# Chapter 14
# Cultivation and Breeding of Commercial Perfumery Grass Vetiver

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**Abstract** *Chrysopogon zizanioides* (Roberty) or Vetiver is a member of the grass family Poaceae. In the Indian subcontinent, the Vetiver, a tropical grass has been known since long for its several characteristics, the grass promises for commercial benefits for farmers for its high-cost essential oil and for several industries along with sustainable management of soil erosion in tropical and semi-arid zones. Since long Vetiver was known to be used and recognized for hedging in the field on the contour to stop soil erosion, Vetiver can improve crop production through retaining moisture and nutrient conservation. Vetiver and its products were used in India for household needs, in perfumery, and many other traditional usages along with Indian Ayurvedic system medicines. In addition to its specific aromatic values, it has numerous applications in traditional medicines as well. It is rich in Khusimol, Khusinol, Vetivone, and Khusimone. Genus Vetiver shows variation, and DNA fingerprinting was used extensively to analyze the variability found in the Vetiver genus. This is of utmost benefit in creating a well-organized way of maintaining the genetic diversity in Vetiver. In this chapter, we have summarized different morphological characteristics, chemical composition, and its cultivation strategies along with molecular fingerprints developed in this perfumery grass Vetiver. Because of increasing population and less income, indigenous system of farming in the tropical and subtropical areas are changing drastically. Therefore, farmers have increased the proportion of land under cultivation for enhancing crops per capita per year and cultivating aromatic crops in the marginal land for increasing per capita produce thus also for increasing income. *C. zizanoides* is very much suitable for fulfilling all these needs in this challenging scenario; therefore, we have discussed significance of this Poaceae family member for preventing soil erosion and increase in essential oil yields by developing superior elite genotypes, cultivars along with its various improved methods of cultivation and breeding.

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## 14.1 Introduction

*Chrysopogon zizanioides* (Roberty) or Vetiver belongs to grass family Poaceae which is an important perennial and aromatic C4 plant. In India, it is popularly known as Khus, found in plains and hills of India and distributed worldwide nearly all riverside and marshy land. Vetiver essential oil is used in perfumery, for fragrances, toiletries, and cosmetics industries. It has extensive use in aromatherapy. Its roots are used as a carminative, stimulant, diaphoretic, and in many traditional medicines. Vetiver oil also holds sedative properties. Vetiver is planted in June–July and harvested in the month of September to October of next year. Growth of Vetiver roots is affected by different climatic parameters like rainfall intensity, temperature, and soil. Essential oil of Vetiver is composed of many complex chemicals containing sesquiterpenes and its derivatives. In this, Vetivone and khusimone are main and important constituents. Other than this Vetiverols, ester and carbonyl group is the main compound, which is responsible for essential oil quality. Globally, Vetiver essential oil production is 250 tons per annum, globally approximately 50 million USD (250 tons/annum) http://www.synbiowatch.org/commodities/Vetiver. This volume of production comprises various varieties of Vetiver oil: Haiti (100 tons), Indonesia (80 tons), China (20 tons), India (20 tons), Brazil (15 tons), Dominican Republic (12 tons), Vietnam (3 tons), Madagascar (2 tons), Nepal (0.5 tons), Reunion (0.5 tons), and Ghana (0.4 tons) (Thwaites 2010). Unique and most diverse varieties with high essential oil yield of Vetiver are developed and released by CSIR—Central Institute of Medicinal and Aromatic Plants, Lucknow, India. (Lal et al. 2013). There are two forms of Vetiver grass: one originated from North India and other from South India. DNA-based molecular marker, miRNA, DNA barcoding, microarrays, and next-generation sequencing (NGS) technology are useful in molecular tagging. Molecular marker technologies are useful in management of germplasm collections, classification, and phylogenetic studies not only by avoiding redundancy but also in authentication of the genus (Chakrabarty et al. 2015). The present chapter describes that Vetiver is a crop of choice for farmers by providing additional income with very low maintenance that will improve their livelihood.

