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Chemical composition and biological properties of *Chrysopogon zizanioides* (L.) Roberty syn. *Vetiveria zizanioides* (L.) Nash- A Review

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Vetiver [*Chrysopogon zizanioides* (L.) Roberty syn. *Vetiveria zizanioides* (L.) Nash] commonly known as *khas-khas*, *khas, khus-khus* or *khus* grass belongs to the family Poaceae. The roots of this grass on steam distillation yield an essential oil mainly consisting of sesquiterpenes (3-4 %), sesquiterpenols (18-25 %) and sesquiterpenones (7-8 %). Among these, the major economically important active compounds are khusimol, α-vetivone and β-vetivone which constitute about 35 % of oil. The commercial grades, viz. *Dharini*, *Gulabi* and *Kesari* and Pusa Hybrid-7, Hybrid-8, Sugandha, KH-8, KH-40, are available in North India and South India, respectively for commercial cultivation. The insecticidal, antimicrobial, herbicidal and antioxidant activities of essential oil and its components like vetivone, zizanal, epizizanal and nootkatone are well known. This review is an effort to collect all the information regarding chemical composition and biological activities of vetiver oil.

Keywords: Biological activities, Chemical composition, *Chrysopogon zizanioides* (L.) Roberty, *Vetiveria zizanioides* (L.) Nash, Vetiver essential oil.

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Introduction

The essential oils also known as ethereal oils are defined as odiferous bodies of an oily nature, obtained almost exclusively from all vegetative parts such as flowers, buds, stems, leaves, fruits, seeds and roots, etc.[1-3]. The amount of essential oil found in most plants is 1-2 % but can contain amounts ranging from 0.01-10 %. In recent years, there is an increasing trend in research on essential oils extracted from various herbs and aromatic plants due to the continuous discoveries of their multifunctional properties other than their classical roles as food additives, cleaning products, cosmetics, air fresheners as well as in medicinal uses[4-6]. Antibacterial, antifungal, antioxidant and anti-inflammatory properties of essential oils have been found and confirmed[7-9].

Now-a-days, approximately 3000 essential oils are known of which 300 are commercially available. The major constituents of essential oils are terpenes/terpenoids, aromatic and aliphatic compounds, which are characterized as low-molecular weight aroma chemicals responsible for various properties of the plant.

Vetiver commonly known as *resbira or sugandbmula* (Sanskrit), *khas-khas*, *khas, khus khus* or *khus* grass (Hindi), *valo* (Gujrati), *vala* (Marathi) is a fast growing perennial grass belonging to family Poaceae. It has thick fibrous adventitious roots which are aromatic and highly valued. This tufted grass grows throughout the plains of India ascending up to an elevation of 1200 m. Though it originated in India, vetiver is widely cultivated in tropical regions of the world. During Mogul times, French traders introduced this plant to Bourbon Island in the Indian Ocean and to the new world colonies of Louisiana and Haiti.

The most commonly used commercial genotypes of vetiver are sterile and this grass has rhizome buds for propagation. Pruning techniques are applied to promote root and leaf growth; this grass can grow vigorously on any kind of soil and climatic conditions. It has been reported that almost all vetiver grown worldwide found to be a single clone (no variation in the DNA examined) called 'Sunshine' in the United States, after the town of Sunshine, Louisiana used for commercial essential oil production are Sunshine or very similar cultivars[10].

Vetiver is most closely related to Sorghum but shares morphological characteristics with other fragrant grasses such as lemongrass [*Cymbopogon citratus* (DC.) Stapf], citronella [*C. nardus* (L.) Rendle] and palmarosa [*C. martinii* (Roxb.)W.Watson]. The two genera *Chrysopogon* and *Sorghum* are closely related

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to each other[10], based on an overlap of genetic and morphological data, the two genera *Vetiveria* and *Chrysopogon* have been combined under *Chrysopogon*[11] and this led to the recognition of *Chrysopogon zizanioides* (L.) Roberty as valid name for *Vetiveria zizanioides* (L.) Nash[12].

