ketobeyeran-19-oic acid | *Rhizopus arrhizus* | *7β*-OH derivative; Ent-*7α*-hydroxy-16-ketobeyeran-19-oic acid | 26 |

## DISCUSSION AND CONCLUSION

Terpenes are produced by plants; insects etc. are often strong-smelling. They protect the plants by deterring herbivores as well as helping in attracting predators of herbivores [83]. Most of the terpenes are aromatic hydrocarbons and usually possess a protective function. The basic difference between terpenes and terpenoids is that terpenes are basically hydrocarbons whereas terpenoids possess additional functional groups [101].

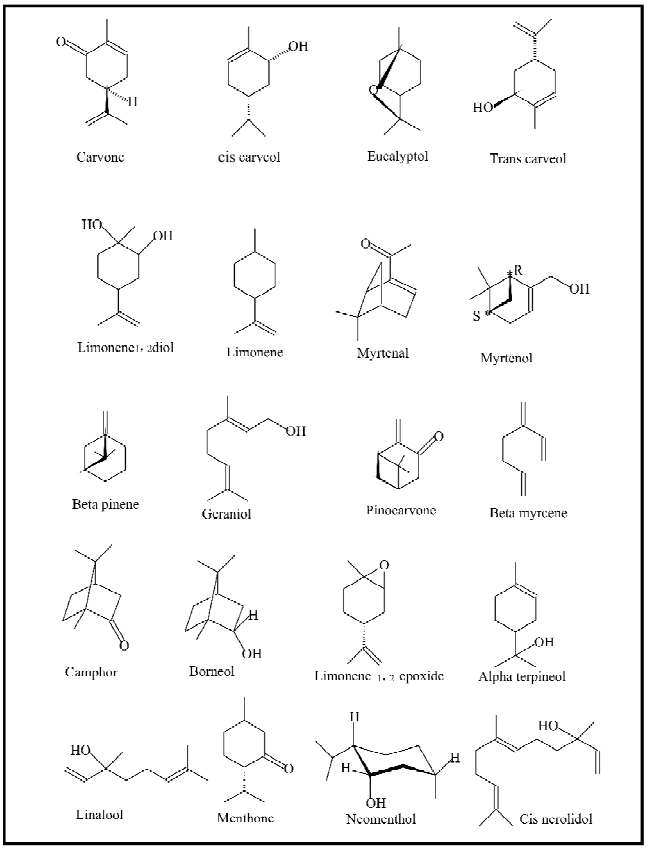
Biotransformation of various natural products into more useful substances by various microorganisms have gain tremendous importance since this approach help in functionalization of the unactivated carbon atom [121]. There exist a number of studies on microbial biotransformation of terpenoids that have resulted in production of those compounds which have enhanced biological activity. Some examples are microbial hydroxylation of patchoulol that leads to the preparation to fragrant compounds [114] or formation of insecticidal derivatives of cadinanes by incubation with *Beauveria bassiana* [7]. Structures of some

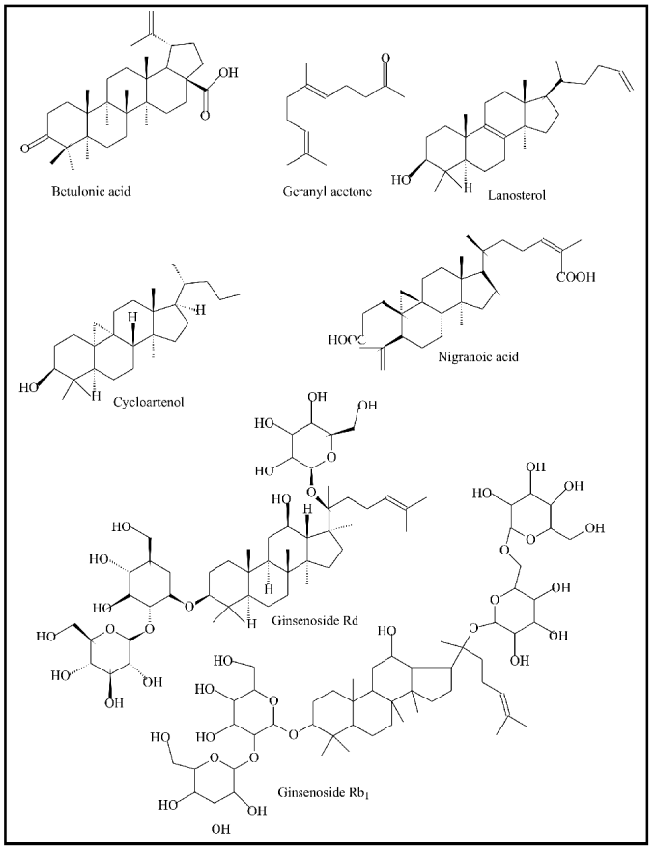
## Table5- Biotransformation of triterpene