## 14.2 Geographical Distribution of Vetiver

In India, *Vetiveria zizanioides* grow usually in wild throughout tropical and subtropical plains, near the river side and in marshy areas. It has extensive range of natural distribution that ranges from sandy costal area to hills and plains in the Kumaun hills of Uttar Pradesh. In India, two most diverse morphological variations in Vetiver

are present in diverse geographical regions: First is found in the Indogangetic plains of north in the states of Rajasthan, Madhya Pradesh, Uttar Pradesh, and Bihar and second in the southern region of east and west coast of Indian peninsula in the states of Andhra Pradesh, Karnataka, Tamil Nadu, and Kerala. These two types of Vetiver are different from each other. The north type is known as "Bharatpur type," and its characteristics features are like the leaves are narrow, with high seed and flowering and produce high quality of root oil (Khus oil), whereas the southern type is known as "cultivated type." In this, no seed formation usually occurs with late flowering with broad leaves and produces low root oil (Guenther 1972; Gupta and Pareek 1995). These two morphologically distinct Vetiver complexes were differentiated in Table 14.1 (Chahal et al. 2015).

In India, the diverse type of Vetiver is found due to different environmental and geographical changes. It has variation at phenotypic, at molecular level as well as physiological behavior (Lal et al. 1997, Lal 2000, Lal and Sharma 2000). However, other than India, Vetiver is also distributed in major parts of the world like Asia, South Africa, and USA, etc.

**Table 14.1** Comparative analysis of northern and southern types of Vetiver

| S. No. | Parameters | North Indian or Bharat type | South Indian or cultivated type |
|---|---|---|---|
| 1 | Geographical regions | Indo-Gangetic Plains adjoining areas mainly in the states of Rajasthan, Madhya Pradesh, Uttar Pradesh, and Bihar | The east and west coast of Indian peninsula in the states of Andhra Pradesh, Karnataka, Tamil Nadu, and Kerala |
| 2 | Morphological characters | Profuse flowering, high seed setting having narrow leaves with vigorous roots | Late and low flowering with high pollen sterility and non-seed setting with wider leaves |
| 3 | Essential oil type | Produce low concentration superior quality laevorotatory root oil (Khus oil) | Producing low-quality dextrorotatory root oil (Vetiver oil) known as Java Vetiver |
| 4 | Essential oil quality | Higher specific gravity, free alcohol, and ester value after acetylation | Higher refractive index, acid value, ester value, combined alcohols, ester content, and carbonyl values |
| 5 | Yield (%) | 0.28 | 2.37 |
| 6 | General appearance | Brown, clear liquid | Yellow brown, clear liquid |
| 7 | Odor | Heavy woody, earthy, sweet, persistent | Harsh woody, spicy |

## 14.3 Phytochemistry of Vetiver Root Essential Oil Composition

Vetiver is a perennial grass with stiff erect leaves and aromatic roots. Vetiverroot oil is very complex in composition and therefore very complicated with more than hundred sesquiterpene constituents and their derivatives. Main chemical constituents in Vetiver essential oil are **sesquiterpene hydrocarbons, sesquiterpene alcohol derivatives,** (Vetiverol, Khusimol), **sesquiterpene carbonyl derivatives** (Vetivone, Khusimone), and **sesquiterpene ester derivatives** (Khusinolacetate). The major constituents that are known to influence the aroma are **α-Vetivone, β-Vetivone**, and **Khusinol** (Ramanujam et al. 1964; Smith et al. 2012)**.**The major compound in Vetiver essential oil includes firstly, (sesquiterpene hydrocarbons) clovene, cadenene, amorphine, aromadendrine, junipene, secondly, (sesquiterpene alcohol derivatives) Vetiverols–khusimol, epiglobulol, spathulenol, khusinol, thirdly, (sesquiterpene carbonyl derivatives) vetivones–vetivone, khusimone, and lastly (sesquiterpene ester derivatives) khusinol acetate. The most important components used in Vetiver oil have the highest boiling points (Lavania 2003) (Lavania et al. 2000, 2009).

In another report, *V. zizanioides* Nash roots from Thai-type plant, total 36 volatiles, were detected in the oil. Khusimone (20.91%), (Z)-9, 10-dehydro–2–norzizaene (14.71%), khusimol (12.21%), and (E)–opposita-4(15), 7(11)–dien–12–al (10.55%) were present as the major odors were extracted by using GC-MSand SPME method (Pripdeevech et al. 2006). Matsuo et al. (2016) reported three unique sesquiterpenoids: Vetiverianines A, B and C and a known eudesmane sesquiterpenoid in Vetiver root, and the structures were determined by NMR spectroscopic, X-ray crystallography, and vibrational circular dichroism data analysis. GC-FID and GC–MS have studied the essential oils extracted from Vetiver (*V. zizanioides* (L.) Nash.) roots obtained from four different sites of South India. Eighty constituents were identified, accounting for 94.5–97.8% of the oils. Bangalore, Hyderabad, Kundapur, and Mettupalayam oils were rich in sesquiterpenes and oxygenated sesquiterpenes with skeletons of cedrane, bisabolane, eudesman, eremophilane, and zizaane. Major constituents found in different varieties of Vetiver developed by CSIR-CIMAP are discussed in Table 14.2.