Extraction of vetiver oil from grass is known in India since the time of Vedas. It is viscous, light to dark brown oil obtained from the aromatic roots by steam distillation method. Depending upon the biotype, cultural practices, age of roots, mode and duration of distillation vetiver may yield about 0.3 to 2 % essential oil on fresh root weight basis. The colour and scent can vary according to the source. Reunion (Bourbon) and Haitian oil with roseate note is highly regarded in perfumery industry but the vetiver oil obtained from wild roots in India is considered to be the best for its balsamic woody note. Vetiver genotype producing oil worth roseate and saffron note has been identified from North Indian plains[13]. Two morphologically distinct complexes of vetiver are found to inhabit spatially separated geographic regions of India yielding oil with different characteristics: Bharatpur or North Indian type found along the Indo-gangetic plains and adjoining areas mainly in the states of Rajasthan, Madhya Pradesh, Uttar Pradesh and Bihar has profuse flowerings, high seed setting having narrow leaves with vigorous roots producing low concentration superior quality laevorotatory root oil (*khus* oil). The South Indian or cultivated type found along the east and west coasts of Indian peninsula in the states of Andhra Pradesh, Karnataka, Tamil Nadu and Kerala is late and low flowering with high pollen sterility and non-seed-setting with wider leaves producing low quality dextrorotatory root oil (vetiver oil) resembling Java vetiver[14]. The essential oil of these two varies in both quality and yield.

Vetiver oil extracted from North Indian variety has the typical earthy note, higher specific gravity, free alcohols and ester value after acetylation while the South Indian has the dominant spicy character, higher refractive index, acid value, ester value, combined alcohols, ester content and carbonyl value (Table 1). The roots of North Indian vetiver dug out every year from local areas are sold in the market in three commercial grades namely *lachha*, *nakhuni* and *munjhar*. The oil yield ranged from 0.076-0.45 % and highest yield is obtained from *lachha* followed by *nakhuni* and *munjhar*[15]. Other commercial grades available in North India are *Dharini*, *Gulabi* and *Kesari*. Among South Indian types, Pusa Hybrid-7, Hybrid-8, CIMAPKS-2, Sugandha, KH-8, KH-40 and ODV-3 are varieties available for commercial cultivation.

The vetiver oil is traditionally known as Vetiver oil in trade. It is also known as Oil of tranquility and has a fragrance of its own for which no synthetic substitute is available. The annual world trade in vetiver oil is estimated around 250 tons (approximately $ 20-200 million per annum), with Haiti, Indonesia, China, Japan, India and Brazil being the main producers and USA, Europe, India and Japan being the main consumers[16].

Table 1—Physico-chemical parameters of Indian vetiver oils

Test parameters	North Indian	South Indian
Yield (%)	0.28	2.37
General appearance (visual observation)	Brown, clear liquid	Yellowish brown, clear liquid
Odour	Heavy woody, earthy, sweet, persistent	Harsh woody, spicy
Specific gravity at 27 ºC	1.0118	1.0026
Refractive Index at 27 ºC	1.5147	1.5220
Optical rotation	-57.70	+28.23
Acid value	21.30	28.45
Ester value	17.89	24.10
Ester value after acetylation	91.90	133.57
Free alcohol present	79.79	47.76
Combined alcohol	7.026	9.46
Total alcohol	86.81	57.20
Ester content	8.36	11.27
Carbonyl value	8.15	35.45
Solubility in 80 % ethanol	1:1	1:1

Source: Dubey *et al*[42]