| Compound | Organism responsible for biotransformation | Resulting compound | Ref no |
|---|---|---|---|
| Squalene | *Corynebacterium* sp. strain (SY-79) | Squalenedioic acid | 125 |
| Squalene | *Corynebacterium* sp. strain (S-401) | 2-Hydroxy-2,3-dihydrosqualene | 107 |
| Squalene | *Arthrobacter* sp. strain (Y-11) | Geranylacetone | 59 |
| Betulin | a) Fungus<br>b) *Aspergillus oryzae* AS3498 | a) Betulinic acid<br>b) Transformation of the C-28 carboxyl group into a C-28 hydroxyl group | 15 |
| Ursolic acid | *Nocardia* sp. (NRRL 5646), *Nocardia* sp. (44822) and *Nocardia* sp. (44000) | Ursolic acid methyl ester; Ursonic acid; Ursonic acid methyl ester; 3-Oxoursa-1,12-dien-28-oic acid; 3-Oxoursa-1,12-dien-28-oic acid methyl ester | 76 |
| Betulonic acids | *Nocardia* sp (NRRL5646) | 28-Methyl ester, 3-oxo-lup-20(29)-en-28-oate;<br>2*α*-Acetoxy-3-oxo-lup-20(29)-en-28-oate | 103 |
| a) Betulinic acids<br>b) Betulonic acids | *Bacillus megaterium* (ATCC13368) | a) Hydroxylation at the C-*6α and C-7βsites.* Dehydrogenation of the C-3 secondary alcohol group.<br>b) *Ketone α*-hydroxylation at the C-2 site. Hydroxylation at the C-1 or C-11 site. | 10 |
| Glycyrrhetinic acid | *Curvularia lunata* (ATCC 13432) | *7β*-Hydroxy glycyrrhetinic acid | 124 |
| 20(S)-Protopanaxatriol | *Mucor spinosus* (AS 3.3450) | 12-Oxo-*15α*-hydroxy-20(*S*)-protopanaxatriol; 27-Hydroxy-20(*S*)-protopanaxatriol;<br>29-Hydroxy-20(*S*)-protopanaxatriol;<br>12-Oxo-20(*S*)-protopanaxatriol | 129<br>116 |
| 20(*S*)- and 20(*R*)-Dihydroprotopanaxatriol | *Mycobacterium sp.*<br>(NRRL B-3805) | 3-Oxo-<br>and 3-oxo-25-hydroxylated derivatives | 119 |
| Betulinic acid | *Cunninghamella*<br>Sp. (NRRL 5695) | I*ntroduction of a β*-D-glycopyranosyl at the C-28 carboxylic acid group. | 11 |
| Oleanolic acid | *Chaetomium longirostre* (RF-1095) | Oxidative ring-A cleavage, hydroxylation at the C-*21β site*. | 110 |
| Squalene | *Nocardia* (BPM 1613) | Squalene dioic acid | 96 |
| Squalene | *Corynebacterium* sp (SY-79) | Squalene dioic acid | 108 |
| Squalene | *Rhodococcus* spp | Squalen-12-one | 109 |
| Eburicoic acid. | *Glomerella fusarioides*.<br>(ATCC 9552) | 4-Hydroxy-3,4-*seco*-eburica-8,24(28)-diene-3,21-dioic acid | 72 |
| Lanosterol | *Mycobacteriun sp.*(NRRL B-3805) | Androsta-4,8(14)-diene-3,17- dione;*5α*-Androst-8(14)-ene-3,17-dione and other C-19 steroids | 120 |
| Cycloartenol, | *Glomerella fusarioides*<br>( IFO8831) | Cycloart-25-ene-*3β,24*-diol, Cycloartane-*3β,24,25*-Triol | 3 |
| Cycloartenol,24 methylene cycloartanol and Cycloartenone | *Mycobacteriun sp.*(NRRL B-3805) | Androsta-4,8(14)-diene-3,17- dione;<br>*5α*-Androst-8(14)-ene-3,17-dione and other C-19 steroids<br>*3α*-Hydroxy-*5α*-androst-8(14)-en-17-one;<br>*3α,17β*-Dihydroxy-*5α*-androst-8(14)-ene | 120,<br>75<br><br>74 |
| 24 Methylene cycloartanol | *Glomerella fusarioides* (IFO8831) | Cycloeucalenol, 24-methylcycloartane-*3β,24,241*-triol, 241-methoxy-24-methylcycloartane-*3β,24*-diol | 3 |
| Cycloartenone | *Glomerella fusarioides* (IFO8831) | *4α,4β,14α*-Trimethyl-*9β,19*-cyclopregnane-3,20-dione; Cycloartane-3,24-dione; 24-Hydroxycycloart-25-en-3-one ;24,25-Dihydroxycycloartan-3-one | 3 |