Interestingly, the Vetiver oil is one of the most complex of the essential oils. Its chemistry is complicated, and steam distillation is slow, but as the Vetiver essential oil is least volatile compared to other essential oils, it retains its place in perfumery for fixing of more volatile, other costly essential oils for preventing them from volatilizing fast. For extraction of the high-quality essential oils through steam distillation, specially designed separators were used for further value-added processing into important constituents such as Vetiverol and Vetiveryl acetate. The Vetiver essential oil trade is highly specialized and operated in a specific chain of farmers, processors, exporters, distillers, chemists, and industries being a commodity crop. Demand for unprocessed Vetiver root is increased immensely being a premier commodity cash crop also added benefits of hedging, for conservation of soil nutrient and water.

**Table 14.2** Chemical diversity among different varieties of Vetiver released by CSIR-CIMAP

| S.No | Varieties | Major constituents |
|---|---|---|
| 1 | KS-1 | > 30% Khusimol |
| 2 | KS-2 | > 20% Khusimol |
| 3 | Sugandha | > 21% Khusimol |
| 4 | Dharini | > 8.9% Khusol |
| 5 | Gulabi | > 23.98% Khusimol |
| 6 | Kesari | > 24.21% Khusimol |
| 7 | CIM Viriddhi | > 25% Khusimol |
| 8 | CIMAP Khus-40 | > 45% Khusinol |
| 9 | G-15 | > 18% Khusimol |
| 10 | G-22 | > 20% Khusimol |
| 11 | Khusnalika | > 45–50% Khusinol |
| 12 | CIM-Samriddhi | > 30% Khusilaland > 19% Khusol |

## 14.4 Medicinal Properties and Various Usage of Vetiver

Vetiver essential oil contains many benefits. It is traditionally used in aromatherapy to release stress, anxiety, tension, and depression in brain. This is also useful for stretch marks, fat cracks, rashes, and burning, etc. Further, it helps get rid of nervous system disorders, afflictions, epileptic and hysteric attacks, and nervous and neurotic disorders such as Parkinson's disease and deficiency in control over limbs. (Upadhyay et al. 2007). It regulates sebaceous oil gland function, has deodorizing properties, and helps to normalize oily skin and clear acne. It helps in treatment of cut, wound, and inflammation in skin (Lavania 2003). Additional, advantages of Vetiver are that its essential oil helps in strengthening of bones, muscle aches, rheumatism, arthritis, gout, cramps, and dry skin. Extract of Vetiver helps in enhancing and boosting up the metabolism as well as in digestive system. Antiseptic properties of this plant are recognized to help in the healing of wounds and protecting from fungus and bacterial infections growth (Kumar 2008).

In the recent study, Lavanya et al. (2016) investigated the antiviral medicinal properties present in the *V. zizanioides* against dengue virus. Analysis of active substance was examined for antiviral properties using docking method along with reference ligand. As a result, it showed that Ethyl 4–(4–methylphenyl)–4–pentenoate is a good candidate for the development of an effective anti-dengue compound from Vetiver plant. Root extracts and fractions of *V. zizanioides* were evaluated by Saikia et al. (2012) for antimycobacterial activity against *Mycobacterium tuberculosis* H(37)Rv and H(37)Ra strains using radiometric BACTEC 460 TB that showed the promising candidature of *V. zizanioides* root extract and hexane fraction act as antituberculosis agent.

Vetiver is also known for its medicinal properties in Ayurvedic literature. It is mentioned that plant is used to cure problem related to digestive system, antigout

carminative stomachic, antispasmodic, hematinic, antimicrobial, anti-asthmatic, diuretic, and anthelmintic. Vetiver roots are also used in the treatment of anemia, boils, fever, epilepsy, rheumatism, weakness, mouth and stomach ulcer, etc. (Jain 1991) It is also used in malaria treatment (Rao and Suseela 2000; Jain 1991; Singh and Maheshwari 1983). Vetiver roots are also used in making of the roofs, hats, and other household products in India. Local villagers are making beautifully hand-crafted items from Vetiver leaves, stems, and roots by weaving. The unprocessed cut leaves could be utilized for mulching. Mulch is much in demand in agriculture and horticulture, Vetiver yields higher volume of leaves for such purposes, because its high carbon-to-nitrogen ratio ensures its long life within heat and humidity of the tropical regions Therefore, Vetiver is a unique incredible grass with many beneficial usages as for conservation of soil and moisture, restoration of industrial wasteland, purifying polluted water bodies, providing shades and shelter for cattles, stabilizing dam river banks, and many others.