The commercial and social utility of this plant was first realized on account of its aromatic roots and lately overwhelmed by environmental applications of the plant as such, as well as diverse industrial uses of above ground plant parts[17]. It is well known as an eco-friendly plant that prevents soil erosion and rehabilitates metalliferous polluted land[18,19]. It is cultivated for the production of a commercially important essential oil used in perfumery and aromatherapy[20-22]. Vetiver oil owes several beauty benefits, replenishes moisture in dry and dehydrated skin and rejuvenation effect on mature skin, as well as cuts, wounds, irritated and inflamed skin[23] and prevents stretch marks after pregnancy. The oil strengthens the central nervous system and is helpful in overcoming depression, insomnia, anxiety, stress, tension and nervousness[24,25]. It makes a useful warming and pain-relieving rubbing oil, suitable for deep massage of muscular aches and pains, sprains, stiffness, rheumatism and arthritis[26]. Roots are stimulant, tonic, cooling, stomachic, diuretic, antispasmodic and emmenagogue and used in fevers, inflammations, irritability of stomach and relieving embrocation[27]. Vetiver oil has been used in the treatment of several diseases, including mouth ulcers, fever, headache, inflammation and gastritis[28,29]. Thus, vetiver is an omni-useful plant, almost all parts of which are used in one or more ways having multifarious cultural and industrial applications. In the present review, scientific papers published on chemical composition and biological properties of vetiver are compiled and presented for further research work.

Chemical composition

The chemical composition of vetiver oil is influenced by various factors. Different methods of cultivation have significant effect on both the percentage yield and composition of vetiver oils. Among the three cultivated systems (normal soil, normal soil with added microbes and semi-hydroponic), the system utilizing microbes gave the highest yield of essential oil along with higher content of γ-vetivenene in addition to some low molecular weight volatiles such as 2-norzizaene and its derivatives. However, volatile component profile of oils obtained by normal soil and hydroponic cultivation were found to be similar[30]. Similarly, tissue cultured vetiver (cleansed of bacteria and fungi) produced only trace amounts of oil and a strikingly different composition compared to the oils from non-cleansed (normal) vetiver plants. GC/MS analysis of the oils revealed that the non-cleansed vetiver had the typical vetiver oil profile, whereas the cleansed vetiver produced large amounts of C_{19}–C_{29} alkanes plus several alkanols along with typical vetiver oil compounds, but lacked presumed fungal metabolites such as β-funebrene, prezizaene, α-amorphene and β-vetispirene. It seems that the biotic factors enhance the oil production in normal vetiver by both increasing yield and the generation of signature oil compounds[31].

The essential oil composition of natural and two types of *in vitro* regenerated plants referred as morphotypes were compared. The two morphotypes showed varied essential oil content of 2.2 % (long), 1.9 % (short) while the control showed 1.8 %. The major compounds present were khusimol, valencene, vetiverol, vetivone, vetivenene, vetiselinol and nootketone[32]. The phytochemical screening of the powdered leaves showed the presence of alkaloids, flavonoids, tannins, phenols, terpenoids and saponins.

The growth, yield and composition of essential oil are also influenced by environment and location. In a study, twenty one accessions of vetiver (*V. zizanioides*, sterile, oil type) and Khus (*V. zizanioides*, fertile, non-oil type) were analyzed by random amplified polymorphic DNAs (RAPDs). The largest growth was recorded in Nepal, followed closely by Florida and Mediterranean site in Portugal. Essential oil yields[33] (% oil/dry wt.) ranged from 0.29 to 9.61 %.

The chemical composition of vetiver essential oils from nine countries (Brazil, China, Haiti, India, Java, Madagascar, Mexico, Reunion and Salvador) were analysed using GC/MS which revealed presence of about 110 compounds. The data was subjected to multivariate statistical analyses and no meaningful differences were observed[34]. The hierarchical clustering analysis grouped the samples of nine geographical origins into one significant cluster. The characteristic constituents were β-vetispirene (1.6-4.5 %), khusimol (3.4-13.7 %), vetiselinenol (1.3-7.8 %) and α-vetivone (2.5-6.3 %).

Vetiver oil is considered to be among the most complex essential oils dominated by a woody balsamic tonality of a very special kind. This tonality indicated the presence of some volatile compounds which are mainly sesquiterpenoids, hydrocarbons and their oxygenated derivatives. Vetiver oils have long been a challenge for the analytical chemists as about 100-200 compounds with cedrane, bisabolane, eudesmane, eremophilane and zizaane skeletons have been already identified and mentioned in the literature. Most of them are sesquiterpenic derivatives including hydrocarbons, alcohols, aldehydes, ketones and acids but vetiver oil is also reported to contain some phenols and nitrogen compounds as minor constituents.