| | | | |
|---|---|---|---|
| Argentatin A | *Gibberella saubinetti* (ATCC 20193) *Septomyxa affinis*(ATCC 6737) | 3*β*,16*β*,30- Trihydroxycycloarta-20,24-diene; Methyl 16*β*-acetoxy-20*R*, 24*R*-epoxy-25-hydroxy-3,4-*seco*-cycloart-4(28)-en-3-oate | 81 |
| Incanilin | *Gibberella saubinetti*(ATCC 20193) *Septomyxa affinis* (ATCC 6737) | Methyl 16*β*-acetoxy-20*R*,24*R*-epoxy-25-hydroxy-3,4-*seco*lanosta-1,4(28),8-trien-3-oate | 81 |
| Argentatin B | *Nocardia corallina* var. *taoka* (ATCC 31338), *Mycobacterium* sp. (NRRL B3683) *Septomyxa affinis* (ATCC 6737). | Isoargentatin D | 82 |
| Cucurbitacin E 2-*O*-*β*-D-glucopyranoside | *Curvularia lunata* (NRRL 2178) | Cucurbitacin E; (24*R*)- and (24*S*)-Hydroxy-23,24-dihydrocucurbitacin E; 3-Acetoxy-3-methylbutyl ester of (23-27)-penta-*nor*-cucurbitacin I 22-oic acid | 80 |
| Nigranoic acid | *Gliocladium roseum* (YMF 1.00133) | *15β*-Hydroxynigranoic acid; *6α,15β*-Dihydroxynigranoic acid;*7β,15β*-Dihydroxynigranoic Acid | 36 |
| Nigranoic acid | *Caryospora carllicarpa* (YMF 1.01026) | *6β*-Hydroxynigranoic acid | 33 |
| Ginsenoside Rb1 | *Rhizopus stolonifer* (AS 3.822) | Ginsenoside Rd; Ginsenoside Rg3; Ginsenoside Rh2 | 35 |
| Ginsenoside Rb1 | *Microbacterium* sp.(GS514) | Ginsenoside Rd; Ginsenoside Rg3 | 20 |
| Ginsenoside Rb1 | *Curvularia lunata*(AS 3.1109) | Ginsenoside Rd | 35 |
| Ginsenoside Rb1 | *Bifidobacterium sp.*(Int57), *Bifidobacterium sp.* (SJ32), *Aspergillus niger* and *Aspergillus usamii* | Ginsenoside compound K | 21 |
| Ginsenosides Rb1 | *Caulobacter leidyia* (GP45) | Ginsenoside compound K | 17 |
| Ginsenosides Rb1 | *Lactobacillus delbrueckii, Leuconostoc paramesenteroides* | Ginsenosides Rh2 | 21 |
| Ginsenosides Rb1 | *Bifidobacterium sp.* (SH5) | Ginsenosides F2 | 21 |
| Ginsenosides Rb1 | *Intrasporangium sp.* (GS603) | Ginsenosides F2 | 18 |
| Ginsenoside Re | *Bifidobacterium sp.* (Int57) *Bifidobacterium* sp. (SJ32) | Ginsenoside Rh1 | 13 |
| Ginsenoside Re | *Aspergillus usamii* | Ginsenoside Rg2 | 21 |
| Ginsenoside Re | *Absidia coerulea* (AS 3.3389) | Ginsenoside Rh4; 3*β*,12*β*,25-trihydroxydammar-(*E*)-20(22)-ene-6-*O*-*β*-D-glucopyranoside | 13 |
| Ginsenosides Rb1 | *Acremonium strictum* (AS 3.2058) | *12β*-Hydroxydammar-3-one-20(*S*)-*O*-*β*-D-G*lucopyranoside; 12β,25*-Dihydroxydammar-(*E*)-20(22)-ene-3-*O*-*β*-D-glucopyranosyl-(1? 2) -*β*-D-glucopyranoside | 14 |
| Ginsenoside Rg1 | *Aspergillus niger* (AS 3.1858)*, Absidia coerulea* (AS 3.3538) | Ginsenoside Rh1 | 34 |
| Sipholenol A | *Mucor ramannianus* (ATCC 9628) | *9β*-Hydroxysipholenol A; 16-Oxosipholenol A; Sipholenol G; 28-Hydroxysipholenol A | 60 |
| Sipholenone A | *Cunninghamella elegans* (ATCC 7929) | 22-Hydroxy-16-oxosipholenone A; *15β,16β*-Epoxy-22-hydroxysipholenone A | 60 |
| Ginsenoside Rg1 | *Aspergillus usamii* | Ginsenoside Rh1 | 21 |
| Notoginsenoside R1 | *Absidia coerulea* (AS 3.3389) | 20(*S*)-Notoginsenoside R2; 20(*R*)-NotoginsenosideR2; *3β,12β,25*-trihydroxydammar-(*E*)-20(22)-ene-6-*O*-*β*-D-xylopyranosyl-(1? 2)-*β*-D-glucopyranoside | 13 |
| Ginsenoside Rg1 | *Absidia coerulea* (AS 3.3389) | GinsenosideRh1; Ginsenoside Rh4; *3β,12β,25*-Trihydroxydammar-(*E*)-20(22)-ene-6-*O*-*β*-D-glucopyranoside; 20(*S*)-Ginsenoside Rh1 | 13 |