## 14.5 Cultivation, Breeding, and Domestication of Different Varieties of Vetiver

There are several specific characteristics of Vetiver grass which makes it as a special essential oil commodity for farmers, because of roots and many physiological, ecological characteristics and ability to grow without attracting pests. Vetiver has a unique fine root system. The native strength of Vetiver root enables it to grow well through difficult soils due to their tensile strength, and this deep root system also makes the plant drought tolerant. Vetiver can tolerate prolonged drought, fire, flood, submergence, and extreme temperatures. And in many of the cases, it may be the only plant to survive. Its ability to regrow quickly after being affected by drought, fire, frost, salt, soil salinity, soil sodicity and varied range of pH, and other unfavorable soil conditions is reasonably incomparable.

Therefore, CSIR-CIMAP, India, has developed twelve superior elite varieties of *C. zizanioides* through mutation, selection, and breeding approaches (Bahl et al. 2018). Specific characteristics of these high yielding genotypes are discussed below in Table 14.3, and the field images of the varieties are depicted in Figs. 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 14.10, 14.11 and 14.12. US patents of variety CIMAP Khus-40 (https://patents.google.com/patent/US20120278945P1/en) and Variety Khusnalika (https://patents.google.com/patent/USPP28388P3/en) are also with CSIR-CIMAP. Now the varieties developed were immensely popular among farmers as being high yielder and superior to others with diverse chemical note as described in Table 14.3.

**Table 14.3** High yielding varieties of Vetiver released by CSIR-CIMAP

| S.No. | Varieties | Dry root yield (ql/ha) | Oil yield (kg/h) | Note/odor | Characters | Remarks |
|---|---|---|---|---|---|---|
| 1 | KS-1 | 25.00 | 26.00 | Khus note | Tall, medium, light green leaves, inflorescence long, white color | For drought/marginal land |
| 2 | KS-2 | 24.00 | 25.00 | Khus note | Medium tall, yellowish green leaves, inflorescence long, purple color | For drought/marginal land |
| 3 | Sugandha | 24.00 | 22.00 | Khus note | Tall, medium, light green leaves, inflorescence long, white colure | Induced tetraploid variety developed from KS-1 |
| 4 | Dharini | 31.00 | 32.00 | Khus note | Very tall, very fast growth, long and broad dark green leaves, early flowering, inflorescence long, dance light brown color | Suitable for flood areas having dense and long network of roots a suitable soil binder–cum high oil yielder |
| 5 | Gulabi | 28.00 | 34.00 | Rose note | Medium dwarf, light green leaves, late flowering, inflorescence dark in purple color | Suitable for drought/marginal, water logging areas, high pH, alkaline soils |
| 6 | Kesari | 29.00 | 30.00 | Saffron note | Dwarf, very light green thin leaves, earliest flowering, inflorescence greenish white color | Suitable for irrigated and non-irrigated both areas and specific purpose |

(continued)

**Table 14.3** (continued)

| S.No. | Varieties | Dry root yield (ql/ha) | Oil yield (kg/h) | Note/odor | Characters | Remarks |
|---|---|---|---|---|---|---|
| 7 | CIM Viriddhi | 27.00 | 33.00 | Khus note | Medium tall, light green leaves, very late flowering inflorescence very dark purple color | Suitable for irrigated and non-irrigated both areas |
| 8 | CIMAP Khus-40 Patent:USPP28388P3 | 25–30 | 25–30 | Khus note | Lax inflorescence with enlarged floret size | A novel seed infertile autotetraploid (4x = 40)clone of Vetiver |
| 9 | G-15 | 9–22 | 35–40 | Khus note | Plant has robust erect growth habit | Suitable for wide climatic conditions |
| 10 | G-22 | 18–20 | 28–30 | Khus note | Plant has robust erect growth habit | Suitable for wide climatic conditions |
| 11 | Khusnalika Patent:USPP28388P3 | 18–20 | 18–20 | Khus note | Spreading canopy and inflorescence bearing flowers with white feathery stigma | Suitable for wide climatic conditions northern climates |
| 12 | CIM-Samriddhi | 30–35 | 35 | Khus/fruity note | Plant has yellow–green inflorescence and broad dark green leaves are the two unique distinctive features of this variety | Suitable for wide climatic conditions northern climates |