Haitian vetiver oil (neutral part) characterized by ^{1}H- and ^{13}C-NMR showed presence of 155 constituents. The constituents in polar part were converted to the methyl ethers, separated by distillation and repeated flash chromatography and characterized by ^{1}H and ^{13}CNMR[35,36]. Applying comprehensive two-dimensional gas chromatography technique 135 constituents were identified in the 4 types (Haiti, Brazil, Bourboun and Java) of veiver oils. In the usual GC chromatograms, prezizaene, zizaene, α-amorphene, β-vetisprene and β-vetivenene sequiterpenes hydrocarbons were present, followed by tertiary and secondary eudesmane alcohols, α-cadinol, the two cyclocopacamphanols, khusinol a series of aldehydes including zizanal and zizaenones. Vetiselineol, khusimol, (*E*)-isovalencenol, vetivones and zizanoic acid were detected in the last part of the chromatogram[37].

The important compounds that impart the characteristic vetiver odour were: khusimene, δ-selinene, β-vetivenene, cyclocopacamphan-12-ol (epimers A and B), vetiselinenol, khusimol, isovalencenol, khusimone, eudesmol, prezizaene, alpha-vetivone and β-vetivone[38-40]. The sesquiterpenoids α-vetivone, β-vetivone and khusimol always occurred in the oil up to 35 %. As a result, these are considered to be finger print of the oil even though they do not possess the typical odour characteristic associated with vetiver[37,41-45] (Table 2).

In an analysis of Indian vetiver oil, a total of 29 and 33 compounds were identified in South and North Indian vetiver oils, respectively. The major compounds identified[42] included khusimol (16.25 %), khusinol (10.28 %), germacrene-D (9.73 %), junipene (5.54 %) and γ-muurolene (4.56 %) (North Indian vetiver oil) and khusimol (15.77 %), bicyclovetivenol (10.76 %) and viridiflorene (4.64 %) (South Indian vetiver oil) (Table 3). Further, the essential oils isolated from vetiver roots collected from 4 locations (Bangalore, Hyderabad, Kundapur and Mettupalayam) in South India were analysed by GC-FID and GC-MS. The main components of the 4 essential oils were: eudesma-4,6-diene (δ-selinene) + β-vetispirene (3.9-6.1 %), β-vetivenene (0.9-9.4 %), 13-nor-trans-eudesma-4(15),7-dien-11-one + amorph-4-en-10-ol (5.0-6.4 %), trans-eudesma-4(15),7-dien-12-ol (vetiselinenol) + (E)-opposita-4(15),7(11)-dien-12-ol (3.7-5.9 %), eremophila-1 (10),11-dien-2α (nootkatol) + ziza-6(13)-en-12-ol (khusimol) (16.1-19.2 %), and eremophila-1(10),7(11)-dien-2α (isonootkatol) + (E)-eremophila-1(10),7(11)-12-ol (isovalencenol) (5.6-6.9 %). The chemical profiles of the oils were comparable to Haitian vetiver oil[46].

Thus, the main constituents of vetiver oil comprises of sesquiterpene hydrocarbons such as cadenene, cloven, amorphine, aromadendrine, junipene and their alcohol derivatives– vetiverols such as khusinol, epiglobulol, spathulenol, khusimol and khusol. Carbonyl derivatives– vetivones such as α-vetivone and β-vetivone, khusimone, nootkatone acid derivatives such as khusenic acid and ester derivative such as khusinol acetate[47,48] have also been reported in majority of the collections. Compounds and their structures under each category are given in Figure 1.