| | | | |
|---|---|---|---|
| Oleanolic acid | *Cunninghamella blakesleeana* | *3β*-Hydroxyoleana-11,13(18)-dien-28-oic acid; *3β,7β*-Dihydroxyolean-12-en-28-oic acid; *3β*-Hydroxy-11-oxoolean-12-en-28-oic acid | 53 |
| Oleanolic acid | *Fusarium lini* | *3β*-Hydroxyoleana-11,13(18)-dien-28-oic acid; *3β*-Hydroxy-11-oxoolean-12-en-28-oic acid | 55 |
| Oleanolic acid | *Colletotrichum phomoides* | 21-Oxo derivative of oleanolic acid | 54 |
| Oleanolic acid | *Aspergillus ochraceus* (NG1203) | *11α*-Hydroxy derivative | 118 |
| Senegenin | *Nocardia sp.* (NRRL 5646) | Senegenic acid 28-methyl ester | 128 |
| Glycyrrhizin | *Aspergillus terreus* | Glycyrrhetinic acid; 3-Oxo-glycyrrhetinic acid | 38 |
| Glycyrrhetinic acid | *Trichothecium roseum* (ATCC 8685) | *7β-,15α*-H*ydroxy and 7β,15α*-dihydroxy derivatives | 9 |
| Glycyrrhetinic acid | *Streptomyces sp.* (G-20) | *22α*-Hydroxy derivative and the minor, a *22α,23- and a 22α,24*-dihydroxy derivatives | 106 |
| Glycyrrhizin | *Cryptococcus magnus (MG-27)* | Glycyrrhetinic acid 3-*O*-mono-*β*-D-glucuronide | 67 |
| Ursolic acid methyl ester | *Mucor plumbeus (ATCC 4740).* | *3β,7β,21β*-Trihydroxyursa-9(11),12-dien-28-oate | 23 |
| Quinovic acid 3-*O*-*β*-6-deoxy-D-glucopyranoside | *Nocardia sp.* (NRRL 5646) | Aglycone; Quinovic acid; Cincholic Acid | 19 |
| *18α*-Glycyrrhetinic acid liquiritic acid | *Curvularia lunata* (ATCC 13432), *Trichothecium roseum* (ATCC 8685), | *7β*-Hydroxy derivatives; *7β,15α*-Dihydroxy derivatives | 40 |
| Glycyrrhetinic acid | *Chainia antibiotica* (IFO 12,246) | 3,4-*seco*-Oleanane-type compounds; seven-membered ring lactones | 105 |
| Glycyrrhetinic acid | *Sphingomonas paucimobilis* (strain G5) | *3β*-Hydroxy-11-oxoolean-12-ene-23,30-dioic acid | 126 |
| Betulinic acids | *a)Bacillus megaterium* (ATCC 14581) b) *Cunninghamella elegans* (ATCC 9244) | *a)Betulonic acids,7β-hydroxy and 6α,7β*-dihydroxy derivatives. b) *1β,3 β,7β* -Trihydroxy-lup-20(29)-en-28-oic acid | 65 |