### *14.5.1 Planting of the Material*

Vegetative propagation through stem and root cuttings is a cheaper source of cultivation of Vetiver. Nurseries should be fertilized (150 kg/ha of nitrogen) and irrigated timely mostly in dry areas. Loamy to sandy–clay soils are best for Vetiver nurseries. Vetiver can grow in drought areas for long period of time. Vetiver should be planted


**Fig. 14.1** Var. KS-1 of Vetiver released by CSIR-CIMAP (A) field view of plant (B) root


**Fig. 14.2** Var. KS-2 of Vetiver released by CSIR-CIMAP (C) field view of plant (D) root


**Fig. 14.3** Var. Sugandha of Vetiver released by CSIR-CIMAP (E) field Plant (F) Root

on the edges of the field on very small farms and fields where land is limited and where farmers are unable to plant through their fields. Gap filling is necessary and should be done at the start of the wet season.


**Fig. 14.4** Var. Dharani of Vetiver released by CSIR-CIMAP (G) field plant (H) root


**Fig. 14.5** Var. Gulabi of Vetiver released by CSIR-CIMAP (I) field view of plant (J) root


**Fig. 14.6** Var. Kesariof Vetiver released by CSIR-CIMAP (K) field view of plant (L) root


**Fig. 14.7** Var. Vriddhi of Vetiver released by CSIR-CIMAP (M) field view of plant (N) Root


**Fig. 14.8** Var. CIMAP Khus-40 of Vetiver released by CSIR-CIMAP (M) field view of plant (N) root


**Fig. 14.9** Var. G-15 of Vetiver released by CSIR-CIMAP (Q) field view of plant (R) root


**Fig. 14.10** Var. G-22 of Vetiver released by CSIR-CIMAP (S) field view of plant (T) root


**Fig. 14.11** Var. Khusnalika of Vetiver released by CSIR-CIMAP (U) field view of plant (V) root


**Fig. 14.12** Var. CIM-Samriddhi of Vetiver released by CSIR-CIMAP (W) field view of plant (X) root

### 14.5.2 Propagation Methods

Vetiver was propagated mainly by root division or slips. The slip was separated from the main clump and planted in soil as seedlings, and the plants develop quickly once roots are established. The plant responds well to fertilizer and irrigation. Ratooning-like sugarcane, the Vetiver plant, can be cut and sown in the light soil to sprout again. Lateral buds could be utilized successfully for developing Vetiver "eyes" which are intercalary buds on the surface of the crown developed. Through culms, young stems easily form new roots, therefore culms can be utilized effectively to propagate the new plants. Through cuttings,Vetiver could be grown from stem cuttings with two nodes with treatment with a rooting hormone like indole acetic acid (IAA). Multiplication by using culm–cuttings, back clumps of Vetiver of about 30 to 50 cm could be utilized for tillering.

### 14.5.3 Planting Time

In general, planting of Vetiver is done in monsoon (mid-June–September), but the ideal time of planting of Vetiver as an annual crop is winter season. The other most suitable time of planting is January and February in North India. In South Indian conditions, where temporal and diurnal variation in temperature are not significant and monsoon sets early, the ideal planting time is February to April. But for the rainfed area, monsoon planting only is considered to be the most ideal. On undulating and problematic soils also, it should be planted in rainy season only.

### 14.5.4 Cultivation Calendar

| Major activity | Month | Activity details |
|---|---|---|
| Land preparation | May–June | 2–3 deep plowing and removal of perennial weeds |
| Manure and fertilizer | May–June | Application of basal dose of recommended dose of FYM/compost and fertilizers |
| Plantation | June–July | Slips from healthy, disease-free clumps with rhizome portion intact having 15–20 cm of aerial portion are planted at a spacing of 60 × 30 cm/60 × 45 cm/60 × 60 cm |
| Irrigation | June–July | Irrigation should be given immediately after transplanting and up to establishment. Later on 8–10 irrigations are required throughout the cropping period |

(continued)

(continued)

| Major activity | Month | Activity details |
|---|---|---|
| Fertilizer | July–August | Application of first top dressing of nitrogen 25 kg/ha at one month after planting |
| Harvesting | December–February | Digging the clumps along with its roots at eighteen months after planting either by manual or mechanical means |

The input cost for various intercultural operations is clearly defined in Table 14.4, in which cost is in INR based on recent rates approximately.