Biological Properties/Activities

Insecticidal

Vetiver oil has great potential to be used as insecticide. Extracts of vetiver oil has repellent and toxicant properties towards ants, ticks and cockroaches[49]. Earlier it was believed that tricyclic sesquiterpenoids, zizanal and epizizanal isolated from vetiver oil were responsible for insect repellent activity[50]. Later on it was observed that at least 6

Table 2—Composition of vetiver essential oil from different geographical regions of the world

S. No.	Geographical region	Major compounds	Reference
1	Southeast Medierranean (Turkey)	Khusinol, β-vetivenene and dehydro-aromadendrene	41
2	Brazil, China, India, Java, Madagascar, Mexico, Reunion and Salvador	β-vetisprene, khusimol, Vetiselineol and α-vetivone	37
3	India	North India: Khusimol, khusinol, germacrene-D, junipene and γ-muurolene. South India: Khusimol, bicyclovetivenol and viridiflorene	42
4	Sri Lanka ecotype	Khusimol, longipinene, valerenol, epizizanal, α-vetivone and β-vetivone	43
5	Taiwan	Cedr-8-en-13-ol, α-amorphene, β-vatirenene and α-gurjuene.	44
6	Bangladesh	2,6-Dimethyl-10-methylene-12-oxatricyclo[7.3.1.0(1,6)]tridec-2-ene and 2-(4a,8-dimethyl-1,2,3,4,4a,5,6,7-octahydro-napthalen-2yl)prop-2-en-1-ol	45

Table 3—Chemical composition of two Indian vetiver oil

S. No.	Name of the components	Concentration (%)	
		North India	South India
1	β-caryophyllene	-	0.37
2	Sativen	0.65	-
3	Khusimene	0.66	1.59
4	α-Humulene	-	0.03
5	α-Amorphene	0.22	1.68
6	α-Bisabolol	0.19	-
7	γ-Cadinene	0.82	-
8	β-Caryophyllene oxide	0.28	-
9	Allo-aromadendrene	0.17	-
10	Cubenol	1.64	-
11	δ-Guaiene	-	1.42
12	Valencene	-	1.31
13	β-Vetivenene	-	0.14
14	β-Vatirenene	-	0.72
15	Caryophyllenyl alcohol	-	2.30
16	Humulene 1,6-diene-ol	0.87	1.42
17	10 Epi-γ-eudesmol	0.46	-
18	β-Lonol	0.46	-
19	β-Bisabolol	0.57	1.00
20	Epiglubulol	1.95	-
21	Selina-6-en-4ol	-	2.11
22	Globulol	-	1.91
23	Junipene	5.54	1.60
24	α-Cadinol	1.46	1.74
25	Guaiol	1.03	1.58
26	α-Eudesmol	0.49	-
27	β-Eudesmol	0.97	1.28
28	Allo-aromadendren oxide	-	0.83
29	β-Cedren-9-α-ol	1.76	-
30	Farnesol	2.65	-
31	Khusinol	10.28	-
32	γ-Muurolene	4.56	-
33	E-Caryophyllene	0.74	-
34	γ-Cadinene aldehyde	1.28	-
35	Patchouli alcohol	-	1.61
36	γ-Gurjunepoxide	-	1.14
37	Cyclosativene	-	2.06
38	Cedryl acetate	-	0.29
39	Spathulene	1.28	2.37
40	γ-Maaline	1.57	-
41	Calerene	1.57	-
42	γ-Himachalene	0.23	-
43	Viridiflorene	-	4.64
44	Khusimol	16.25	15.77
45	Bicyclovetivenol	2.88	10.76
46	α-Vetivone	2.01	3.04
47	Velerenol	-	3.44
48	Germacrene-D	9.73	-
49	Cedrene-13-ol-8	2.23	1.05

Source: Dubey *et al*[42]