| Betulinic acids | *Chaetophoma* (DPB125), *Dematium* (DPB 157) | Betulonic acid | 4 |
| Betulinic acids | *Colleototrichum* (DPB136) | *15α H*ydroxyl betulonic acid | 4 |
| Ursolic acid | *Aspergillus flavus* (ATCC 9170) | 3-Oxo-ursolic acids; Ursonic acid | 58 |
| a)Glycyrrhetinic acid b)Liquiritic acid c)Oleanolic acid | *a)Mucor spinosus* (AS 3.3450)*, Mucor polymorphosporus* *b)Curvularia lunata (*ATCC 13432), *Cunninghamella* (ATCC 3229), *Mucor griseo-cyanus* (ATCC 1207-a) c)*Cunninghamella blakesleena* | *a)7β H*ydroxy glycyrrhetinic acid b) *7β Hydroxy,15α –hydroxy,7β-15α*-dihydroxy derivatives c) Diverse hydroxylations at the C-*1β, C-7β*, C-*13 β sites. 3β*-Hydroxy-11-oxo derivative and lactone | 99 |
| Ginsenoside Rb1 | *Fusarium sacchari* | Deglycosylations at the C-3 and C-20 sites. | 47 |
| Ginsenoside Rb1 | *Bacillus megaterium* (GP27) | Ginsenoside Rd | 62 |
| Betulonic acids | *Chaetomium longirostre* (RF-1095) | Oxidative ring cleavage, hydroxylation and decarboxylation | 2 |
| Betulonic acids | *Chaetomium longirostre* (IFO 9873) | 4-Hydroxy-3,4-*seco*-lup-20(29)-ene-3,28-dioic acid; 4,7*β,17*-Trihydroxy-3,4-*seco*-28-*nor*-lup-20(29)-en-3-oic acid | 2 |
| Betulonic acid | *Arthrobotrys* (DPB 134) | *7β,15α*-Dihydroxy derivative; *along with 7β*-H*ydroxybetulonic acid and 7β,30*-Dihydroxybetulonic acid | 4 |
| Betulonic acid | *Colletotricum* (DPB136) | *15α H*ydroxybetulonic acid | 4 |
| Betulin | *Chaetomium longirostre* (IFO 9873) | 4, 28-Dihydroxy-3,4-*seco*-lup-20(29)-en-3-oic acid | 2 |
| Betulin | *Rhizopus oryzae* (ATCC 11145) | No biotransformation | 84 |
| Ceanothic acid | *Mycobacterium sp.* (NRRL B-3805). | Dimethyl ester derivative | 73 |
| 3-Dehydroceanothic acid dimethyl ester | *Mycobacterium sp.* (NRRL B-3805). | 3-Dehydro-1-*epi*-ceanothic acid 2,28-dimethyl ester | 73 |