Cultivation costs are based on the prices as prevailing in March 2019, and distillation rates are based on the rates charged by the private distillers.

## 14.6 Biotechnological Interventions for Analyzing Diversity in Vetiver

Vetiver grass (*Veteveria zizanioides*), because of its outstanding qualities, has now become important to classify for using the correct species and types for producing inferior-quality Vetiver oil. DNA-based markers have been utilized extensively for studying genetic relationship in different species of *V. zizanioides*, as summarized in Table 14.5. Whole genomic and transcriptomic sequences have become available in

**Table 14.4** Economics of the cultivation of Vetiver

| Operations | Cost of cultivation (Rs/ha) |
|---|---|
| Field preparation | 3000 |
| Layout preparation | 1000 |
| Planting material | 35,000 |
| Planting | 3000 |
| Water management | 3000 |
| Weed management | 4000 |
| Nutrient management | 4000 |
| Plant protection and contingency | 1000 |
| Digging | 36,000 |
| Distillation | 5000 |
| Land rent | 15,000 |
| Total | 1,10,000 |
| Oil yield (Kg/ha) | >25 |
| Gross return @Rs 8000/Kg oil | 2,00,000 |
| Net return (Rs./ha) | 90,000 |

*Source* Farm bulletin CSIR-CIMAP

**Table 14.5** Molecular markers used for analyses of polymorphism in *Vetiveria zizanioides*

| S. No. | Name of species/cultivars | Place of collection | Type of Marker used | % polymorphism or % similarity | Purpose of the study | References |
|---|---|---|---|---|---|---|
| 1 | 21 accessions | USA, Louisiana, Colombo, Lilongwe, Northern India, Kassel, Germany, Guang Dong, China, Florida, Nepal, and Portugal | RAPD | 100% polymorphism | Genetic diversity | (Adams et al. 2003) |
| 2 | 131 accessions | Northern and Southern parts of India | RAPD ISSR | 89.02% polymorphism 85.18% polymorphism | Genetic diversity | (Singh et al. 2014) |
| 3 | 10 accessions | Brazil | AFLP | 61.73% polymorphism | Molecular characterization | (Celestino et al. 2015) |
| 4 | 18 accessions | CSIR-CIMAP | RAPD | 73% polymorphism | Genetic diversity | (Dhawan et al. 2018) |
| 5 | 25 accessions | India | ISSR | 79.4% polymorphism | Genetic diversity | (Raja et al. 2019) |

many model organisms over the last several years, which have significantly enhanced knowledge of the nature of physiological processes in higher plants like Vetiver. Chakrabarty et al. (2015) reported transcriptome analysis of North and South Indian type Vetiver to know the role of genetic makeup on oil quality and root morphology. North Indian type showed higher activity of flavonoid and terpenoid biosynthesis-related genes, i.e., ERF, MYB, bHLH, bZIP, and WRKY and were upregulated in development of root and regulation in hormones.

In another study, numerous genes reported by George et al. (2017) during drought and salt stress to be upregulated in *C. zizanioides*. This includes genes encoding dehydration responsive proteins, peroxidases, late embryogenesis abundant (LEA) proteins, enzymes scavenging reactive oxygen species (ROS), transporters, enzymes in the flavonoid biosynthetic pathways, protein kinases, ethylene receptors, etc. Responsive genes expressed toward both salt and drought stress were found total 108 in both tissues.