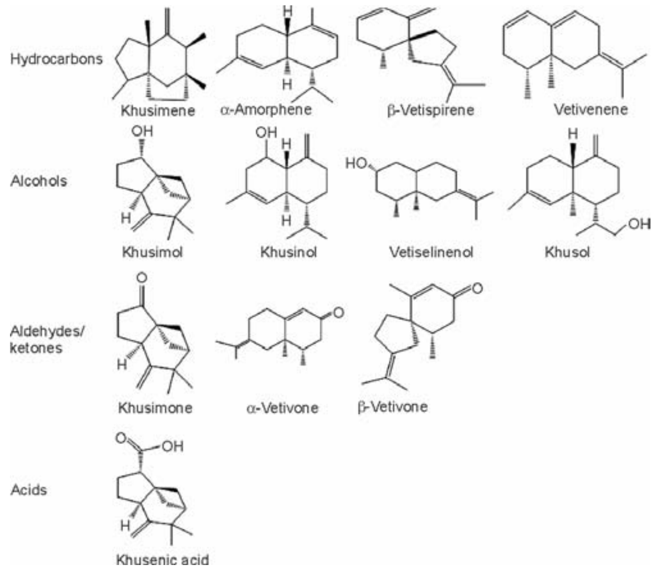

Fig. 1—Structure of *Vetiveria zizanioides* constituents

compounds i.e. α and β-vetivone, khusimone, zizanal, epizizanal and (C) - (1S,10 R)-1,10-dimethylbicyclo [4,4,0]-dec-6-en-3-one were found to be repellent to different insects[51].

Vetiver oil extracts showed repellent and anti-oviposition properties when applied to *Ceratitis capitata*[52]. Flavonoids isolated from aqueous extracts of vetiver oil showed 80 % insecticidal activity against Lepidopterous stem borers on maize[53] in the humid tropics of Western Africa at a concentration of 0.07 mg/mL.

The crude oil extracted from *V. zizanioides* significantly reduced the leaf damage caused by larvae of subterranean termite[54]. Three compounds, viz. nootkatone, zizanol and bicyclovetivenol isolated from vetiver oil showed repellent activity against Formosean subterranean termite (*Coptotermes formosanus*). Simple chemical modifications such as oxidation and reduction can be used to target different compounds present in vetiver oil so that the end product is directly used for pest control[55,56]. Vetiver oil in combination with nootkatone and disodium octaborate tetrahydrate acted as arrestant, repellent and feeding deterrents against *C. formosanus* and its symbiotic fauna significantly decreases their tunneling activity, wood consumption and survival[57-59].

Vetiver oil also found to be effective against stored grain pests. Adults of *Tribolium castaneum* were repelled by contact with food medium treated with 2 and 5 g of vetiver grass oil dust/10 g flour[60]. Root extracts of vetiver in petroleum ether, ethyl acetate, acetone and methanol showed insecticidal activity against XSM, SMC, SKS and JTC strains of red rust flour beetle *T. castaneum.* In larval bioassay the highest toxicity was recorded for petroleum ether (LD_{50} = 0.051 g/cm^2) in XSM strain whereas lowest toxicity using methanol extract (LD_{50} =11.351 g/cm^2) in SMC strain[61].

Similarly, non polar petroleum ether fractions of vetiver oil consisting mainly of four non-adjacent bis-tetrahydrofuranic acetogenins, named squamostatins B to E showed insecticidal activity against *Sitophilus oryzae* infesting wheat seeds[62] whereas acetone extracts from fresh and stored leaves were toxic to adults of *Callosobruchus maculates* whereas ethanol extracts were found to be non-insecticidal[63].

The oil also showed larvicidal and repellent activity against malarial vector, *Anopheles stephensi* causing 85 % mortality. The observed mortality rate suggested that the extracts can be used as biopesticides. The LC_{50} values of 2nd, 3rd and 4th instar larvae of *A. stephensi* were 0.276, 0.285 and 0.305 %, respectively[64].

Vetiver root extracts were able to control the growth of ticks during larval and adult stage including egg laying stage of cow ticks *Boophilus microplus*. The ethanol extract had highest potential as compared to other extracts in controlling cow ticks[65].