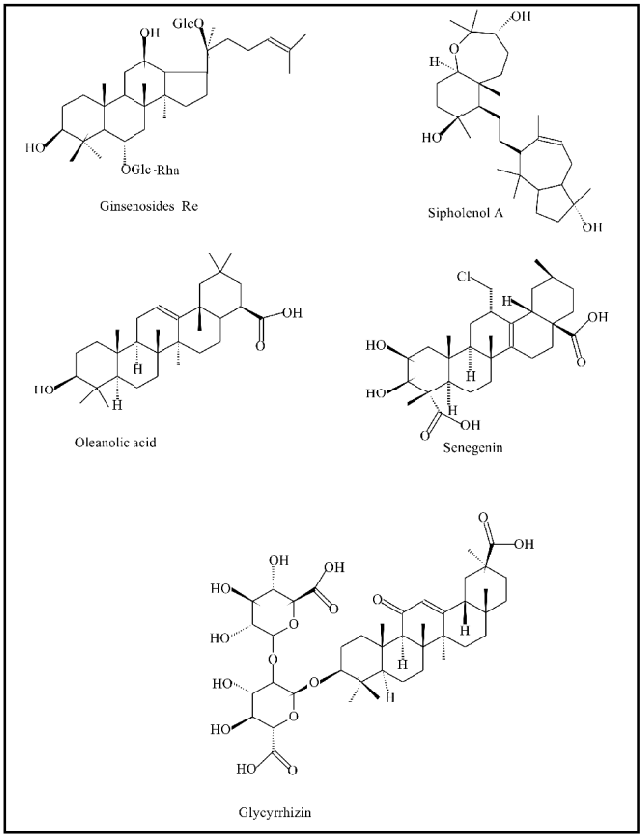




**Figure 1: Chemical structure of important terpenoids that have been successfully bio-transformed by microbial agents**

terpenoids present in essential oil being biotransformed are shown in Fig 1.

A variety of terpenes are frequently used in food, pharmaceutical, dyes, perfumery, cosmetic and industries. Due to the complex structure of various terpenes there exists typical and lengthy process for their synthesis in the laboratory. Different plants possess different type of terpenes but some in very minute quantity that impart fragrance to the plant. However if the extraction process for such terpenoids is attempted from these plants then the process is highly expensive and leads to extraction of designed product in very less amounts. Biotransformation provides an easy pathway to synthesis these valuable terpenes in less expensive manner with increase productivity. The biotransformation of these terpenoids when carried out by various bacteria, fungi and enzymes leads to the production of various mono, sesqui and diterpenoid. All these terpenoids produced which are otherwise difficult to synthesize chemically are produced in a very short duration easily with the help of biotransformation process by microorganisms. Hence an attempt was made to document all the useful data in a form of review so that these useful biotransformation studies can be used for the purpose of synthesizing useful terpenoids. This review also gives a potential idea for synthesizing the other terpenoids which are not yet synthesized.

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