In a recent study, the complete and annotated chloroplast genome sequences of *C. zizanioides* reported by Sigmon et al. (2017) include three Sunshine, Capitol, and Huffman non-fertile cultivars and two fertile accessions from Punjab and Allahabad from northern India sites. Non-fertile accessions of Vetiver grass have been used for environmental remediation and erosion control in many parts of the world but fertile plants can turn into harmful weeds. Unique polymorphisms are important to differentiate between non-fertile and fertile plants; therefore, cp genomes of both were sequenced. Total 28 polymorphisms, which include 14 SNPs, 11 microsatellites, 2 small indels, and one micro inversion, were reported in the sterile Sunshine from fertile accessions of Vetiver. This study will help in conservation of germplasm. Micro-RNAs are small, non-coding RNAs which regulate posttranscription gene expression. They typically bind to their target mRNAs' 3'-UTR (untranslated region) and repress protein production by destabilizing mRNA and translational silencing. Recently, total 80 miRNA were identified with 25 miRNA families in leaf and 31 in root. miR169 and miR5021 were reported to regulate most of the target in leaf and root. Some miRNA like miR2102, miR854, and miR5658 regulate terpenoid metabolism as well as primary metabolism like photosynthesis (miR5021 and miR854), etc., in Vetiver. The sesquiterpene (+)-zizaene is the direct precursor of Khusimol, the main fragrance constituent of the Vetiver essential oil. Improved production and in situ recovery of sesquiterpene (+)-Zizaene were done by using metabolically engineered *E. coli* (Aguilar et al. 2019). This research provides additional information for the incorporation of terpene bioprocesses by in situ product recovery, which could be extended to industrializing fragrant molecules in other terpene studies.

*V. zizanoides* L. Nash is considered to be effective for the heavy metal phytoremediation. In *V. zizanoides* plantlets, an arsenic (As) accumulation, translocation, and tolerance investigation were performed by (Singh et al. 2017) upon exposure to specific arsenic concentrations (10–200 μM). The upregulation of the antioxidant enzyme activities of superoxide dismutase (SOD), ascorbate peroxidase (APX), guaiacol peroxidase (GPX), catalase (CAT), and glutathione s-transferase (GST) showed increased tolerance to plants against arsenic-induced oxidative stress.

## 14.7 Future Perspectives

Traditionally, Vetiver is used in several countries as aromatic and medicinal plants. Vetiver is the most important, highly diverse herb with vast potential. It is known to produce aroma from its roots essential oil and is used in fragrance/perfume, cosmetic, and pharma industries. Different communities use the various sections of Vetiver such as mouth ulcer, boiling, epilepsy, fire, snakebite, nausea, rheumatism, and headache. There is increasing demand and interest in this plant as it is useful for human health and wellness that is why Vetiver can be a natural defense against in the treatment for several diseases. Therefore, C4 plant that is Vetiver would become a profitable crop for providing specific molecules as well as a hub for basic understanding of biosynthesis of various chemical compounds and the gene regulation involved in this complex cross-linking, thus, providing support to farmers to improve their livelihood. Future research should focus on Vetiver for the evaluation of its pharmacological properties and for the control of various diseases for human welfare. The genome analysis of Vetiver provides a basic model for the understanding of biosynthesis and gene regulation of other aromatic plant species. Therefore, this plant is providing a model plant system for medicinal as well as for aromatic plant species.

## 14.8 Conclusion

The immediate advantages of Vetiver plants are for retaining the moisture in the soil, thus conserving the soil moisture. Wherever Vetiver grass were planted by the farmers, their fields retained sufficient moisture to sustain the seedlings and, even in drought conditions, the farmers were able to harvest a good crop, not only the large-scale farmers, but because of its low cost, it can benefit the small marginal farmer as well. *V. zizanioides* are used to stabilize mine dumps, landfills, road cuttings, eroded slopes, etc., and Vetiver helps agricultural production by maintaining moisture and nutrients in the soil in rainfed cultivation, depending on the weather to get a harvest. The economic rate of Vetiver is good in market. Improved elite cultivars with superior features for disease and drought resistance, animal fodder, formation of hedge, fodder, and insect have been established in India. For environmental conservation purposes, the Vetiver could be efficiently used. Once successfully developed, the Vetiver will provide a low-cost, natural method of environmental protection, particularly for the restoration of polluted lands, as well as for arid and desert areas.

Due to its unique features by maintaining soil moisture and preventing soil erosion, Vetiver can significantly improve in harsh environments. In holistic view, the Vetiver is a nature-gifted plant material, which could be utilized for improving income by utilizing superior, high yielding low-cost-consuming varieties with suitability to grow in almost all diverse climates and soil types. It will provide good alternate for marginal farmers and waste lands with additional income to the farmer and boon for industry

based on its high-valued essential oil. The superior varieties developed at CSIR-CIMAP, India, are developed with unique qualities like with diversified chemical note and immensely popular among farmers because of the increasing demand at industrial level providing additional income by using marginal and wastelands, and this is again beneficial with greater impact on to soil conservation.

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