Antibacterial

Several studies have shown that vetiver oil possesses antibacterial activity against various bacterial strains like *Staphylococcus aureus, Streptococcus pyogenes, Escherichia coli* and *Corynebacterium ovis*. The inhibition by pure oil was 60-70 % more than penicillin[66]. The hexane extracts of inflorescence, intact roots and spent roots, upon hydrodistillation of the essential oil from two genotypes ('Gulabi' and 'KS-1') of *V. zizanioides* were evaluated for antibacterial activity against wild-type, drug-resistant strains of *Mycobacterium smegmatis* and *E. coli* using disk diffusion and micro-broth dilution methods. The extract showed antibacterial activity against both the strains[67]. The antibacterial activity of vetiver oil extracts (10 mg/mL) in polar solvents (methanol, chloroform) and non polar solvent (hexane) were tested against *S. aureus*. Chloroform extract showed antibacterial activity using cup borer method on the solid agar media[68,69].

The crude root extract of *V. zizanoides* (L.) Nash cultivar 'Surat Thani' showed antimicrobial activity against four pathogenic bacteria. The alkaloid-vetiverin[70] showed minimum inhibitory concentration of 1.626 mg/mL. Polar ethanolic extract showed better antibacterial activity against *S. aureus, E. coli, Pseudomonas aeruginosa* and *Bacillus subtitils* as compared to aqueous extract. The phytochemical analysis revealed the presence of flavonoids, glycosides, phenol, tannins, saponins and alkaloids[71].

Vetiver oil also showed antibacterial activity against various strains of bacteria like *Acinetobacter baumannii*, *Aeromonas veronii*, *Candida albicans*, *Enterococcus faecalis*, *E. coli*, *Klebsiella pneumoniae*, *P. aeruginosa*, *Salmonella enterica*, *Serratia marcescens* and *S. aureus*. The minimum inhibitory concentration[72] was found to be 0.008 % (v/v).

The root extract showed larger zone of inhibition than leaf extract against two pathogenic bacteria *E. coli* (MTCC 443) and *S. aureus* (MTCC 737). All these results confirmed that the extracts of vetiver are pharmacologically important and could be used for human ailments[73].

Antifungal

Vetiver oil showed a broad range of natural fungicidal effect against pathogens. Antifungal activity of transformed products of sesquiterpenoids present in vetiver oil was tested against two phytopathogenic fungi *i.e. Alternaria alternata* (causing early blight of tomato and potato) and *Fusarium oxysporium* (causing wilt of tomato) using spore germination inhibition technique. Out of various compounds tested (Fig. 2) khusinodiol monobrosylate was found to be effective antifungal agent against both the fungi[74]. Schiff bases of sesquiterpenoid i.e. N-(Khusilidene)-*p*-methoxy aniline and N-(Khusilidene)-*p*-bromo-aniline were synthesized by reaction with *p*-methoxy aniline and *p*-bromo aniline. It was found that N-(Khusilidene)-*p*-methoxy aniline inhibited the growth of *A. alternata* upto 84.7 %

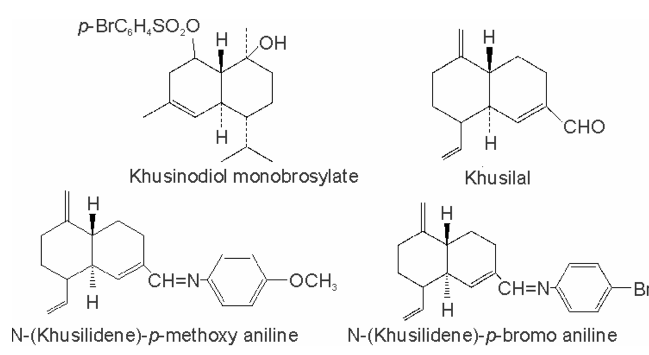

Fig. 2—Some compounds present in vetiver oil tested for antifungal effect

whereas N-(Khusilidene)-*p*-bromo-aniline inhibited the growth of *F. oxysporium* upto 74.5 % at 1 mg/mL level[75].

The antifungal potential of vetiver oil was also observed against *Rhizoctonia bataticola* and *Sclerotium rolfsii*[76]. Antifungal potential of root and shoot extracts of vetiver was studied against two potent pathogenic fungi, *Candida albicans* and *Cryptococcus neoformens*. The results of MIC of root and leaf fractions against pathogens[73] were 10 mg/mL and IC_{50} of these fractions varied between 5-7.5 mg/mL.

Two types of Indian vetiver oils, namely North and South Indian types were evaluated and found to exhibit antifungal activity against *Rhizoctonia solani*. Fungal toxicity of South Indian vetiver oil was slightly higher than North Indian oil[42].

The antifungal activity of vetiver oil was further screened against certain pathogenic microorganisms using Flucanozole as positive control. Among the tested fungal cultures, *Aspergillus niger* exhibited a highest mean zone of inhibition (30 and 32 mm) against vetiver leaves and roots extracts[68].

Antioxidant

Vetiver oil showed antioxidant and anti-inflammatory activities and can be used in medicine and perfumery[44]. Antioxidant properties of vetiver oil were evaluated by two different *in vitro* assays; the $DPPH^{\bullet}$ (1,1-diphenyl-2-picrylhydrazyl) free radical scavenging assay and the Fe^{2+} metal chelating assay. Results revealed that the vetiver oil possessed a strong free radical scavenging activity as compared to standard antioxidants such as butylatedhydroxytoluene (BHT) and alpha-tocopherol. Vetiver oil (0.01 mg/mL) dissolved in methanol exhibited 93 and 34 % free radical scavenging activity in the $DPPH^{\bullet}$ and Fe^{2+} chelating activity in the metal chelating assay, respectively. In the crude vetiver oil, β-vetivenene, β-vetivone, and α-vetivone showed strong antioxidant activities[77].

Ferric reducing free radical scavenging and antioxidant activity of two genotype namely ‘KS1’ and ‘Gulabi’ of vetiver oil were investigated using *in vitro* assay - the ferric reducing antioxidant power (FRAP), DPPH, total phenolic content (TPC), total antioxidant capacity and reducing power (RP). ‘KS1’ genotypes showed higher FRAP values, DPPH inhibition, TPC and RP potential as compared to ‘Gulabi’. The antioxidant activity increased with the extract concentration (0.01-1 mg/mL)[29].

The ethanolic and ethyl acetate extracts of roots of *V. zizanioides* showed free radical scavenging activity by DPPH model. The extracts showed significant dose dependent free radical scavenging activity[78].

Herbicidal

It was earlier hypothesized that certain substances excreted by the vetiver plant had allelopathic action due to inhibition of the growth of other plants. Now it has been confirmed that root and stem extracts of vetiver inhibited the germination of soybean seeds and thus it could be applied for weed control[79]. Germination tests in petri-dishes were carried out to test the effect of vetiver oil and one of its minor component nootkatone on six common weed species; redroot pigweed, common lambs quarters, giant ragweed, pitted morning-glory and velvet leaf. Vetiver oil inhibited germination of these weeds, in addition to inhibition of seedling expansion of redroot pigweed and common lambs quarters acting as useful herbicide[80]. Vetiver oil and its component nootkatone also reduced plant growth in *Pisum sativum* L. (plant height, root length, dry weight) in the laboratory and citrus trees under field conditions[81]. Allelopathic interaction of vetiver oil with two non-edible oil yielding fence plants *Jatropha curcas* L. and *Ricinus communis* L. were tested and found that vetiver plant promoted the growth of jatropha seedlings and inhibited the growth of *R. communis* seedlings suggesting vetiver, jatropha to be a suitable fence plant option for plant-plant interaction[82].

Conclusion

Vetiver has been in use since ancient times for its aromatic roots and its essential oil. Essential oil of vetiver has versatile uses as biopesticides. The complex composition of the essential oils and the variety of chemical structures of their constituents are responsible for a wide range of biological activities. Simple chemical modification of compounds present in vetiver can be useful in pest control. The insecticidal activity of vetiver essential oil may be due to the synergistic action of mixture of compounds and there would be negligible chances of resistance development in insects. Thus, multifarious properties of vetiver oil can be further explored.

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